Journal of Fundamentals of Renewable Energy and Applications

Njoku et al., J Fundam Renewable Energy Appl
2018, 8:5
DOI: 10.4172/2090-4541.1000270

Research Article Open Access

Characterization of Sky Conditions at Benin City and Owerri in Nigeria

Njoku MC[1*], Ofong I[2], Ogueke NV[2] and Anyanwu EE[2]

[1]*Department of Mechanical Engineering, Federal Polytechnic, Nekede, P.M.B. 1036 Owerri, Imo-State, Nigeria*

[2]*Department of Mechanical Engineering, Federal University of Technology, P. M. B. 1526 Owerri, Imo-State, Nigeria*

[*]**Corresponding author:** Njoku MC, Department of Mechanical Engineering, Federal Polytechnic, Nekede, P.M.B. 1036 Owerri, Imo-State, Nigeria, Tel: +2349029776883; E-mail: mnjoku@fpno.edu.ng

Received date: October 15, 2018; **Accepted date:** October 25, 2018; **Published date:** October 30, 2018

Abstract

Characterization of sky conditions at Benin City and Owerri located in the south-south and south-east parts of Nigeria has been carried out using clearness index, diffuse ratio, diffuse coefficient and relative sunshine. An average yearly global solar radiation of 160.31 MJ/m^2 and 168.35 MJ/m^2 was calculated, with daily range of 17.44 MJ/m^2 to 12.50 MJ/m^2 and 16.15 to 12.94 MJ/m^2 estimated at Benin City and Owerri, respectively. For both study locations, the months of December and January recorded the highest variability of global solar radiation, while the month of August recorded the lowest level of solar radiation.

The monthly value of clearness index K_T calculated for each study location indicates cloudy sky conditions devoid of clear days, though it also indicate the possibility of harvesting more solar radiation in Benin City than Owerri. Five seasonal periods were identified for both locations, and their K_T curves followed the same line pattern for that of Ibadan, hence, the generalized K_T curves of Liu and Jordan may not be applicable to the locations.

Keywords: Clearness index; Global solar radiation; Seasonal period; Sky conditions

Introduction

Solar energy is a form of renewable energy harnessed from the sun. Its non carbon emission makes it an environmental friendly source of energy for sustainable development. The availability of abundant solar energy in Nigeria makes it a viable alternative source of energy resource for domestic and industrial usage. Knowledge of the sky conditions in a particular location is important for the deployment of solar energy conversion system. This is because the quantity and quality of solar radiation of the location are necessary considerations for effective design of such systems as aptly reported [1].

Ideriah and Suleman (1989) identify the following parameters for study of sky conditions; (i) relative sunshine $(n/\overline{N})$ which is a measure of the cloud cover, (ii) the clearness index (K_T) which is the ratio of global solar irradiance incident on the earth to the extraterrestrial radiation available (iii) the diffuse ratio (K_D) which is the ratio of the diffuse irradiation to the global solar irradiance and (iv) the diffuse coefficient (K_d) which is the ratio of diffuse irradiation to the extraterrestrial radiation. The separation of global solar radiance into various components is also necessary for a wide range of solar application [2]. Hence, as solar irradiance traverses the atmosphere, it scatters following successive reflections/refractions due to aerosol, resulting in diffuse solar radiation as a component. The ratio of diffuse solar radiation to global solar radiation is the so called cloudiness index (K_d) of the atmosphere and the ratio of diffuse solar radiation to the extraterrestrial solar radiation is known as diffuse coefficient (K_D). These two parameters mirror the effectiveness of sky in scattering the incoming radiation. The technique of using clearness index, cloudiness index and diffuse coefficient was originated [3] based on the work of Whiller, [4]. They developed generalized monthly variation of K_T as a function of its cumulative frequency within the months, known as "monthly K_T curves" based on data for several cities in the United States and Canada. Later extensions of this work were undertaken [5] for the US. Thus, other researchers have used similar technique to study the sky conditions of their locality among which [6,7] worked on data for Indian location. A study [8] studied for locations in Italy [9] examined locality of Bangkok [10] worked on data for Baghdad. The locality of Kumasi, Ghana was carried out [11]. In Nigeria, similar studies have also been carried out where a study [12] investigated Ibadan, a study [13] studied Port-Harcourt, a study [14] examined IIorin, a study [15] carried out for IIe-Ife, and one study [16] worked on Nsukka location. Thus, in this work, characterization of the sky conditions of two more locations in Nigeria namely Benin City and Owerri is undertaken.

Materials

The city of Benin City is in Edo state, situated in the south-south geopolitical zone of Nigeria with longitude and latitude 6.320E and 5.620N respectively, while Owerri is in Imo state which is located in south-east part of Nigeria with longitude and latitude and 7.030E and 5.490N, respectively. In Nigeria, the season is usually divided into two periods; the rainy and dry season. Basically, the rainy season consists of the following months May, June, July, August September and October during which every part of the country experience rainfall, albeit at different level. While, the months of November, December, January, February, March and April make up the dry season during which dry and dusty wind from the Sahara desert blows across the country.

The data used in carrying out analysis in this work were collected from different sources, this was as result of non availability of the require data from a particular source. Data for Benin City was sourced from the website of World Radiation Center for a period of 1965-1992 (27 years of data). For Owerri study location, daily global solar radiation was collected from Owerri meteorological center and this data spanned a period of 1984-1995 (11 years). The monthly average hours of bright sunshine for 25 years was sourced [11] for both study locations.

Methodology

Global solar radiation

The average monthly global solar radiation on horizontal surface for Benin City and Owerri are given in Tables 1 and 2, respectively. It can be seen that in an average year the total global solar radiation received on a horizontal surface at Benin City and Owerri are 187.74 MJ/m^2 and 168.35 MJ/m^2, respectively. The average daily global solar radiation received on a horizontal surface at Benin City ranges from 17.44MJ/m^2 in the month of November to 12.50 MJ/m^2 in the month of August. While for Owerri, the average daily solar radiation incident on a horizontal surface ranges from 16.15 MJ/m^2 in the month of February to 12.94 MJ/m^2 in the month of August. In an average year, the rainy season (April to October) contributes 46.87% and 46.39% for Benin City and Owerri, respectively. The worst month for Benin City and Owerri is August and is responsible for 7.80% (August) and 7.69% (August) respectively of mean annual total. This is expected as the month of August in Nigeria is usually characterized by high level of rainfall, hence will exhibit heavily overcast sky conditions. For Benin City, the highest and lowest mean monthly total occurred in November (17.44 MJ/m^2) and August (12.50 MJ/m^2) while the months of February (17.51 MJ/m^2) and August (14.43 MJ/m^2) recorded the highest and the lowest respectively for Owerri. The variability from year to year for the annual total is 24.32% (Benin City) and 52.79% (Owerri) of the mean value. It is observed that the month of January is recorded as the most variable month with a range of monthly mean value of 42.42% and the steadiest month is November which recorded a range of 25.69% for Benin City. At Owerri, the months of December and November are recorded as the most variable and steadiest with a range of monthly mean value of 22.79% and 9.86%, respectively.

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	MEAN
1965	11.69	13.78	14.80	13.99	16.00	15.00	11.36	10.28	10.37	13.55	14.73	14.76	160.31
1966	-	-	17.99	18.22	16.97	17.77	14.64	13.32	14.42	16.63	17.80	15.95	163.71
1967	16.74	16.44	17.94	18.10	19.57	15.46	11.90	14.40	13.85	16.45	17.04	14.72	192.61
1968	13.24	15.45	15.09	15.09	16.87	13.84	12.53	13.71	14.94	17.49	18.42	17.85	184.52
1969	17.64	19.38	18.50	19.63	19.34	16.20	12.55	13.01	15.31	17.84	18.82	17.67	205.89
1970	15.41	17.68	20.51	17.58	15.38	16.17	13.91	12.17	14.66	18.72	19.21	17.93	199.33
1971	15.07	17.44	17.63	18.29	19.24	15.45	12.86	13.03	13.43	16.72	17.94	16.93	194.03
1972	16.36	17.71	17.94	17.58	17.56	15.08	13.13	12.85	14.41	15.98	17.42	12.55	188.57
1973	15.69	16.64	16.82	17.57	16.76	14.78	15.21	13.32	14.96	16.55	17.91	15.77	191.98
1974	14.46	17.69	17.44	16.92	17.12	16.00	12.49	13.61	13.79	14.80	17.25	16.79	188.36
1975	17.11	17.47	16.28	17.61	16.99	16.37	12.92	11.44	12.56	14.91	15.42	16.95	186.03
1976	15.13	15.84	17.17	16.08	15.26	15.11	10.97	11.78	14.25	13.92	17.07	15.31	177.89
1977	14.31	16.88	16.46	17.59	16.74	14.30	12.04	11.13	12.67	14.71	16.43	15.26	178.52
1978	16.73	16.62	17.77	15.69	16.86	15.59	12.39	13.69	14.07	15.76	18.52	15.91	189.6
1979	16.16	15.84	16.71	17.78	16.34	14.74	14.62	11.85	15.54	15.33	16.82	16.33	188.06
1980	15.94	16.54	17.20	16.87	15.80	14.89	12.29	12.95	14.42	14.70	16.42	15.66	183.68
1981	15.26	17.68	16.90	16.01	16.38	16.12	12.37	12.20	14.13	15.78	17.35	15.84	186.02
1982	14.86	15.62	16.93	16.85	15.85	14.55	11.69	12.00	12.88	14.78	15.94	15.38	177.33
1983	15.43	17.59	16.87	17.44	16.07	11.92	12.76	10.11	13.85	15.73	17.33	14.84	179.94
1984	15.17	17.24	17.41	16.02	16.47	16.61	15.56	14.73	14.94	16.36	17.44	16.53	194.48
1985	16.31	17.97	17.14	18.43	18.01	17.72	13.77	14.08	15.82	16.88	18.44	17.02	201.59
1986	17.65	18.14	17.80	18.19	17.95	18.21	14.09	12.82	12.82	15.64	18.23	17.01	198.55

1987	16.98	18.32	17.27	18.89	17.72	16.38	14.54	13.03	14.52	16.96	18.59	16.97	200.17
1988	15.48	17.21	16.86	17.13	16.77	15.04	11.88	10.78	12.37	15.90	18.36	15.15	182.93
1999	18.38	17.28	16.20	17.48	15.83	13.74	13.51	11.64	14.42	15.49	17.88	16.33	188.18
1990	17.27	18.06	18.25	17.67	16.11	16.13	11.83	11.15	14.98	16.18	16.72	17.01	191.36
Mean	15.77	17.06	17.23	17.26	16.92	15.51	12.99	12.50	14.02	15.91	17.44	16.09	160.31
Max	18.38	19.38	20.51	19.63	19.57	18.21	15.56	14.73	15.82	18.72	19.21	17.93	205.89
Min	11.69	13.78	14.8	13.99	15.26	11.92	10.97	10.11	10.37	13.55	14.73	12.55	160.31
Max-Min	6.69	5.60	5.71	5.64	4.31	6.29	4.59	4.62	5.45	5.17	4.48	5.38	45.58
(Max-Min/ Mean) x100	42.42	32.83	33.14	32.68	25.47	40.55	35.33	36.96	38.87	32.50	25.69	33.44	24.32

Table 1: Average monthly solar radiation for Benin City (H) ($MJ/daym^2$).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1984	15.64	16.22	16.22	16.10	15.64	16.24	14.44	14.43	13.73	14.06	14.88	15.03	182.63
1985	14.39	15.78	15.46	14.67	15.29	14.61		14.09	15.08	14.93	15.01	14.92	164.23
1986	14.84	15.62	15.85	15.46	15.00	14.67	12.03	13.97	14.26	14.53	14.60	15.17	176
1987	15.30	15.35	15.11	16.57	15.65	15.31	14.77	13.85	15.11	15.00	15.61	14.99	182.62
1989	17.04	16.83	15.95	16.09	15.54	14.63	12.82	13.64	14.49	15.64	15.54	15.53	183.74
1990	13.81	15.96	16.69	14.96	15.11	13.28	12.48	12.08	13.54	13.78	14.70	13.50	169.89
1991	15.00	15.41	15.20	15.68	13.95	14.32	12.57	12.55	13.14	13.54	15.34	15.86	172.56
1992	16.13	17.51	15.53	15.33	16.32	13.44	12.03	11.57	14.01	14.28	15.86	16.98	178.99
1993	16.02	16.69	15.79	15.36	15.01	13.52	11.95	12.16	14.53	16.55	15.27	15.73	178.58
1994	15.64	16.67	16.10	15.93	15.35	14.41	13.40	12.08	13.30	13.40	14.37	15.16	175.81
1995	14.30	15.63	14.29	14.65	14.07	13.80							86.74
MEAN	15.28	16.15	15.65	15.53	15.18	14.38	12.94	13.04	14.12	14.57	15.12	15.29	168.35
Max	17.04	17.51	16.69	16.57	16.32	16.24	14.77	14.43	15.11	16.55	15.86	16.98	183.74
Min	13.81	15.35	14.29	14.65	13.95	13.28	11.95	11.57	13.14	13.40	14.37	13.50	86.74
Max-Min	3.23	2.16	2.40	1.92	2.37	2.96	2.82	2.86	1.97	3.15	1.49	3.48	97.00
(Max-Min/ Mean)*100	21.13	13.37	15.33	12.37	15.62	20.58	21.79	21.93	13.95	21.62	9.86	22.76	57.61

Table 2: Average monthly solar radiation for Owerri $(H)(MJ/daym^2)$.

At Benin City, during the dry season, it is noted that the months of December (33.44%) and January (42.42%) recorded the highest variability. This same trend is observed at Owerri, where the months of December (22.76%) and January (21.13%) were noted to have the highest variability. This may be as a result of the fact that during this seasonal period, the atmosphere is filled with dust from the Sahara desert which is likely to reduce the quality of global solar radiation within both localities. While for both cities the month of November is recorded as the steadiest month, followed by the month of April. These two months may be said to exhibit similar characteristics as they mark the end and beginning of rainy season, though, more solar radiation is harvested in the month of November than in April for both locations. During the rainy season, the months of May and October, which mark the start and end of rainy period, are observed to record the lowest range for both Benin City and Owerri. The month of September (38.87%) and August (21.93%) recorded the most variable months for Benin City and Owerri, respectively, hence, they are likely to be the worst months for the harvest of solar radiation.

The percentage frequency distribution of daily global solar radiation for the study locations are given in Tables 3-5. It is observed that the

class modal group of 15-20 MJ/m^2 recorded the highest yearly percentage frequency distribution, 54.45% for Benin City and 48.75% for Owerri. Also noted is that month of this modal class has more days with higher frequency. Remarkable noted is that in this class modal for Owerri, no solar radiation level was noted for the months of January and February. Hence, the rainy season contributes about 54.72% to the frequency distribution of daily global solar radiation. It is worth noting that the class modal of 10-15 and 15-20 MJ/m^2 contributed 81.44% and 88.89% of global solar radiation for Benin City and Owerri, respectively. This indicates that an average the day of the year is likely to have solar radiation within these modal groups. Solar radiation level within the class moda of 20-25 and >25 MJ/m^2 for both study locations is very low as seen in Tables 3 and 4. At Benin City class modal 20-25 contributes 9.04% of the yearly percentage frequency distribution of daily global solar radiation while a very low level of 0.36% of this class modal is recorded for Owerri.

Radiation Level (MJ/m^2)	0-5	5-10	10-15	15-20	20-25	25
Jan.	0.11	3.20	31.11	61.88	3.68	0
Feb.	0.0	0.79	15.97	73.04	10.21	0
March	0.12	3.12	15.61	63.84	17.34	0
April	0.00	4.06	15.50	61.50	18.94	0
May	0.24	6.72	19.33	54.38	19.33	0
June	0.24	7.99	31.11	53.99	6.68	0
July	0.90	26.30	43.75	26.30	2.59	0.12
Aug.	0.46	28.65	47.41	22.09	1.27	0.12
Sept.	0.48	17.58	36.82	42.28	2.85	0
Oct.	0.36	8.25	26.68	53.59	11.12	0
Nov.	0.24	1.32	12.50	74.16	11.79	0
Dec.	0.0	1.28	26.05	69.19	3.29	0
Year	0.27	9.23	26.99	54.45	9.04	0.24

Table 3: Percentage Frequency distribution of daily global solar radiation for Benin City.

Radiation Level (MJ/m^2)	0-5	5-10	10-15	15-20	20-25	25
Jan.	1.30	39.09	59.61	0.0	0.0	0.0
Feb.	0.36	27.05	72.60	0.0	0.0	0.0
March	0.0	3.24	28.80	66.67	1.94	0.0
April	0.34	3.36	27.52	67.45	1.34	0.0
May	0.0	4.21	39.48	55.99	0.32	0.0
June	0.0	4.71	47.48	47.48	0.34	0.0
July	4.37	12.45	33.19	50.0	0.0	0.0
Aug.	0.0	7.61	23.19	69.20	0.0	0.0
Sept.	0.0	5.62	37.08	55.81	1.12	0.38
Oct.	0.0	6.23	43.96	49.82	0.0	0.0
Nov.	0.0	1.13	38.11	60.76	0.0	0.0
Dec.	0.0	1.84	34.19	63.97	0.0	0.0
Year	0.72	10.00	40.14	48.75	0.36	0.03

Table 4: Percentage Frequency distribution of daily global solar radiation.

Clearness index

The condition of the sky during a given period or month of the year can be determined by the clearness index. Since K_T is a ratio, it is a dimensionless parameter which represents the fraction of the extraterrestrial radiation transmitted through the atmosphere. A large value of K_T indicates a clear atmosphere of low turbidity and cloudiness and a small value of K_T indicates an atmosphere of high turbidity and cloudiness. Hence, different researchers have adopted different values. Reindl et al., (1990) proposed $K_T > 0.6$ and $K_T < 0.2$ for clear and cloudy sky, respectively. Previous studies [17-19] used K_T values of 0-0.15, > 0.15-0.7 and > 0.7 for overcast, partly cloudy and clear skies respectively and [13] used $K_T > 0.65$ and $0.12 \leq K_T \leq 0.35$. The clearness index ratio is given as

$$K_T = \frac{H}{H_O} \quad (1)$$

The monthly mean daily extraterrestrial radiation for the study locations is determined from eqn. (2) [20]

$$\bar{H}_O = \frac{24 \;\; x3600 G_{sc}}{\pi}\left(1 + 0.033cos\frac{360n}{365}\right) \;\; x \left(cos\,\emptyset \;\; cos\delta \;\; sin\omega_s + \frac{\pi\omega_s}{180} \;\; sin\,\emptyset \;\; sin\delta\right) \quad (2)$$

Where is solar constant given as 1367W/m2, the declination and sunset hour angle can be calculated from the following equations

$$\delta = 23.45sin\left[\frac{360}{365}(284 + h)\right] \quad (3)$$

$$\omega_s = cos^{-1}(-tan\,\emptyset \;\; tan\delta) \quad (4)$$

Where φ is the latitude of the study location and h is the average day for each month

Thus, by monitoring the cumulative frequency for a given month of the year, the statistical distribution of clearness index for a given location is known [3] defined the cumulative frequency (f) in terms of percentage as

$$f = \frac{number \;\; of \;\; days \;\; with \;\; K_T \leq K_T(fixed \;\; value)}{number \;\; of \;\; days \;\; in \;\; the \;\; month} \;\; x100 \quad (5a)$$

Tables 5 and 6 presents the results obtained by applying eqns. (1) and (5) on the global solar radiation of both study locations. The

monthly average value ranges from 0.34-0.49 with an overall average of 0.43 for Benin City while Owerri has an overall range of 0.41 with a ranges of 0.34-0.46. The average monthly cumulative frequency distribution of daily clearness index for Benin City and Owerri during the months of rainy season is 0.39 and 0.38, respectively. Using the range given [13], Tables 5 and 6 clearly reveal that both study locations has no clear days i.e.$\left(K_T > 0.65\right)$. Following a study [12], the two season period is classified into six subdivisions based on the values of the monthly clearness index for the two study locations; the dry season has two while the rainy season has four subdivisions. The result for our study locations is presented in Table 7 for individual months and monthly average seasonal classification of clearness index along side with those of Ibadan [12], Port-Harcourt [13], Ile-Ife [15], Nsukka [16]. It is observed that for Benin City and Owerri five subdivisions are clearly identified as the clearness index value for Benin City in the month of May (0.46) can be grouped along side with those of Feb (0.44), March (0.46) and April (0.44), similar trend is also observed for Owerri where Feb (0.40) can also be grouped with those of Feb (0.45), March (0.42) and April (0.41). A study [13] also got similar result for Port-Harcourt another city in South-South Nigeria. This is expected as the month of May marks the beginning of rainy season, hence, the seasonal atmospheric attenuation is not too significant during the onset of the rainy season. However, the K_T value for Benin City and Owerri increases as the months progress into the peak of the rainy season (0.46 > 0.40 > 0.35) and (0.40 > 0.40 > 0.39), respectively. It can also be deduce from Tables 5 and 6 that clear days $\left(K_T \geq 0.65\right)$ are not common in Benin City and Owerri. Though, for each subdivision of the seasonal period it noticed that the monthly average values of Benin City is more than those of Owerri, indicating the likelihood of harvesting more solar radiation intensity in Benin City than in Owerri

	Value of f for $K_T \leq K_T$ (fixed value)													***Monthly Average K_T***
	0.1	0.2	0.3	0.35	0.4	0.45	0.5	0.6	0.65	0.7	0.8	0.9	1	
Jan (843)	0	0.12	3.32	6.64	16.61	36.06	65.96	97.15	97.15	100	100	100	100	0.464
Feb (764)	0	1.31	1.57	5.11	13.61	30.24	59.95	96.47	99.87	99.87	100	100	100	0.438
Mar. (857)	0.23	1.17	4.78	9.57	17.74	36.99	63.48	96.62	98.13	98.37	100	100	100	0.458
April (808)	0	1.36	7.8	12.38	20.92	39.85	65.84	96.41	99.13	100	100	100	100	0.442
May (836)	0.24	2.75	10.53	10.53	25	39.24	59.21	93.54	99.16	99.88	100	100	100	0.459
June (839)	0.12	2.38	10.73	19.55	33.85	52.32	74.97	98.21	99.64	100	100	100	100	0.401
July (864)	0.46	8.13	31.59	47.69	65.51	79.86	92.36	99.31	98.61	99.77	100	100	100	0.352
Aug. (864)	0.55	7.18	39.35	54.4	74.88	87.15	94.1	99.88	100	100	100	100	100	0.339
Sept. (838)	0.36	5.13	24.94	37.59	52.74	74.7	89.02	99.52	99.76	100	100	100	100	0.362
Oct. (862)	0	1.51	9.51	17.87	31.9	48.26	70.53	96.4	99.19	100	100	100	100	0.437
Nov. (833)	0	0.72	1.92	3.12	7.44	16.93	36.62	90.52	97.96	99.88	100	100	100	0.493
Dec (859)	0.11	0.47	1.51	3.73	11.18	25.61	52.39	94.53	99.19	99.77	99.77	100	100	0.484

Table 5: Monthly percentage cumulative frequency distribution of daily clearness index for Benin City.

	Value of f for $K_T \leq K_T$ (fixed value)													***Monthly Average K_T***
	0.1	**0.2**	**0.3**	**0.35**	**0.40**	**0.45**	**0.50**	**0.60**	**0.65**	**0.70**	**0.80**	**0.9**	**1.0**	
Jan (307)	0.00	0.00	1.30	3.58	12.38	48.21	84.04	100.0	100.0	100.0	100.0	100.0	100.0	0.447
Feb (281)	0.00	0.00	0.71	4.63	17.08	46.26	86.83	100.0	100.0	100.0	100.0	100.0	100.0	0.445
Mar. (309)	0.00	0.32	4.85	11.97	32.36	65.70	93.85	100.0	100.0	100.0	100.0	100.0	100.0	0.418
April (297)	0.00	1.01	5.39	14.14	31.65	67.68	93.94	100.0	100.0	100.0	100.0	100.0	100.0	0.414
May (309)	0.00	0.00	8.74	19.42	37.54	66.34	90.94	100.0	100.0	100.0	100.0	100.0	100.0	0.404
June (297)	0.00	0.00	7.74	19.19	42.42	65.32	91.25	100.0	100.0	100.0	100.0	100.0	100.0	0.402
July (229)	0.00	0.00	18.78	40.61	68.12	88.65	97.82	100.0	100.0	100.0	100.0	100.0	100.0	0.339

Aug. (276)	0.00	0.00	15.22	46.02	74.64	98.91	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.358
Sept. (267)	0.00	0.00	15.36	32.58	59.55	84.64	96.26	99.63	99.63	99.63	100.0	100.0	100.0	0.379
Oct. (276)	0.00	0.36	9.78	19.93	41.67	73.19	92.39	100.0	100.0	100.0	100.0	100.0	100.0	0.404
Nov. (266)	0.00	0.00	1.88	8.65	20.30	53.76	88.72	99.62	100.0	100.0	100.0	100.0	100.0	0.438
Dec (272)	0.00	0.00	1.84	4.78	13.60	36.03	81.62	100.0	100.0	100.0	100.0	100.0	100.0	0.455

Table 6: Monthly percentage cumulative frequency distribution of daily clearness index for Owerri.

	KT Values					
Period	**Ibadan**	**Port Harcourt**	**Ile-Ife**	**Nssuka**	**Benin City**	**Owerri**
	Ind. Ave	**Ind. Ave**	**Ind. Ave**	**Ind. Ave**	**Ind. Ave**	**Ind. Ave**
Dry Season						
a.Nov, Dec, Jan	0.53, 0.51, 0.49 0.51	0.42, 0.45, 0.43 0.44	0.53, 0.50,0.45 0.5	0.34	0.49, 0.48, 0.46 0.48	0.44, 0.46, 0.45 0.45
b.Feb, Mar, Apr	0.53, 0.53, 0.52 0.53	0.43, 0.41, 0.42 0.42	0.51, 0.49, 0.48 0.49	0.35	0.44, 0.46, 0.44 0.45	0.45, 0.42, 0.41 0.43
Rainy Season						
a.Aug	0.35 0.35	0.33 0.33	0.31 0.31	0.3	0.34 0.34	0.36 0.36
b.July, Sept	0.39, 0.40 0.39	0.35, 0.37 0.36	0.33, 0.38 0.36	0.28	0.35, 0.36 0.36	0.34, 0.38 0.36
c.June, Oct	0.47, 0.47 0.47	0.39, 0.39 0.39	0.44, 0.45 0.45	0.35	0.40, 0.44 0.42	0.40, 0.40 0.41
d.May	0.50 0.50	0.42 0.42	0.48 0.48		0.46 0.46	0.40 0.40

Table 7: Seasonal classification of average clearness index values.

The graphs of the monthly K_T curves for six different locations are shown in Figure 1. For comparison, the value of the second months of the dry season subdivision is used. It is noted that all the graphs for each of the locations followed the same line pattern and the graph of the Ibadan, Ife and Benin City followed a distinct line pattern while those of Port-Harcourt, Nsukka and Owerri cross one another. This confirms the earlier finding of a study [12] that the generalized clearness index curves of Liu and Jordan (1963) may not be applicable to sky conditions that are very cloudy and devoid of clear sky which are quite different from those studied by Liu and Jordan with $K_T$values usually up to 0.8 or more.

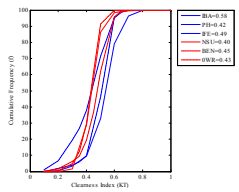

Figure 1: Cumulative frequency curve.

From Figure 1, it can be deduced that during the period of the second subdivision of the dry season, that has the following months February, March and April, clearness index increases in the following order for the locations; Ibadan > Ife > Benin City > Nsukka, Owerri, Port-Harcourt. Hence, this reveals that more solar radiation is likely to be harvest in Benin City compared to Owerri.

Diffuse Ratio and Diffuse Coefficient

To determine the monthly average value of diffuse ratio component from the incoming solar irradiance, a study [21] developed the following correlations

For $\omega_s \leq 81.4^o$ and $0.3 \leq \bar{K}_T \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.391 - 3.560\bar{K}_T + 4.189\bar{K}_T^2 - 2.137\bar{K}_T^3 \quad (5b)$$

And for $\omega_s > 81.4^o$ and $0.3 \leq \bar{K}_t \leq 0.8$

$$\frac{\bar{H}_d}{\bar{H}} = 1.311 - 3.022\bar{K}_T + 3.427\bar{K}_T^2 - 1.821\bar{K}_T^3 \quad (6)$$

From eqn. (4) sunset hour angle for Benin City and Owerri is greater than 81.4°. Thus using eqn. (6) for both study locations, the

diffuse coefficient which mirrors the effectiveness of the sky in scattering the incoming radiation can also be estimated.

Relative sunshine

The relative sunshine is a ratio of monthly average daily hours of bright sunshine (n), to monthly average of maximum possible daily hours of bright sunshine (N). For a given month, the monthly average of maximum possible daily hours of bright sunshine can be calculated from eqn. (7) (Duffie and Beckman).

$$N = \frac{2}{15} cos^{-1}(-tan\ \emptyset \quad tan\delta) \qquad (7)$$

Following the work of a study [12], the complete set of parameter determining sky conditions, namely the clearness index $(\bar{K}_T)$, the diffuse ratio $(\bar{K}_D)$, the diffuse coefficient $(\bar{K}_d)$ and the relative sunshine hour $(n/N)$are given in Table 8 and the results are summarized by the plot of Figures 2 and 3 for Benin City and Owerri, respectively.

Figures 2 and 3 shows that clearness index and relative sunshine hours followed the same line pattern with minimum values occurring in the month of August, during which the following values were recorded 0.338 and 0.210 for Benin City and 0.354 and 0.177 for Owerri. Also Observed from both Figures 2 and 3 is that the diffuse ratio has an opposite shape to the relative sunshine, with a maximum value occurring in the month of August for both study locations. This reveals that during the year when the value of relative sunshine decrease, that of diffuse ratio increase. It is seen from both figures for both study locations that the values of the diffuse coefficient has an almost constant value throughout the year, with a constant value of 0.2 recorded for both study locations. This indicates that for both study location the transmission characteristic of diffuse radiation is independent of cloud conditions and incidence angle.

Locations	Para-meters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Benin City		0.469	0.477	0.461	0.459	0.462	0.433	0.360	0.338	0.376	0.441	0.512	0.489
		0.423	0.414	0.431	0.433	0.430	0.461	0.552	0.584	0.531	0.452	0.379	0.402
		0.198	0.198	0.199	0.199	0.199	0.200	0.199	0.197	0.200	0.200	0.194	0.197
		0.505	0.514	0.465	0.457	0.491	0.38	0.218	0.210	0.249	0.389	0.518	0.567
Owerri		0.449	0.449	0.417	0.413	0.417	0.405	0.362	0.354	0.379	0.402	0.440	0.46
		0.443	0.444	0.479	0.484	0.480	0.495	0.550	0.561	0.527	0.498	0.454	0.432
		0.199	0.199	0.200	0.200	0.200	0.200	0.199	0.199	0.200	0.200	0.200	0.199
		0.465	0.468	0.434	0.413	0.416	0.240	0.224	0.177	0.249	0.345	0.460	0.500

Table 8: Monthly average of $\bar{K}_T$, $\bar{K}_D$, $\bar{K}_d$ and n/N.

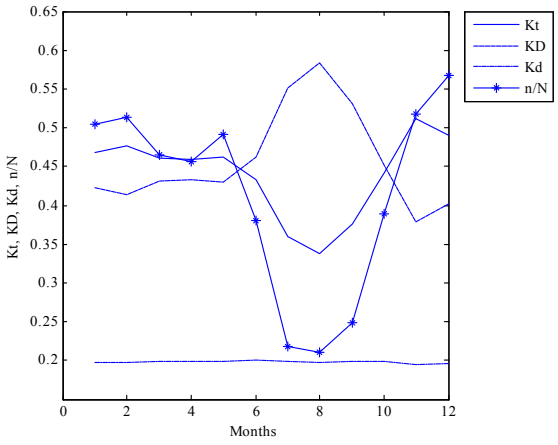

Figure 2: Monthly average of for Benin City.

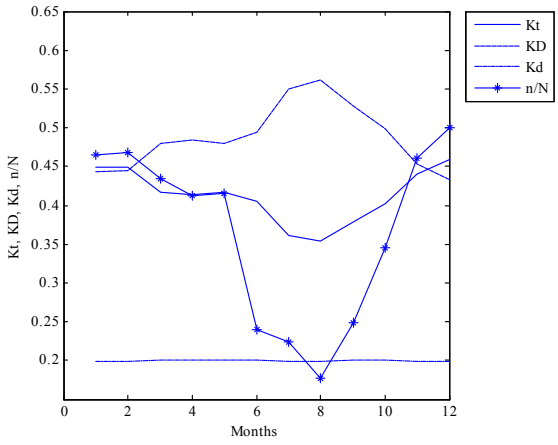

Figure 3: Monthly average of $\bar{K}_T$, $\bar{K}_D$, $\bar{K}_d$ and n/N for Owerri.

Conclusion

The analysis of global solar radiation on horizontal surface for Benin City and Owerri is presented in this study using measured solar radiation intensity from different sources. The rainy season period (April-October) contributes 46.87% and 46.39% of the year solar radiation in Benin City and Owerri, respectively. While for both study locations the month of August was identified as the month with the lowest level of solar radiation intensity and the months of January and December were noted as the months with the highest level of variability. It was deduced from the values of calculated clearness index for both study locations that Benin City and Owerri are usually cloudy and completely lacking of clear skies. Five seasonal periods were also identified for both study locations as against six seasonal periods suggested by a study [12] for Ibadan. The result of clearness index obtained for the two study locations indicate that the curves followed the same line pattern with that of Ibadan, IIe-Ife and Nsukka and hence, the generalized K_T curves of Liu and Jordan may not be applicable in our study locations.

References

1. Ogueke NV, Abam F, Nwaigwe KN, Okoronkwo CA, Ugwuoke PE, et al. (2013) The Effect of Seasonal Variation and angle of Inclination on the Performances of Photovoltaic Panels in South Eastern Nigeria. Res J App Sci Eng Tech 5: 794-800.
2. Iqbal M (1983) An Introduction to Solar Radiation (1stedn), Academic Press, Toronto, Canada.
3. Liu BYH, Jordan RC (1960) The inter-relationship and characteristic distribution of direct, diffuse and total solar radiation. Solar Energy 4: 1.
4. Whillier A (1953) Solar Energy Collection and Its Utilization for House Heating. Leaves 171-172.
5. Bendt P, Collares-Pereira M, Rabl A (1981) The frequency distribution of daily radiation values. Solar Energy 27: 1.
6. Choudhury NKD (1963) Solar radiation at New Delhi. Solar Energy 7: 44.
7. Hawas M, Muneer T (1984) Generalized monthly KT-curves for India. Energy Conv Mgmt 24: 185.
8. Barbaro SS, Leone CC, Sinagra E (1979) An atmospheric model for computing direct and diffuse solar radiation. Solar Energy 22: 225.
9. Saunier GY, Reddy TA, Kumar S (1987) A monthly probability distribution function of daily global irradiation values appropriate for both tropical and temperate locations. Solar Energy 38: 169.
10. Al-Riahi MN, Al-Hamdani, Tahir T (1990) Contribution to the study of solar radiation climate of Baghdad environment. Solar Energy 44: 7-12.
11. Akuffo FO, Brew-Hammond A (1993) The frequency distribution of global solar irradiation at Kumasi. Solar Energy 50: 145-154.
12. Ideriah FJK, Suleman SO (1989) Sky conditions at Ibadan during 1975-1980. Solar Energy 43: 325-330.
13. Kuye A, Jagtap SS (1992) Analysis of Solar Radiation Data for Port-Harcourt, Nigeria. Solar Energy 49: 139-145.
14. Udo S (2000) Sky conditions at Ilorin as characterized by clearness index and relative sunshine. Solar Energy 69: 45-53.
15. Okogbue EC, Adedokun JA (2000) Characterization of Sky Conditions over IIe-Ife, Nigeria Based on 1992-1998 Solar radiation observations. Meteorolog J 6: 419-423.
16. Egeonu DI, Njoku HO, Enibe SO (2014) Sky Conditions at Nsukka as Characterized by Clearness Index and Cloudiness Index. Int J Scientific Res Innov Tech 1: 67-82.
17. Ojosu JO (1980) Data Bank: The Iso-Radiation Map of Nigeria. Solar Wind Technol 7: 563-575.
18. Li DHW, Lam JC (2001) An Analysis of Climate Parameters and Sky Condition. Build Environ 36: 435-445.
19. Li DHW, Lau CCS, Lam JC (2004) Overcast Sky Conditions and Luminance Distribution in Hong Kong. Build Environ39: 101-108.
20. Duffie JA, Beckman WA (2013) Solar Engineering of Thermal Processes (4thedn), John Wiley & Son Inc.
21. Erbs DG, Klein SA, Duffie JA (1982) Estimation of the Diffuse Radiation Fraction for Hourly, Daily and Monthly-Average Radiation. Solar Energy 28: 293-295.