Correlation between Monthly Rainfall and Solar Activity in Lagos-Nigeria during Different Solar Epochs

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ABSTRACT

Rainfall and solar activity are vital components of Earth's environment system. This study investigates the correlation between monthly rainfall and solar activity during three different solar epochs at Lagos (Lat 6.56 ^{o}N Long. 3.34 ^{o}E), Nigeria. Despite the established influence of solar activity on Earth's climate, the relationship between monthly rainfall patterns and solar activity during different solar epochs remains poorly understood. Using Pearson correlation coefficient analysis, this study examines the variations of solar activity (sunspot numbers) and monthly rainfall patterns from 2002 – 2012 a full solar cycle. Contrary to explanations, results show no significant correlation between monthly rainfall and solar activity during the different solar epochs. However, further analysis reveals weak correlations varying across solar maxima (0.024), moderate (0.273) and minima (0.237) phases respectively. These findings suggest that the relationship between rainfall and solar activity is more complex than previously thought, highlighting the need for further research into the underlying mechanisms. This study contributes to improved understanding of solar-climate relationships.

Keywords: Rainfall, Solar Activity, Solar Epochs, Correlation, Variation.

INTRODUCTION

Solar activity, characterized by phenomena such as sunspots, solar flares, and variations in solar irradiance, has long been recognized as a driver of space weather and climate variability on Earth. Solar cycles, typically lasting about 11 years, represent fluctuations in the Sun's magnetic activity, with peak periods known as solar maxima and low periods as solar minima [1]. These changes in solar activity have been linked to variations in climate, particularly through their influence on atmospheric circulation patterns, rainfall, and temperature [2]. However, the regional effects of solar activity, especially on rainfall patterns, remain an area of ongoing investigation, as the relationship between solar variability and rainfall can be complex and inconsistent across different geographical regions [3].

Lagos, Nigeria, located in the tropical region of West Africa, experiences distinct wet and dry seasons, with rainfall being a key climatic factor that influences agriculture, water resources, and urban planning. Understanding the drivers of rainfall variability in this region is critical, particularly as climate change and population growth increase pressure on water resources [4]. Scientists from various fields, including astronomy, space physics, climate science, and hydrology, have conducted numerous studies to explore the relationship between solar activity and climatic and weather phenomena. Substantial evidence supports a correlation between solar activity and weather patterns, particularly disaster-related weather events [5]. One

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widely recognized example of this relationship is the statistical connection between solar activity, such as the annual sunspot number, and rainfall levels on Earth. Research has shown that fluctuations in the water level of Lake Victoria in Africa, often used as an indirect measure of tropical rainfall, were positively correlated with the 11-year solar cycle from 1880 to 1930 [6]. This evidence contributed to the understanding that solar activity influences rainfall patterns, leading many to acknowledge that rainfall could be linked to variations in solar activity [7].

However, after 1930, the correlation between solar activity and rainfall appeared to weaken or disappear. Studies have shown that on a global scale, the relationship between sunspot numbers and rainfall can vary—it may be positive, negative, or even nonexistent depending on regional or temporal factors [8]. This variability complicates efforts to definitively attribute rainfall changes to solar activity, indicating the need for further research to understand the mechanisms behind these fluctuations [9]. Several mechanisms have been proposed to explain how solar activity influences Earth's climate. First, variations in total solar irradiance (TSI) affect the amount of solar energy reaching Earth's surface, influencing atmospheric and oceanic temperatures. Studies suggest that even small changes in TSI can have significant long-term climate impacts [10]. Secondly, ultraviolet radiation (UV) from the Sun varies significantly with solar activity. Increased UV radiation during solar maxima leads to changes in the stratosphere, particularly in ozone concentrations, which can alter atmospheric circulation patterns and affect climate systems ([11];[12]. Thirdly, the Sun's magnetic field modulates the flux of galactic cosmic rays reaching Earth. During periods of high solar activity, the Sun's magnetic field strengthens and reducing cosmic ray penetration into the Earth's atmosphere. Some studies propose that cosmic rays may influence cloud formation and, therefore, Earth's energy balance and climate [13], although this mechanism remains under investigation.

Recent studies have highlighted the potential role of solar activity in modulating rainfall in tropical regions, suggesting that solar cycles could influence the timing and intensity of rainfall [13]. Lagos, like many tropical locations, may experience rainfall variations linked to changes in solar irradiance, although these effects are often modulated by other factors such as sea surface temperatures and atmospheric dynamics [14]. Lagos, located on the southwestern coast of Nigeria, experiences a tropical monsoon climate characterized by distinct wet and dry seasons. Its rainfall patterns are influenced primarily by the movement of the Intertropical Convergence Zone (ITCZ), a band of low pressure near the equator that shifts north and south with the seasons, and by the southwest monsoon winds from the Atlantic Ocean as well as Sea Surface Temperature (SST) anomalies. The city proximity to the ocean also plays a key role in modulating its rainfall variability throughout the year.

Rainfall in Lagos is typically bimodal, with two major seasons: a long rainy season and a short rainy season, separated by a relatively short dry season. The long rainy season occurs from March to July, peaking in June. This period is marked by heavy downpours due to the strong influence of the monsoon winds and the Inter-tropical Convergence Zone (ITCZ) moving northward across the region [15]. During this time, Lagos experiences its highest rainfall amounts, contributing significantly to the city's annual rainfall. The short rainy season takes place from September to November, with a peak in September, after the ITCZ has moved back southward. Between these two rainy seasons is the "August break," a brief dry period where rainfall significantly decreases, particularly in August. This interruption in the rainy season is a common feature in southern Nigeria and is thought to be caused by the temporary weakening of the monsoon winds [15]. The dry season in Lagos extends from December to February and is dominated by the dry northeasterly harmattan winds from the Sahara Desert. This period is characterized by low rainfall and lower humidity, although coastal influences mean that Lagos often remains relatively humid compared to more northern parts of Nigeria.

Monthly rainfall patterns in Lagos show considerable variability, with rainfall gradually increasing from March and peaking in June. The month of June typically receives the highest average rainfall, sometimes exceeding 300 mm. July also records significant rainfall, although it starts to decline towards the end of the month, leading into the August break. In contrast, the dry season months (December, January, and February) experience minimal rainfall, often less than 10 mm, making this period the driest in Lagos. The variability in monthly rainfall is critical for urban planning and water resource management, especially considering the city's susceptibility to flooding during peak rainy periods. Understanding these rainfall patterns is essential for sectors such as agriculture, water supply, and disaster management in Lagos. With recent studies suggesting

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changes in rainfall intensity and distribution due to climate change, there is a growing need to monitor and adapt to these shifts to mitigate the impacts on urban infrastructure and livelihoods [14 - 15].

This study aims to explore the correlation between monthly rainfall and solar activity in Lagos, Nigeria, across different solar epochs. By examining rainfall data alongside solar indices such as sunspot numbers, this research seeks to determine whether solar variability plays a significant role in modulating rainfall patterns in Lagos. Understanding this relationship can provide valuable insights into regional weather dynamics and improve the accuracy of long-term weather predictions.

DATA AND METHOD

The monthly rainfall dataset from 2002 to 2012 (a full solar cycle) were obtained from Nigeria Meteorological Administration (NiMet), Lagos with geographical coordinate (Lat 6.56 ºN Long. 3.34 ºE). The relative sunspot number dataset for the same period were obtained from National Geophysical Data Center (NGDC) now National Center for Environmental Information NCEL website (https://www.ngdc.noaa.gov/stp/solar/ssndata.html). The sunspot data from 2002 to 2012 covered period of high solar activity HSA, moderate solar activity MSA and low solar activity LSA phases. Adopting the classification method used by [16], [23]. The rainfall and sunspot data set for each of the year were tabulated on monthly basis as shown in Table 1 and 2 respectively. The monthly data is the mean values of the daily data for that month evaluated using equation 1

$$Monthly\ Mean\ (m) = \frac{1}{N}\sum_{r=1}^{N} X_r \qquad (1)$$

where x is rainfall and sunspot values, m is the monthly mean rainfall and sunspot values and N is the total number of available data set in each of the day in a month.

Table 1: Showing Monthly Rainfall (2002 – 2012) Ikeja

YR/M	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
2002	0.8	65.6	35.1	336.3	145.9	329.5	346.0	45.2	188.6	142.7	149.2	9.7
2003	53.4	79.1	308.1	157.4	320.7	69.5	18.5	185.2	141.0	184.8	0.0	0.0
2004	45.7	122.8	291.1	306.2	213.5	94.5	68.5	321.2	160.9	49.4	20.5	0.0
2005	0.0	93.1	78.2	94.1	185.3	392.3	225.3	15.0	194.2	94.8	96.4	16.2
2006	44.2	10.7	121.8	26.4	294.3	264.0	52.8	65.7	327.6	191.3	95.3	4.6
2007	0.0	0.0	76.1	31.6	253.7	367.7	228.0	287.9	160.1	120.3	118.3	5.4
2008	0.8	3.3	69.6	96.8	230.0	365.0	442.7	134.3	226.8	98.8	98.9	49.0
2009	1.6	16.3	33.9	115.5	154.2	463.4	119.0	12.0	84.1	342.7	48.7	0.0
2010	37.2	42.4	68.0	126.9	159.3	368.7	30.8	190.6	235.7	122.8	92.3	3.2
2011	0.0	87.2	21.6	74.7	170.5	251.9	476.9	43.7	185.3	209.3	240.5	0.O
2012	0.0	122.2	78.1	124.7	134.9	478.8	152.1	33.3	214.1	148.9	123.2	17.4

Table 2: Showing monthly Sunspot Number (2002 – 2012) and Rz Annual Mean values

YR/M	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	Annual Mean	Level of Solar activity
2002	114.1	107.4	98.4	120.7	120.8	88.3	99.6	116.4	109.6	97.5	95.5	80.8	104.1	High
2003	79.7	46.0	61.1	60.0	54.6	77.4	83.3	72.7	48.7	65.5	67.3	46.5	63.6	High
2004	37.3	45.8	49.1	39.3	41.5	43.2	51.1	40.9	27.7	48.0	43.5	17.9	40.4	Moderate
2005	31.3	29.2	24.5	24.2	42.7	39.3	40.1	36.4	21.9	8.7	18.0	41.1	29.8	Low
2006	15.3	4.9	10.6	30.2	22.3	13.9	12.2	12.9	14.4	10.5	21.4	13.6	15.2	Low
2007	16.8	10.7	4.5	3.4	11.7	12.1	9.7	6.0	2.4	0.9	1.7	10.1	7.5	Low
2008	3.3	2.1	9.3	2.9	3.2	3.4	0.8	0.5	1.1	2.9	4.1	0.8	2.9	Low
2009	1.3	1.4	0.7	0.8	2.9	2.9	3.2	0.0	4.3	4.8	4.1	10.8	3.1	Low
2010	13.2	18.8	15.4	8.0	8.7	13.6	16.1	19.6	25.2	23.5	21.5	14.4	16.5	Low
2011	18.8	29.6	55.8	54.4	41.5	37.0	43.8	50.6	78.0	88.0	96.7	73.0	55.6	Moderate
2012	58.3	32.4	63.4	55.5	69.7	64.5	68.0	63.1	61.5	53.3	61.4	40.5	57.6	Moderate

$Rz \geq 60$ indicates HSA, $30 \leq Rz < 60$ indicates MSA, and $0 \leq Rz \leq 30$ indicates LSA [16]. Analysis was done under different solar epochs using the stacked area and clustered column bar charts, thereafter correlation

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analysis was carried out across the three solar activity periods i.e. HSA, MSA and LSA using the Pearson Product Moment Correlation Coefficient formula (PPMCC) shown in equation 2 below

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (2)$$

where n is the number of data points, x and y are the variables being compared, in this case rainfall and sunspot number [17]. Correlation coefficient, r, which is a statistical parameter or tool that quantifies the strength and direction of a linear relationship between two variables. It ranges from -1 to +1, the closer to these values, the stronger the positive or negative relationship. If the correlation coefficient is 0, it means that there is no relationship [17]. Table 3 below shows the interpretation of r

Table 3: Interpretation of the correlation coefficient

Size of r	**Interpretation**
0.9 to 1.00	Very high correlation
0.70 to 1.89	High correlation
0.50 to 0.69	Moderate correlation
0.30 to 0.49	Low correlation
0.00 to 0.29	Very weak or no correlation

RESULTS AND DISCUSSION

3.1 Comparison of the Variation of Monthly Rainfall and Sunspot Number during High Solar Activity Year (2002 And 2003)

Figures 1 and 2, depict the comparison of the variation between monthly rainfall and sunspot numbers during high solar activity for 2002 and 2003 respectively. The stacked area bar chart (blue) represent the rainfall data while the clustered column bar chart (purple) represent the sunspot data.

From Figure 1 during the year 2002 which corresponds to a period of high solar activity (near the peak of Solar Cycle 23), sunspot numbers are high throughout the year, though there is some fluctuation from month to month with the lowest peak sunspot numbers recorded during the month of June (88.8) and December (80.8). Rainfall shows clear seasonal variation, with peaks likely during the middle of the year (June and July) coinciding with the rainy season in many regions. Despite the high sunspot numbers, rainfall appears to be driven more by regional climate patterns than by the variations in solar activity. Low rainfall were observed during the months of January to March and November to December which correspond to the dry season periods while high peak values of rainfall were observed during April to July and September to October corresponding to the wet season period with a break at August. Observation from Figure 1 shows that no strong monthly correlation between the peak sunspot values which were consistently high and peak rainfall for all the months were observed except at April, June and July where peak rainfall correspond with peak sunspot fairly. The rainfall continues to follow seasonal trends regardless of sunspot variability. Recent work by [14 - 15] indicates regional rainfall is more responsive to atmospheric teleconnections than direct solar indices.

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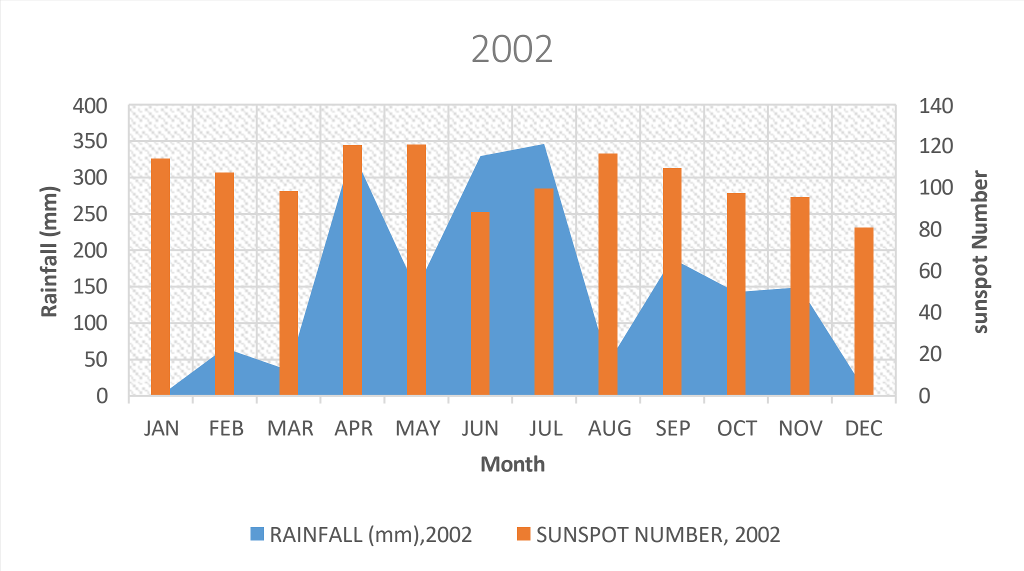

Fig 4.1: Histogram diagram

Figure 1: Comparison of variation of rainfall and sunspot number during high solar activity (2002).

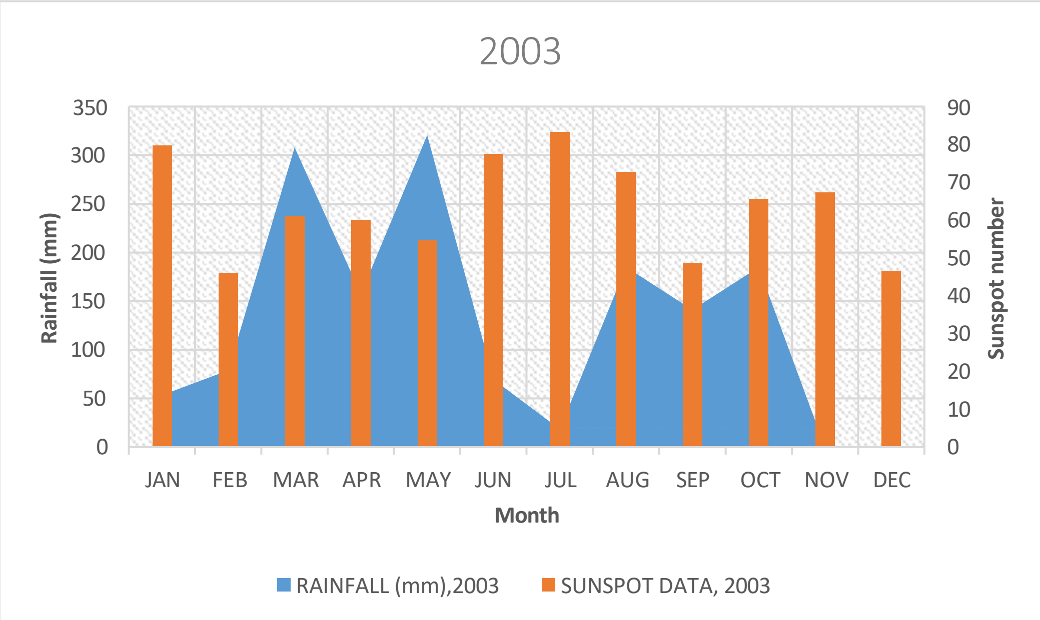

Figure 2: Comparison of variation of rainfall and sunspot number during high solar activity (2003).

From Figure 2, above sunspot numbers remain high in 2003, though there was a slight decline compared to 2002 as the solar cycle begins to descend from its peak. Rainfall again follows a seasonal cycle, with high amounts during the rainy season and lower amounts during the dry season. Just as in Figure 1 (2002), the sunspot numbers do not show a clear monthly influence on rainfall. In spite of the high solar activity, the variation in rainfall does not show direct correlation with sunspot numbers except at March and May, where rainfall increase correspond with a slight sunspot increase fairly. Rainfall continues to be dominated by seasonal climatic factors.

Comparison of the Variation of Monthly Rainfall and Sunspot Number during Moderate Solar Activity Year (2004, 2011 and 2012)

Figure 3 shows variation of rainfall and sunspot number during period of moderate solar activity, with sunspot numbers lower than that observed during the peak years but still showing noticeable monthly fluctuations with lowest values of 27.7 and 17.9 during the months of September and December respectively. Rainfall continues

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to follow seasonal trends, with increases during the rainy months (March to October) and decreases during the dry months (November to February). There may be minor variations, but overall, the relationship between sunspot numbers and rainfall remains weak in most of the months except March where a noticeable increase in rainfall correspond a little with moderate increase in sunspot value. No strong correlation is evident between monthly rainfall and sunspot numbers variation during moderate solar activity. The two variables seem largely independent, with rainfall more influenced by local weather patterns. Minor correspondence in March and June observed was not consistent across year. [13], demonstrated that aerosols significantly suppress rainfall, reinforcing that radiative forcing from aerosols may outweigh solar influence.

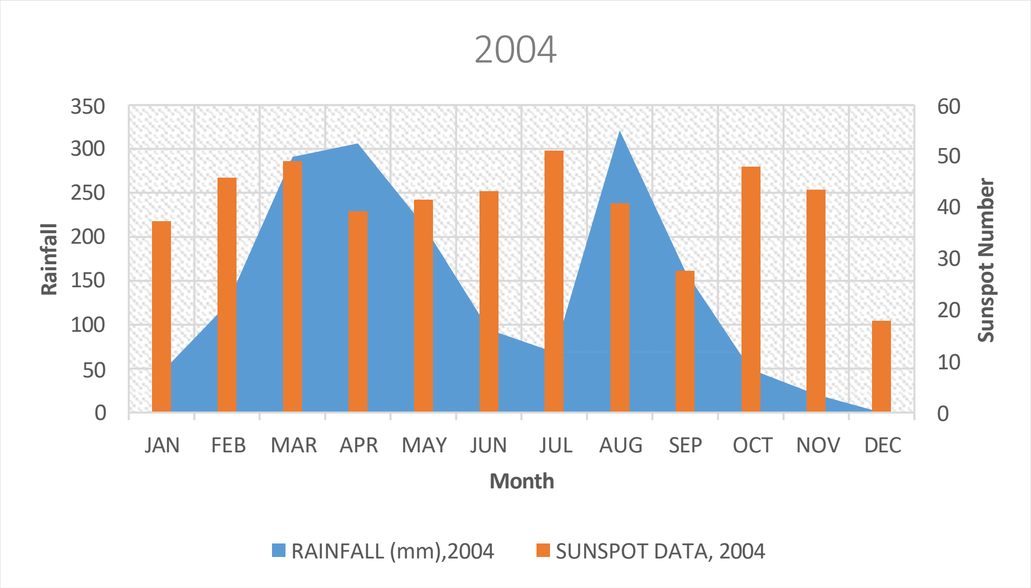

Fig 4.1.2: Histogram diagram

Figure 3: Comparison of variation of rainfall and sunspot number during moderate solar activity (2004).

Depicted in Figure 4 below is the monthly rainfall and sunspot numbers during moderate solar activity for the year 2011 (solar cycle 24). Sunspot numbers increase as Solar Cycle 24 progresses, but they are still considered moderate compared to that of peak years. Rainfall shows similar seasonal variation, with distinct peaks in the wet season and low amounts during dry season. Sunspot numbers fluctuated moderately, but no clear pattern emerged in relation to rainfall. There is no obvious monthly correlation between sunspot numbers and rainfall in 2011. The rainfall patterns appear to be governed more by seasonal weather dynamics.

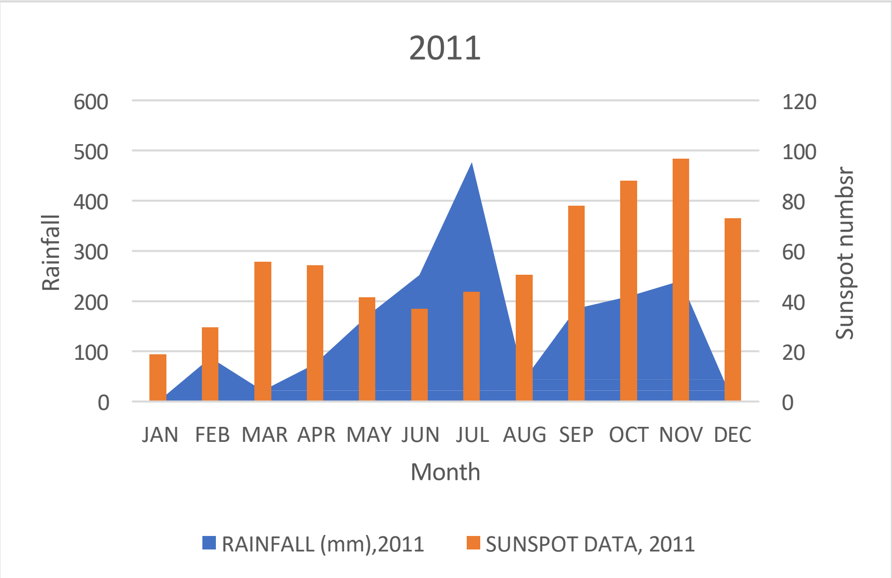

Figure 4**:** Comparison of variation of rainfall and sunspot number during moderate solar activity (2011).

Figure 5 below shows variation of rainfall and sunspot number during moderate solar activity (2012) of solar cycle 24**.** During this period solar activity continues to rise, with sunspot numbers reflecting a moderate phase of activity. Rainfall remains seasonally driven, with the wet season bringing higher rainfall values and the dry season experiencing lower amounts. Sunspot numbers fluctuated between high and low values, but the rainfall patterns do not directly correspond to these changes for all the months except June where it fairly corresponded. Similar to previous years, there is no significant monthly correlation between sunspot numbers and rainfall. The variation in solar activity appears to have minimal impact on rainfall distribution as observed from Figure 5 below

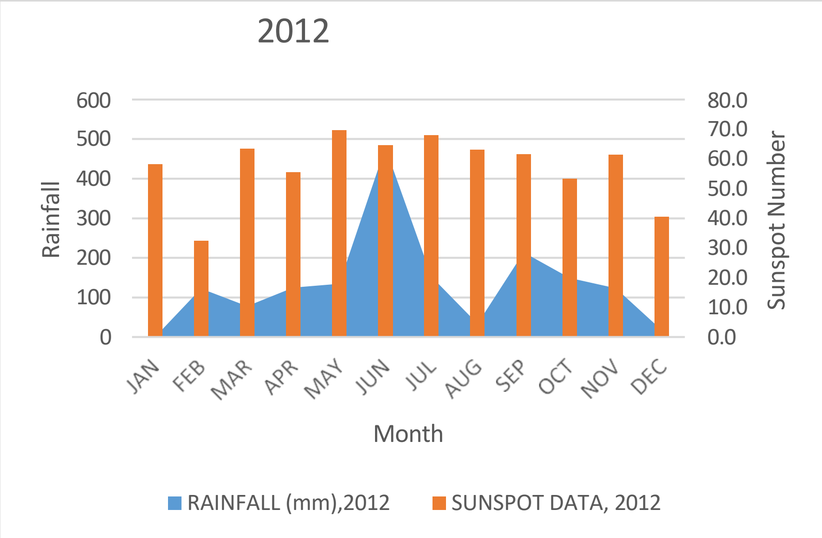

Figure 5: Comparison of variation of rainfall and sunspot number during moderate solar activity (2012).

Comparison of the Variation of Monthly Rainfall and Sunspot Number during Low Solar Activity Year (2005 - 2010).

Highlighted in Figures 6, 7, 8, 9, 10 and 11 are variations of rainfall and sunspot number during low solar activity years of solar cycle 23 and 24. During this period, solar activity reaches a low point, with sunspot numbers remaining minimal, particularly between 2007 and 2008 (solar minimum). Throughout these years, rainfall consistently follows seasonal trends, with rainy season peaks and dry season troughs. The low sunspot number values do not appear to affect the timing or intensity of rainfall. During the low solar activity period, there is no discernible monthly relationship between rainfall and sunspot number. Rainfall is primarily driven by regional seasonal cycles rather than changes in solar activity (sunspot number).

From Figure 6 (2005), rainfall and sunspot number generally show low correlation. Rainfall patterns fluctuate monthly, but sunspot number remain relatively stable due to low solar activity. Except during the months of June, September and October, no direct correlation between rainfall and sunspot number were observed. During 2006 both rainfall and sunspot number experience minor fluctuations as seen in Figure 7. Although the sunspot number values remain low, rainfall values show variability, with peaks in the wet season. Weak correlation was observed only during the month of March. Figure 8 shows a slight increase in rainfall variability, but sunspot activity is still minimal during 2007. The observed correlation between rainfall and sunspot number are weak for all the months except June where the correlation indicates a slight relationship

During year 2008 which is similar to previous years, the sunspot numbers remain very low, with only minor variations. Rainfall patterns continue to fluctuate with seasonal cycles but show little direct relationship with the sunspot number as shown in Figure 9. From Figure 10 LSA year 2009, rainfall shows a clear seasonal trend, with high rainfall values during the rainy season and low during dry months. Sunspot number remains low near solar minimum. Depicted in Figure 11, the end of the low solar activity period (2010) shows a small rise in sunspot number, but this does not correspond to significant changes in rainfall. From the above, throughout these periods of varying solar activity, rainfall remains seasonally driven and unaffected by solar activity or weakly affected by solar activity.

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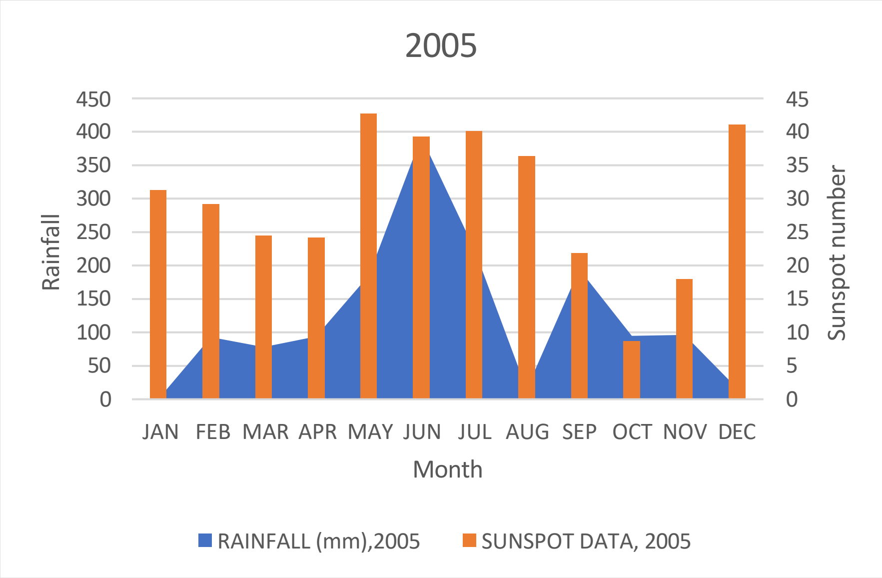

Figure 6: Comparison of variation of rainfall and sunspot number during low solar activity (2005)

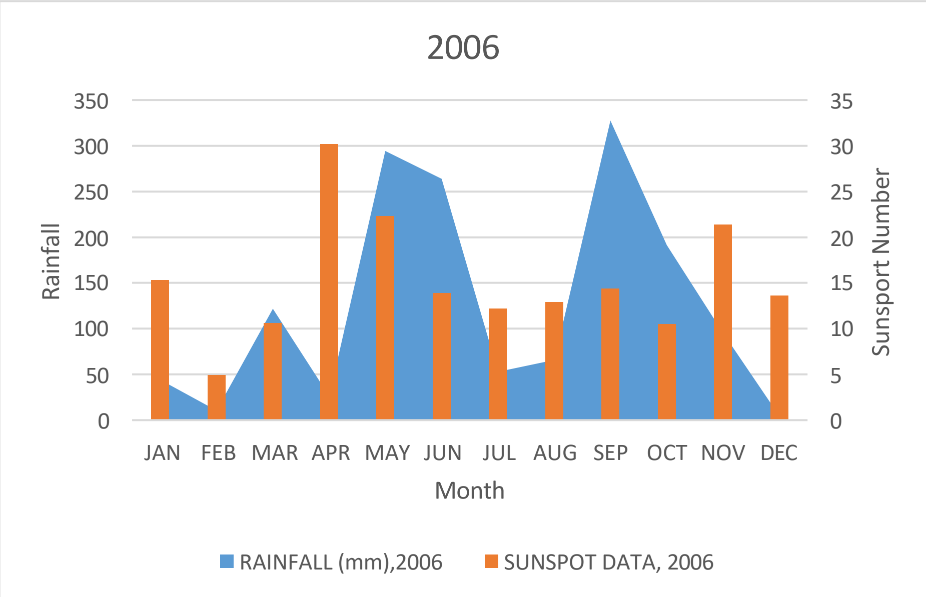

Figure 7: Comparison of variation of rainfall and sunspot number during low solar activity (2006)

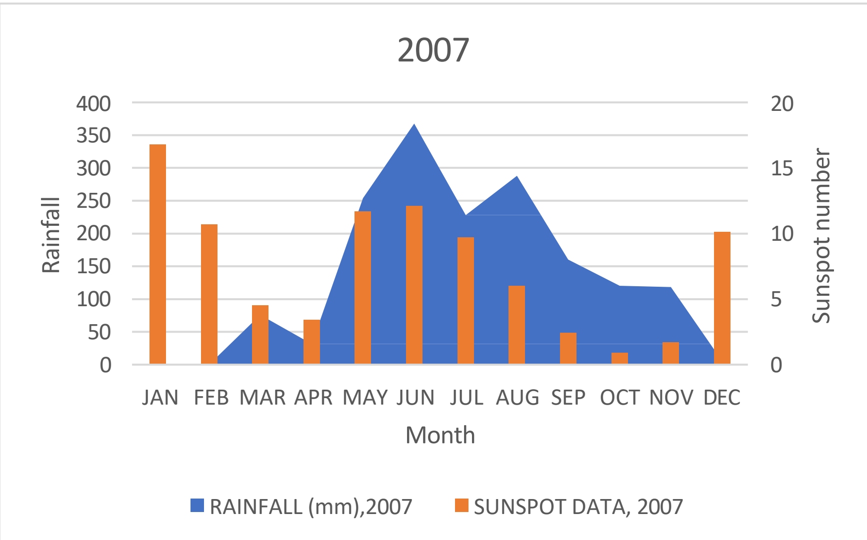

Figure 8: Comparison of variation of rainfall and sunspot number during low solar activity (2007).

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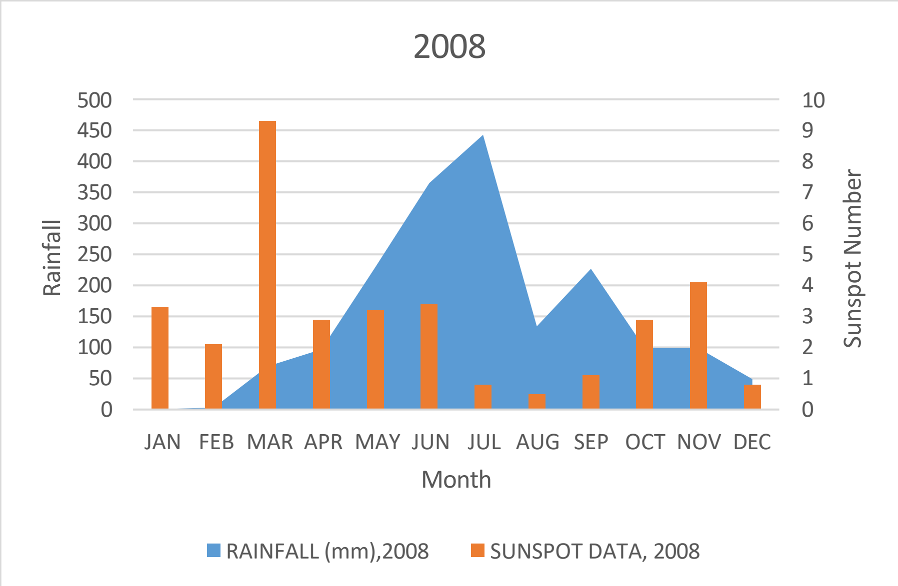

Figure 9: Comparison of variation of rainfall and sunspot number during low solar activity (2008).

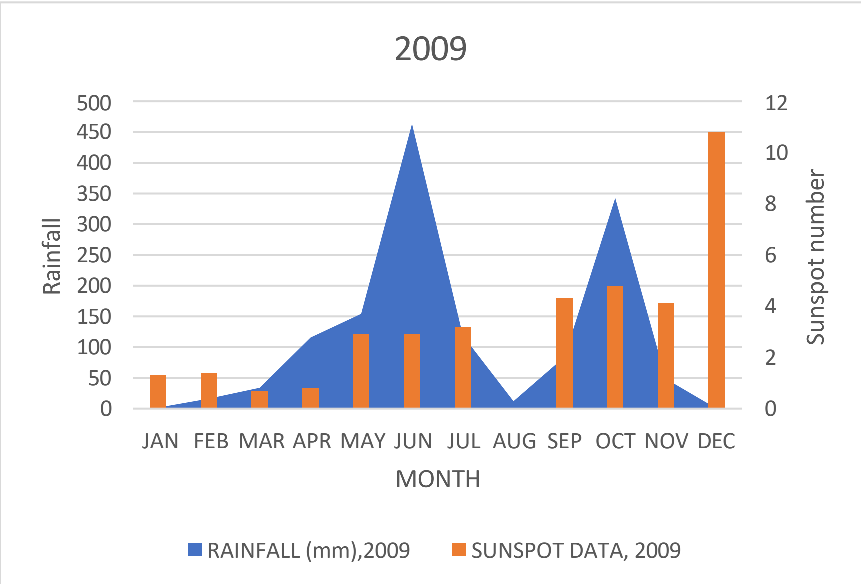

Figure 10: Comparison of variation of rainfall and sunspot number during low solar activity (2009).

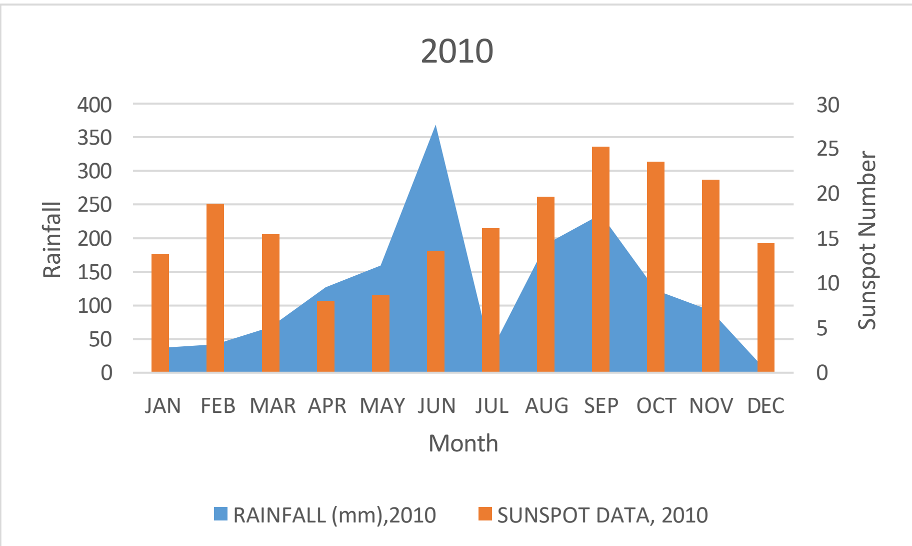

Figure 11: Comparison of variation of rainfall and sunspot number during low solar activity (2010)

Across these different periods of solar activity, rainfall appears to be more influenced by local seasonal and regional climatic conditions than by the monthly fluctuations in sunspot numbers. [21], observed similar disconnection between river discharge and solar activity across Nigeria. This supports the reports of [18] and [19] who observed that direct solar activity effect on rainfall were weak in equatorial climates. [23] and [24] observed strong relationship between sunspot number (solar activity) and ionospheric parameters like peak electron density, TEC and critical frequency of F2 layer in the equatorial region especially during the December solstices months (November, December and January) and September equinox months (July August and September).

The comparison of monthly rainfall and sunspot number revealed a nonlinear relationship. Several reasons attributed to this include; *Complexity of Earth's climate system:* Rainfall is influenced by many factors, including atmospheric circulation patterns, temperature, humidity and topography.

Indirect solar influences: Solar activity affects Earth's climate primarily through variations in total solar irradiance (TSI), which impacts global temperatures and atmospheric circulation. However, this influence is often indirect and can take years to manifest. *Regional variability:* Solar activity's impact on rainfall can vary significantly across different regions due to local climate dynamics

Time lag: Solar activity's effects on rainfall may be delayed due to the time it takes for changes in solar radiation to propagate through the atmosphere and oceans.

Pearson Product Correlation Coefficient between Monthly Rainfall and Sunspot Number for the Three Solar Activity Periods

Table 4 below shows the correlation (r) results between monthly rainfall and sunspot number dataset used in this research work. The correlation values show the strength of the relationship

Table 4: Pearson Product correlation coefficient r- values for all years

Year	Epoch	r-value	Interpretation
2002	HSA	0.024	Very Weak
2003	HSA	-0.219	Very Weak
2004	MSA	0.203	Very Weak
2011	MSA	0.151	Very Weak
2012	MSA	0.273	Very Weak
2005–2010	LSA	Range: -0.246 to 0.237	Very Weak

From Table 4 above, the Pearson's coefficient r obtained by correlating the monthly rainfall data with the monthly sunspot number data for all the years (2002-2012) covering HSA, MSA and LSA indicated very weak correlation which implies that there is very little or no correlation between the monthly rainfall and solar activity (sunspot number).

CONCLUSION

Rainfall and solar activity play significant roles in shaping Earth's climate. This study reveals that monthly rainfall in Lagos, Nigeria (2002 - 2012) does not significantly correlate with solar activity. While solar cycles may exert broad atmospheric modulation, rainfall appears primarily governed by local climate systems, ITCZ movement, SST anomalies, and aerosol forcing. However, a closer examination indicates very weak and varying correlations during the moderate (0.273) and minima (0.237) solar phases respectively. These results suggest that the connection between solar activity and rainfall is more intricate than initially assumed, warranting further investigation into the mechanisms involved. Nonetheless, this study contributes to improved understanding of solar-climate correlations and characteristics.

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AUTHOR CONTRIBUTIONS:

E.O.O. conceptualized the research and its methodology. A.T.S., Y.O.K., J.W., A.C.E., and O.R.O., processed the data. E.O.O. performed the analysis, and O. F., E.O.S. and A.S.O. validated the results. E.O.O. prepared the initial manuscript. J.A.A. and A.T.S. reviewed the manuscript. All authors read and approved the final manuscript

CONFLICT OF INTEREST

The authors declared that there is no conflict of interest in the course of this research work.

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