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Signatures of solar activity fluctuations on Nigerian precipitation patterns

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Variations in solar activity on different timescales are a good measure of solar radiation. Solar radiation reaching the earth's atmosphere impacts on the earth's climate. Sunspot numbers and F10.7 are widely accepted as good parameters for monitoring solar activity and in this paper. These two solar indices have been employed in determining their effects on Nigerian precipitation on annual and seasonal scales for the period of 102 years covering eleven complete solar cycles that is, from 1902 to 2021. Pearson's rank correlation and covariance were employed in the study. Results show that there were weak positive and negative correlations between solar activity and rainfall in Nigeria on annual scale and during the rainy season, high amount of dry seasonal rainfall as well as Harmattan rainfall were recorded during low solar activity and a negative covariance existed between rainfall and solar activity during the dry season and Harmattan period and the wet season rainfall and annual rainfall recorded positive covariance.

Keywords: Dry season, F10.7, Precipitation, Solar activity, Sunspot, Wet season

INTRODUCTION

It is a widely accepted fact by majority of the science and even non-scientific community that the world climate has been changing over the past decades; however, opinions differ on the reasons for the change. This led to the idea of climate change and the formation of various governmental and inter-governmental agencies on climate change initiatives. Variation in solar activity is one of the reasons cited by scientists for climate change. Literatures abound on the relationship between solar activity and climatic variables in other climatic regions of the world; particularly rainfall but studies in this area on Nigerian rainfall and solar activity are scarce. In this paper we are focusing on the impacts or influences of changes in solar activity on Nigerian rainfall. This will be beneficial to farmers in Nigeria majority of who are peasant farmers that practice rain-fed farming as well as to water resources managers, policy makers among others.

Climate change is noticed in many forms like variability in intensity, rate and amount of rainfall, rise in sea level, extreme weather events like flooding and drought. There is an increase in precipitation rate by about 0.05 to 0.1% per annum in the majority of middle and high latitude regions of the Northern Hemisphere but a decrease in the sub-tropical areas in the last century (Zhang et al., 2021). Nigeria which lies between latitude 4^0N and 14^0N is within

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the tropics and sub-Saharan West Africa where these change in rainfall are reported. Nigerian rainfall is highly variable (Animaushaun et al., 2020; Ugwu et al., 2023**)** on seasonal, annual and decadal scales just like in a few other places. This variability could be due to anthropogenic factors as suggested by Hanson and Okeke (2021) that found a very weak correlation between rainfall and sea surface temperature in Port Harcourt, Nigeria and Abidjan, Cote D'voire which is not likely linked to solar activity. Similarly, Hiremath (2006) attributed correlation between SSN and Indian rainfall at moderate-to-high significance in some solar cycles to presence of aerosols on rain forming clouds and/or interstellar dust particles and not on solar activity.

Maximum precipitation in Loess Plateau Region of China coincided with the peak of SSN and a downward trend in precipitation was witnessed when Southern Oscillation Index was negative showing that solar activity and El Nino have significant impacts on precipitation (Li et al., 2017). Rainfall variability in amount, intensity, duration and in extreme events such as drought and flooding are associated with North Atlantic Oscillation (Trigo et al., 2004; Laurenz et al., 2019), the 11-year solar activity (Wood and Lovett, 1974; Li et al., 2017; Czymzik et al., 2016) and galactic cosmic rays caused by volcanic eruptions (Rao et al., 2017; Nitka and Burnecki, 2019). Low solar activity is linked to disasters like cold temperatures, irregular precipitations and cold floods (Liu et al., 2022) and deviations from the variations of Monsoon annual rainfall from the normal (Ambily et al., 2018). For instance, during periods of low solar activity associated with North Atlantic Oscillation, flooding frequency increased in the United States of America and there was a significant increase in average monthly rainfall due to rise in the number of galactic cosmic rays that act as condensation nuclei at the same period of solar minimum.

Correlation between solar activity and rainfall has been reported in many places around the globe. Selvaraj et al. (2013) reported negative correlation between Indian rainfall and sunspot numbers (SSN) and they found this useful in analyzing rainfall cycles. Mohamed and El-Mahdy (2014) found a weak negative correlation between total rainfall and SSN, but on temporal and spatial scales, they found no significant relationship between the two indices in both Sudan and South Sudan.

MATERIALS AND METHOD

Study area

Nigeria is a country located in the West African coast bounded by Niger Republic to the North, Atlantic Ocean in the South, Benin Republic to the South and Cameroon and Chad to the East. It is within latitude 4 - 14^0N and longitude 3^0E -14°E. Thus, Nigeria is in the East of Greenwich Meridian, North of the Equator and South of the Sahara Desert. With a population of over 193 million as at 2022, it is the most populous country in Africa and the sixth in the world. Nigeria has only two seasons: the dry season and wet (rainy) season and three major climatic zones namely: tropical monsoon to the South, tropical Savanna which covers most of the central region and the Sahelian hot semi-arid climate in the far North. The tropical Monsoon climatic zone in the South experiences more rainfall than the other two regions with an average annual rainfall of 2,000 mm and, even up to 4,000 mm in the Niger Delta Regions of River Niger. The wet season starts in late March and lasts till October in this region. The tropical Savanna that covers over half of the entire country has an annual average rainfall of 1,200 mm within the six months of wet season (April to September). The Sahelian hot and semi-arid zone has the least annual rainfall average of 500 -750 mm and only five months of wet (rainy) season between May and September. The overall average annual rainfall of Nigeria is 1,650mm and average monthly temperature of 21°C within December and January and 35°C in April. Jos Plateau is the coldest place in Nigeria and Sokoto is the hottest.

The topography of Nigeria varies from hills and plateaus at the centre to plains in the South and North. There are also the flat valleys of the two major rivers (River Niger and River Benue) found in Nigeria. The Chappal Waddi Mountain (known as the Mountain of Death) in Taraba State, at 2,419m above sea level, is the highest mountain in West Africa.

Sources of data

Rainfall dataset is got from the Climatic Research Unit gridded Time Series (CRU TS v4) of the University of East Anglia, United Kingdom (http://www.cru.uea.ac.uk/cru/data/hrg/). The interpolation process of the current version (CRU TS v4) uses the angular-distance weighting (ADW) which helps in the assessment of variability of dataset quality by climatic zones. The dataset is a high-resolution data with no missing values for the period studied.

Sunspot number (SSN) data is sourced from WDC-SILSO, Royal Observatory of Belgium, and Brussels while the F10.7cm (simply referred to as F10.7) data were downloaded from OMNI website https://omniweb.gsfc.nasa.gov/cgi/nx1.cgi. Solar radio flux (F10.7) measures the hourly strength of solar radio emission at a wavelength of 10.7cm. The adjusted values of solar flux, which are not modulated by the varying sun-earth distances like the observed values, are used in this article because they compare well with other solar indices like sunspot number (SSN). The correlation coefficient between SSN and F10.7 is 0.99. Along with SSN, F10.7 is one of the best and widely used indices of solar activity (Tapping, 2013). It is actually a flux density measurement and spans more than fifty (50) years with no missing data. Sunspot number counts (SSN) are the only solar dataset that cover a longer period. The SSN data and rainfall data cover the period between 1902 and 2021 while the F10.7 data covers the period 1964 to 2021.

Data analysis

Following Animashauan et al. (2020), we classified rainfall as annual rainfall (ANN) and the seasons as: early rainfall (AMJ) covering April, May and June; main season rainfall (JASO) for the months of July, August, September and October; dry season rainfall which covers the entire dry season months of November, December, January, February and March (NDJFM); and the Harmattan Period rainfall (DJF) of December, January and February. This is to enable us get a holistic idea of the relationship between solar activity annual/seasonal rainfall in Nigeria as it rains throughout the entire year in some parts of Nigeria.

The period under study (1902-2021) has eleven solar cycles

Table 1. Statistical results of rainfall between 1902 and 2021.

Variable	Early Rainfall (AMJ)	Main Rainfall (JASO)	Dry Season Rainfall (NDJFM)	Harmattan Rainfall, (DJF)	ANN rainfall
Max (mm)	490.3(1911)	929.8(1957)	151(1932)	56.8(2007	1463(1957)
Min (mm)	257.1(1987)	556.7(1983)	30.7(2000)	3.5 (2012)	901.4(1983)
Mean (mm)	365.9	766.12	80.11	22.35	1212.12
SD (mm)	44.82	66.10	22.21	9.74	94.24
Skewness	-0.0139	-0.3337	0.7096	0.8791	-0.2619
Kurtosis	-0.2746	0.8177	0.9570	1.3074	0.4397
Regression equation for rainfall	$y = -0.304x + 384.3$	$y = 0.069x + 630.2$	$y = -0.229 + 530.3$	$y = -0.071x + 163.1$	$y = -0.46x + 2123$
r^2	0.055	0.001	0.129	0.065	0.029

ANN = Annual Rainfall; Max = Maximum rainfall; Min = Minimum rainfall; AMJ = April, May and June; JASO = July, August, September and October; NDJFM = November, December, January, February and March; DJF = December, January and February.

starting with solar cycle 14 and ending with the last complete solar cycle, solar cycle 24. Solar cycle 22 which started in September 1986 and ended in September 1996 is the shortest while cycle 23 that started in September 1996 and ended in December 2008 is the longest. Cycles 22 and 23 had period of nine years eleven months and twelve years four months respectively and average SSN/day of 106 and 82 respectively.

Various statistical tools were used for the study and these include Pearson's rank correlation coefficient, regression analysis, covariance, skewness, kurtosis among others. Kurtosis and skewness were employed to explain the distribution of seasonal and annual rainfall. Both are dimensionless. Skewness tells the position of the outliers while kurtosis shows whether the distribution is peaked and possesses thick tails or not. Positive kurtosis means that the weight is more in the tails.

RESULTS AND DISCUSSION

From Table 1, annual rainfall, early rainfall, dry season rainfall and Harmattan rainfall have negative gradients, an indication of decreasing trend from 1902 to date; only the main season rainfall showed a positive gradient value. However, low values of coefficient of determinism, r^2, mean that the variations cannot be explained satisfactorily by regression equations only. Dry season rainfall and Harmattan rainfall had positive skewness while the rest had negative skewness. From the results, the values of coefficient of skewness showed that the rainfall data ranged from being nearly symmetrical to being slightly skewed. Only early rainfall has a negative value of coefficient of kurtosis which implies it has less weight in the tails than normal distribution.

Low values of correlation coefficient between the two solar indices (SSN and F10.7) and annual or seasonal rainfall were obtained (Table 2). Weak positive values of correlation were found between SSN and AMJ, SSN and JASO and, SSN and ANN while anti-correlation existed between SSN and NDJFM and, SSN and DJF. Only AMJ showed weak positive correlation with F10.7, the rest have anti-correlation with F10.7. Covariance between SSN and rainfall were positive for AMJ, JASO and ANN and negative for NDJFM and DJF. Only AMJ showed positive values of covariance between them and F10.7 while others had negative values of covariance. Negative values of covariance mean that as one value is increasing, the other is decreasing and vice versa while positive values mean that the two variables are varying in the same direction. The regression equations for rainfall between 1964 and 2021 for ANN, JASO, NDJFM and DJF rainfall were all negative; an indication of decrease in rainfall for the period that is, 1964-2021 but early rainfall amount increased. The coefficient of determinism is low for annual and seasonal rainfall.

Relationship between rainfall and solar activity indices

Early rainfall (AMJ) and solar activity

Rainfall starts in April and ends in October. In this article, any rain in the months of April, May and June is considered early rain. Figure 1a, the year

Table 2. Statistical results of rainfall and solar activity indices between 1964 and 2021.

Variable	AMJ	JASO	NDJFM	DJF	ANN
CORREL (SSN)*	0.0424	0.0532	-0.0929	-0.0781	0.0356
CORREL (F10.7)	0.1040	-0.0174	-0.3297	-0.2067	-0.0168
COV (SSN)*	88.015	162.763	-95.435	-35.187	155.013
COV (F10.7)	202.408	-46.050	-291.063	-69.14	-63.008
Regression equation for rainfall	$y = -0.202x + 757$	$y = 0.578x - 393.5$	$y = -0.107x + 383.7$	$y = -0.050x + 119.0$	$y = 0.269x + 646.2$
r^2	0.005	0.024	0.013	0.011	0.002

CORREL = Correlation coefficient; COV = Covariance; r^2 = coefficient of determination, *1902 – 2021.

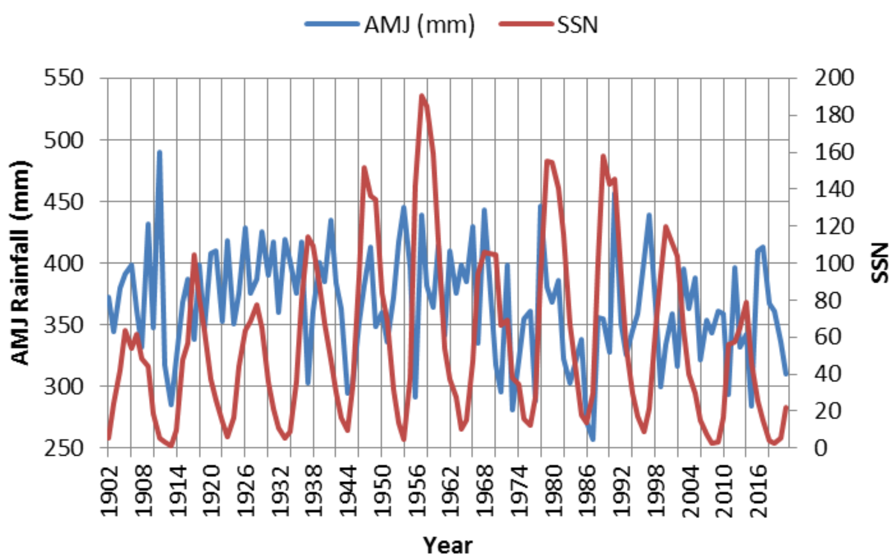

Figure 1a. Linear plot of early rainfall (AMJ) and SSN.

1911 recorded the highest amount of AMJ rainfall (490.3 mm) with a very low SSN (9.6). Only two other years (1997 and 2017) showed similar relationship of high early rainfall and low SSN and low F10.7 (Figures 1a and 1b). The least AMJ rainfall (257.1 mm) was in 1987 with SSN of 29.4 which is not low. From Figures 1a and 1b**,** there are no well-defined relationship between early rainfall and solar activity. Even though, the covariance between AMJ and SSN is 88.015 and, AMJ and F10.7 are 202.408 which imply that variation is in the same direction, low values of correlation coefficient of 0.042 and 0.104 respectively show there is a very weak relationship between AMJ rainfall and solar activity within the season.

Main season rainfall (JASO) and solar activity

Most of the rain in Nigeria falls in the months of July, August, September and October (JASO) and this period is referred to as main season rainfall. The Southern parts of Nigeria have bimodal rainfall maxima in July and September while the Northern parts experience only one maximum in September. During this period, temperature is generally low (< 30°C) and humidity is high. From Table 1, the highest amount of JASO rainfall (929.8 mm) was in the year 1957 and the least rainfall amount of 556.7 mm was in 1983. With a covariance of 162.76 and coefficient of correlation of 0.053, both rainfall and SSN increased in the positive direction and there was no strong correlation between SSN and main season rainfall. Again from Figures 2a and 2b, there is no clear pattern between the SSN/F10 and main season rainfall (JASO). Its pattern is very similar to what obtained in AMJ and SSN/F10.7.

Dry season rainfall (NDJFM) and solar activity

In Nigeria, dry season lasts from November through March (NDJFM). It is a period of little or no rain in most

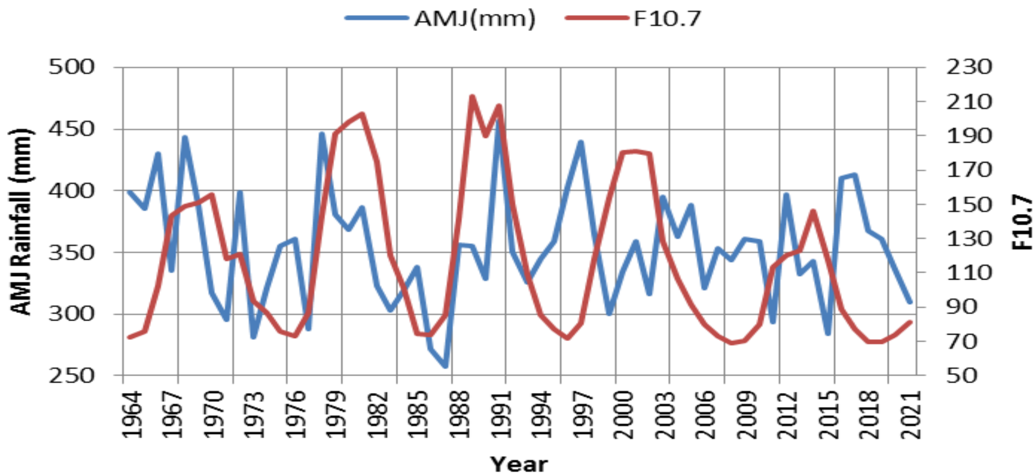

Figure 1b. Linear plot of early rainfall (AMJ) and F10.7.

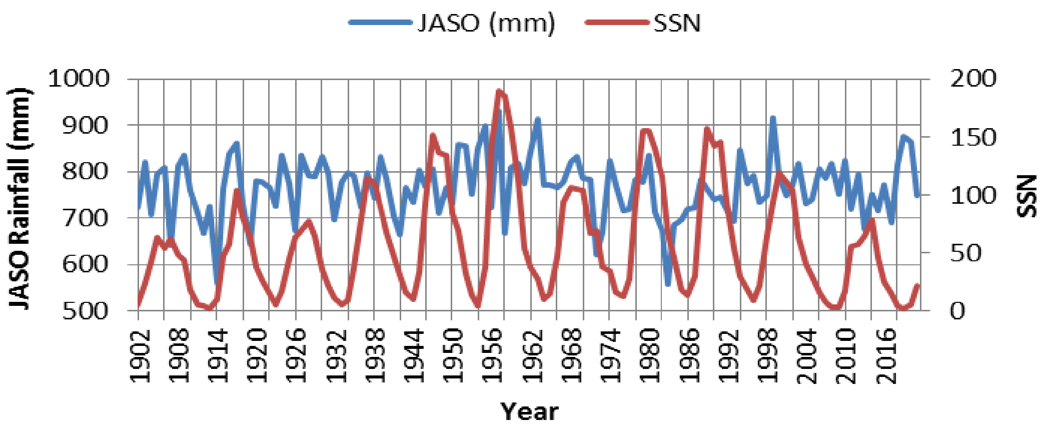

Figure 2a. Linear plot of main season (JASO) rainfall and SSN.

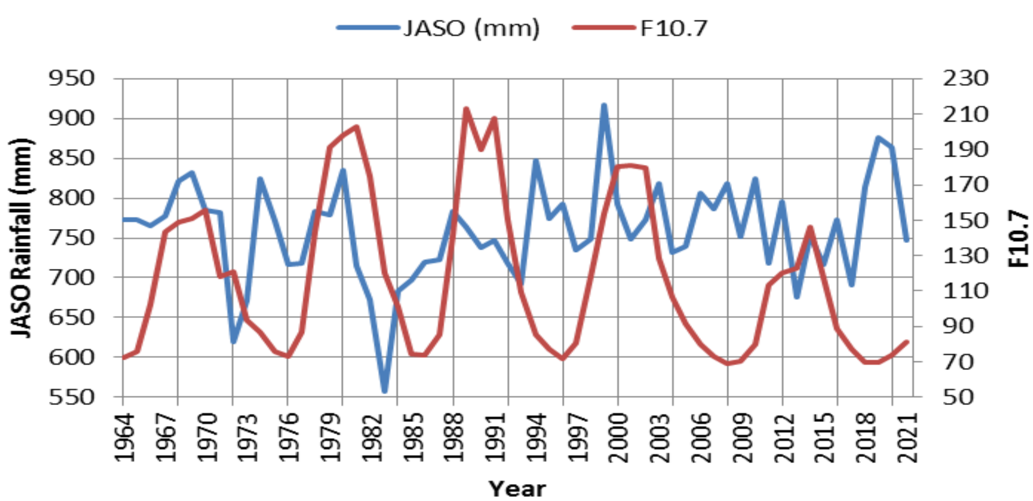

Figure 2b. Linear plot of main season rainfall (JASO) and F10.7.

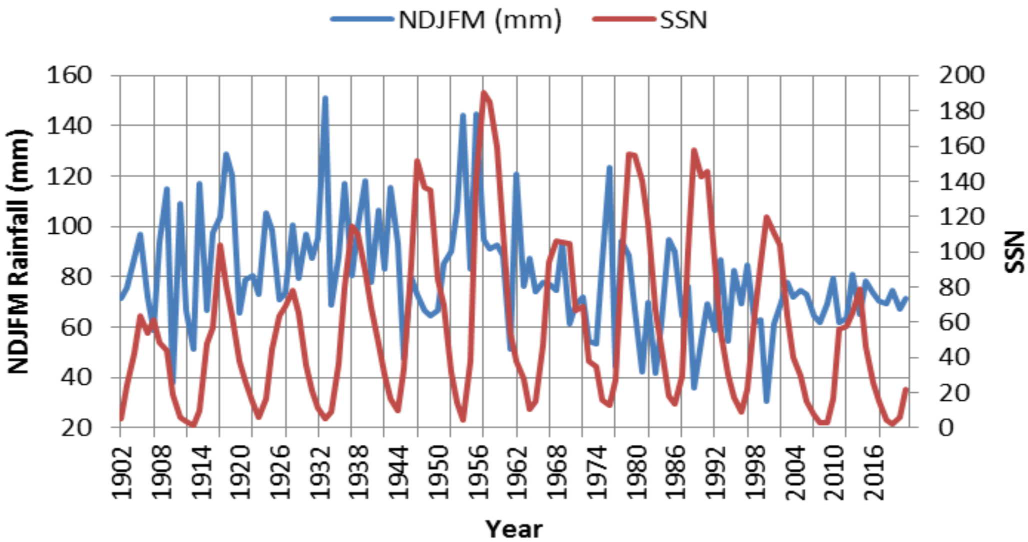

Figure 3a. Linear plot of dry season (NDJFM) rainfall and SSN.

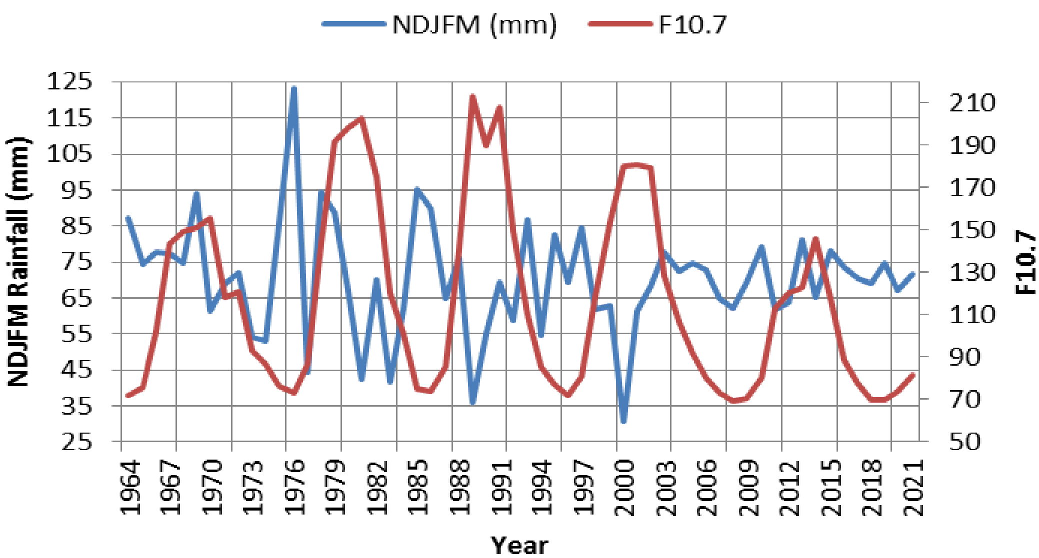

Figure 3b. Linear plot of dry season (NDJFM) rainfall and F10.7.

parts of Nigeria. The little amount of rainfall recorded is only in the southernmost parts of the country. This is a season of high temperatures (> 35°C) and low humidity. From Table 1, the highest amount of rainfall during this season was 151 mm in 1932 and the least was 30.7 mm in 2000. From Figures 3a and 3b, it appears that years of highest amount of dry season rainfall had low SSN and low F10.7 while years of high SSN and high F10.7 witnessed low dry season rainfall amount. With a covariance of -95.43 and anti-correlation coefficient of -0.093 (Table 1) between dry season rainfall and SSN/F10.7, it follows that as the dry season rainfall is increasing, the solar activity is decreasing and vice versa.

Harmattan rainfall (DJF) and solar activity

Harmattan is a dry, dusty easterly or north easterly wind blowing from the Sahara Desert over the entire West African Region. In Nigeria, it occurs within the dry season; mostly between December and February. It causes wide fluctuations in daytime and nighttime

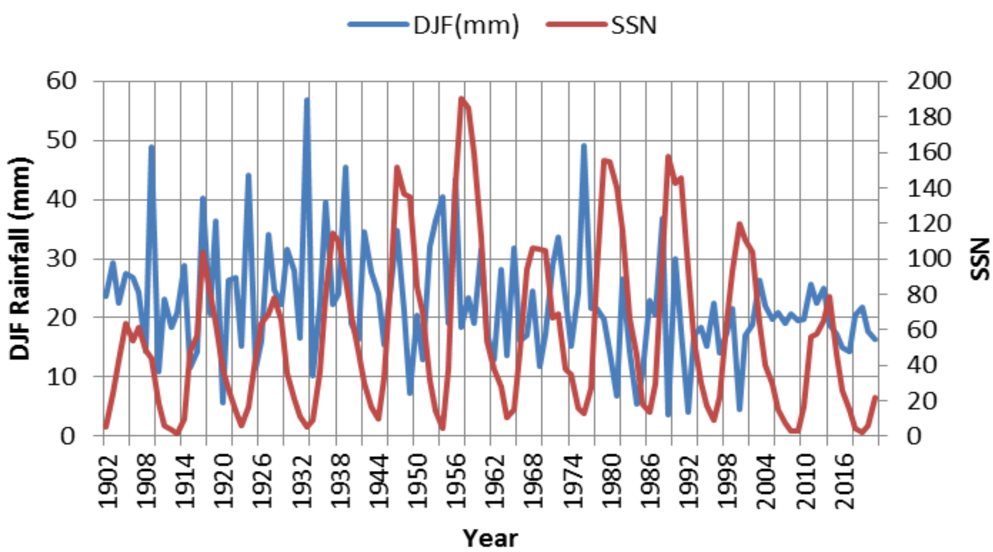

Figure 4a: Linear plot of dry season (DJF) rainfall and SSN.

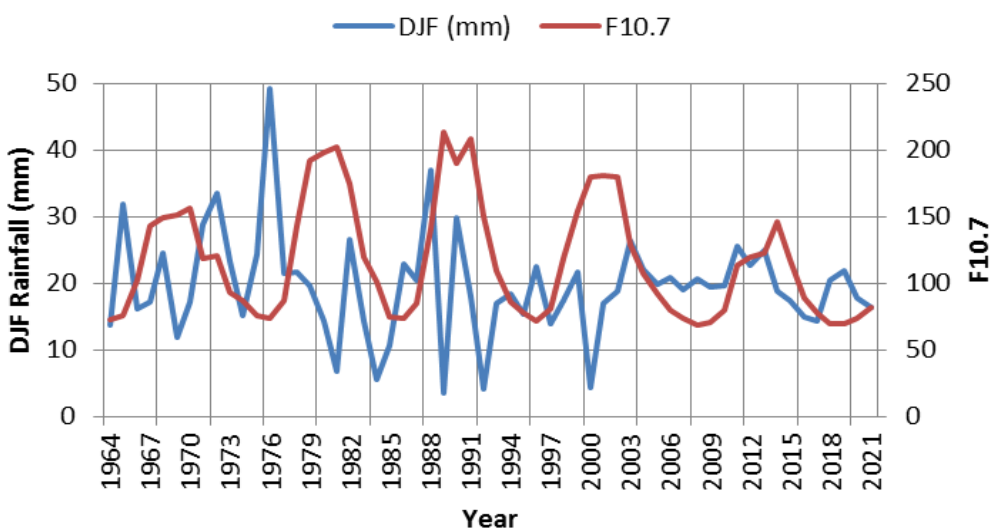

Figure 4b. Linear plot of Harmattan season (DJF) rainfall and F10.7.

temperatures, low humidity, desert storms and sandstorms, poor visibility and human skin dryness. Harmattan dissipates cloud cover leading to very low rainfall.

It appears that high Harmattan rainfall is associated with low solar activity and vice versa (Figures 4a and 4b). Results shown in Table 1 are that the covariance and correlation coefficient are -35.19 and -0.078 respectively. This means that there was a negative linear relationship between Harmattan rainfall and solar activity. Figures 4a and 4b appears to support this as the highest amount of dry season rainfall occurred at low solar activity and low dry season rainfall was obtained during periods of high solar activity. Both the skewness (value = 0.88) and kurtosis (value = 1.31) are within the acceptable good ranges of -3 to +3 and -10 to +10 respectively for the two statistics.

Annual rainfall (ANN) and solar activity

Annual rainfall refers to the total rainfall recorded each

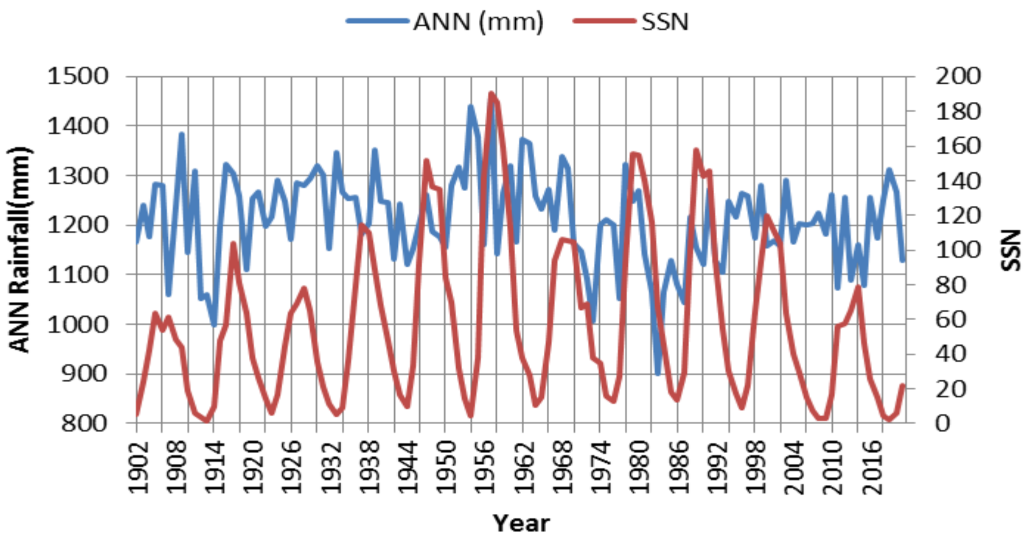

Figure 5a. Linear plot of annual (ANN) rainfall and SSN.

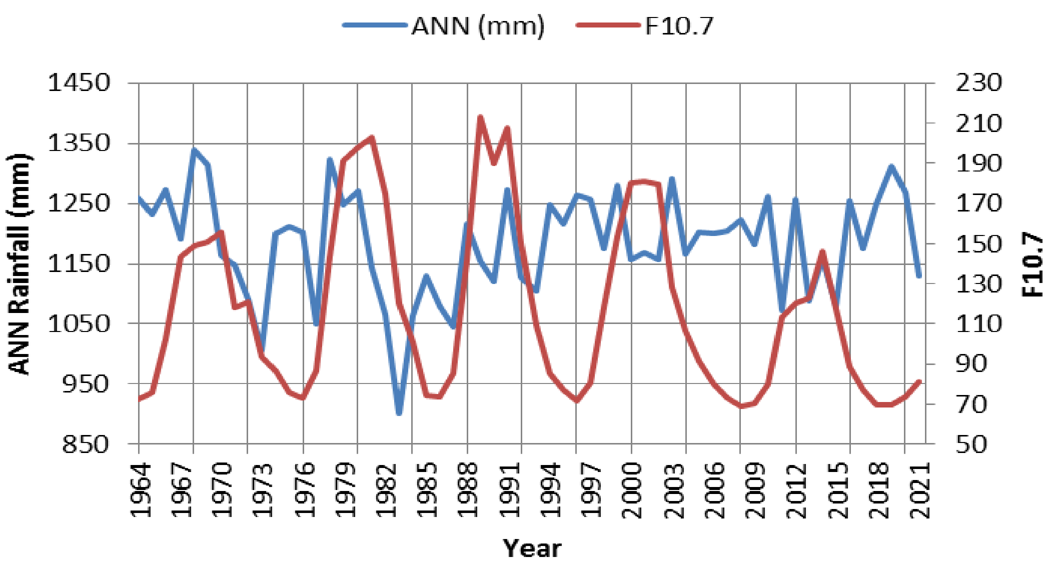

Figure 5b. Linear plot of annual rainfall (ANN) and F10.7.

year. Its highest value in 1957 and least value in 1983 are 1463mm and 901.4mm respectively (Table 1). There are no clear relationship between annual rainfall and solar activity indices (Figures 5a and 5b). For instance, in 1975 and 2019, rainfall were high while solar activity indices were low but 1978, 1980 and 1991 recorded high values of rainfall and solar activity indices. Also, 1957 had the highest amount of annual rainfall and SSN while 1983 with the least annual rainfall did not record high SSN or F10.7. The coefficient of correlation and covariance between annual rainfall and SSN were 0.0356 and 1555.01 respectively which showed that there was little or no correlation between the annual rainfall and SSN as both varied positively.

Conclusion

From the correlation analysis, there is generally weak correlation between rainfall and solar activity (SSN and F10.7), hence solar activity may not be the only factor influencing rainfall amount in Nigeria. This agrees with the work of Mostafa et al., 2021 and Hanson and Okeke, 2021. It is only the dry season rainfall and Harmattan rainfall that there appears to be anti- correspondence between solar activity and rainfall. Within these periods, weak anti-correlation exists between rainfall and solar activity and the values of covariance between solar indices and rainfall are negative. Negative values of covariance are indications of the two variables varying in the opposite directions. Rainfall in the tropics is influenced mainly by the inter-tropical convergence zone (ITCZ) which controls the seasons as it moves with the Sun. ITCZ is a low pressure area around the equator where the North East trade wind from the Northern Hemisphere meets with the South West trade wind from the Southern Hemisphere. ITCZ and anthropogenic factors are likely factors to the intensity, rate and amount of rainfall in Nigeria.

Data availability

The datasets generated and/or analyzed during the current study are available in the following sources: (1) Rainfall: University of East Anglia, United Kingdom, Climatic Research Unit gridded Time Series (CRU TS v4) (http://www.cru.uea.ac.uk/cru/data/hrg/), (2) sunspot number (SSN) data: WDC-SILSO, Royal Observatory of Belgium, Brussels and (3) F10.7cm (simply referred to as F10.7): OMNI (https://omniweb.gsfc.nasa.gov/cgi/nx1.cgi).

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

REFERENCES

Ambily S, Haritha VG, Morais CSK, Girish TE (2018). Solar activity changes during prolonged sunspot minima as inferred from Indian Monsoon rainfall variations. International Astronomical Union 13(S340):209-210. doi: 10.1017/S174392131800163.

Animaushaun IM, Oguntunde PG, Akinwumju AS, Olubanjo OO (2020). Rainfall analysis over Niger Central Hydrolysis Area, Nigeria: Variability, trend, and change point detection. Scientific African 8:e00419. https://doi.org/10.1016/j.sciaf.2020.e00419.

Czymzik M, Dreibrodt S, Feeser I, Adolphi F, Brauer A (2016). Mid-Holocene humid periods reconstructed from calcite varves of the Lake Woserin sediment record (north-eastern Germany). The Holocene 26(6). doi.org/10.1177/0959683615622549.

Hanson EA, Okeke FN (2021). Impacts of sunspot number and geomagnetic aa-index on climate of Wet Zone West Africa during solar cycles 22-24. Scientific Reports 11:11500 doi: 10.1038/s41598-021-90999-6.

Hiremath KM (2006). The influence of solar activity on the rainfall over India: Cycle-to-cycle variations. Journal of Astrophysics and Astronomy 27:367-372.

Laurenz L, Lüdecke H-J, Lüning S (2019). Influence of solar activity changes on European rainfall. Journal of Atmospheric and Solar-terrestrial Physics 185:29-42. https://doi.org/10.1016/j.jastp.2019.01.012.

Li HJ, Gao JE, Zhang HC, Zhang YX, Zhang YY (2017). Response of extreme precipitation to solar activity and El Nino events in tropical regions of the Loess Plateau. Advances in Meteorology 2017. Article ID 9823865, 9 p, https://doi.org/10.1155/2017/9823865.

Liu J-Y, Chen Y-I, Lee P-H, Huang CS, Fang T-W (2022): Severe weather disasters in China linked to solar activity during 1-1825 Common Era. Geoscience Letters 9(1):13. https://doi.org/10.1186/s40562-021-00210-x

Mostafa AM, Mohamed EE (2021). Impact of sunspot activity on the rainfall patterns over Eastern Africa: A case study of Sudan and South Sudan. Journal of Water and Climate Change 12(5):2104-2124. https://doi.org/10.2166/wcc.2021.312.

Nitka W, Burnecki K (2019). Impact of solar activity on precipitation in the United States. Physica A: Statistical Mechanics and its Applications 527:121387. doi.org/10.1016/j.physa.2019-121387.

Rao MP, Cook BI, Cook ER, D'Arrigo RD, Krusic PJ, Anchukaitis KJ, LeGrande AN, Buckley BM, Davi NK, Leland C, Griffin KL (2017). European and Mediterranean hydroclimate responses to tropical volcanic forcing over the last millennium. Geophysical Research Letters 44(10):4377-5245. doi.org/10.1002/2017GL073057.

Selvaraj RS., Umarani R, Mahalakshmi N, May MA (2013). Correlative study on solar activity and all India rainfall: Cycle to Cycle Analysis. Journal Indian Geophysical Union 17(1):59-63.

Tapping KF (2013). The 10.7 cm solar radio flux (F10.7). Space Weather 11:394-406. doi:10.1002/swe.20064.

Trigo RM, Pozo-Vázquez D, Osborn TJ, Castro-Díez Y, Gámiz-Fortis S, Esteban-Parra MJ (2004). North Atlantic oscillation influence on precipitation, River flow and water resources in the Iberian Peninsula. International Journal of Climatology 24(8):925-944.

Ugwu EBI, Ugbor DO, Agbo JU, Alfa A (2023). Analyzing rainfall trend and drought occurrences in Sudan Savanna of Nigeria. Scientific African 20(2023):e01670, https://doi.org/10.1016/j.sciaf.2023.e01670.

Wood CA, Lovett RR (1974). Rainfall, drought and the solar cycle. Nature 251(5476):594-596.

Zhang F, Cai H, Ma X, Bai H (2021). Evaluation and development of empirical models for estimating daily and monthly mean daily diffuse horizontal solar radiation for different climatic regions of China. Renewable and Sustainable Energy Reviews 105:168-186.