Solar Radiation Evaluation in North-East Geo-Political Zone of Nigeria

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Abstract*- Sky condition evaluation in north-east geo-political zone of Nigeria has been carried out in this paper. Twenty years (2000-2020) data of daily global solar radiation and monthly average bright sunshine hours are sourced from National Aeronautics and Space Administration (NASA) and Nigeria Meteorological Agency (NIMET), respectively. The zone consists of six states. Total average global solar radiation on horizontal surface of 69.05 kWhrm^{-2}day^{-1} is estimated for the zone. Monthly average clearness index ranges from 0.42 – 0.69. These depict that cloudy sky condition is prevalent in north-east of Nigeria. A monthly bright sunshine hour of the geo-political zone is estimated at 94.16 hrs. Five (5) seasonal classification periods are recorded in Bauchi, Damaturu and Yola. In Gombe and Maidugri, six seasonal classification periods were observed. While in Jalingo, seven seasonal periods were identified. Coefficients of determination are estimated for Angstrom-Page equation for the study locations and zone.

***Indexed Terms*- clearness index, north-east, seasonal periods, sky condition, solar radiation, sunshine hour**

I. INTRODUCTION

Energy generation and supply are essential for economic and sustainable development in any nation. The accelerating increase in conventional energy consumption of modern society has caused serious environmental issues such as global warming, air-pollution and other environmental related problems. The desire to save the planet has necessitated a change for energy usage that is environmentally friendly, readily available, abundant and safe (Li, Ma, Lian and Wang, 2010 and Jakhrani, Raza, Rigit, and Kamboh, 2013). Among the non-conventional form of energy, solar energy is perhaps most feasible alternative and sustainable energy resource in the world (Shukla, Sudhakar and Rangnekar, 2015).

Solar energy is a form of renewable energy harnessed from the sun. Being pollution free makes it an environmental friendly, sustainable source of energy. The abundant supply of solar energy in Nigeria makes it a vital alternative source of energy for domestic and industrial use. Solar radiation is fairly well distributed in Nigeria. Average sunshine hours are estimated at 6 hrs per day and mean-average of total solar radiation varies from 3.5 kWhm^{-2}day^{-1} in coastal latitudes to about 7 kWhm^{-2}day^{-1} along semi-arid areas in far North (Sambo, 2009). Harvesting this large quantity of energy is essential for economic growth and reduces dependence on fossil fuel.

Conversion of sun's energy to more useful forms requires solar collector (photovoltaic and solar thermal systems). The optimization, design and performance evaluation of these solar collectors require use of meteorological data of location where the solar appliances are to be used. Among meteorological data, incident solar radiation on horizontal surface and subsequently titled solar radiation are of utmost importance.

Liu and Jordan (1960), based on statistical analysis of daily global solar radiation incident on horizontal surface for twenty-seven locations with approximately five years of data collection in temperate region of North-America presented a set of generalized clearness index curves. They postulated that long term distribution of daily global irradiation over a month correspond to a given value of monthly average clearness index, which is independent of location and month. The basic implication of this statement is that corresponding generalized probability density function, must also be of generalized validity and thereby applicable to any location and month. The universal applicability of the generalized cumulative distribution curves in the tropical regions had been questioned by Saunier, Reddy and Kumar (1987), also Akuffo and Brew-Hammond (1993) using solar radiation data of Bangkok and Kumasi, respectively. They found out that the generalized cumulative frequency curves of Liu and Jordan is not applicable in tropical locality of their study.

In Nigeria, similar results have been obtained by several authors who studied sky conditions of different localities. Kuye and Japta (1992), presented for Port-Harcourt. Ideriah and Suleman (1989), studied for Ibadan. Udo (2000), investigated for Ilorin. Anyanwu and Oteh (2003), analyzed for Owerri. Okogbue, Adedokun and Holmgren (2009), evaluated for IIe-Ife. Egeonu, Njoku and Enibe (2014), studied for Nsukka. Yusuf (2017), worked on Iseyin. Njoku, Ofong, Ogueke and Anyanwu (2018), studied for Owerri and Benin City. Due to paucity of solar radiation data in Nigeria, authors have used privately measured data or data from different sources, which are often incomplete due to interruptions as a result of malfunctioning of instrument used in their studies.

The need to analyze the long-term solar radiation and relative sunshine data of any given locality is important for seasonal characteristic distribution of this metrological parameter. The aim of this paper is to process and analyze global solar radiation of the geo-political zone and quantify the characterization of sky conditions of each study location by using global solar radiation, clearness index and relative sunshine. This will enable for proper exploitation of solar energy and effective design, sizing and deployment of solar collectors in north-east geo-political zone of Nigeria

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.

North-east is a geo-political zone located in northern part of Nigeria. This zone consists of six states which include Bauchi (Bauchi), Yobe (Damaturu), Gombe (Gombe), Taraba (Jalingo), Borno (Maidugri) and Adamawa (Yola) States.

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 Locations	Latitude	Longitude
Bauchi	10.3010^{O}N	9.83237^{O}N
Damaturu	11.7470^{O}N	11.9662^{O}N
Gombe	10.2792^{O}N	11.1731^{O}N
Jalingo	8.8927^{O}N	11.3771^{O}N
Maidugri	11.8311^{O}N	13.151^{O}N
Yola	9.035^{O}N	12.4953^{O}N

III. METHODOLOGY AND ANALYSIS

- Global Solar Radiation

Table 2 shows monthly average solar radiation on horizontal surface for the zone during 2000 – 2020. Table 2 reveals that total average global radiation received on horizontal surface in this zone is 69.05 kW-hrm^{-2}day^{-1}. The city of Damaturu recorded highest mean-total global solar radiation of 70.86 kW-hrm^{-}

^{2}day^{-1}. The minimum average global solar radiation is estimated in Jalingo with a value of 65.67 kW-hrm^{-2}day^{-1}. In Bauchi, the average global solar radiation incident on horizontal surface range from 6.03 kW-hrm^{-2}day^{-1} (November) to 5.08 kW-hrm^{-2}day^{-1} (August). The range for Damaturu is 6.42 (March) to 5.24 (August) kW-hrm^{-2}day^{-1}. In Gombe, the range of average global solar radiation is 6.29 (March) to 5.45 (August) kW-hrm^{-2}day^{-1}. Average global solar radiation in Jalingo ranges from 5.97 (February, March and November) to 4.25 (August) kW-hrm^{-2}day^{-1}. Maidugri and Yola have their global solar radiation range from 6.54 (March) to 5.01 (August) kW-hrm^{-2}day^{-1} and 6.27 (March) to 4.71 (August) kW-hrm^{-2}day^{-1}, respectively.

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	SEP	OCT	NOV	DEC	Total
Bauchi	5.73	5.91	6.24	6.16	5.95	5.73	5.38	5.08	5.54	5.91	6.03	5.75	69.35
Damaturu	5.8	6.07	6.42	6.39	6.16	5.82	5.49	5.24	5.78	6.03	6.00	5.72	70.86
Gombe	5.76	5.99	6.29	6.27	6.08	5.77	5.29	4.87	5.45	5.92	6.01	5.76	69.39
Jalingo	5.87	5.97	5.97	5.82	5.52	5.04	4.52	4.25	5.48	5.48	5.97	5.83	65.67
Maidugri	5.88	6.23	6.54	6.46	6.14	5.69	5.34	5.01	5.63	6.01	6.05	5.75	70.69
Yola	5.84	6.03	6.27	6.17	5.88	5.54	5.09	4.71	5.18	5.81	6.04	5.82	68.33
Mean	5.81	6.03	6.29	6.21	5.95	5.6	5.19	4.86	5.51	5.86	6.02	5.77	69.05
Max	5.88	6.23	6.54	6.46	6.16	5.82	5.49	5.24	5.78	6.03	6.05	5.83	70.86
Min	5.73	5.91	5.97	5.82	5.52	5.04	4.52	4.25	5.18	5.48	5.97	5.72	65.67
Max-Min	0.15	0.33	0.57	0.65	0.65	0.78	0.98	0.99	0.6	0.55	0.09	0.12	5.19
(Max-Min)/Mean x 100	2.57	5.36	8.99	10.44	10.88	13.82	18.87	20.31	10.78	9.32	1.40	1.97	7.52

Months of the rainy season contributes 48.71, 49.14, 48.51, 46.34, 48.42 and 47.59 % for Bauchi, Damaturu, Gombe, Jalingo, Maidugri and Yola, respectively. It is observed from Table 1, that August recorded the minimum average global solar radiation for the study locations. This is expected as August is typically characterized by high level of rainfall; hence will exhibit heavily overcast conditions. For the geo-political zone, March (6.29 kW-hrm^{-2}day^{-1}) and August (4.86 kW-hrm^{-2}day^{-1}) recorded the highest and lowest mean values of global solar radiation. Variability ((max-min)/mean) global solar radiation for the zone is in value of 7.52 kW-hrm^{-2}day^{-1} of the mean value. The most variable month is August where the range is 20.31 % of the monthly mean value in that month and the steadiest month is November with a range of 1.40 % of the monthly mean value in that month. Percentage frequency distribution of monthly average global solar radiation for the geo-political zone is shown in Table 3.

For the study locations, class intervals of 3.00 – 3.99, 4.00 – 4.99, 5.00 – 5.99 and 6.00 – 6.99 kWhrm^{-2}day^{-1} recorded relatively high percentage frequency distribution of monthly average global solar radiation. The values of percentage frequency distribution within these class intervals range in value of 1.56 – 49.3 %. Though, larger percentage of frequency distribution falls into class intervals of 5.00 – 5.99 and 6.00 – 6.99 kW-hrm^{-2}day^{-1}. It is also observed that class modals of 0 – 0.99 and 8 – 8.99 recorded low percentage frequency distribution of global solar radiation.

Table 3 Percentage frequency distribution of monthly global solar radiation

Radiation Levels (KWhr)	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

Bauchi	0.00	0.29	1.57	4.19	10.76	33.91	44.54	4.75	0.03
Damaturu	0.03	0.45	1.02	3.02	8.89	31.33	49.30	5.99	0.02
Gombe	0.02	0.57	1.70	4.18	10.75	32.38	45.35	5.09	0.02
Jalingo	0.03	0.98	3.15	7.50	15.85	38.04	32.93	1.56	0.00
Maidugri	0.03	0.66	1.40	3.54	8.28	31.48	48.00	6.64	0.02
Yola	0.02	0.80	2.19	5.44	11.15	32.49	44.09	3.86	0.00

- 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).

$$H_O = \frac{24\ x 3600 G_{sc}}{\pi}\left(1 + 0.033 cos\frac{360n}{365}\right) x \left(cos\emptyset cos\delta sin\omega_s + \frac{\pi\omega_s}{180} sin\emptyset sin\delta\right) \qquad (2)$$

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 (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)

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

Tables 4a-f, presents 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 $\overline{K}_T$ 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 Bauchi

	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 (651)	0.00	0.00	0.00	0.47	1.24	2.47	8.47	19.69	38.74	68.08	99.73	100.00	0.65
Feb (594)	0.00	0.51	0.51	0.51	1.53	5.74	16.35	34.87	57.94	82.86	99.36	100.00	0.62
Mar (680)	0.00	0.15	1.04	2.22	5.17	10.32	17.09	38.12	60.92	85.63	99.02	100.00	0.61
Apr (600)	0.00	0.34	1.84	2.84	6.34	14.01	28.01	50.18	74.68	90.02	99.02	100.00	0.59
May (650)	0.00	1.70	3.09	6.48	10.18	17.88	31.12	52.36	78.98	96.37	99.76	100.00	0.58
Jun (661)	0.31	2.74	5.77	10.16	14.70	22.87	32.56	55.11	81.59	99.14	100.00	100.00	0.56
Jul (649)	0.93	4.94	8.95	14.35	21.60	33.78	48.27	70.15	90.80	99.28	100.00	100.00	0.53
Aug (620)	0.97	6.30	13.4	20.18	30.02	45.67	61.97	82.62	95.53	99.41	100.00	100.00	0.49
Sep (630)	0.96	4.46	6.85	10.82	15.75	27.98	42.11	63.07	82.60	99.11	100.00	100.00	0.55
Oct (651)	0.16	1.09	2.17	3.71	6.17	9.86	18.16	34.45	55.96	86.07	100.00	100.00	0.61
Nov (662)	0.00	0.16	0.16	0.16	0.16	1.07	3.34	12.56	26.16	53.36	97.93	100.00	0.68
Dec (619)	0.00	0.00	0.00	0.49	1.14	2.76	5.35	12.14	26.52	49.63	95.52	100.00	0.68

Table 4b monthly percentage cumulative frequency distribution of daily clearness index for Damaturu

	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 (651)	0.00	0.00	0.00	0.00	0.31	1.70	4.93	12.92	29.98	56.87	96.66	100.00	0.67
Feb (593)	0.00	0.00	0.00	0.00	0.31	1.70	4.93	12.92	29.98	56.87	96.66	100.00	0.65
Mar (651)	0.00	0.00	0.17	0.34	1.19	2.54	8.45	22.79	43.87	75.58	98.35	100.00	0.64
Apr (630)	0.00	0.16	0.47	1.24	2.78	5.70	11.54	26.75	49.03	80.22	98.35	100.00	0.61
May (651)	0.00	0.16	1.43	1.59	3.02	9.06	17.16	38.75	64.79	88.92	99.88	100.00	0.59
Jun (630)	0.00	1.23	2.00	3.08	5.54	12.92	23.83	46.72	73.3	95.73	100.00	100.00	0.57
Jul (651)	0.64	1.76	2.72	6.06	9.72	17.50	31.79	59.89	87.99	99.90	100.00	100.00	0.53
Aug (636)	1.54	5.39	9.54	12.46	18.15	28.75	43.66	67.63	91.14	99.90	100.00	100.00	0.51
Sep (628)	1.58	3.63	8.51	16.38	26.61	39.04	55.08	75.37	92.36	100.00	100.00	100.00	0.57
Oct (651)	0.48	3.19	6.38	9.25	14.67	22.32	31.08	46.69	73.45	97.66	100.00	100.00	0.63
Nov (661)	0.47	0.47	1.24	2.78	4.17	6.94	12.17	26.15	48.12	80.69	99.90	100.00	0.69
Dec (654)	0.00	0.00	0.16	0.47	0.63	1.09	3.06	9.57	21.22	44.52	97.63	100.00	0.68

Table 4c monthly percentage cumulative frequency distribution of daily clearness index for Gombe

	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 (651)	0.00	0.00	0.00	0.00	0.62	2.47	6.93	17.84	38.28	66.55	98.97	100.00	0.66
Feb (593)	0.00	0.00	0.00	0.00	0.62	2.47	6.93	17.84	38.28	66.55	98.97	100.00	0.63

Mar (634)	0.00	0.00	0.17	0.68	2.37	6.25	14.18	29.87	51.29	81.14	99.36	100.00	0.62
Apr (600)	0.00	0.32	1.27	2.06	3.48	9.01	17.69	34.10	58.40	83.96	99.58	100.00	0.60
May (679)	0.00	0.50	1.50	2.84	6.01	11.18	21.02	44.52	69.86	89.70	99.70	100.00	0.59
Jun (631)	0.30	1.48	2.96	5.32	7.98	14.02	24.78	45.99	73.24	94.75	100.00	100.00	0.57
Jul (650)	0.32	2.39	4.77	8.10	13.49	21.10	33.62	53.91	79.27	99.08	100.00	100.00	0.52
Aug (649)	1.85	6.01	11.09	16.79	25.56	37.10	50.64	69.11	90.19	99.27	100.00	100.00	0.47
Sep (629)	2.32	10.49	17.43	24.99	35.16	51.81	68.61	85.87	96.66	100.00	100.00	100.00	0.54
Oct (651)	1.44	4.62	8.44	13.53	21.64	30.87	43.43	63.15	84.94	99.41	100.00	100.00	0.62
Nov (627)	0.31	0.78	1.55	2.94	5.40	9.71	16.47	32.60	58.10	88.67	100.00	100.00	0.68
Dec (653)	0.00	0.00	0.16	0.48	0.64	0.96	3.68	10.86	25.38	54.73	99.39	100.00	0.68

Table 4d monthly percentage cumulative frequency distribution of daily clearness index for Jalingo

	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 (650)	0.00	0.00	0.00	0.00	0.47	1.24	4.01	18.32	41.71	76.64	100.00	100.00	0.65
Feb (594)	0.00	0.00	0.00	0.00	0.47	1.24	4.01	18.32	41.71	76.64	100.00	100.00	0.61
Mar (651)	0.00	0.00	0.00	1.02	3.21	8.60	18.37	39.25	65.35	93.13	100.00	100.00	0.58
Apr (630)	0.16	0.93	2.16	4.16	5.70	12.77	27.52	52.41	78.68	94.51	99.89	100.00	0.56
May (651)	0.32	2.39	3.35	5.89	10.50	21.77	37.49	63.05	85.75	97.82	100.00	100.00	0.54
Jun (630)	0.93	4.47	9.85	12.16	17.23	27.83	41.35	65.32	87.29	98.82	100.00	100.00	0.50
Jul (651)	1.75	5.56	9.37	17.63	25.57	40.81	60.50	81.77	95.74	99.87	100.00	100.00	0.45
Aug (651)	2.31	10.76	19.21	31.96	43.18	62.69	80.05	94.80	98.95	100.00	100.00	100.00	0.42
Sep (630)	3.54	14.6	26.74	39.19	55.48	76.07	90.36	98.35	99.58	100.00	100.00	100.00	0.47
Oct (651)	2.07	9.22	17.16	24.63	37.97	54.17	71.32	89.10	97.84	100.00	100.00	100.00	0.56
Nov (630)	0.31	1.24	2.47	4.47	10.00	21.99	37.66	65.01	85.29	98.04	100.00	100.00	0.65
Dec (651)	0.00	0.16	0.16	0.16	0.48	2.55	5.41	15.10	38.60	74.64	100.00	100.00	0.67

Table 4e monthly percentage cumulative frequency distribution of daily clearness index for Maidugri

	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 (651)	0.00	0.00	0.00	0.00	0.16	1.39	3.70	8.93	23.07	50.42	97.12	100.00	0.68
Feb (594)	0.00	0.17	0.17	0.34	0.68	1.70	4.40	15.35	31.85	65.02	97.52	100.00	0.66
Mar (681)	0.00	0.00	0.15	1.04	1.63	4.28	9.42	22.05	43.49	74.77	98.56	100.00	0.65
Apr (600)	0.00	0.17	0.67	1.51	3.18	7.02	14.69	34.53	63.70	85.04	99.71	100.00	0.62
May (651)	0.00	0.47	1.40	4.63	6.63	14.93	25.69	47.20	73.01	92.98	100.00	100.00	0.59
Jun (630)	0.32	2.55	5.09	8.59	12.88	23.68	36.70	63.53	87.98	99.57	100.00	100.00	0.55
Jul (620)	0.97	5.65	9.53	15.18	23.09	35.84	50.36	74.40	92.79	99.89	100.00	100.00	0.52
Aug (651)	4.77	10.3	16.14	22.90	30.59	46.72	62.39	79.29	93.58	99.88	100.00	100.00	0.49
Sep (630)	1.27	5.40	7.94	12.07	15.88	25.25	36.84	53.04	77.17	98.29	100.00	100.00	0.56

Oct (651)	0.00	0.77	1.54	2.16	4.62	7.85	12.31	27.98	50.26	80.07	100.00	100.00	0.63
Nov (630)	0.00	0.00	0.00	0.16	0.32	0.80	1.92	7.00	17.48	41.14	98.61	100.00	0.69
Dec (651)	0.00	0.00	0.00	0.16	0.16	2.47	3.55	7.55	16.77	42.89	97.58	100.00	0.69

Table 4f monthly percentage cumulative frequency distribution of daily clearness index for Yola

	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 (651)	0.00	0.00	0.00	0.00	0.31	2.47	6.16	19.22	35.97	68.23	99.57	100.00	0.66
Feb (625)	0.00	0.00	0.32	1.12	2.40	6.72	15.52	29.76	53.76	81.28	99.68	100.00	0.63
Mar (620)	0.00	0.33	0.82	2.76	4.38	9.22	17.45	37.62	60.85	87.63	99.57	100.00	0.62
Apr (630)	0.16	0.64	1.60	3.35	6.21	13.04	23.20	47.81	73.85	93.06	99.73	100.00	0.59
May (651)	0.62	3.08	6.62	9.85	14.31	20.77	29.53	50.73	73.62	96.67	100.00	100.00	0.57
Jun (630)	0.96	4.30	8.11	13.04	18.12	27.49	38.29	61.31	81.63	99.41	100.00	100.00	0.55
Jul (651)	2.16	8.00	13.69	20.30	27.99	42.59	55.81	77.47	91.45	100.00	100.00	100.00	0.50
Aug (651)	3.38	11.37	19.52	28.90	39.96	56.55	74.22	89.74	98.65	100.00	100.00	100.00	0.46
Sep (630)	1.75	6.83	14.14	20.02	26.53	38.60	51.30	73.69	92.43	99.9	100.00	100.00	0.51
Oct (651)	0.31	1.24	2.78	3.71	6.48	12.94	20.78	40.45	67.80	94.53	100.00	100.00	0.60
Nov (660)	0.00	0.00	0.00	0.16	0.32	0.93	2.90	10.48	27.30	63.97	99.58	100.00	0.67
Dec (651)	0.00	0.00	0.00	0.31	0.78	2.01	3.86	10.93	24.15	57.95	99.58	100.00	0.67

Monthly average clearness index ($\bar{K}_T$) values for the political zone range from 0.42 - 0.69. 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 means that atmosphere in this zone is typically cloudy throughout the year. Therefore, it is anticipated that a large fraction of global solar radiation incident on horizontal surface is diffuse. Thus, concentrated solar devices such as parabolic trough and dish will not be effective in this zone as compared with locality with higher $\bar{K}_T$ values. For the cities of Bauchi, Damaturu and Gombe $\bar{K}_T$ values range from 0.49 - 0.68, 0.51 - 0.69 and 0.47 - 0.68, respectively. In the other cities, range of $\bar{K}_T$ values of 0.42 - 0.67, 0.69 - 0.49 and 0.46 - 0.67 are estimated for Jalingo, Maidugiri, and Yola, respectively.

Curves of $\bar{K}_T$ are presented in Fig 1 for the study locations. It is seen that $\bar{K}_T$ curves followed same pattern with depression in August. This further reveals that August is worst month of harvest of solar radiation in the geo-political zone. From Fig. 1, it is seen that Jalingo recorded the least $\bar{K}_T$ value while those of Maidugiri and Damaturu are observed to be close to each other and lead. Though, Gombe, Yola and Bauchi are seen to cluster together from Febuary - July and September - December. This also reveals possibility of harvesting more solar radiation in Maidugiri and Damaturu than in the other cities of the study locations and possibility of harvest of low solar radiation in Jalingo. It also confirms that in Gombe, Bauchi and Yola similar level of solar radiation is predictable excluding in August during which each city is likely to experience different level of rainfall and cloudiness. It is also observed that in November, December, January, Febuary, March, and April, Maidugiri and Damaturu are likely to have similar level of solar radiation as $\bar{K}_T$ curves are seen to cluster together in these months. Those of Yola and Gombe are seen to follow similar trend.

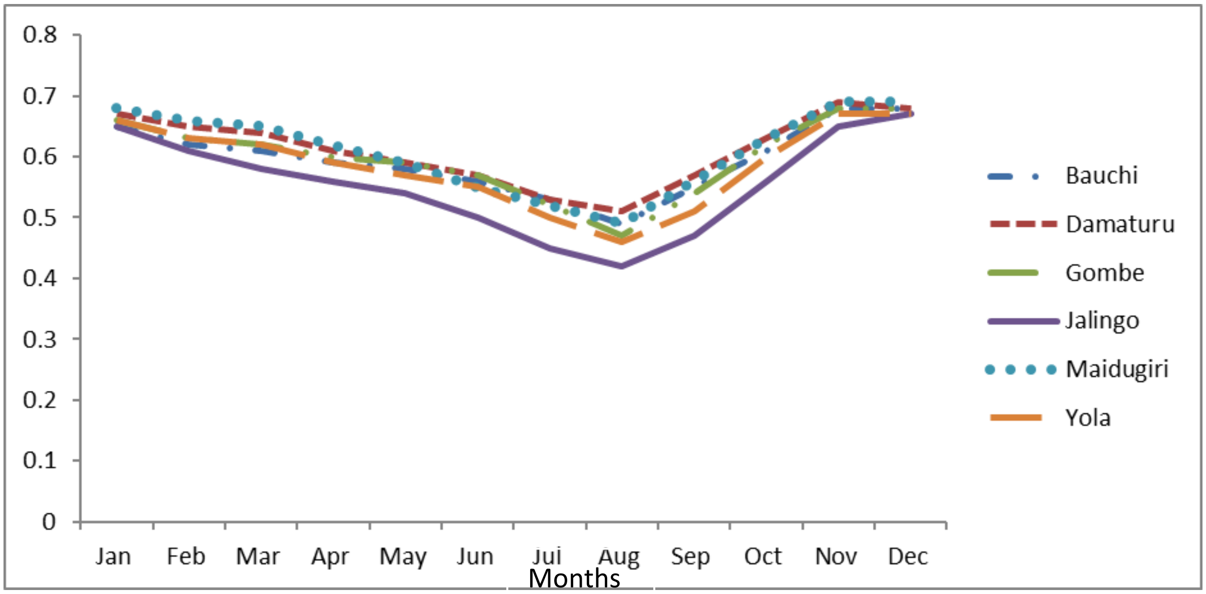

Fig. 1 monthly average clearness index for the study locations

Curves of monthly percentage cumulative percentage frequency distribution of clearness index for August for the study locations are shown in Fig. 2. It is observed that in August, Damaturu followed by Gombe will yield higher level of solar radiation in the geo-political zone as their curves are seen to lead. Those of Maidugiri and Bauchi are seen to cluster together, and are consequently likely to have similar solar radiation during rainy season. Trailing behind curves of Maidugiri and Bauchi are those of Yola and Jalingo with a distinctive gap between. This further reveals that in August Jalingo is likely to produce the least level of solar radiation in the geo-political zone.

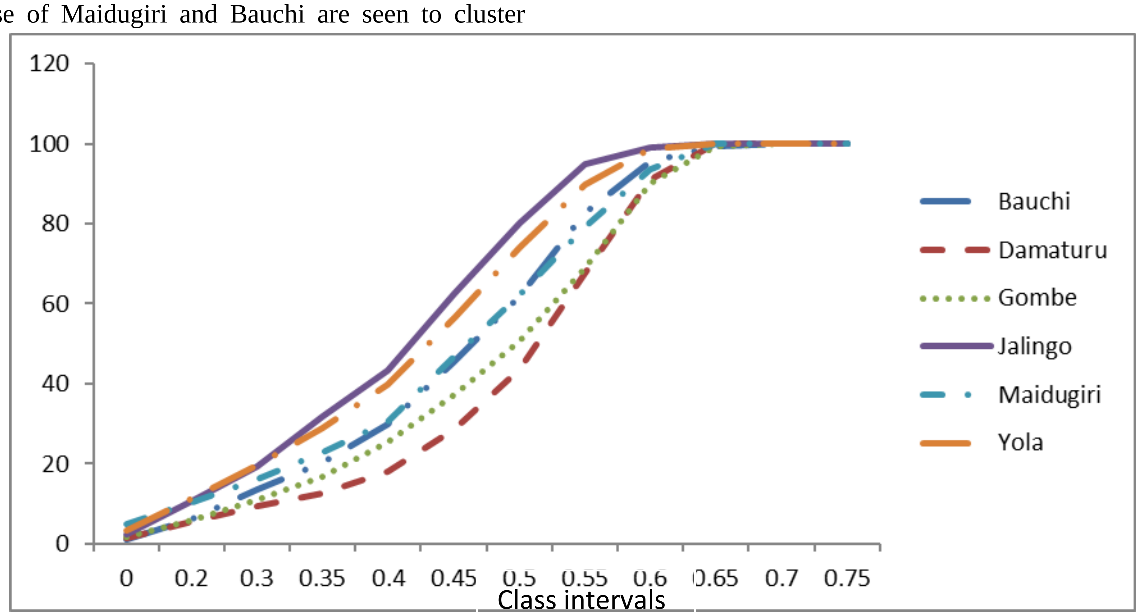

Fig 2 Curves of monthly percentage cumulative frequency distribution of daily clearness index for August

Seasonal classifications of monthly average clearness index are presented in Table 5. Anyanwu and Oteh (2003), aptly reported that months that have same $\overline{K}_T$ values have similar statistical distribution of global solar radiation. Considering the class intervals used in development of Tables 4a-f, it can be seen in Table 5 that Bauchi, Damaturu and Yola have five seasonal classifications. In these set of study locations, two and three groups are obtained in the dry and rainy seasons, respectively. In Jalingo, seven seasonal classifications are obtained. The dry season period and rainy season period recorded three and four groups, respectively. Six seasonal classifications were observed in Gombe and Maidugri. The dry season period recorded two groups while four groups are produced in the rainy season period.

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

K_T Values								
Bauchi			Damaturu			Gombe		
Periods	Ind.	**Ave**	Periods	Ind.	**Ave**	Periods	Ind.	**Ave**
Dry Season			***Dry Season***			***Dry Season***		
a. Nov, Dec,	0.68, 0.68,	**0.67**	**a.** Nov, Dec, Jan,	0.69,0.68,0.67,		**a**. Nov, Dec,	0.68,0.68,0.	**0.67**
Jan,	0.65	**0.61**	Feb	0.65	**0.6**	Jan,	66	**0.62**
b. Feb, Mar,	0.62, 0.61,		**b**. Oct, Mar,	0.63, 0.64	**7**	**b.** Feb, Mar,	0.63,0.62,0.	
Oct	0.61				**0.6**	Oct	62	
			Rainy Season		**4**			**0.60**
Rainy Season		**0.57**	**a**. April	0.61		***Rainy Season***		**0.58**
a. April, May,	0.59, 0.58,	**0.53**	**b.** May, June,	0.59, 0.57,0.57		**a**. April	0.60	**0.53**
June,	0.56,	**0.49**	Sept	0.53,0.51	**0.6**	**b.** May, June	0.59,0.57	**0.47**
Sept	0.55		**C.** July, Aug		**1**	**C**. July, Sept	0.52,0.54	
b. July	0.53				**0.5**	**d.** Aug	0.47	
C. Aug,	0.49				**8**			
					0.4			
					6			

K_T Values								
Jalingo			Maidugri			Yola		
Periods	Ind.	**Ave**	Periods	Ind.	**Ave**	Periods	Ind.	**Ave**
Dry Season			***Dry Season***			***Dry Season***		
a. Nov, Dec,	0.65, 0.67,	**0.67**	**a.** Nov, Dec, Jan	0.69, 0.69,		**a.** Nov, Dec,	0.67,0.67,0	**0.6**
Jan	0.65	**0.65**	Feb, Mar	0.68	**0.67**	Jan	.66	**7**
b. Feb	0.65	**0.63**	**b.** Oct	0.66, 0.65	**0.63**	**b**. Feb, Mar,	0.63,0.62,0	**0.6**
c. Mar, Oct	0.63, 0.63			0.63		Oct	.60	**2**
			Rainy Season					
Rainy Season		**0.56**	**a.** April					
a. April	0.56	**0.52**	**b.** May, Jun, Sept	0.62	**0.62**	***Rainy Season***		
b. May, June	0.54, 0.50	**0.47**	**c.** July	0.59,		**a.** April, May,	0.59,0.57,0	**0.5**
C. Sept	0.47	**0.44**	**d.** Aug	0.55,0.56	**0.57**	Jun	.55	**7**
d. July, Aug	0.45, 0.42			0.52	**0.52**	**b.** Jul, Sept	0.50, 0.51	**0.5**
				0.49	**0.49**	**c.** Aug	0.46	**1**
								0.4
								6

- Sunshine Duration

Table 6 shows values of monthly bright sunshine hours for the study locations. The mean monthly bright sunshine hours of the geo-political zone are estimate at 94.16 hrs. Months of the dry and rainy seasons contributes 54.67 % and 45.33 %, respectively of the mean monthly bright sunshine hour value. Monthly total of bright sunshine hours in the zone ranges from 95.72 – 95.92 hrs. On monthly basis, mean monthly total of bright sunshine hours fall within the ranges of 9.46 - 5.59 hrs. It is observed that August recorded the least hour of bright sunshine both in the maximum (6.53 hrs) and minimum (5.59 hrs) columns. This low level of bright sunshine is seen to have occurred in Jalingo.

Table 6 Monthly values of bright sunshine hours

Years/ Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Monthly Total
Bauchi	9.10	9.00	8.24	7.23	7.73	6.98	6.90	6.12	7.10	8.74	9.46	9.32	95.92
Damaturu	8.72	8.92	8.08	7.35	7.90	7.39	6.70	6.33	7.29	8.43	9.45	9.16	95.72
Gombe	8.50	9.15	7.10	8.25	7.75	7.20	6.40	6.20	7.40	8.52	8.20	9.35	94.02
Jalingo	8.35	8.34	7.26	7.75	7.58	7.16	6.01	5.59	6.33	8.01	8.37	8.93	89.68
Maidugri	8.34	8.84	7.91	7.47	8.07	7.80	6.50	6.53	7.48	8.12	9.43	9.00	95.49
Yola	8.86	7.85	7.38	8.17	8.03	7.86	6.72	6.09	6.73	8.72	8.74	9.02	94.17
Mean	8.65	8.68	7.66	7.7	7.84	7.40	6.54	6.14	7.06	8.42	8.94	9.13	94.16
Max	9.10	9.15	8.24	8.25	8.07	7.86	6.9	6.53	7.48	8.74	9.46	9.35	95.92
Min	8.34	7.85	7.10	7.23	7.58	6.98	6.01	5.59	6.33	8.01	8.20	8.93	95.72

- Angstrom-Page Equation

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

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

Where $\bar{n}$ is hours of bright sunshine, $\bar{N}$ is daily theoretical sunshine in hours and $a\ and\ b$ are local constants that 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
Bauchi	0.276	0.473	0.749	0.904
Damaturu	0.245	0.531	0.776	0.923
Gombe	0.232	0.552	0.784	0.756
Jalingo	0.023	0.903	0.926	0.879
Maidugri	0.181	0.640	0.821	0.858
Yola	0.155	0.651	0.806	0.859
Average	0.185	0.625	0.810	0.863

The coefficient of determination is observed to be high for each study location. This indicates 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. Though, the coefficient of determination for Gombe is lesser, indicating that the scatter for this study location is higher. The average values of a and b is 0.185 and 0.625, respectively, for the geo-political zone. These set of parameters in Table 7 can be used to estimate global solar radiation for entire zone and/or other locations close to the state capitals with similar meteorological conditions where sunshine measurement is available.

CONCLUSION

Measured meteorological parameters such as global solar radiation, monthly average clearness index and hours of bright sunshine have been used to characterize the sky conditions of six cities in the north-east geo-political zone of Nigeria. It is observed that August is the worst month of harnessing solar radiation in the zone. Different numbers of seasonal classifications are identified for each study location. Coefficients for the Angstrom-Page equation is estimated for the cities and the associated coefficient of determination exhibit low variation for each study location as a general Angstrom–Page equation is developed for the zone. Hence, they are recommended for use in localities with similar metrological condition.

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