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ANALYSIS OF SOLAR RADIATION MEASUREMENT IN SOUTH-WEST GEO-POLITICAL ZONE OF NIGERIA

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ABSTRACT

Analysis of solar radiation measurement in south–west geo-political zone of Nigeria has been carried out in this paper. Twenty years (2000-2021) data of daily global solar radiation and monthly average hours of bright sunshine are sourced from National Aeronautics and Space Administration (NASA) and Nigeria Meteorological Agency (NIMET), respectively. Monthly average solar radiation on horizontal surface and monthly clearness index values ranges from 3.5 $kWhrm^{-2}day^{-1}$ to 5.18 $kWhrm^{-2}day^{-1}$ and 0.35 – 0.57, respectively, for the geopolitical zone. August is considered as the worst month of solar radiation harvest in the zone. Six seasonal classification periods are identified for Abeokuta, Akure, Ibadan and Oshogbo. While, five seasonal classification periods are observed in Ado-Ekiti and Ikeja. Coefficients of determinations are estimated for Angstrom-Page equation for the study locations and the zone.

Key words: Angstrom-Page, clearness index, seasonal periods, sky condition, solar radiation, south-west, sunshine hour

1.0 INTRODUCTION

Energy is an essential component of modern society. This is so because production and manufacturing activities revolve around it. Energy is considered a prime agent in generation of wealth and a significant factor in economic development. Its importance in economic development is recognized universally and historical data verify that there is a strong relationship between the availability of energy and economic activity (UNDP, 2012). Conventional energy sources provide majority of energy utilization around the world, accounting for about 80% of energy production (Vanek and Albright, 2008). In future, the world will face energy crises due to lack of fossil fuels. This is a matter of concern for the entire countries whose economy heavily depends on its use (Ashok, Rajesh and Atul 2012). Unfortunately, it is now universally accepted that fossil fuels are finite and it is only a matter of time before their reserves become exhausted (Sambo, 2009). It has been reported that proven reserves of oil and gas at current rates of consumption would be adequate to meet demand between 41 to 67 years, while the reserve for coal would be adequate for at least the next 230 years (Goswani, 2007). Most developing countries of the world still depend on convectional energy to meet their energy demands. The problem with over dependence on this form of energy is that it is rapidly depleting and its exploration, production and sell has become a political and environmental issue that has hampered effective distribution world wild. Increased dependence on convectional energy has no doubt been of benefit at large to most countries by providing employment, development of infrastructures, opportunities for strategic alliance among counties and primary source of income. The industrial and economic development which have been made possible through the use of convectional energy resources have also brought about significant environmental degradation and climate change with severe impact on human and ecosystem. The gradual depletion and environmental consequence in the use of this type of fuel has called for a shift in energy sources.

With influx of solar collector into the country for electrification, water heating, space cooling, water pumping and purification, agricultural and industrial utilization. It is necessary to analysis quality and quantity of solar radiation at location of application. This is important for estimation of long term performance, optimization of design and evaluation of cost and maintenance. Thus, this paper tends to (i) analysis solar radiation intensity for the study locations as the principle input meteorological parameter required during design stages of solar collectors. (ii) Characterize the sky conditions of the study location. (iii) Develop Anstrong-Page equation(s) for the study location and the zone in general.

1.0 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-West is a geo-political zone in Nigeria. It is located in southern part of Nigeria. This zone consists of six states which include; Ogun State (Abeokuta), Ekiti State (Ado-Ekiti), Ondo State (Akure), Oyo State (Ibadan), Lagos State (Ikeja) and Osun State (Oshogbo)

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 (^{O}N)	Longitude (^{O}E)
ABEOKUTA	7.1475	3.3619
ADO-EKITI	7.6124	5.237
AKURE	7.2571	5.2058
IBADAN	7.3775	3.9470
IKEJA	6.6018	3.3515
OSHOGBO	7.7827	4.5418

3.0 Methodology and Analysis

3.1 Global Solar Radiation

Table 2 presents monthly average solar radiation on a horizontal surface for the study locations. The total mean monthly average solar radiation for the region is estimated at 55.66 kWhrm^{-2}day^{-1} and it ranges from 54.95 kWhrm^{-2}day^{-1} (Akure) to 56.63 kWhrm^{-2}day^{-1} (Oshogbo). For the study locations, monthly average solar radiation on horizontal surface ranges from 3.5 kWhrm^{-2}day^{-1} (August) to 5.18 kWhrm^{-2}day^{-1} (November). The most variable month for the region is August (16.13 %), while, the steadiest month is March (0.80 %).

Table 2 Monthly Averages Solar Radiation on a Horizontal Surface $(H)(kW-hrm^{-2}day^{-1})$

Years/ Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Total
ABEOKUTA	4.92	4.81	5	5.07	4.92	4.42	3.87	3.55	4.07	4.68	5.04	4.93	55.28
ADO-EKITI	5.07	4.87	5.02	5.02	4.98	4.53	4.11	3.81	4.23	4.71	5.18	5.10	56.63
AKURE	5.07	4.87	5.02	5.02	4.98	4.53	4.11	3.81	4.23	4.71	5.18	5.10	56.63
IBADAN	4.92	4.81	5,00	5.07	4.92	4.42	3.87	3.55	4.07	4.68	5.04	4.94	55.29
IKEJA	4.88	4.77	4.98	5.01	4.69	3.97	3.89	4.10	4.20	4.66	5.07	4.97	55.19
OSHOGBO	4.91	4.81	5.01	4.98	4.88	4.41	3.80	3.50	4.01	4.57	5.09	4.98	54.95
mean	4.96	4.82	5.01	5.03	4.90	4.38	3.94	3.72	4.14	4.67	5.10	5.00	55.66
max	5.07	4.87	5.02	5.07	4.98	4.53	4.11	4.10	4.23	4.71	5.18	5.10	56.63
min	4.88	4.77	4.98	4.98	4.69	3.97	3.80	3.50	4.01	4.57	5.04	4.93	54.95
max-min	0.19	0.10	0.04	0.09	0.29	0.56	0.31	0.60	0.22	0.14	0.14	0.17	1.68
(max-min/mean)100	3.83	2.07	0.80	1.79	5.92	12.79	7.87	16.13	5.32	3.00	2.75	3.40	3.02

Table 3 presents percentage frequency distribution of daily global solar radiation for the study locations. It is observed from Table 3, that larger percentage of global solar radiation in the region falls within class intervals of 3.00 – 3.99, 4.00 – 4.99 and 5.00 – 5.99. Percentage of solar radiation value within these class intervals ranges from 14.5 to 41.18 %. Class intervals of 0.0 – 0.99, 1.0 – 1.19 and 7.0 – 7.99 are seen to recorded relatively low percentage frequency distribution of daily global solar radiation for all the study locations.

Table 3 Percentage frequency distribution of daily 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
ABEOKUTA	0.02	0.03	5.92	16.58	41.18	32.81	3.47	0.03	0
ADO-EKITI	0.00	0.06	4.29	14.50	39.79	37.06	4.29	0.05	0
AKURE	0.00	0.06	4.29	14.50	39.79	37.06	4.29	0.05	0
IBADAN	0.02	0.03	5.92	16.58	41.18	32.81	3.47	0.03	0
IKEJA	0.21	0.47	10.22	14.58	30.46	38.07	6.03	0.00	0
OSHOGBO	0.02	0.02	6.47	17.16	41.03	31.95	3.37	0.03	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 (Duffie and Beckman, 2013).

$$H_O = \frac{24\, x3600 G_{sc}}{\pi}\left(1 + 0.033 cos\frac{360n}{365}\right) x \left(cos\varnothing cos\delta sin\omega_s + \frac{\pi\omega_s}{180} sin\varnothing sin\delta\right) \qquad (2)$$

Where G_{sc} is solar constant given as 1367W/m^2, $\varnothing$ 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 (Iqbal, 1983).

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 (Duffie and Beckman, 2013)

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

where (n) is average day for each month

Sunset hour angle (ω_s) is given as (Duffie and Beckman, 2013)

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

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 Liu and Jordan (1960), several authors have used similar pattern of seasonal classification without a distinctive method on how to group average monthly $\bar{K}_T$ 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 Abeokuta

	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	MONTHLY $\bar{K}_T$
Jan (621)	0.00	0.17	1.3	1.95	6.14	21.76	49.3	88.76	99.72	100.00	100.00	100.00	0.54
Feb (565)	0.18	0.89	2.31	5.85	20.37	51.17	80.91	96.67	99.68	100.00	100.00	100.00	0.50
Mar (620)	0.17	1.79	4.54	10.03	24.55	55.52	80.85	95.05	99.09	99.90	100.00	100.00	0.49
Apr (600)	1.00	3.84	7.18	12.68	25.52	49.52	73.69	93.03	98.87	99.87	100.00	100.00	0.49
May (620)	1.30	6.95	10.83	16.16	26.65	50.69	74.24	91.34	98.76	100.00	100.00	100.00	0.49
Jun (600)	1.00	4.67	13.84	26.68	46.18	74.52	89.86	98.53	99.70	100.00	100.00	100.00	0.45
Jul (620)	1.30	12.27	28.73	52.61	78.91	94.4	98.6	100.00	100.00	100.00	100.00	100.00	0.39
Aug (620)	1.62	26.26	49.29	72.32	90.52	98.09	99.54	100.00	100.00	100.00	100.00	100.00	0.35
Sep (600)	1.34	7.18	23.35	46.19	72.53	93.03	99.37	99.71	100.00	100.00	100.00	100.00	0.40
Oct (620)	0.00	2.91	6.62	14.37	29.21	59.38	81.97	96.33	99.4	100.00	100.00	100.00	0.48
Nov (600)	0.17	0.51	1.01	2.51	5.51	20.01	46.35	81.69	98.69	100.00	100.00	100.00	0.55
Dec (620)	0.00	0.33	0.50	1.47	5.02	15.99	40.51	78.26	96.97	100.00	100.00	100.00	0.56

Table 4b Monthly percentage cumulative frequency distribution of daily clearness index for Ado-Ekiti

	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	MONTHL Y$\bar{K}_T$
Jan (621)	0.00	0.00	0.33	1.78	5.01	17.09	38.67	77.48	98.1	100.00	100.00	100.00	0.56
Feb (565)	0.18	1.07	1.61	5.33	19.67	51.00	74.37	95.44	98.63	99.70	100.00	100.00	0.50
Mar (620)	0.00	1.46	4.05	9.86	24.86	54.86	80.83	93.74	98.42	99.72	100.00	100.00	0.49
Apr (600)	0.84	6.01	9.51	14.35	25.52	50.86	76.7	94.54	99.04	100.00	100.00	100.00	0.49
May (620)	1.13	6.46	10.01	15.34	23.57	45.51	71.97	90.04	98.59	100.00	100.00	100.00	0.49
Jun (600)	0.50	5.17	11.34	19.68	40.52	68.36	90.53	97.7	100.00	100.00	100.00	100.00	0.46
Jul (620)	0.17	7.11	20.02	38.25	66.64	91.81	97.94	99.56	100.00	100.00	100.00	100.00	0.41
Aug (620)	0.65	13.24	34.05	62.93	84.71	97.46	99.40	100.00	100.00	100.00	100.00	100.00	0.38
Sep (600)	1.17	6.34	17.51	37.85	63.02	88.52	97.69	99.86	100.00	100.00	100.00	100.00	0.42
Oct (620)	0.65	3.24	8.57	15.03	27.13	56.97	80.85	95.53	99.24	100.00	100.00	100.00	0.48
Nov (600)	0.00	0.34	1.34	2.34	4.68	15.35	40.02	72.69	91.86	100.00	100.00	100.00	0.56
Dec (620)	0.00	0.00	0.17	0.98	3.08	10.99	28.90	64.71	91.65	99.72	100.00	100.00	0.57

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

	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	MONTHLY $\bar{K}_T$
Jan (621)	0.00	0.00	0.33	1.78	5.01	17.09	38.67	77.48	98.1	100.04	100.00	100.00	0.56
Feb (565)	0.18	1.07	1.61	5.33	19.67	51.00	74.37	95.44	98.63	99.70	100.00	100.00	0.50
Mar (620)	0.00	1.46	4.05	9.86	24.86	54.86	80.83	93.74	98.42	99.72	100.00	100.00	0.49
Apr (600)	0.84	6.01	9.51	14.35	25.52	50.86	76.70	94.54	99.04	100.00	100.00	100.00	0.49
May (620)	1.13	6.45	10.00	15.32	23.54	45.61	72.02	90.06	98.60	100.05	100.00	100.00	0.49
Jun (600)	0.50	5.17	11.34	19.68	40.52	68.36	90.53	97.70	100.00	100.00	100.00	100.00	0.46
Jul (620)	0.17	7.11	20.02	38.25	66.64	91.81	97.94	99.56	100.00	100.00	100.00	100.00	0.41
Aug (620)	0.65	13.24	34.05	62.93	84.71	97.46	99.40	100.05	100.00	100.00	100.00	100.00	0.38
Sep (600)	1.17	6.34	17.51	37.85	63.02	88.52	97.69	99.86	100.00	100.00	100.00	100.00	0.42
Oct (620)	0.65	3.24	8.57	15.03	27.13	56.97	80.85	95.53	99.24	100.00	100.00	100.00	0.48
Nov (600)	0.00	0.34	1.34	2.34	4.67	15.32	39.95	72.73	91.87	100.00	100.00	100.00	0.56
Dec (620)	0.00	0.00	0.17	0.98	3.08	10.99	28.90	64.71	91.65	99.72	100.00	100.00	0.57

Table 4d Monthly percentage cumulative frequency distribution of daily clearness index for Ibadan

	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	MONTHLY $\bar{K}_T$
Jan (621)	0.00	0.17	1.30	1.95	6.14	21.76	49.30	88.76	99.72	100.00	100.00	100.00	0.54
Feb (565)	0.18	0.89	2.31	5.85	20.37	51.17	80.91	96.67	99.68	100.00	100.00	100.00	0.50

Mar (620)	0.17	1.79	4.54	10.03	24.55	55.52	80.85	95.05	99.09	99.90	100.00	100.00	0.49
Apr (600)	1.00	3.84	7.18	12.68	25.52	49.52	73.69	93.03	98.87	99.87	100.00	100.00	0.49
May (620)	1.30	6.95	10.83	16.16	26.65	50.69	74.24	91.34	98.76	100.00	100.00	100.00	0.49
Jun (600)	1.00	4.67	13.84	26.68	46.18	74.52	89.86	98.53	99.70	100.00	100.00	100.00	0.45
Jul (620)	1.30	12.27	28.73	52.61	78.91	94.4	98.60	100.00	100.00	100.00	100.00	100.00	0.39
Aug (620)	1.62	26.3	49.37	72.28	90.51	98.1	99.56	100.00	100.00	100.00	100.00	100.00	0.35
Sep (600)	1.34	7.18	23.35	46.19	72.53	93.03	99.37	99.71	100.00	100.00	100.00	100.00	0.40
Oct (620)	0.00	2.91	6.62	14.37	29.21	59.38	81.97	96.33	99.40	100.00	100.00	100.00	0.48
Nov (600)	0.17	0.51	1.01	2.51	5.51	19.99	46.28	81.73	98.71	100.00	100.00	100.00	0.55
Dec (620)	0.00	0.33	0.50	1.47	4.86	15.83	40.03	78.10	96.98	100.00	100.00	100.00	0.56

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

	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	MONTHLY $\overline{K}_T$
Jan (621)	0.65	2.27	4.37	6.31	10.98	25.32	53.34	90.54	98.92	100.00	100.00	100.00	0.53
Feb (565)	1.07	3.55	5.68	11.35	24.63	51.71	79.15	96.32	100.00	100.00	100.00	100.00	0.49
Mar (620)	0.81	5.17	9.05	15.35	27.77	48.42	74.88	92.79	99.41	100.00	100.00	100.00	0.49
Apr (600)	2.34	9.01	14.68	20.52	29.02	43.69	66.36	88.36	98.20	100.00	100.00	100.00	0.49
May (620)	5.97	12.59	18.56	26.31	36.15	51.15	68.25	88.58	98.75	100.00	100.00	100.00	0.47
Jun (600)	8.84	25.18	35.85	44.52	55.52	70.36	83.53	96.20	99.20	100.00	100.00	100.00	0.40
Jul (620)	5.49	22.11	34.53	49.37	62.92	79.70	91.16	98.58	99.88	100.00	100.00	100.00	0.39
Aug (620)	2.26	14.04	31.14	45.50	61.96	82.45	92.45	99.23	100.00	100.00	100.00	100.00	0.41
Sep (600)	3.84	15.84	27.51	37.35	56.19	77.53	92.87	99.37	99.87	100.00	100.00	100.00	0.41
Oct (620)	2.75	11.16	18.43	25.87	33.14	47.68	68.36	91.14	99.55	100.00	100.00	100.00	0.47
Nov (600)	1.00	2.50	5.17	7.51	12.68	23.02	39.19	74.53	96.87	99.71	100.00	100.00	0.54
Dec (620)	0.49	1.14	2.44	4.70	9.38	17.45	39.71	76.49	94.4	99.08	100.00	100.00	0.55

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

	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	MONTHLY $\overline{K}_T$
Jan (621)	0.00	0.33	0.82	2.11	6.46	24.34	50.75	87.95	99.71	100.00	100.00	100.00	0.54
Feb (565)	0.00	0.71	2.31	6.92	21.62	53.31	79.69	95.80	99.34	100.00	100.00	100.00	0.49
Mar (620)	0.00	1.94	4.2	8.72	23.08	57.60	82.28	93.74	98.74	99.87	100.00	100.00	0.49
Apr (600)	1.34	5.01	8.18	14.35	26.35	54.02	77.52	94.69	99.03	100.00	100.00	100.00	0.48
May (620)	1.13	5.97	11.14	16.63	27.28	52.28	76.32	91.32	98.26	99.88	100.00	100.00	0.48
Jun (600)	0.50	6.00	14.00	27.00	45.67	75.51	90.68	98.02	99.86	100.00	100.00	100.00	0.44
Jul (620)	1.62	14.69	33.08	54.86	79.54	95.67	98.90	99.71	100.00	100.00	100.00	100.00	0.38
Aug (620)	2.26	25.81	52.91	75.98	93.08	97.92	99.70	100.00	100.00	100.00	100.00	100.00	0.35
Sep (600)	0.84	10.01	26.68	49.35	72.85	94.35	99.19	99.69	100.00	100.00	100.00	100.00	0.40
Oct (620)	0.33	3.56	8.24	17.12	35.03	66.16	87.46	97.79	99.57	99.90	100.00	100.00	0.47
Nov (600)	0.34	0.68	1.02	2.86	5.70	20.04	43.04	77.38	97.55	100.00	100.00	100.00	0.55
Dec (620)	0.00	0.17	0.50	1.63	3.73	13.09	37.45	74.07	96.17	100.00	100.00	100.00	0.56

From Table 4a-f, monthly clearness index values ($\overline{K}_T$) ranges from 0.35 – 0.57 for the geopolitical zone. Referencing the works of Li and Lam (2001) and Li, Lau and Lam (2004), 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 reveals that sky condition in the geopolitical zone is expected to be of cloudy condition yearly. Thus, the use of concentrate solar collector for harvest of solar radiation may not be feasible. As large quantities of diffuse radiation is expected in the region. The $\overline{K}_T$ for Abeokuta, Ibadan and Oshogbo range from 0.35 – 0.56. Ado-Ekiti and Akuru have their $\overline{K}_T$ values estimated within the range of 0.38 – 0.57. The monthly clearness index for Ikeja ranges from 0.39 – 0.57.

Fig. 1 represents curves of monthly clearness index for the study locations. It is observe that $\overline{K}_T$ curves for the study locations followed same pattern. Sharp depression of the curves is noted in August for the study locations. Thus, August is likely worst month of solar radiation in the geopolitical zone. This is expected as August is usually characterized with high level of rainfall in Nigeria. Therefore, August is expected to be cloudier. The cluster of $\overline{K}_T$ curves from October – December and January – April indicates that these study locations are likely to have

similar sky conditions characteristics. Though, slight variation in sky condition may exit as the level of $\overline{K}_T$ is not of same value for the study locations. During May – September, monthly clearness curves are seen to deviate from one another. Expect those of Ibadan and Abeokuta, and Akure and Ado-Ekiti that are seen to completely cross one another. Considerably, trailing behind those of Ibadan and Abeokuta is the curve of Oshogbo. The curve of Ikeja is seen to fluctuate within this period.

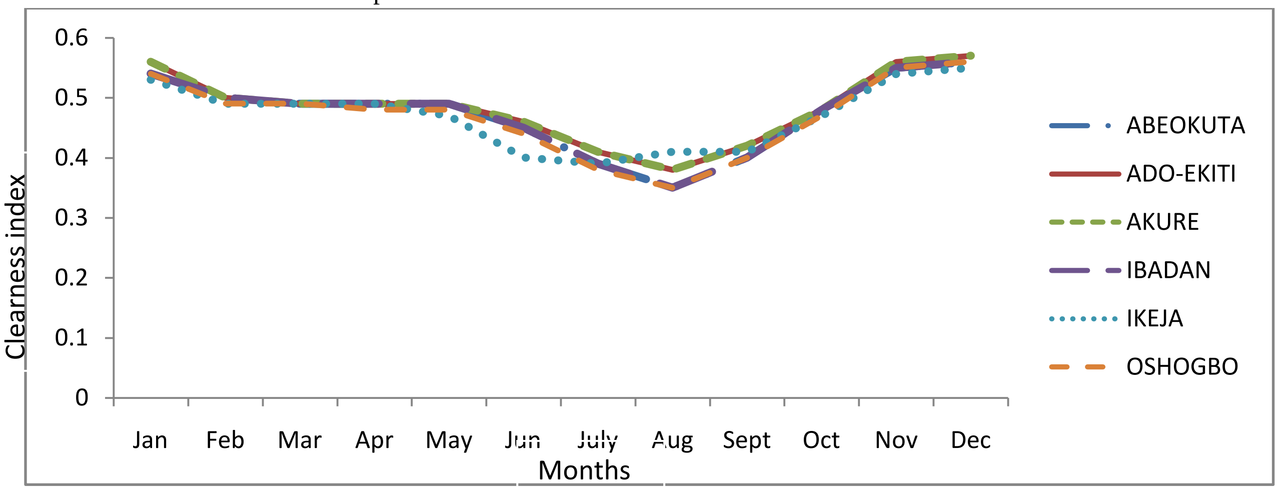

Fig. 1 monthly average clearness index for the study locations

Fig. 2 presents cumulative frequency curves of August for the study locations. It is observed from Fig. 2 that cumulative frequency curve for Ikeja recorded the lowest $\overline{K}_T$ values. This indicates that in the geopolitical zone, Ikeja (Lagos State) is likely to have worst sky condition. This is expected as Lagos State is bound on her southern boundary by the Atlantic Ocean. Trailing behind the curve of Ikeja are those of Akure and Ado-Ekiti and Ibadan and Akure. Curves of Akure/Ado-Ekiti and Ibadan/Akure are observed to completely cross each other. Similar phenomenon for these cities is observed in Fig 1. Thus, it may be infer that Akure and Ado-Ekiti and Ibadan and Akure may have similar sky conditions. Slightly trailing behind those of Ibadan/Akure is the curve of Oshogbo. The curve for Oshogbo is observed to almost blend with those of Ibadan/Akure. Thus, indicating almost similar sky condition characteristics in Oshogbo, Ibadan and Akure.

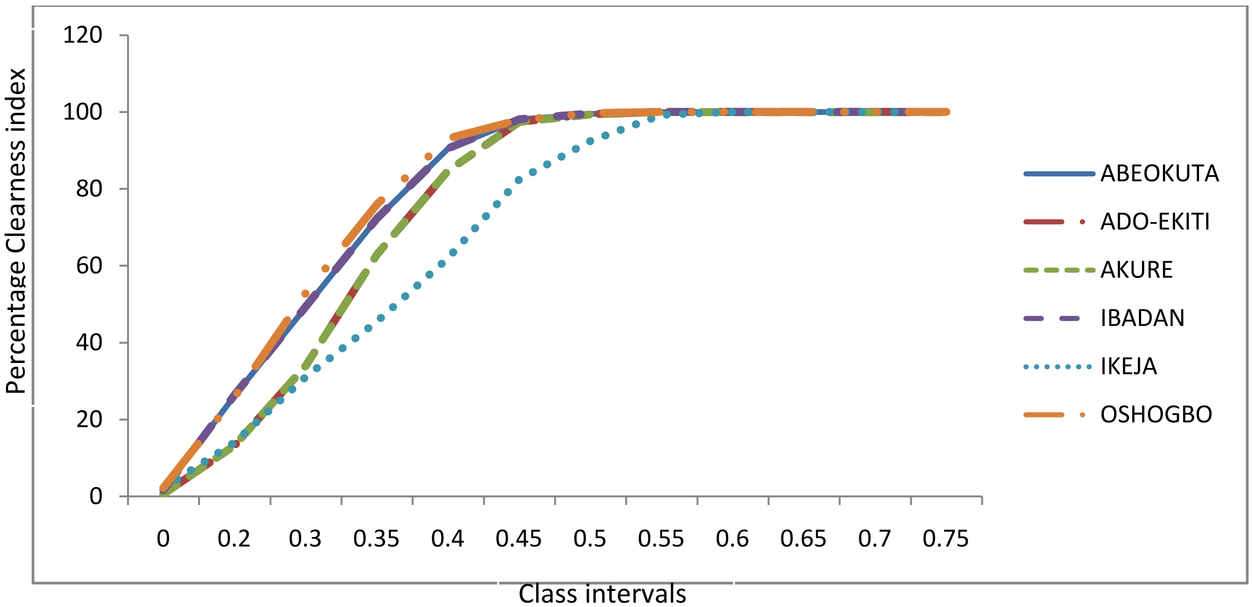

Fig 2 Curves of monthly percentage cumulative frequency distribution of daily clearness index for August

Table 5 present seasonal classifications of monthly average clearness index for the study location. Anyanwu and Oteh (2003) aptly reported that months that have the same $\bar{K}_T$ values have similar statistical distribution of global solar radiation. Considering class intervals used in the development of Tables 4a-f. In Abeokuta, Akure, Ibadan and Oshogbo six seasonal classification patterns are identified. For these cities, three seasonal classification groups are observed in dry and rainy season. The result obtained for Ibadan in this study is in agreement with that of Ideriah and Suleman (1989) where six seasonal classifications were obtained. Five seasonal classification patterns are determined for Ikeja and Ado-Ekiti. Dry and rainy season produced two and three seasonal classification periods, respectively.

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

K_T Values								
Abeokuta			Ado-Ekiti			Akure		
Periods	Ind.	**Ave**	Periods	Ind.	**Ave**	Periods	Ind.	**Ave**
Dry Season			***Dry Season***			***Dry Season***		
a. Nov, Dec	0.55, 0.56	**0.56**	**a.** Nov, Dec, Jan,	0.56, 0.57, 0.56	**0.57**	**a.** Nov, Dec, Jan	0.56, 0.57, 0.56	**0.57**
b. Jan, Feb	0.54, 0.50	**0.52**	**b.** Feb, Oct, Mar	0.46, 0.48, 0.49	**0.48**	**b.** Feb	0.50	**0.50**
c. Mar, Oct	0.49, 0.48	**0.49**				**c.** Mar, Oct	0.49, 0.48	**0.47**
Rainy Season			***Rainy Season***			***Rainy Season***		
a. April, May, June	0.49, 0.49, 0.45	**0.48**	**a.** April, May, June	0.49, 0.49, 0.46	**0.48**	**a.** April, May, June	0.49, 0.49, 0.46	**0.48**
b. July, Aug	0.39, 0.35	**0.37**	**b.** July, Sept	0.41, 0.42	**0.42**	**b.** Aug	0.38	**0.38**
c. Sept,	0.40	**0.40**	**c.** Aug	0.38	**0.38**	**c.** July, Sept	0.41, 0.42	**0.42**

K_T Values								
Ibadan			Ikeja			Oshogbo		
Periods	Ind.	**Ave**	Periods	Ind.	**Ave**	Periods	Ind.	**Ave**

Dry Season			***Dry Season***			***Dry Season***		
a. Nov, Dec	0.55, 0.56	**0.56**	**a.** Nov, Dec, Jan	0.54, 0.55,0.53	**0.54**	**a.** Nov, Dec	0.55, 0.56	**0.56**
b. Jan, Feb	0.54, 0.50	**0.52**	**b.** Feb, Mar, Oct	0.49, 0.49, 0.47	**0.48**	**b**. Jan	0.54	**0.54**
c. Mar, Oct	0.49, 0.48	**0.49**				**c.** Feb, Mar, Oct	0.49,0.49, 0.47	**0.48**
Rainy Season			***Rainy Season***			***Rainy Season***		
a. April, May, June	0.49, 0.49, 0.47	**0.47**	**a.** April, May	0.49, 0.47	**0.48**	**a.** April, May,	0.48, 0.48	**0.48**
b. July, Aug	0.39, 0.35	**0.37**	**b.** Jun, Aug, Sept	0.40, 0.41,0.41	**0.41**	**b.** Jun, Sept	0.44, 0.40	**0.42**
c. Sept	0.40	**0.40**	**c.** July	0.39	**0.39**	**c**. July, Aug	0.38, 0.35	**0.37**

Table 6 shows average monthly values of bright sunshine hours for the study locations. In the geopolitical zone, a mean total of 62.22 hrs of monthly bright sunshine is estimated. Months of the dry and rainy seasons contribute 59.13 % and 40.87 %, respectively of the mean monthly total. The monthly total hours of bright sunshine in the zone varies from 55.75 hrs (Abeokuta) – 69.89 hrs (Oshogbo). The average monthly values of hours of bright sunshine range from 2.15 to 7.54 hrs for the study locations. In all the study location, August recorded the least value of solar radiation. This indicates that August is worst month of harvest of bright hours of sunshine. Hence, yearly, August is likely to be cloudier therefore resulting in poor performance of solar collector during this month.

Table 6 Average monthly values of bright sunshine hours

Years/ Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Monthly Total
ABEOKUTA	5.00	5.35	5.53	5.55	5.90	4.30	3.03	2.15	3.06	4.15	5.73	6.00	55.75
ADO-EKITI	6.17	6.00	6.20	5.99	5.40	4.68	3.09	2.68	3.30	5.23	6.59	6.62	61.95
AKURE	6.52	5.86	6.30	6.37	5.30	4.24	2.74	2.65	3.50	4.83	6.37	6.40	61.08
IBADAN	5.82	6.05	6.09	5.60	6.37	5.11	3.44	2.70	3.10	5.63	6.80	6.84	63.55
IKEJA	6.13	6.92	6.05	5.91	5.80	3.46	2.43	3.06	3.36	5.28	6.27	6.38	61.05
OSHOGBO	6.81	6.90	7.14	6.27	6.70	5.73	3.64	2.55	3.44	5.83	7.34	7.54	69.89
MEAN	6.08	6.18	6.22	5.95	5.91	4.59	3.06	2.63	3.29	5.16	6.52	6.63	62.22
MAX	6.81	6.92	7.14	6.37	6.70	5.73	3.64	3.06	3.50	5.83	7.34	7.54	69.89
MIN	5.00	5.35	5.53	5.55	5.30	3.46	2.43	2.15	3.06	4.15	5.73	6.00	55.75

3.4 ANGSTROM-PAGE EQUATION

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

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

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
ABEOKUTA	0.257	0.551	0.808	0.882
ADO-EKITI	0.284	0.457	0.741	0.908
AKURE	0.295	0.437	0.732	0.870
IBADAN	0.247	0.505	0.752	0.938
IKEJA	0.305	0.383	0.688	0.858

OSHOGBO	0.256	0.431	0.687	0.927
ABEOKUTA	0.257	0.551	0.808	0.882
MEAN	0.272	0.474	0.745	0.895

Coefficient of determination is observed to be high for each study location. This indicates that a low variation between $\bar{K}_T$ and $\bar{n}/\bar{N}$ exist. Thus, it reveals that a strong linear relationship between these metrological parameters in the Angstrom-Page equation for the study locations. The values of a and b in Angstrong-Page equation for the entire zone is estimated at 0.272 and 0.474, respectively. These set of parameters in Table 7 can be used to estimate global solar radiation for the geo-political zone and/or other locations close to the state capitals with similar meteorological conditions where sunshine measurement is available.

4.0 Conclusion

With the aid of global solar radiation, clearness index and sunshine hour, sky condition of South – West Geopolitical zone has been characterized. The worst month for harvest of solar radiation in the zone is August as it recorded the lowest level of clearness index and hours of bright sunshine. The city of Ikeja is considered the worst location for harvest of solar radiation in the geopolitical zone. Coefficients for the Angstrom-Page equation is estimated for the cities and the associated coefficient of determination exhibited 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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