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RAINFALL AND SOLAR IRRADIANCE MONITORING IN NSUKKA ZONE, NIGERIA

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ABSTRACT: *This work presents statistical analyses of rainfall and solar irradiance in Nsukka, Nigeria using Nigerian Environmental and Climatic Observation Programme (NECOP) data obtained from National Space Research and Development Agency (NASRDA), Abuja, Nigeria. The findings showed that rainfall in the study region is extremely variable and showed a potential for a downward trend, while solar irradiance is less variable but still had a downward trend. Monthly rainfall was found to be increasing from April and peaks around September, then decreased from November through March. Solar irradiance is at maximum value in April and least in August. Between August and December, there was a rise in solar irradiance which values are even higher between February and March. At 95% confidence limit statistically significant decreasing trend are detected for rainfall* ($\rho < 0.05, Sen's\ Slope = -7.617$. *The result of solar irradiance reveals a statistically significant decreasing trend* ($\rho < 0.05, Sen's\ Slope = -5.032$) *which is statistically significant at 99% confidence limit.*

KEYWORDS: Agriculture; rainfall; solar irradiance; tropical savanna

INTRODUCTION

Generally, the study of weather and climate elements, especially temperature and rainfall, of a region is vital as they are essential for agricultural development and planning. There are differences in climate around the world because of differences in the amounts of radiation received from the sun at different parts of the Earth at different times of the year. For instance, there are wide differences in average temperatures around the world in January and July with January recording the lowest temperatures over the northern hemisphere while the warmest areas are the landmasses of the southern hemisphere, particularly South Africa and Australia. In July, the reverse is the case with the Northern Hemisphere recording temperatures well above 30^0C.

Rainfall and solar radiation are vital for life on our planet. Their importance has necessitated many researchers to carry out studies on the subjects. Various aspects of the rainfall and solar radiation in Nigeria have been studied based on daily, weekly, monthly, and annual rainfall values. These include the onset, advance, retreat, normality, trends, and periodicities but none has been done within Nsukka region, which is an agrarian area, and with the present emphasis on self-sufficiency in food production by the Federal Government of Nigeria, there is the need for a detailed study.

Results of precipitation patterns showed that the amount and area of the secondary rainfall maxima of 9^o-10^oN latitude of Nigeria has depreciated, and secondly, that the belt of minimum rainfall, with east-west axis which is almost coincident with the channels of the River Niger and River Benue, appears to be expanding with time (Adefolalu, 1986) which suggest a drier environment in the long term with Enugu estimated to be between 265.37mm and 320.21mm in 2009 (Enete and Ebenebe, 2009). Chukwukere (2005) found a trend in rainfall at Isu Njaba, Nigeria which showed a regular cyclical movement. Olaniran and Summer (1990) reported a long-term variation of annual and growing season rainfalls in Nigeria, particularly with a noticeable decline, in September and October which coincides with the end of rainy season in most parts of Nigeria. Also, Anyadike (1992) observed non-random changes in fluctuations and trends with decreasing tendency in rainfall totals that were significant in all regions of Nigeria, though no significant persistence was evident in all the regions. Chinago (2020), however, found no significant climatic variability in the pattern of rainfall or change in climatic pattern over Port Harcourt even though the trend and intensity of rainfall deceased over the years, there were still double maxima with an August break in between the two peak months of July and September.

It was observed that solar radiation over Abakiliki, Nigeria varied between dry and rainy seasons' maxima irradiance values of 1095.10W/m^2 and 689.48W/m^2 during dry and rainy seasons respectively (Nwankwo and Nnabuchi, 2015) while in Birnin Kebbi Usman and Abubakar (2019) reported highest variability in solar radiation in the months of January through March. Generally, there are alternate decreasing trends in mean annual precipitation and air temperature in Nigeria with a tendency towards a wetter condition, which implies that rainy season length is becoming longer than dry season period with increasing temperature causing a warmer environment (Akinsanola and Ogunjobi, 2014, Olujumoke et al. (2016).

Purpose of the Study

Nsukka Zone comprises of seven local government areas in the present Enugu State, Nigeria and lies within latitude 5^0 N and longitude7^0E in the arid Guinea Savanna climatic zone. The inhabitants are mainly farmers with cassava, cocoyam, yam, yellow pepper and vegetables like tomatoes, telfaria. Over the past years, farmers have been complaining of low farm output which they attribute to variable and declining rainfall pattern and temperatures leading to a shift from the traditional crops to cultivating other crops like cucumber, garden egg, carrot, etc. hitherto cultivated only in the Sahel Savanna of Northern Nigeria. This work examines the trend in annual rainfall and solar irradiance over the past two and half decades. This will help us to contribute ideas to the best agricultural practices for maximum crop and animal production.

Data Source

The Nigerian Environmental Climatic Observation Programme (NECOP) station data used for this work were obtained from National Space Research and Development Agency (NASRDA), Abuja, Nigeria at: www.carnasrda.com. The dataset is made of daily values of rainfall and solar

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irradiance over Nsukka (6.86ºN, 7.39ºE), Enugu State which spans from 2008 through 2017 (10 years).

The Study Area

Nsukka Zone (6.86^{0}N, 7.39^{0}E), Nigeria is in tropical Guinea Savanna climate of sub-Saharan West Africa. The Guinea Savanna separates the tropical moist forests of the rainforests in the south from the more interior Sudan Savanna. It is warm every month with both wet season, from late March to mid-October and dry season, from mid-October to late March. The most common form of precipitation throughout the year is rain; hail occurs infrequently. The average annual temperature is 32ºC and an average of 502 mm of rain in a year. Most of the rain falls during the 31 days centered on September, with an average total accumulation of 226.06. The rainless period of the year lasts from late November to mid – February. The least rain falls around January 5, with an average total accumulation of 2.54mm. It has an estimated population of 1.6million people who are predominantly peasant farmers, and it is an agricultural centre for yams, cassava, maize, palm oil, palm kernel, goat, pigs etc.

Theory And Method Of Data Analyses

The mean($\overline{X}$), standard deviation (SD) and coefficient of variance (M-K), of the average monthly rainfall and solar irradiance were calculated using the equations 4.1, 4.2, and 4.3 respectively.

Mean $\overline{X} = \frac{(\Sigma x)}{n}$ 4.1

where x is each of the value of the monthly average of rainfall and solar irradiance; n is the number of these values

(ii) Standard Derivation (SD)= $\sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$ 4.2

where x is each of the values of the monthly average; $\bar{x}$ is the mean; n is the number of these values.

(iii) Coefficient of variation (M-K)= $\frac{SD}{\bar{x}} \times 100\%$ 4.3

where SD is the standard derivation and $\bar{x}$ is the mean

(iv) Mann-Kendall Trend Test

The Mann-Kendall (M-K) test is a statistical non-parametric test used for the analysis of trend in climatology and in hydrologic time. It is computed as follows;

$S = \sum_{k=1}^{n-1}\sum_{j=k+1}^{n} Sign \quad (x_j - x_k)$ 4.4

where:

$Sign\left(x_j - x_k\right) = 1 \text{ if } x_j - x_k > 0$

$Sign\left(x_j - x_k\right) = 0 \text{ if } x_j - x_k = 0$

$Sign\left(x_j - x_k\right) = -1 \text{ if } x_j - x_k < 0$

x_1, x_2, x_3 ...... x_n represent n data points where x_j represents the data point at time j. A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates

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a decreasing trend.The value of Z in M-K test is used to find out if the time series information is demonstrating a significant trend or not. The Z value is computed as follows:

$$Z = \begin{pmatrix} \frac{s-1}{\sqrt{\mathrm{var}(s)}} \text{ if } s > 0 \\ 0 \quad \text{ if } s = 0 \\ \frac{s+1}{\sqrt{\mathrm{var}(s)}} \text{ if } s < 0 \end{pmatrix} \qquad 4.5$$

The positive and negative values of Z reflect the increasing and decreasing trend, respectively. The probability of shifting year (P-value) is computed as follows:

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-z^2}{2}} \qquad 4.6$$

The trend is said to be increasing (decreasing) if Z is positive (negative) and the computed probability is less than (greater than) the significance level,α. If the probability (p-value) is less than the significance level, the null hypothesis is considered to be rejected. A very high positive value of S is an indicator of an increasing trend and a very low negative value indicates a decreasing trend.

Sen's slope test method was performed A positive value of Sen's slope indicates an upward or increasing trend and a negative value gives a downward or decreasing trend. A significance level, α was used to test whether the null hypothesis (H_0) (increase or decrease) trend existed. If p-value is less than the significance levelα, the null hypothesis (H_0) is rejected implying that the trend is statistically insignificant.

RESULTS AND DISCUSSION

Table 5.1: Average monthly statistical information of rainfall

Month	**Maximum**	**Minimum**	**Mean**	**SD**	**M-K (%)**
January	40.5	0	6.58	12.9778	197.1112
February	66.2	0	14.19	19.9726	140.7512
March	101.5	0.1	24.73	32.2186	130.2814
April	312.8	2.9	89.12	93.1571	104.5300
May	314.1	11.4	149.74	101.7641	67.9605
June	210.9	19.5	155.99	57.3204	36.7462
July	258.1	2	179.29	85.1809	47.5101
August	382.6	100.8	185.66	91.0829	49.0590
September	393.5	141.4	262.06	90.2290	34.4307
October	372.5	5.9	171.99	99.0220	57.5743
November	48.8	2.8	30.18	15.7760	52.2782
December	18.54	0	6.42	7.8846	122.8131

Average % of coefficient of variation (M-K) = 86.7538%

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Table 5.2: Monthly average statistical information of Solar Irradiance

Month	Maximum	Minimum	Mean	SD	M-K (%)
January	134.87	80.87	105.676	17.395	16.4607
February	177.13	81.71	123.442	28.117	22.7775
March	181.79	99.78	144.654	25.865	17.8806
April	182.21	102.32	158.571	25.550	16.1126
May	179.12	103.20	144.02	23.153	16.0762
June	154.76	107.49	131.284	15.116	11.5142
July	136.30	74.74	110.319	21.408	19.4060
August	124.80	62.97	92.120	21.873	23.7444
September	134.26	67.86	102.411	23.182	22.6361
October	144.02	71.10	103.775	36.718	35.3822
November	143.71	82.96	114.526	22.177	19.3642
December	185.45	87.40	120.747	30.764	25.4777

Average % of coefficient of variation (M-K) = 20.5694%

From Table 5.1, the average percentage of monthly variation for rainfall throughout the years was 86.75% and the average monthly rainfall coefficient of variation (M-K) ranges from 34.43% in September to 197.11% in January. From literature, M-K is used to classify the degree of variation as less (M-K<20%), moderate (20<M-K<30%), high (M-K>30%), very high (M-K>40%) and M-K>70% indicates extremely high inter-annual variability of rainfall (Gomes, 1985). Hence, inter-annual rainfall variability in Nsukka ranges from high to extremely high. With an average of 86.75%, the variability of inter-annual rainfall could be described as extremely high. The coefficient of variation (M-K) for the monthly average of solar irradiance ranges between 11.51% in June and 35.38% in October and with an average percentage of 20.57%, which shows moderate variability (Table 5.2).

Table 5.3: Average yearly statistical information of rainfall

Year	Maximum	Minimum	Mean	SD	M-K (%)
2008	226.4	0.2	104.667	84.2741	80.5164
2009	372.5	0	145.700	129.4786	88.8666
2010	382.6	0	148.108	146.4737	98.8965
2011	275.6	0	109.433	71.2587	65.1163
2012	329.2	0	127.850	111.1271	86.9290
2013	258.1	4.2	114.650	101.9975	88.9642
2014	393.5	0	75.268	113.6477	150.9907
2015	323.2	4.5	121.570	115.4251	94.9454
2016	144.7	0	45.917	53.9576	117.5112
2017	214.9	0	70.192	87.1650	124.1808

Average % of coefficient of variation (M-K) = 99.6917%

Table 5.4: Average yearly statistical information of solar irradiance

Year	Maximum	Minimum	Mean	SD	M-K (%)
2008	181.79	117.08	149.132	24.9462	16.7276
2009	172.58	111.69	140.508	20.2691	14.4256
2010	182.21	117.21	138.634	20.0715	14.4781
2011	172.45	90.66	132.084	23.0060	17.4177
2012	153.14	87.17	114.495	25.8646	22.5902
2013	130.97	78.84	107.973	101.7048	94.1947
2014	153.77	62.97	104.231	117.6050	112.8311
2015	140.88	73.06	97.023	118.2383	121.8663
2016	185.45	85.24	118.134	92.7410	78.5049
2017	177.15	74.13	107.408	95.6584	89.0608

Average % of coefficient of variation (M-K) = 58.2097%

From Table 5.3, it was observed that the yearly rainfall coefficient of variation (M-K) ranges from 65.12% in 2011 to 150.99% in 2014 with an average of 99.69% which implies an extremely variable rainfall for the period under study. Table 5.4 shows that the yearly solar irradiance coefficient of variation (M-K) varies from 14.43% in 2009 to 121.87% in 2015 and the average of 58.21% means a very high variability of solar irradiance.

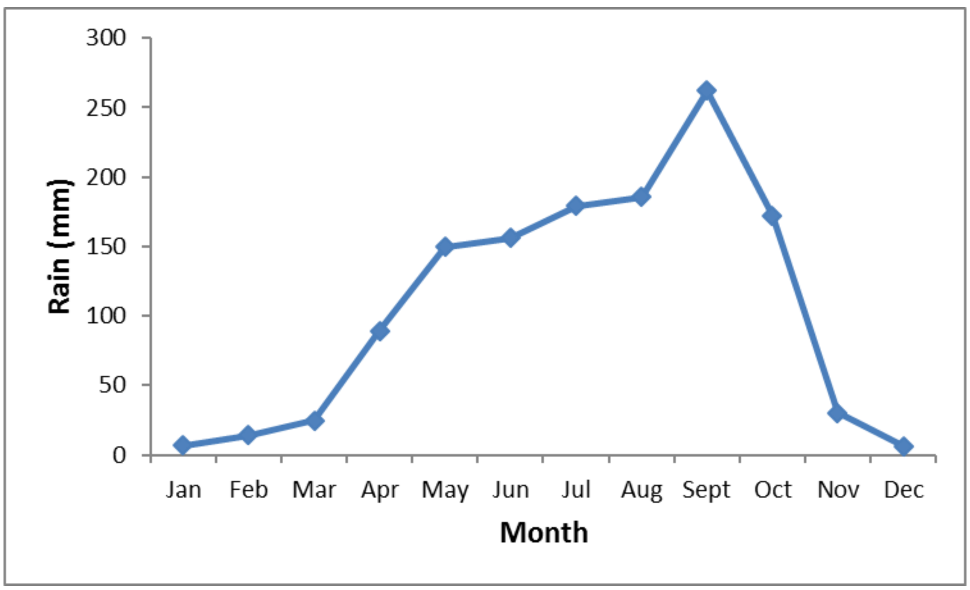

Fig. 5.1: Mean monthly pattern of rainfall

Figures 5.1shows that the mean monthly rainfall in Nsukka starts to increase from March to September, with a slight decline in August, before it starts to decrease. The peak is in September with highest value of approximately 262 mm. The slight decline in August may be attributed to the August break. There is low rainfall between late October and mid-March with least value of approximately 6mm in December. The low level of rainfall coincides with long dry season in

Nigeria with peak dry conditions between early December and late February. This finding is in agreement with Oguntoyinbo (2011).

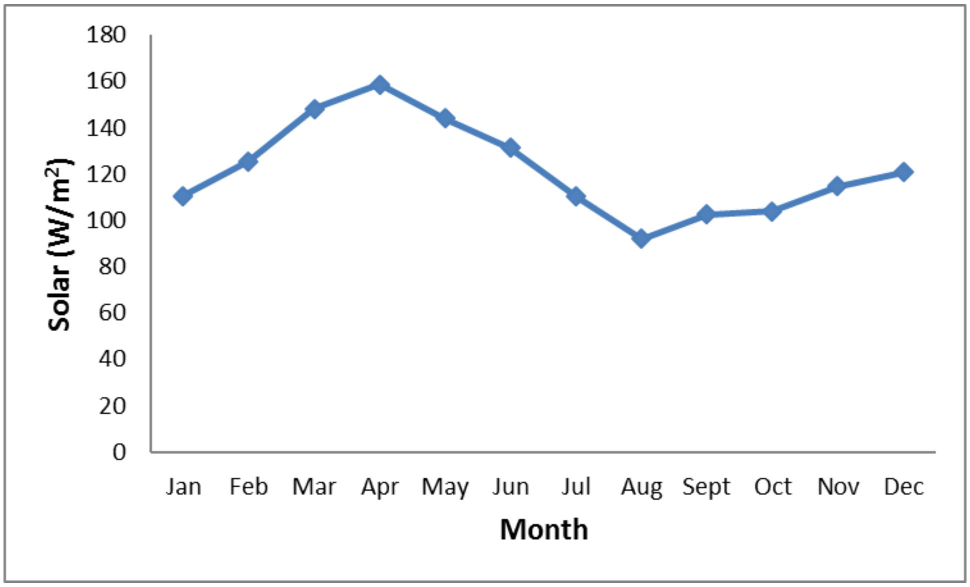

Figure 5.2: Mean monthly pattern of solar irradiance

Figure 5.2 shows that the mean monthly pattern of solar irradiance increases from the month of January to the highest value of 159W/m^2 in April and thereafter starts to decrease to the minimum value of 92W/m^2 in August and then rises again till December The low value in August could be attributed to short dry season (August break), which appears between late July and early September. The small increase in the month of September – October could be as a result of brief wet period (short rainy season) that is observed from early September to mid – October. There was a reduction in the direct solar irradiance of approximately 107 W/m^2 in the month of January. This is due to strong attenuating effects of the harmattan dust, which occurs between the late November and early–March. The effect of harmattan is high during the months of November and January (Awachie and Okeke, 1985). The decline in solar irradiance from April – August could be attributed to the long rainy season, which starts in March and lasts to the end of July or early August.

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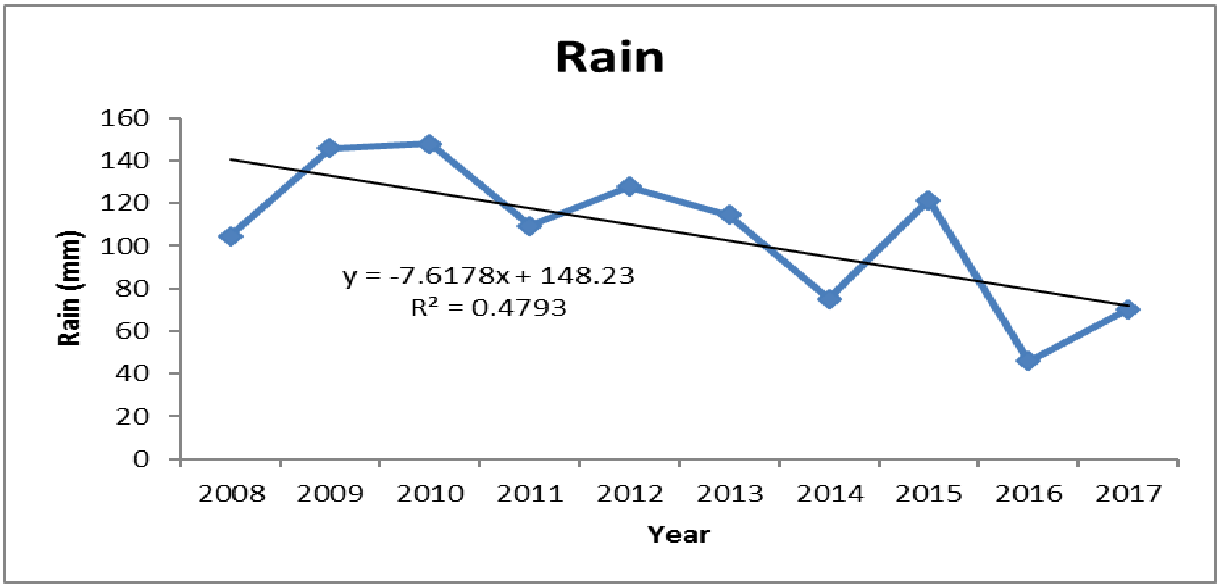

Figure 5.3 Average yearly trend of rainfall

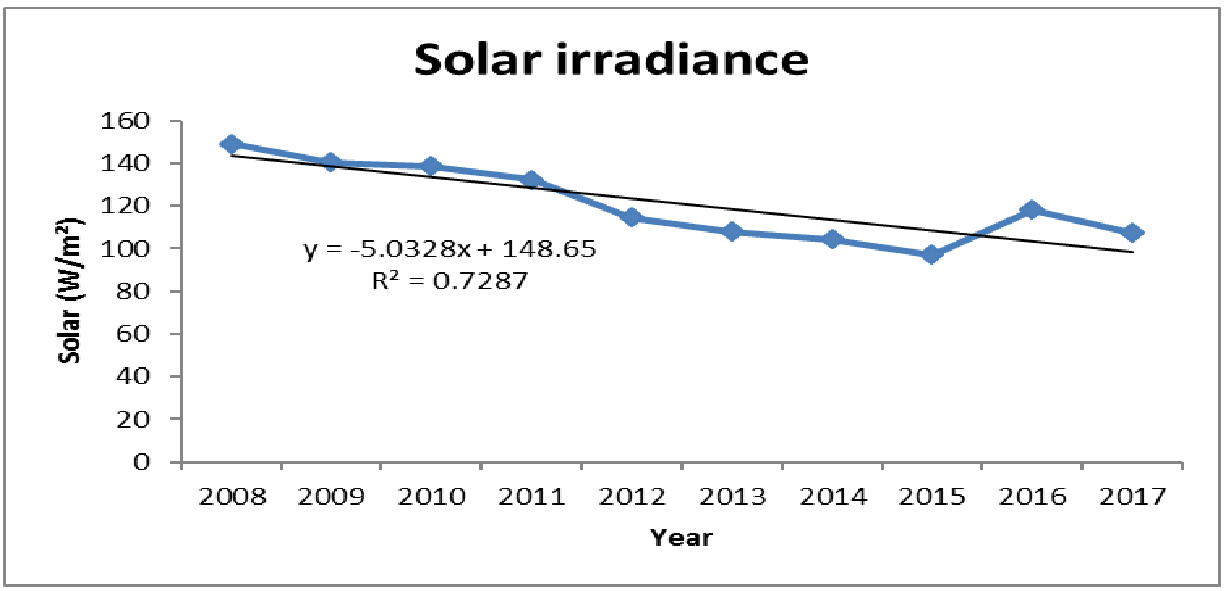

Fig. 5.4: Average yearly trend of solar irradiance

There is a general decreasing trend of rainfall (Sen's slope = -7.617) and the coefficient of determination value (R^2 = 0.479) and about 48% of the variability in the rainfall is explained by this linear regression (Fig. 5.3). Similarly, solar irradiance shows a decreasing trend (Sen's slope = -5.032) with approximately 73% of variability in the solar irradiance is explained by this linear regression mode.

Table 5.5: Mann-Kendall trend analysis for rainfall and solar irradiance

Parameter	Rainfall (mm)	Solar Irradiance (W/m^2)
α	0.05	0.05
Sen's slope	-7.617	-5.032
M-K-stat., S	-19	-33
Z-stat	-1.966	-2.367
P-value	0.085	0.045
Significance	Not significant	Significant
Null Hypothesis, H_0	Accepted	Rejected
Trend	No	Yes

From Table 5.3, there is a potential for a downward trend in rainfall i.e. rainfall is decreasing (S = -19) and this agrees with the line chart of Figure 5.3 but statistically insignificant at 5% level (P>0.05) and also statistically insignificant at 95% confidence limit which was decided on the basis of Z score value. The null hypothesis was accepted implying that there was no monotonic decreasing trend for rainfall within the period under study. The solar irradiance for the observed period showed a decreasing trend (S = -33). The results also indicated that solar irradiance were statistically significant at 5% level (P<0.05), and also statistically significant at 99% confidence limit which was decided on the basis of Z score value (Table 5.5). The null hypothesis was rejected for solar irradiance since the probability of shifting year (p-value) is less than the significance level,α (Saul, 2019). This means that solar irradiance showed a monotonic decreasing trend in Nsukka for the period studied.

CONCLUSION

This research investigated the monthly pattern, variability and trend of rainfall and solar irradiance at Nsukka zone for the period of 2008 – 2017 (10 years). It was observed that the amount of rainfall in the study region is extremely variable, while solar irradiance is less variable. At the monthly scale pattern, the result showed that rainfall is high from May – September and low from October – November and January - March. For solar irradiance, the monthly pattern showed that it is high as from January with the highest value in April, which shows that there may be excess of solar irradiance in dry season.

For trend detection, the M-K test indicates a significant trend for both rainfall and solar irradiance at a significance level $\alpha = 0.05$ over the studied region. Sen's slope showed a downward trend for both rainfall and solar irradiance with values -7.617 and -5.032 respectively. On the whole, the result of the study could serve as a means of information needed by people in the studied region for effective planning and basis for in-depth climate change impacts on water resources in the area.

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