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ESTIMATION OF GLOBAL SOLAR RADIATION IN NORTH-WEST GEO-POLITICAL ZONE OF NIGERIA

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ABSTRACT

Estimation of global solar radiation in north-west geo-political 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 seven states. Mean global solar radiation estimated in the zone is 72.50 kW-hrm^{-2}day^{-1} and monthly $\bar{K}_T$ values ranges in value from 0.44 – 0.68. Thus, most days in the zone are adjudged to be cloudy. Monthly bright sunshine hour in the zone is estimated at 96.57 hrs. Four seasonal classification periods are determined for Duste, Kano, Bernin-Kebbi, Sokoto, Gusau, and Katsina. Kaduna recoded five season classification patterns. Angstrom-Page equation is developed for the zone and study locations and applicable in locations with similar meteorological conditions.

Key words: clearness index, seasonal periods, sky condition, solar radiation, north-west

1.0 INTRODUCTION

Clean, reliable and affordable energy services are very important for global prosperity and makes intense impact on numerous aspects of human development, from poverty to health, food security and climate change. There is basically two types of energy resources namely; convectional energy resources which are non renewable such as fossil fuel, nuclear energy etc and non conventional energy resources which are renewable such as solar, wind, hydropower and biomass.

Among renewable energy sources, solar energy is one of the most feasible and promising alternative and sustainable energy resource in the world (Sawin, 2013 & Abudul, Al-Khaid, Andrew, and others 2012). Solar energy is predicted by numerous analyses to become the most used energy resource by 2050 (World in Transition, 2011). It is the world most abundant stable source of energy and provides the energy that drives the earth. The greatest advantage of solar energy as compared with other forms of energy is that it is available, clean and can be supplied without environmental pollution. Solar energy usage has experienced phenomenal growth in recent years due to both technological improvements resulting in cost reductions and government policies supportive of renewable energy development and utilization.

It has been observed that there is an abundant solar radiation across Nigeria (Abudlsalam, Mbamali, Mamman and Saleh 2012 & Akintola and Alamu, 2010). Nigerian Electricity Regulatory Commission (2008) estimated an annual average of daily solar radiation to vary from as high as 7 KW/m^2/day in the northern border regions to as low as 3.5 KW/m^2/day in the coastal regions of southern region, and an annual average daily sunshine hours vary from as high as greater than 8 hrs/day in the northern border regions to as low as less than 6hrs/day in the coastal regions of southern part. Given an average solar radiation level of about 5.5 kWhm^{-2}day^{-1}, and the prevailing efficiencies of commercial solar-electric generators, then if solar collectors or modules were used to cover 1% of Nigeria's land area of 923,773 km^2, it is possible to generate 1850 x 103 GWh of solar electricity per year, however, only about 0.005% is actually converted into energy (Sambo 2009 & IFPRI 2003).

Thus, solar energy if properly harnessed can contribute significantly to lives and economy in Nigeria. Some of the possible applications of solar energy in Nigeria are village electrification, water heating, space cooling, water pumping and purification, agricultural and industrial utilization. The use of solar energy will greatly reduce the energy demand on grid connected electricity.

There is an increasing call and desire to deploy solar energy systems for energy generation in Nigeria because of the abundant solar radiation. However, it is necessary to know the useful solar energy output and sky conditions at each location or region where the solar collectors will be installed for effective performance (Ideriah and Suleman 1989, Kuye and Japtag 1992, Udo 2000, Anyanwu and Oteh 2003, Okogbue, Adedokun and Holngren 2009, Yusuf 2017 and Njoku, Ofong, Ogueke and Anyanwu 2018). This will aid in estimation of long term performance of solar thermal collectors as well as in their design optimization, cost evaluation and maintenance requirements. Thus, to achieve this aim, this paper characterized the sky conditions in North-West geo-political zone of Nigeria using monthly average global solar radiation, clearness index and hours of sunshine duration.

2.0 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.

North-West Geo-Political Zone of Nigeria is located in northern part of Nigeria. This zone consists of seven states which include Jigawa (Duste), Kaduna (Kaduna), Kano (Kano), Kebbi (Birnin Kebbi), Sokoto (Sokoto), Zamfara (Guasu) and Katsina (Katsina).

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)
DUTSE	11.7024	9.334
KADUNA	10.5105	7.4165
KANO	12.002	8.592
BIRNIN KEBBI	12.431	4.1956
SOKOTO	13.0059	5.2476
GUSAU	12.1628	6.6745
KATSINA	12.9816	7.6223

3.0 Methodology and Analysis

3.1 Global Solar Radiation

Table 2 presents monthly average solar radiation on horizontal surface for the zone during 2000 – 2020. The total mean monthly average solar radiation in north-west is estimated at 72.50 kWhrm^{-2}day^{-1}. Months of dry and rainy season periods contributes 49.51 % and 50.49 %, respectively of the total mean monthly average solar radiation value. This shows that more solar radiation intensity is likely to be harvested during the rainy season than dry season. This may be expected as during the dry season dust ridden wind blow in from the Sahara Desert that cause the atmosphere to be haze thereby affect the attenuation of solar radiation intensity. Total monthly average solar radiation intensity for the zone ranges from 67.20 kWhrm^{-2}day^{-1} (Kaduna) to 71. 87 kWhrm^{-2}day^{-1} (Sokoto). The most variable and steadiest months are April (6.27 %) and August (5.31 %), respectively. It is observed from Table 2 that in all the study location, August recorded the lowest value of solar radiation intensity.

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

Years/ Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Total
DUTSE	5.58	5.83	6.2	6.27	6.09	5.76	5.51	5.31	5.79	5.94	5.9	5.55	69.73
KADUNA	5.68	5.86	6.12	6.17	5.9	5.42	4.94	4.53	5.19	5.7	5.98	5.71	67.20
KANO	5.52	5.85	6.3	6.49	6.36	6.1	5.76	5.54	6.03	6.08	5.86	5.5	71.39
BIRNIN KEBBI	5.41	5.72	6.03	6.24	6.13	5.89	5.53	5.15	5.75	5.98	5.76	5.46	69.05
SOKOTO	5.59	6.07	6.38	6.46	6.28	6.05	6.05	5.54	6.06	6.07	5.82	5.5	71.87
GUSAU	5.44	5.77	6.15	6.31	6.18	6.00	5.59	5.21	5.85	5.97	5.78	5.46	69.71
KATSINA	5.45	5.77	6.19	6.38	6.26	6.02	5.64	5.33	5.94	6.01	5.78	5.45	70.22
mean	5.68	6.07	6.38	6.49	6.36	6.1	6.05	5.54	6.06	6.08	5.98	5.71	72.50
max	5.41	5.72	6.03	6.17	5.9	5.42	4.94	4.53	5.19	5.7	5.76	5.45	67.20
min	0.27	0.35	0.35	0.32	0.46	0.68	1.11	1.01	0.87	0.38	0.22	0.26	4.67
max-min	4.95	6.07	5.65	5.02	7.35	11.30	19.68	18.95	14.65	6.32	3.81	4.77	6.65

(max-min/mean) 100	5.58	5.83	6.2	6.27	6.09	5.76	5.51	5.31	5.79	5.94	5.9	5.55	69.73

Table 3 presents percentage frequency distribution of daily global solar radiation for the study locations. From Table 3, it is observed that bulk of the solar radiation intensity falls in class intervals of 4.00 - 4.99, 5.00 - 5.99 and 6.00 - 6.99 $kWhrm^{-2}day^{-1}$. While, relatively few solar radiation intensity data are recorded in class intervals of 2.00 - 2.99, 3.00 - 3.99 and 7.00 - 7.99 $kWhrm^{2}day^{1}$.

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
DUTSE	0.02	0.00	1.48	3.33	11.09	35.21	44.38	4.52	0.00
KADUNA	0.00	0.02	1.78	5.26	15.20	39.22	35.59	2.96	0.00
KANO	0.02	0.02	0.91	2.61	9.53	32.38	47.55	7.00	0.03
BIRNIN KEBBI	0.02	0.05	1.83	3.69	11.05	38.58	40.97	3.85	0.02
SOKOTO	0.02	0.00	1.07	2.30	8.38	33.73	47.02	7.48	0.03
GUSAU	0.00	0.05	1.31	3.02	11.61	36.74	42.87	4.41	0.03
KATSINA	0.00	0.00	0.95	3.06	11.56	35.51	43.44	5.51	0.02

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).

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

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 (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 4 a-e, 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 $\overline{K}_T$ 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 Dutse

	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	0.00	0.77	1.85	6.00	12.75	24.87	41.29	67.52	99.27	100.00	0.65
Feb (565)	0.00	0.17	0.34	1.36	4.06	8.44	16.69	35.89	55.42	84.72	98.70	100.00	0.62
Mar (620)	0.00	0.00	0.93	3.39	5.39	9.24	17.69	38.89	60.55	86.52	98.97	100.00	0.61
Apr (600)	0.00	0.00	0.64	1.28	3.51	10.02	23.04	48.28	71.30	90.04	99.57	100.00	0.59
May (620)	0.31	1.08	2.16	3.85	6.31	13.07	26.29	49.95	78.37	95.73	100.00	100.00	0.59
Jun (600)	0.32	1.28	3.03	5.10	9.87	18.29	33.37	65.44	93.22	99.89	100.00	100.00	0.56
Jul (620)	0.62	4.93	7.24	12.31	19.69	30.60	44.28	67.17	90.22	99.75	100.00	100.00	0.54
Aug (620)	1.39	6.62	11.23	16.15	23.68	38.28	52.11	75.31	91.60	99.75	100.00	100.00	0.52
Sep (600)	0.96	3.19	4.62	7.64	12.88	19.87	30.19	50.19	75.12	97.82	100.00	100.00	0.57
Oct (620)	0.00	0.93	1.86	2.79	4.48	8.17	14.78	30.30	56.88	83.31	99.90	100.00	0.62
Nov (600)	0.00	0.00	0.00	0.16	0.32	1.44	5.10	13.99	29.23	55.11	98.13	100.00	0.67
Dec (620)	0.00	0.00	0.16	1.09	1.86	3.71	8.94	21.23	32.29	53.49	97.27	100.00	0.66

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

	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	0.00	0.16	0.47	1.70	7.08	19.99	42.73	80.68	99.73	100.00	0.65
Feb (565)	0.00	0.00	0.34	0.34	1.69	4.89	14.31	36.67	64.41	90.80	100.00	100.00	0.62
Mar (620)	0.00	0.31	1.40	2.80	4.51	10.39	20.44	41.16	68.52	90.78	99.44	100.00	0.60
Apr (600)	0.00	0.16	0.48	2.07	4.61	11.76	26.05	51.29	75.42	93.20	99.40	100.00	0.59
May (620)	0.31	0.62	2.47	6.16	10.01	19.08	31.53	58.88	81.00	97.59	100.00	100.00	0.57
Jun (600)	0.48	3.34	6.36	11.44	17.48	32.09	49.56	73.37	92.11	99.73	100.00	100.00	0.53
Jul (620)	0.00	4.61	9.22	19.06	31.05	52.25	72.38	91.74	98.5	99.73	100.00	100.00	0.48
Aug (620)	1.39	9.54	19.07	31.21	48.57	69.62	84.06	96.05	99.74	100.05	100.00	100.00	0.45
Sep (600)	0.64	3.03	7.00	12.08	22.72	39.07	58.92	81.94	95.75	99.72	100.00	100.00	0.51
Oct (620)	0.31	0.78	1.71	2.94	6.02	15.55	27.84	46.12	69.93	90.37	100.00	100.00	0.60
Nov (600)	0.00	0.00	0.00	0.32	0.96	2.23	4.46	11.29	28.12	57.81	97.66	100.00	0.67
Dec (620)	0.00	0.00	0.16	0.16	0.63	2.48	4.94	12.01	27.53	55.03	98.05	100.00	0.67

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

	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	MONTH LY$\bar{K}_T$
Jan (621)	0.00	0.00	0.00	0.62	1.70	5.08	11.99	24.11	38.53	68.14	99.43	100.00	0.65
Feb (565)	0.00	0.00	0.00	0.85	2.71	5.91	14.33	30.33	53.23	82.19	99.20	100.00	0.63
Mar (620)	0.00	0.16	0.78	1.55	3.40	7.86	14.93	32.29	53.19	83.00	98.67	100.00	0.63
Apr (600)	0.00	0.64	0.80	1.44	2.71	6.68	15.10	33.68	60.83	86.87	98.78	100.00	0.62
May (620)	0.16	0.63	1.10	1.87	4.03	9.26	18.94	37.53	67.34	91.92	99.91	100.00	0.61
Jun (600)	0.16	1.28	2.24	3.83	6.53	11.61	20.66	45.11	81.31	98.93	100.00	100.00	0.59
Jul (620)	0.31	2.47	5.70	10.16	14.77	23.99	34.90	57.79	84.98	99.89	100.00	100.00	0.56
Aug (620)	1.39	5.39	8.01	12.93	19.39	31.53	45.21	66.11	87.93	99.46	100.00	100.00	0.55
Sep (600)	0.32	1.12	3.03	5.73	7.96	12.57	21.15	40.20	66.24	96.56	100.00	100.00	0.60
Oct (620)	0.00	0.16	0.16	1.09	2.17	4.94	9.09	23.69	43.82	76.54	99.43	100.00	0.64
Nov (600)	0.00	0.00	0.00	0.16	0.64	1.28	3.19	12.72	26.22	51.78	97.66	100.00	0.68
Dec (620)	0.00	0.00	0.31	0.78	1.86	3.55	7.55	18.46	31.21	52.57	95.74	100.00	0.67

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

	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	MONTH LY$\bar{K}_T$
Jan (621)	0.00	0.16	0.63	1.86	2.63	6.62	11.38	24.12	47.74	78.88	99.90	100.00	0.64
Feb (565)	0.00	0.17	0.51	0.85	2.54	7.09	17.03	37.74	62.66	87.24	99.53	100.00	0.62
Mar (620)	0.00	0.31	1.70	3.39	6.31	12.61	23.83	45.03	67.62	90.51	99.89	100.00	0.60
Apr (600)	0.00	0.48	1.12	2.55	5.41	11.13	20.82	47.65	73.85	93.54	99.42	100.00	0.59
May (620)	0.00	1.85	2.93	4.16	6.62	12.15	23.52	49.02	76.37	97.73	99.89	100.00	0.59
Jun (600)	0.16	1.91	4.30	6.05	10.02	18.12	29.71	56.70	84.01	99.73	100.00	100.00	0.57
Jul (620)	0.77	4.62	8.93	13.70	19.08	31.68	44.28	65.64	88.23	100.00	100.00	100.00	0.53
Aug (620)	3.08	9.84	15.99	21.83	30.13	41.96	57.02	75.61	90.82	99.73	100.00	100.00	0.50
Sep (600)	0.48	2.71	5.25	9.54	13.35	21.45	32.25	50.99	74.65	98.31	100.00	100.00	0.57
Oct (620)	0.00	0.47	0.94	2.17	3.10	4.95	10.64	27.39	49.36	85.62	99.91	100.00	0.63
Nov (600)	0.00	0.16	0.16	0.16	0.48	1.75	3.98	16.52	33.99	61.14	98.29	100.00	0.67
Dec (620)	0.00	0.16	0.32	0.79	1.41	3.41	6.95	14.79	30.77	59.19	98.83	100.00	0.67

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

	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	0.16	0.47	0.63	1.56	3.71	7.86	15.53	31.03	55.42	96.22	100.00	0.67
Feb (565)	0.00	0.17	0.17	0.34	1.52	4.22	6.25	18.21	35.39	64.69	97.52	100.00	0.66
Mar (620)	0.00	0.16	0.47	1.55	2.78	6.16	12.62	27.83	48.88	73.31	96.36	100.00	0.64
Apr (600)	0.00	0.64	0.80	1.92	3.04	7.01	17.65	35.12	62.90	85.60	99.10	100.00	0.62
May (620)	0.00	0.62	1.09	2.02	5.87	11.25	22.62	43.67	71.02	95.45	99.30	100.00	0.60
Jun (600)	0.32	1.91	2.55	5.09	8.27	14.78	23.99	49.23	82.73	99.56	100.00	100.00	0.58
Jul (620)	0.47	2.47	5.09	7.55	13.7	23.08	35.37	56.27	86.69	100.06	100.00	100.00	0.56
Aug (620)	1.08	4.93	9.08	14.31	20.77	31.53	44.9	65.95	86.39	99.76	100.00	100.00	0.55
Sep (600)	0.16	1.12	2.08	4.47	7.01	12.89	21.15	38.77	62.43	95.13	100.00	100.00	0.60
Oct (620)	0.00	0.47	0.63	1.71	2.64	5.10	8.95	20.17	40.45	74.10	98.38	100.00	0.65
Nov (600)	0.00	0.00	0.16	0.16	0.32	0.96	2.87	10.65	25.26	51.14	92.57	100.00	0.68
Dec (620)	0.00	0.00	0.16	0.32	0.79	2.02	5.71	11.55	24.46	45.82	93.90	100.00	0.68

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

	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	MONTH LY$\bar{K}_T$
Jan (621)	0.00	0.00	0.62	1.70	2.47	6.32	12.32	24.00	45.51	75.93	99.59	100.00	0.64
Feb (565)	0.18	0.18	0.54	0.90	2.14	6.03	13.99	35.37	58.87	87.85	99.52	100.00	0.62
Mar (620)	0.00	0.00	0.62	2.01	4.17	10.17	19.39	39.67	65.33	87.45	98.98	100.00	0.61
Apr (600)	0.32	0.64	0.96	2.39	4.30	8.75	18.75	39.87	72.10	92.26	99.57	100.00	0.59
May (620)	0.16	0.63	1.71	3.10	6.02	11.86	23.39	47.82	77.78	96.99	99.91	100.00	0.59
Jun (600)	0.32	2.07	3.66	4.46	9.39	15.90	25.75	48.14	81.64	99.74	100.00	100.00	0.58
Jul (620)	0.77	3.54	7.08	11.39	17.08	29.07	44.13	66.10	89.45	100.00	100.00	100.00	0.54
Aug (620)	2.16	7.08	12.77	20.30	27.52	42.43	57.03	75.47	92.22	99.75	100.00	100.00	0.50
Sep (600)	0.16	1.59	3.50	4.93	9.54	18.75	27.96	49.55	74.48	97.50	100.00	100.00	0.58
Oct (620)	0.31	0.47	0.78	0.94	2.17	6.02	12.78	28.61	52.27	82.38	99.90	100.00	0.63
Nov (600)	0.00	0.00	0.00	0.16	0.32	1.28	4.30	15.42	32.73	60.35	96.70	100.00	0.67
Dec (620)	0.00	0.16	0.63	0.63	1.25	3.41	7.56	17.40	31.23	57.35	96.99	100.00	0.67

Table 4g Monthly percentage cumulative frequency distribution of daily clearness index for Katsina

	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	0.16	0.32	1.25	3.10	7.71	14.16	24.9	41.78	71.08	99.15	100.00	0.64
Feb (565)	0.00	0.00	0.51	1.02	2.54	8.94	16.35	33.19	57.44	85.90	99.71	100.00	0.62
Mar (620)	0.00	0.16	0.78	1.71	4.33	9.86	19.39	38.60	59.80	85.00	98.98	100.00	0.61
Apr (600)	0.16	0.48	0.96	2.23	3.82	9.22	17.64	37.33	67.18	90.52	99.10	100.00	0.61
May (620)	0.16	0.63	1.25	2.18	5.10	10.94	20.78	43.67	71.63	94.52	99.75	100.00	0.60
Jun (600)	0.16	0.96	3.03	4.78	8.75	13.68	24.64	48.61	84.17	99.57	100.00	100.00	0.58
Jul (620)	0.62	2.78	5.55	11.08	17.84	27.06	41.50	63.62	88.20	99.88	100.00	100.00	0.55
Aug (620)	0.93	5.39	10.16	15.08	25.99	38.13	53.96	75.32	90.84	99.75	100.00	100.00	0.55
Sep (600)	0.32	0.96	2.87	4.46	8.27	15.10	25.10	46.22	71.15	96.39	100.00	100.00	0.59
Oct (620)	0.16	0.32	0.79	0.79	1.87	5.25	11.86	26.92	50.43	78.39	99.90	100.00	0.64
Nov (600)	0.00	0.16	0.32	0.32	0.63	1.70	5.95	15.65	33.84	61.12	97.79	100.00	0.66
Dec (620)	0.00	0.00	0.62	0.78	1.86	4.17	9.55	20.15	31.98	55.64	96.66	100.00	0.66

From Table 4a-g, monthly $\bar{K}_T$ values ranges in value from 0.44 – 0.68. 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. Hence, it is inferred that sky condition in North-West Nigeria is mostly cloudy throughout the year. Thus, a colossal amount of diffuse solar radiation is expected in this zone. Consequently, concentrate solar collector will be improper for harvest of solar radiation within the geo-political zone. Fig. 1 shows curves of clearness index for the study locations. It is observed that the curves followed same pattern with a sharp depression in August. This indicates that August is worst month for harvest of solar radiation intensity in the zone. Cluster of the curves expects that of Kaduna indicate possibility of similar sky conditions in those localities.

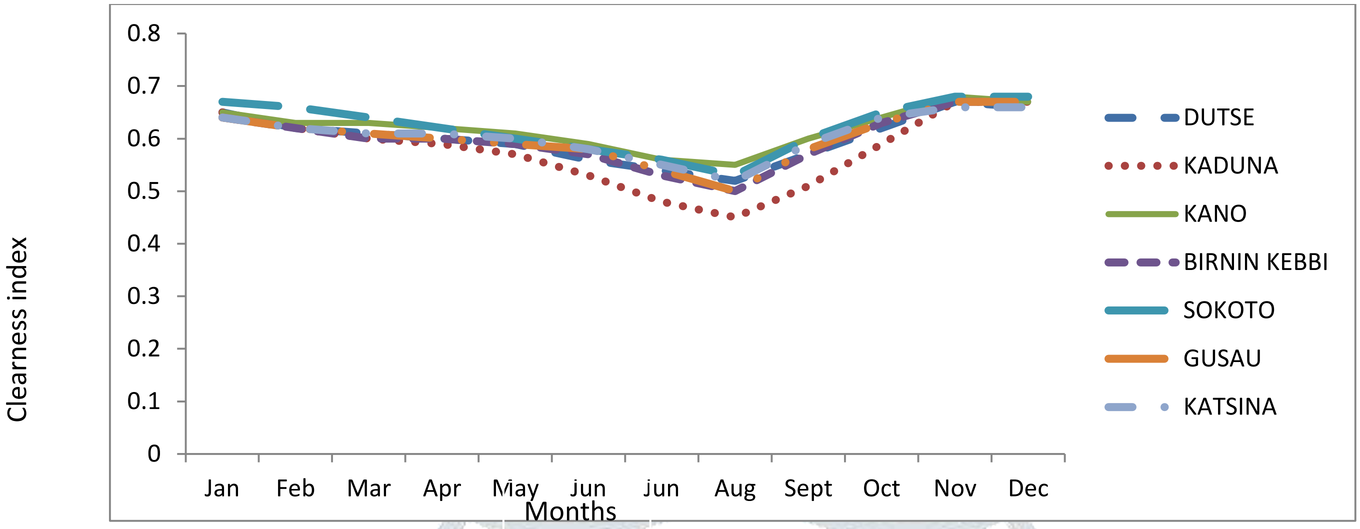

Fig. 1 monthly average clearness index for the study locations

Fig 2, shows curves of monthly percentage cumulative frequency daily clearness index for August. It is seen that the curve of Kaduna trailed behind the other curves. This further indicates that in August, Kaduna will most likely be cloudier and harvest the lowest value of solar radiation intensity in the zone. Curves of Kano and Sokoto and Katsina and Duste are observed to completely cross each other, though with those of Kano and Sokoto slightly leading. This suggests that these cities that crossed each other are likely to have similar level of solar radiation intensity. Vaguely, trailing behind the curves of Katsina and Duste are the curves of Gasau and Birnin Kebbi. It is observed that the curves of Gasau and Birnin Kebbi completely crossed each other at 40 % of 0.4 class interval. This reveals that about 60 % of days in a year in both study locations are likely to have similar solar radiation intensity that has clearness index above 0.4.

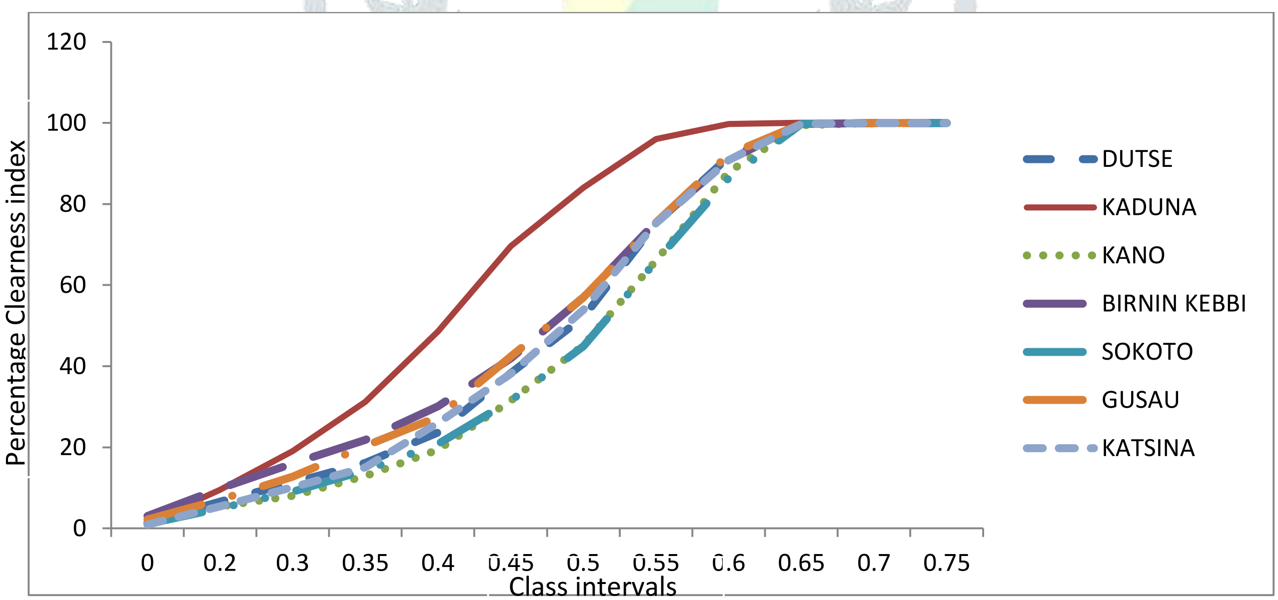

Fig 2 Curves of monthly percentage cumulative frequency distribution daily clearness index for August

Seasonal classification of monthly average clearness index is presented in Table 5. Anyanwu and Oteh (2003) aptly reported that months that have the same $\overline{K}_T$ values have similar statistical distribution of global solar radiation. Considering class intervals used in development of Tables 4a-g. Six seasonal classification patterns are identified in the following cities; Dutse, Kano, Bernin-Kebbi, Sokoto, Gusau and Katsina. For each of these study locations, two seasonal classification groups are observed in dry and rainy season period. In Kaduna, five seasonal periods are identified. The dry and rainy season periods recorded two and three seasonal classification patterns, respectively.

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

$\bar{K}_T$ *Values*

Dutse			Kaduna			Kano		
Periods	Ind.	**Ave**	Periods	Ind.	**Ave**	Periods	Ind.	**Ave**
Dry Season			***Dry Season***			***Dry Season***		
a. Nov, Dec, Jan,	0.67, 0.66, 0.65	**0.66**	**a**. Nov**,** Dec, Jan,	0.67,0.67,0.65	**0.66**	**a**. Nov, Dec, Jan	0.68, 0.67, 0.65	**0.67**
b. Feb, Mar, Oct	0.62, 0.61, 0.62	**0.62**	**b**. Feb, Mar, Oct	0.62, 0.60, 0.60	**0.61**	**b**. Feb, Mar, Oct	0.63, 0.63, 0.64	**0.64**
Rainy Season			***Rainy Season***			***Rainy Season***		
a. April, May, June, Sept	0.59, 0.59, 0.56, 0.57	**0.57**	**a**. April, May	0.59, 0.57	**0.58**	**a**. April, May, Sept	0.62, 0.61, 0.60	**0.61**
b. July, Aug	0.54, 0.53	**0.54**	**b**. June, Sept	0.53, 0.51	**0.52**	**b**. June, July, Aug	0.59, 0.56, 0.55	**0.54**
			c. Aug, July	0.45, 0.48	**0.47**			

Birnin Kebbi			Sokoto			Gusau		
Periods	Ind.	**Ave**	Periods	Ind.	**Ave**	Periods	Ind.	**Ave**
Dry Season			***Dry Season***			***Dry Season***		
a. Nov, Dec	0.67, 0.67	**0.67**	**a**. Oct, Nov, Dec, Jan, Feb	0.65,0.68,0.68, 0.67, 0.66	**0.67**	**a**. Nov, Dec	0.67, 0.67	**0.67**
b. Jan, Feb, Mar, Oct	0.64, 0.62,0.60, 0.63	**0.63**	b. Mar	0.64	**0.64**	**b**. Jan, Feb, Mar, Oct	0.61, 0.62, 0.61, 0.63	**0.62**
Rainy Season			***Rainy Season***			***Rainy Season***		
a. April, May, June, Sept	0.59,0.59, 0.57, 0.57	**0.58**	**a**. April, May, Sept	0.62, 0.60, 0.60	**0.61**	**a**. April, May, Jun, Sept	0.59,0.59, 0.58,0.58	**0.59**
b. July, Aug	0.53, 0.50	**0.52**	**b**. Jun, July , Aug	0.58, 0.56, 0.55	**0.56**	**b**. July, Aug	0.54,0.50	**0.52**

Katsina		
Periods	Ind.	**Ave**
Dry Season		
a. Nov, Dec, Jan, Oct	0.66, 0.66,0.64, 0.64	**0.65**
b. Feb, Mar	0.62, 0.61	**0.62**
Rainy Season		
a. April, May	0.61, 0.60	**0.61**
b. June, July, Sept, Aug	0.58, 0.55, 0.59 0.55	**0.57**

3.3 Sunshine Duration

Table 6 presents average monthly values of bright sunshine hours in North-West zone. Mean total monthly bright sunshine hours in the zone is estimated at 96.57 hrs. Months of the dry and rainy seasons contribute 53.53 % and 46.47 %, respectively of the mean total monthly bright sunshine hours. Birnin Kebbi (89.56 hrs) and Sokoto (105.08 hrs) recorded the lowest and highest level of monthly total bright sunshine hours in the zone, respectively. On monthly basis, minimum for both minimum (5.09 hrs) and maximum (7.42 hrs) occurred in August. This indicates that in the zone August is worst month of bright hours of sunshine.

Table 6 monthly values of bright sunshine hours

Years/ Months	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	Monthly Total
DUTSE	9.24	9.11	8.1	8.07	8.46	8.01	6.58	6.08	7.14	8.28	9.33	9.26	97.66
KADUNA	9.00	9.10	8.10	7.83	8.00	7.66	5.91	5.09	6.35	8.18	9.33	9.26	93.81
KANO	8.52	8.47	8.02	8.29	8.89	8.78	7.69	6.75	7.87	8.47	8.82	8.51	99.08
BIRNIN KEBBI	8.42	7.81	7.34	7.91	7.53	7.15	6.82	5.54	7.35	8.23	6.94	8.52	89.56
SOKOTO	9.15	9.10	8.83	8.62	8.67	9.00	8.10	7.42	8.28	9.28	9.60	9.03	105.08
GUSAU	8.76	8.79	8.06	8.06	8.45	8.22	6.80	5.92	7.11	8.33	9.08	8.89	96.47
KATSINA	9.15	8.10	7.50	7.90	8.50	7.60	6.15	6.40	7.20	8.20	8.55	9.10	94.35

MEAN	8.89	8.64	7.99	8.10	8.36	8.06	6.86	6.17	7.33	8.42	8.81	8.94	96.57
MAX	9.24	9.11	8.83	8.62	8.89	9.00	8.10	7.42	8.28	9.28	9.60	9.26	105.63
MIN	8.42	7.81	7.34	7.83	7.53	7.15	5.91	5.09	6.35	8.18	6.94	8.51	87.06

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
DUTSE	0.317	0.411	0.728	0.929
KADUNA	0.212	0.552	0.764	0.968
KANO	0.205	0.594	0.799	0.877
BIRNIN KEBBI	0.287	0.495	0.782	0.721
SOKOTO	0.162	0.623	0.785	0.941
GUSAU	0.278	0.479	0.757	0.939
KATSINA	0.350	0.386	0.736	0.857
MEAN	0.259	0.506	0.764	0.890

For the study location, the values of R is observed to be high. This shows that strong linear relationship exist between $\bar{K}_T$ and $\bar{n}/\bar{N}$. The values of a and b in Angstrong-Page equation for the entire zone is estimated at 0.259 and 0.506, 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

Sky conditions in North-West geo-political zone of Nigeria have been studied in this paper using global solar radiation, clearness index and sunshine hour. August is confirmed to be the worst month of solar radiation in the zone as the study locations indicate. Coefficients for the Angstrom-Page equation is estimated for the cities and the 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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