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Research Paper

Distribution of Solar Radiation in South-South Geo-Political Zone of Nigeria

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ABSTRACT

Distribution of solar radiation in south-south geo-political zone of Nigeria is presented in this study. Twenty years (2000-2020) data of daily global radiation and monthly average bright sunshine hours were sourced from National Aeronautics and Space Administration (NASA) and Nigeria Meteorological Agency (NIMET), respectively. The zone comprises of six states. Monthly average global solar radiation in the zone is estimated at 52.23 $kWhrm^{-2}day^{-1}$. Cloudy sky condition in the zone is prevalent as average monthly clearness index values range between 0.30 – 0.56. Monthly bright sunshine hours are estimated at 53.90 hrs in the zone. Six seasonal classification patterns are observed in Asaba, Calabar, Port-Harcourt and Uyo. In Benin City and Yanagoa, five seasonal classification patterns are identified. Angstrom-Page coefficients are determined for each study location and the zone and are applicable to locations with similar metrological characteristics.

KEY WORDS: *clearness index, seasonal periods, sky condition, solar radiation, south-south*

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I. INTRODUCTION

As the demand for energy consumption continues to grow globally for economic and political stability. There is need to reduce the level of carbon dioxide which is predominantly responsible for climate change [1]. Among the renewable energy resources, solar energy has the potential to play a major role in mitigation of climate change. Therefore, the knowledge of the quantity and quality of solar radiation availability in a particular proposed locality of solar energy device application is important for cost-effective, performance and maintenance evaluation requirements during the design stage of solar energy conversion device. Solar radiation data has other useful applications in prediction of agricultural potentials, meteorological and evaporation forecast, architectural design and model of land, ocean and hydrologic [2]-[3]. Thus, as with other types of natural resources, the utilization of solar energy requires comprehensive information. Though, many metrological stations in the tropics measure bright sunshine hours rather than global solar radiation [4]. In Nigeria, [5] aptly reported that there is paucity of solar radiation data. Consequently, different methods of estimation of solar radiation by researches have been studied. While in some cases, institutions and other private organizations have attempted to measure solar radiation for a given period.

Ref [6], used sunshine hour data obtained from Nigeria Meteorological Agency (NIMET) to predict the monthly mean daily global sunshine radiation of Ikwo. In Bayelsa state of Nigeria, [7], used eleven years data obtained from National Aeronautics and Space Administration (NASA) to model Kernel regression for estimation of solar radiation values in their study location. Ref [8], characterized the sky conditions of two cities in Nigeria using daily solar radiation data obtained from different sources. Ref [9], obtained fourteen years monthly sunshine hour and global solar radiation from NIMET to develop a linear regression model for the prediction of solar radiation in Ikeja and environment. Thirty years of temperature difference obtained from International Water Management was used to develop Hargreaves equation for seventeen locations in the Niger Delta of Nigeria [10]. Ref [11], used thirty days minimum and maximum daily temperature sources from weatheronline limited to develop Hargreaves-Samani model for prediction of solar radiation in three different Nigerian cities.

Ref [12], collected nine years of global solar radiation and sunshine hour data from NIMET for estimation of global solar radiation using sunshine based models in Bauchi state. Different empirical methods were used b [13] to estimate solar radiation at Makurdi. Ref [14], estimated daily solar radiation from monthly values for some selected cities in Nigeria. Ref [15], used fourteen years data obtained from NIMET to develop linear regression for estimating solar radiation in three different cities in Nigeria.

For proper design analysis of solar devices in south-south geo-political zone of Nigeria there is need to study the distribution of solar radiation and its components. This will help in optimal initial cost analysis of solar devices and maintenance requirement. Also, it will further the reduction in constant failure of solar devices as result of poor sizing during design stage in these locations. Thus, to achieve this aim, this paper characterized the sky conditions in south-south geo-political zone of Nigeria using monthly average global solar radiation, clearness index and hours of sunshine duration.

II. MATERIALS

In Nigeria, seasonal period is divided into two: Dry season which usually commence from November and end in April and rainy (wet) seasons that start from May to October. The dry season can be further classified into three distinct periods. These are:

(i) Harmattan period (December to January) when cold dry and dusty north-eastern trade winds from Sahara desert keep the atmosphere heavily overcast by dust for many days with characteristic hazy weather conditions.

(ii) Dust free period (November, February, and March) which is usually characterized with high irradiation intensity and clear weather condition

(iii) April, a transition period between dust free period of February and March and rainy season.

During, rainy season each part of the country experience different levels of rainfall. However, August is usually characterized as month of highest rainfall in Nigeria. Though, variation in rainfall intensity therefore depends on locality.

South-South geo-political zone of Nigeria is located in southern part of Nigeria. This zone consists of six states which include Akwa-Ibom (Uyo), Bayelsa (Yanagoa), Cross-River (Calabar), Delta (Asaba), Edo (Benin City) and River States (Port-Harcort).

Daily solar radiation data from 2000 – 2020 (20 years) for each of the study locations are sourced from National Aeronautics and Space Administration (NASA) website. The data from NASA prove to be a large data base as data are recorded in all the days of the months. In the same vein, monthly average hours of bright sunshine data from 2000 – 2020 (20 years) are obtained from Nigeria Meteorological Agency (NIMET). Table 1 presents capital cities' latitude and longitude of study locations.

Table 1 study locations

Study Location	Latitude (°N)	Longitude (°E)
Asaba	6.2059	6.6959
Benin City	6.3350	5.6037
Calabar	4.9757	8.3417
Port-Harcort	4.335	7.0498
Uyo	5.0377	7.9128
Yenagoa	4.9212	6.2748

III. METHODOLOGY AND ANALYSIS

3.1 Global Solar Radiation

Table 2 presents monthly average solar radiation on horizontal surface for the zone during 2000 – 2020.

Table 2 Monthly averages global solar radiation on horizontal surface $(H)(kW-hrm^{-2}day^{-1})$

Years/ Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Total
Asaba	4.97	4.73	4.83	4.83	4.76	4.35	3.97	3.84	4.13	4.54	4.98	5.01	54.94
Benin city	4.92	4.63	4.73	4.74	4.68	4.21	3.76	3.68	3.96	4.42	4.96	4.97	53.66
Calabar	4.99	4.85	4.50	4.54	4.41	3.71	3.22	3.04	3.45	3.94	4.34	4.86	49.85
Port-Harcort	4.82	4.71	4.45	4.53	4.28	3.49	3.24	3.38	3.59	3.98	4.30	4.77	49.54
Uyo	5.05	4.90	4.84	4.86	4.69	4.19	3.77	3.72	4.09	4.47	4.81	5.01	54.40
Yenagoa	4.87	4.68	4.46	4.58	4.26	3.53	3.37	3.66	3.69	4.11	4.42	4.87	50.50
mean	4.94	4.75	4.63	4.68	4.51	3.91	3.55	3.55	3.82	4.24	4.64	4.91	52.13
max	5.05	4.90	4.84	4.86	4.76	4.35	3.97	3.84	4.13	4.54	4.98	5.01	54.94
min	4.82	4.63	4.45	4.53	4.26	3.49	3.22	3.04	3.45	3.94	4.30	4.77	49.54
max-min	0.24	0.28	0.40	0.34	0.5	0.87	0.75	0.80	0.68	0.60	0.68	0.25	6.39
(max-min/mean)100	4.7	5.79	8.5	7.17	10.96	22.05	20.92	22.52	17.8	14.09	14.52	4.93	153.95

From Table 2, it is observe that mean total monthly average solar radiation on horizontal surface in the zone is estimated at 52.23 kWhrm^{-2}day^{-1}. The months of dry and rainy seasons contribute 53.91 % and 46.09 % of the total monthly average solar radiation, respectively. It is observed that Asaba and Port-Harcourt recorded maximum (54.94 kWhrm^{-2}day^{-1}) and minimum (49.54 kWhrm^{-2}day^{-1}) of the total global solar radiation, respectively. On monthly basis, the average global solar radiation range in value of 5.05 - 3.04 kWhrm^{-2}day^{-1}. This monthly maximum and minimum range occurred in January and August, respectively. The most variable month is August where the value is 22.52 % of the monthly mean value in that month and the most stable month is January with a value of 4.7 % of the monthly mean value in that month. It is also observed from Table 1, that August recorded the minimum average global solar radiation in each study locations. This is expected as August is usually characterized by high level of rainfall; hence will exhibit heavily overcast conditions.

Table 3 presents percentage frequency distribution of daily global solar radiation for the study locations. It is observed that bulk of the daily global solar radiation falls within the class intervals of 2.00 – 2.99, 3.00 – 3.99, 4.00 - 4.99 and 5.00 - 5.99 kWhrm^{-2}day^{-1}. Percentage of frequency distribution of monthly average global solar radiation in these class intervals varies from 5.44 % to 45.08 %. It is also perceived that class interval 8 - 8.99 did not record any global solar radiation. Table 3 further reveals that the zone recorded solar radiation in class interval of 0 - 0.99 within the range of 0.03 – 0.63 %.

Table 3 Percentage frequency distribution of monthly average global solar radiation

	0.0 - 0.99	1.00 - 1.19	2.00 - 2.99	3.00 - 3.99	4.00 - 4.99	5.00 - 5.99	6.00 - 6.99	7.00 - 7.99	8.0 - 8.99
Asaba	0.03	0.03	5.44	16.29	45.08	30.34	2.81	0.02	0
Benin city	0.07	0.17	7.60	17.91	43.61	28.56	2.09	0.03	0
Calabar	0.36	1.10	19.89	19.18	27.80	28.73	2.95	0.02	0
Port-Harcourt	0.63	1.13	20.86	19.02	26.53	28.12	3.73	0.02	0
Uyo	0.06	0.16	7.03	17.43	40.14	33.29	1.92	0.02	0
Yanagoa	0.50	0.83	17.89	20.47	27.82	28.09	4.43	0.02	0

3.2 Clearness Index

Clearness index is fraction of extraterrestrial radiation that reaches the earth surface as total radiation. It is a measure of depletion by the sky of incoming total global radiation. Clearness index indicates both the level of availability of solar radiation and change in atmospheric condition in any given locality. It is mathematically given as

$$K_T = \frac{H}{H_o} \qquad (1)$$

Where K_T is clearness index, H is global solar radiation and H_o is extraterrestrial radiation

Extraterrestrial radiation in MJm^{-2}day^{-1} for the study locations is given as [16].

$$H_O = \frac{24\ x3600G_{sc}}{\pi}\left(1 + 0.033cos\frac{360n}{365}\right)x\left(cos\emptyset cos\delta sin\omega_s + \frac{\pi\omega_s}{180}sin\emptyset sin\delta\right) \qquad (2)$$

Where G_{sc} is solar constant given as 1367W/m^2, $\emptyset$ is latitude of study location, δ is declination angle and ω_s is hour angle at sunset. Conversion factor of 1 kWhm^{-2}day^{-1} equal to 3.6 MJm^{-2}day^{-1} is used in this study [17].

Angle of declination (δ) in degree for any day of the year is the angle between the line joining the centers of the sun and the earth and its projection on the equatorial plane. It is given as [16]

$$\delta = 23.45\,sin\left(360\ \frac{284+n}{365}\right) \qquad (3)$$

where (n) is average day for each month

Sunset hour angle (ω_s) is given as [16]

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

Tables 4 a-f shows monthly percentage cumulative frequency distribution of daily clearness index for each study location in the geo-political zone. Following the work of Ref [18], several authors have used similar pattern of seasonal classification without a distinctive method on how to group average monthly $\overline{K}_T$ values into a particular class interval that is free from ambiguity. Considering the number of data used in this study, in choosing class intervals, it is observed that most of the estimated daily clearness index values fall within the range of 0.3 - 0.75. For class intervals of 0 - 0.19 and 0.2 - 0.29 a range of unity is used to group the daily clearness index. This is informed by the fact that few daily clearness index falls within these class intervals. For the other class intervals i.e. 0.3 - 0.34 to 0.75 - 0.79 a range of 0.04 is used. The essence is to avoid over population of each class interval and observe the spread of data. These class intervals are further used in grouping individual average monthly clearness index in Table 5 and subsequently in the organization of average monthly clearness index periods into seasonal classification patterns.

Table 4a Monthly percentage cumulative frequency distribution of daily clearness index for Asaba

	Values of f for $K_T \leq K_T$											
Months	0.0 - 0.19	0.20 - 0.29	0.30 - 0.34	0.35 - 0.39	0.40 - 0.44	0.45 - 0.49	0.50 - 0.54	0.55 - 0.59	0.60 - 0.64	0.65 - 0.69	0.70 - 0.74	0.75 - 0.79	Average monthly $\bar{K}_T$
Jan (621)	0.00	0.49	0.66	1.95	7.27	26.28	51.08	86.67	98.59	100.00	100.00	100.00	0.54
Feb (565)	0.36	1.78	4.62	11.70	26.22	60.74	82.87	96.15	99.16	100.00	100.00	100.00	0.48
Mar (620)	0.97	2.75	6.14	15.34	32.76	66.31	86.31	95.67	98.90	99.87	100.00	100.00	0.47
Apr (600)	1.67	5.67	9.84	16.84	30.68	62.68	82.52	96.52	99.86	100.00	100.00	100.00	0.47
May (620)	1.62	7.75	12.75	19.37	29.86	53.74	78.74	93.74	99.07	100.00	100.00	100.00	0.47
Jun (600)	1.34	5.51	13.68	24.52	44.19	75.53	93.37	99.71	100.00	100.00	100.00	100.00	0.44
Jul (620)	1.62	8.56	23.24	44.37	70.99	92.29	99.23	100.00	100.00	100.00	100.00	100.00	0.40
Aug (591)	1.87	13.21	32.50	56.70	81.92	97.32	99.86	100.00	100.00	100.00	100.00	100.00	0.38
Sept (600)	2.00	10.00	18.17	40.01	68.01	92.85	99.19	100.00	100.00	100.00	100.00	100.00	0.41
Oct (620)	1.13	5.33	10.17	18.56	34.86	68.57	88.74	98.42	100.00	100.00	100.00	100.00	0.46
Nov (600)	0.17	1.17	2.84	4.84	9.84	25.51	54.01	85.85	97.35	100.00	100.00	100.00	0.53
Dec (620)	0.00	0.00	0.97	1.78	5.01	17.60	42.60	77.12	95.03	99.87	100.00	100.00	0.56

Table 4b Monthly percentage cumulative frequency distribution of daily clearness index for Benin City

	Values of f for $K_T \leq K_T$											
Months	0.0 - 0.19	0.20 - 0.29	0.30 - 0.34	0.35 - 0.39	0.40 - 0.44	0.45 - 0.49	0.50 - 0.54	0.55 - 0.59	0.60 - 0.64	0.65 - 0.69	0.70 - 0.74	0.75 - 0.79	Average monthly $\bar{K}_T$
Jan (621)	0.00	0.33	1.62	3.24	7.11	28.21	55.91	90.21	99.23	100.00	100.00	100.00	0.53
Feb (565)	1.24	1.95	4.61	12.76	30.64	65.51	88.52	97.73	99.33	99.87	100.00	100.00	0.47
Mar (620)	0.97	2.91	9.04	18.08	40.02	69.54	89.71	95.84	99.39	99.88	100.00	100.00	0.46
Apr (600)	1.84	7.51	11.51	19.68	33.68	64.68	86.02	98.36	100.00	100.00	100.00	100.00	0.46
May (620)	2.42	8.72	14.85	20.02	31.48	58.42	79.88	95.53	99.57	100.00	100.00	100.00	0.47
Jun (600)	2.00	9.00	18.34	29.34	53.34	81.01	94.18	99.02	99.86	100.00	100.00	100.00	0.43
Jul (620)	3.23	16.62	33.24	54.54	77.13	95.04	99.24	100.00	100.00	100.00	100.00	100.00	0.38
Aug (591)	3.23	19.53	40.83	63.74	85.68	97.62	99.88	100.00	100.00	100.00	100.00	100.00	0.36
Sept (600)	3.17	13.51	29.18	49.52	73.19	95.03	99.37	100.00	100.00	100.00	100.00	100.00	0.39
Oct (620)	1.13	8.55	15.33	24.85	39.85	70.50	90.34	98.41	99.87	100.00	100.00	100.00	0.45
Nov (600)	0.34	1.34	2.84	5.18	10.02	25.52	56.86	86.03	98.03	100.00	100.00	100.00	0.53
Dec (620)	0.17	0.50	0.67	2.13	5.20	18.43	44.89	83.44	96.67	99.90	100.00	100.00	0.55

Table 4c Monthly percentage cumulative frequency distribution of daily clearness index for Calabar

	Values of f for $K_T \leq K_T$											
Months	0.0 - 0.19	0.20 - 0.29	0.30 - 0.34	0.35 - 0.39	0.40 - 0.44	0.45 - 0.49	0.50 - 0.54	0.55 - 0.59	0.60 - 0.64	0.65 - 0.69	0.70 - 0.74	0.75 - 0.79	Average monthly $\bar{K}_T$
Jan (621)	0.17	1.95	4.05	6.95	12.91	26.92	53.01	89.73	99.40	100.00	100.00	100.00	0.53
Feb (565)	1.24	4.61	8.86	15.77	25.33	49.05	73.66	94.73	99.16	100.00	100.00	100.00	0.49
Mar (620)	5.81	15.01	22.60	30.83	43.90	63.90	85.68	98.27	99.89	100.00	100.00	100.00	0.44
Apr (600)	5.17	14.01	22.68	31.35	43.52	60.69	77.36	94.53	99.53	100.00	100.00	100.00	0.44
May (620)	5.33	16.30	22.76	30.67	42.61	58.58	76.33	92.3	98.76	99.89	100.00	100.00	0.45
Jun (600)	5.50	26.50	38.84	51.51	65.51	82.35	92.35	98.69	99.69	100.00	100.00	100.00	0.39
Jul (620)	11.30	40.18	57.12	71.80	82.61	92.78	97.62	99.72	100.00	100.00	100.00	100.00	0.33
Aug (591)	15.33	49.04	68.56	80.50	89.86	96.64	98.74	99.87	100.00	100.00	100.00	100.00	0.30
Sept (600)	12.67	35.17	51.84	67.01	81.01	92.35	97.52	99.86	100.00	100.00	100.00	100.00	0.34
Oct (620)	8.23	21.30	33.24	47.60	62.12	78.90	90.36	98.59	99.89	100.00	100.00	100.00	0.40
Nov (600)	4.17	14.17	21.17	28.84	37.51	53.18	73.35	93.85	99.85	100.00	100.00	100.00	0.46
Dec (620)	0.00	2.75	5.01	9.21	15.34	30.02	51.32	88.42	99.39	100.00	100.00	100.00	0.52

Table 4d Monthly percentage cumulative frequency distribution of daily clearness index for Port-Harcourt

	Values of f for $K_T \leq K_T$												Average monthly $\bar{K}_T$
Months	0.0 - 0.19	0.20 - 0.29	0.30 - 0.34	0.35 - 0.39	0.40 - 0.44	0.45 - 0.49	0.50 - 0.54	0.55 - 0.59	0.60 - 0.64	0.65 - 0.69	0.70 - 0.74	0.75 - 0.79	
Jan (621)	0.97	3.87	6.45	12.09	18.21	33.51	61.53	92.94	99.71	100.00	100.00	100.00	0.51
Feb (565)	2.84	6.92	12.06	18.79	29.59	53.67	78.45	96.33	99.87	100.00	100.00	100.00	0.47
Mar (620)	7.10	18.07	23.72	32.60	45.51	64.55	82.30	96.50	99.89	99.89	100.00	100.00	0.43
Apr (600)	6.00	17.50	24.17	33.34	42.84	59.18	73.02	92.52	99.52	100.00	100.00	100.00	0.44
May (620)	7.10	19.85	28.40	38.08	47.60	60.67	76.32	88.74	98.58	100.00	100.00	100.00	0.43
Jun (600)	11.84	34.01	45.85	57.85	71.19	82.86	91.70	98.04	99.71	100.00	100.00	100.00	0.36
Jul (620)	13.23	40.98	57.92	69.05	80.18	89.86	95.83	99.38	100.03	100.00	100.00	100.00	0.33
Aug (591)	11.78	38.08	53.89	68.41	81.00	91.33	96.98	99.57	99.90	100.00	100.00	100.00	0.34
Sept (600)	12.17	32.67	49.34	60.84	74.84	89.01	95.68	99.18	100.00	100.00	100.00	100.00	0.35
Oct (620)	8.55	22.43	33.89	45.19	59.23	74.07	87.14	98.11	100.00	100.00	100.00	100.00	0.40
Nov (600)	5.67	16.84	23.84	29.84	40.68	55.02	71.86	92.36	99.53	100.00	100.00	100.00	0.45
Dec (620)	0.65	4.36	8.56	13.24	20.50	32.12	51.64	86.16	98.91	100.00	100.00	100.00	0.51

Table 4e Monthly percentage cumulative frequency distribution of daily clearness index for Uyo

	Values of f for $K_T \leq K_T$												Average monthly $\bar{K}_T$
Months	0.0 - 0.19	0.20 - 0.29	0.30 - 0.34	0.35 - 0.39	0.40 - 0.44	0.45 - 0.49	0.50 - 0.54	0.55 - 0.59	0.60 - 0.64	0.65 - 0.69	0.70 - 0.74	0.75 - 0.79	
Jan (621)	0.00	0.65	0.65	2.11	6.15	20.83	49.54	87.61	99.87	100.00	100.00	100.00	0.54
Feb (565)	0.36	2.67	4.09	8.17	20.21	47.65	78.63	95.27	98.99	100.00	100.00	100.00	0.50
Mar (620)	0.81	4.52	8.40	17.76	32.60	59.86	86.64	96.64	98.90	100.00	100.00	100.00	0.47
Apr (600)	1.76	5.10	10.72	17.92	30.03	56.53	81.62	97.41	100.05	100.00	100.00	100.00	0.47
May (620)	2.75	6.79	12.12	19.87	31.97	54.88	80.21	95.86	99.74	100.00	100.00	100.00	0.47
Jun (600)	1.50	8.84	16.84	31.51	49.01	78.51	94.51	99.68	100.00	100.00	100.00	100.00	0.43
Jul (620)	2.75	15.17	30.82	52.92	75.18	91.64	98.74	100.00	100.00	100.00	100.00	100.00	0.39
Aug (591)	2.75	17.43	37.76	61.15	84.54	96.48	99.55	100.00	100.00	100.00	100.00	100.00	0.37
Sept (600)	1.67	9.17	20.67	44.01	70.35	93.19	99.19	100.00	100.00	100.00	100.00	100.00	0.40
Oct (620)	1.30	6.47	11.47	19.54	39.54	72.93	93.90	99.71	99.88	100.00	100.00	100.00	0.45
Nov (600)	0.84	2.51	6.18	10.52	17.52	37.52	63.86	89.36	99.53	100.00	100.00	100.00	0.51
Dec (620)	0.00	0.65	1.30	2.76	6.47	20.51	41.16	81.00	99.07	100.00	100.00	100.00	0.55

Table 4f Monthly percentage cumulative frequency distribution of daily clearness index for Yanagoa

	Values of f for $K_T \leq K_T$												Average monthly $\bar{K}_T$
Months	0.0 - 0.19	0.20 - 0.29	0.30 - 0.34	0.35 - 0.39	0.40 - 0.44	0.45 - 0.49	0.50 - 0.54	0.55 - 0.59	0.60 - 0.64	0.65 - 0.69	0.70 - 0.74	0.75 - 0.79	
Jan (621)	0.49	3.07	6.13	9.84	17.25	34.97	58.97	89.25	99.08	100.00	100.00	100.00	0.51
Feb (565)	2.31	7.09	12.05	19.84	32.06	55.43	81.28	96.15	99.69	100.00	100.00	100.00	0.47
Mar (620)	5.17	14.53	23.41	36.00	47.46	65.21	83.76	95.86	99.90	99.90	100.00	100.00	0.43
Apr (600)	5.84	16.51	24.51	30.85	43.19	58.03	72.20	90.87	98.87	100.00	100.00	100.00	0.45
May (620)	8.23	20.17	29.21	38.57	47.93	62.45	76.33	90.37	98.28	100.00	100.00	100.00	0.43
Jun (600)	10.65	32.45	45.93	58.08	71.06	83.88	91.54	98.03	99.70	100.00	100.00	100.00	0.37
Jul (620)	11.78	35.01	50.98	66.47	77.77	88.90	95.03	99.55	100.00	100.00	100.00	100.00	0.35
Aug (591)	6.94	27.75	45.50	59.21	75.34	88.89	95.35	99.23	100.00	100.00	100.00	100.00	0.37
Sept (600)	7.50	26.17	44.51	62.51	75.01	88.85	97.35	99.52	100.00	100.00	100.00	100.00	0.36
Oct (620)	7.26	17.75	28.08	39.70	56.00	75.52	87.30	96.18	99.41	100.00	100.00	100.00	0.41
Nov (600)	3.00	12.67	18.01	25.51	37.51	52.85	70.85	91.19	99.53	100.00	100.00	100.00	0.46
Dec (620)	0.65	3.24	6.31	11.15	18.57	31.16	47.46	80.53	96.83	99.90	100.00	100.00	0.53

From Table 4a-f, it is observed that average monthly clearness index $(\bar{K}_T)$ values in south-south geo-political zone ranges from 0.30 - 0.56. Referencing the works of [19] and [20], that reported use of K_T values of $0 - 0.15$, $> 0.15 - 0.7$ and > 0.7 for overcast, cloudy and clear sky conditions, respectively. This means that frequency of cloudy days is generally high in this zone. Thus, deployment of solar collectors for exploration of solar energy should be the non-concentrating collector type. $\bar{K}_T$ values range from 0.38 - 0.56, 0.36 - 0.55 and 0.3 - 0.53 for Asaba, Benin City and Calabar, respectively. In Port-Harcourt, Uyo and Yanago $\bar{K}_T$ values ranges in values of 0.33 - 0.51, 0.37 - 0.55 and 0.35 - 0.53, respectively.

Monthly average clearness index curves for the study locations are presented in Fig. 1. It is observed from Fig. 1, that curves of monthly average clearness index for the study locations followed similar pattern. Curves of Asaba, Benin-City and Uyo are observed to follow same pattern and cluster together. This may be as a result of their close values in latitude as presented in Table 1. Thus, these cities tend to have similar values of monthly clearness index and exhibit comparable characteristics. The curves of Asaba, Benin-city, calabar and Uyo are noted to have same pattern of depression in August. This indicates that for these study locations August is worst month of solar radiation harvest. Curves of Port-Harcourt and Uyo are seen to have a different pattern of depression that is relatively flat between July to September. The curve of Port-Harcourt is observed to be flat from July (0.33), August (0.34) to September (0.35). This indicates that in Port-Harcourt, these three months are likely to have same meteorological conditions. Though, July will yield the worst level of global solar radiation. As these three months are months of rainy season, they will be characterized with high level of rainfall annually. Hence, heavily cloudy sky conditions will be prevalent. This result is not in agreement with the work of [21] that reported August as the worst month for the study location. A different depression curve pattern is observed for that of Yanago. On the curve of Yanagoa, more depression is observed in the months of July (0.35) and September (0.36). In August (0.37), a little raise in value is noted, a month between July and September. This reveals that in Yanago, July and September are likely to be cloudier, consequently, worst months of solar radiation harvest will be worst in July. The difference in curve pattern of Asaba, Benin-City, Calabar and Uyo from those of Port-Harcourt and Yanago might be the effect of August break.

It is also observed from Fig. 1 that curves of monthly clearness index for the study locations followed the same pattern from January to May and October to December. From October to December, those of Asaba, Benin-City and Uyo are seen to crowd together while those of Calabar, Port-Harcourt and Yanagoa are clustered together. This reveals possibility of having similar sky conditions in these two groups of cities within these months.

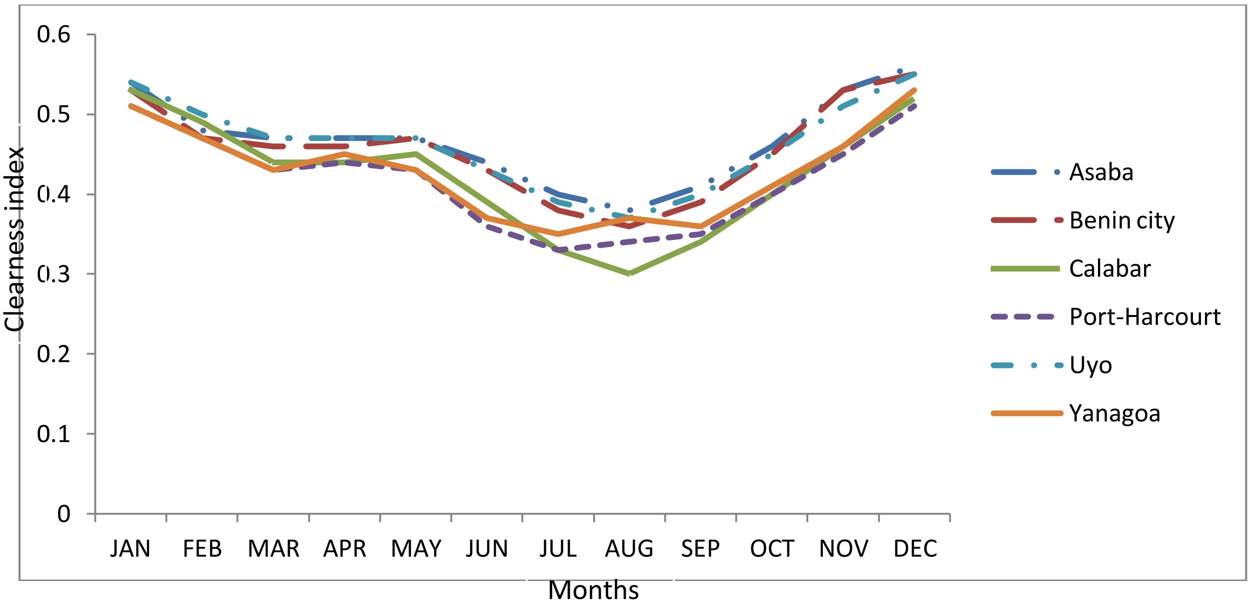

Fig. 1 monthly average clearness index for the study locations

Curves of monthly percentage cumulative frequency distribution of clearness index for August for the study locations are shown in Fig. 2. It is observed from Fig. 2, that curves for Asaba, Benin-City and Uyo followed same pattern. Those of Calabar, Port-Harcourt and Yanago demonstrate a different curve pattern. Change in curve pattern of those of Calabar, Port-Harcourt and Yanagoa is as a result of high $\overline{K}_T$ values in class interval of 0 - 0.99. This further reveals that these three cities have comparable characteristic sky condition in August. Though, in this geo-political zone Calabar is seen to have the lowest monthly percentage cumulative frequency distribution of clearness index followed by those of Port-Harcourt and Yanagoa.

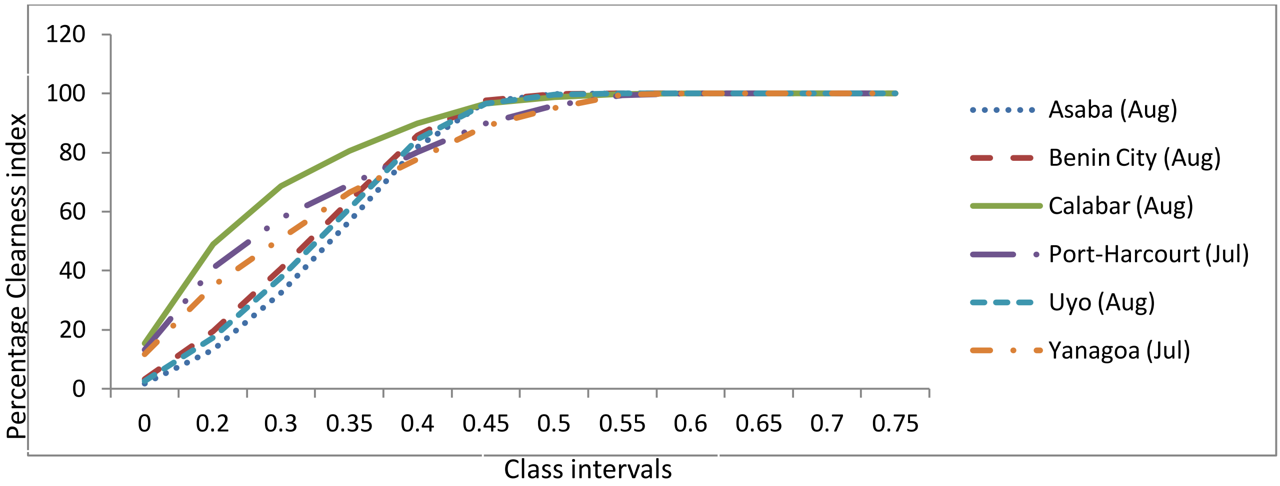

Fig 2 Curves of monthly percentage cumulative frequency distribution of worst daily clearness index values

Seasonal classification of monthly average clearness index is presented in Table 5. Ref [21] aptly reported that months that have same $\bar{K}_T$ values have similar statistical distribution of global solar radiation. Considering the class intervals used in development of Tables 4 a-f, it is observed in Table 5 that six seasonal classification patterns are present in Asaba, Calabar, Port-Harcourt and Uyo. It is of interest to note that in each of these cities, the dry season and rainy season have three groups each. Result obtained in this study for Port-Harcourt by Ref [21] is not in agreement with the finding of this study. This is as a result of disparity in values of monthly clearness index values obtained for each month in Port-Harcourt. In Benin City and Yanagoa, five seasonal classification patterns are observed. The dry season and rainy season in Benin City produced two and three seasonal classifications, respectively. Result obtained in this study is in agreement with the findings of Ref [8] for Benin-City. In Yanagoa, three and two seasonal classification patterns are determined for the dry and rainy seasons, respectively.

Table 5 Seasonal Classification of Monthly Average Clearness Index ($\bar{K}_T$) Values

$K_T\ Values$

Asaba			Benin City			Calabar		
Periods	Ind.	**Ave**	Periods	Ind.	**Ave**	Periods	Ind.	**Ave**
Dry Season **a**. Dec **b.** Jan, Nov **c.** Feb, Mar, Oct	0.58 0.54, 0.53 0.48, 0.47, 0.46	**0.56** **0.54** **0.47**	***Dry Season*** **a.** Nov**,** Dec, Jan, **b.** Feb, Oct, Mar,	0.53,0.55,0.53 0.46, 0.45, 0.46	**0.540.46**	***Dry Season*** **a**. Dec, Jan **b.** Nov, Feb, Mar **c.** Oct	0.52, 0.53 0.46,0.49,0.47 0.40	**0.53** **0.47** **0.40**
Rainy Season **a**. April, May b. June, Sept, July **C.** Aug,	0.47, 0.47 0.44, 0.41, 0.40 0.38	**0.47** **0.41** **0.38**	***Rainy Season*** **a**. April, May b. June **C.** July, Aug, Sept	0.46, 0.47 0.43 0.38, 0.36, 0.39	**0.47** **0.430.38**	***Rainy Season*** **a**. April, May **b.** June **C**. July, Aug, Sept	0.44,0.45 0.39 0.33,0.30,0.34	**0.45** **0.39** **0.53**

$K_T\ Values$

Port-Harcourt			Uyo			Yanagoa		
Periods	Ind.	**Ave**	Periods	Ind.	**Ave**	Periods	Ind.	**Ave**
Dry Season **a.** Dec, Jan b. Feb, Nov **c.** Mar, Oct	0.51, 0.51 0.47, 0.45 0.43, 0.40	**0.67** **0.46** **0.42**	***Dry Season*** **a.** Dec b. Jan, Feb, Nov **b.** Oct, Mar	0.55 0.54, 0.50, 0.51 0.45, 0.47	**0.55** **0.52** **0.46**	***Dry Season*** **a.** Dec, Jan **b**. Nov, Feb **c.** Mar, Oct	0.53, 0.51 0.46, 0.47 0.43, 0.41	**0.52** **0.47** **0.42**
Rainy Season **a.** April, May **b.** June, Sept **C.** July, Aug	0.44, 0.43 0.36, 0.35 0.33, 0.34,	**0.44** **0.36** **0.34**	***Rainy Season*** **a.** April, May **b.** Jun, Sept **c.** July, Aug	0.47, 0.47 0.43, 0.40, 0.39, 0.37	**0.47** **0.42** **0.38**	***Rainy Season*** **a.** April, May, **b.** Jun, Jul, Aug, Sept	0.45,0.43 0.37,0.35, 0.37 0.36	**0.44** **0.36**

3.3 Sunshine Duration

Table 6 shows average monthly values of bright sunshine hours for the study locations. In this geo-political zone the mean total monthly bright sunshine hours is estimated at 53.90 hrs. Months of the dry and rainy seasons contributes 59.46 % and 40.54 % respectively of the mean total bright sunshine hours. The total average monthly bright sunshine hours in the zone ranges in value of 46.17 - 59.56 hrs. While monthly mean of bright sunshine hours range from 1.9 - 7.1 hrs. For the study locations, August is observed as worst month of bright sunshine hours with maximum and minimum values of 2.8 and 1.9 hrs, respectively.

Table 6 Average monthly values of bright sunshine hours

Years/ Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	TOTAL
Asaba	5.62	5.58	4.98	4.85	5.11	3.53	1.93	2.8	2.41	4.27	5.64	5.89	52.61
Benin city	5.9	6.07	5.57	5.55	6.03	4.70	2.91	2.56	3.00	4.61	6.06	6.60	59.56
Calabar	5.4	5.73	5.24	6.27	5.20	4.25	2.55	1.90	2.80	4.50	5.2	7.10	56.14
Port-Harcort	4.79	5.00	4.15	4.58	4.50	3.13	2.09	2.59	2.20	3.14	4.7	5.30	46.17
Uyo	5.4	5.73	5.24	6.27	5.20	4.25	2.55	1.90	2.80	4.50	5.2	7.10	56.14
Yanagoa	5.62	5.58	4.98	4.85	5.11	3.53	1.93	2.80	2.41	4.27	5.64	5.89	52.61
Mean	5.46	5.62	5.03	5.40	5.19	3.90	2.33	2.43	2.60	4.22	5.41	6.31	53.90
Max	5.90	6.07	5.57	6.27	6.03	4.70	2.91	2.80	3.00	4.61	6.06	7.10	59.56
Min	4.79	5.00	4.15	4.58	4.50	3.13	1.93	1.90	2.20	3.14	4.70	5.30	46.17

3.4 ANGSTROM-PAGE EQUATION

Angstrom-Page model equation based on extraterrestrial radiation on a horizontal surface is give as (Duffie and Beckman, 2013)

$$\bar{K}_T = a + b\frac{\bar{n}}{\bar{N}} \qquad (5)$$

Where $\bar{n}$ is hours of bright sunshine, $\bar{N}$ is daily theoretical sunshine in hours and $a\ and\ b$ are local constants which are dependent on latitude and other meteorological parameters.

For a given month, the theoretical sunshine hour is determined from (Duffie and Beckman, 2013)

$$\bar{N} = \frac{2}{15}cos^{-1}(-tan\emptyset\ tan\delta) \quad (6)$$

Where $\emptyset$ is latitude of study location.

The sum of regression coefficients is

$$t = a + b \quad (7)$$

Equ. 7 represent transmissivity of the atmosphere of global radiation under perfectly clear conditions. a and b represents transmissivity of fraction of global radiation under overcast sky condition and sensitivity of normalized global radiation to normalized sunshine duration, respectively. The values of a, b, t and coefficient of determination (R) are presented in Table 7 for each study location.

Table 7 Values of a, b, t and R for the study locations

	a	b	t	R
Asaba	0.309	0.423	0.732	0.850
Benin city	0.265	0.457	0.722	0.879
Calabar	0.222	0.511	0.733	0.855
Port-Harcort	0.216	0.617	0.833	0.922
Uyo	0.306	0.396	0.702	0.848
Yanagoa	0.256	0.463	0.719	0.876
Average	0.262	0.478	0.740	0.872

The coefficient of determination is observed to be high for each study location. This indicates that low variation between $\bar{K}_T$ and $\bar{n}/\bar{N}$ exit. Thus, indicating a strong linear relationship between these metrological parameters in the Angstrom-Page equation for the study locations. The set of parameters in Table 7 can be used to estimate global solar radiation for other locations close to the state capitals with similar meteorological conditions where sunshine measurement is available.

IV. CONCLUSION

Analysis of sky condition in south-south geo-political zone of Nigeria has been carried out using long term data of global solar radiation, clearness index and sunshine hours that span for twenty years. The study reveals the possibility of harvesting solar radiation in this zone under cloudy sky conditions. Different seasonal classifications are determined for each of the study location. The six seasonal periods identified for Port-Harcourt is not in agreement with the work of Ref. [21] Coefficients for Angstrom-Page equation is estimated for the cities and associated coefficient of determination exhibit low variation for each study location. Hence, they are recommended for use in close locality to each of the study location with comparable meteorological conditions.

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