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Relationship between Air Temperature and Rainfall Variability of Selected Stations in Sub-Sahara Africa

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A B S T R A C T

This current study was conducted on rainfall and air temperature data obtained from the archive of the HelioClim website to determine the relationship between the two parameters. The study aimed at the relationship between rainfall and air temperature. The data of thirty-four (34) years spanning from 1985 to 2019 was analyzed using Mann-Kendal statistics on the trend of the rainfall series while the normality of rainfall series was determined using Kolmogorov-Smirnov test across six southwest stations of Nigeria. The results revealed the highest mean rainfall in Akure (198.9 mm) while the least rainfall in Ado-Ekiti (163.4 mm). The maximum rainfall was in Abeokuta (865.8 mm) with Iwo having the highest disparity in rainfall (SD=148.8 mm) compared with other stations. The skewness in Abeokuta (Skewness = 0.9 mm) was higher compared with Ado-Ekiti, Akure, Ibadan, Ikeja and Iwo with skewness values of 0.7 mm, 0.4 mm, 0.7 mm, 0.6 mm and 0.7 mm, respectively. The maximum air temperature was recorded in Iwo (301.7 K) and the minimum air temperature in Ado-Ekiti (293.3 K). The skewness obtained in Akure (-0.2) and Ikeja (-0.3) was less than zero indicating that air temperature decreased more than it increased in these areas while in other stations, Abeokuta (0.01), Ado-Ekiti (0.22), Ibadan (0.02) and Iwo (0.24), the skewness was greater than zero meaning that air temperature increased more than it decreased in these stations.

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INTRODUCTION

The assessment of rainfall and air temperature variability is of great importance in the prediction and forecast of weather across the globe. The relationship of the two parameters is of interest in any environment because it determines one of the climatic weather conditions of any area. Nkuna and Odiyo [1] reported that affiliation concerning rainfall and temperature is mostly explained meteorologically in terms of sea surface temperatures (SSTs) and El Nino Southern Oscillation (ENSO). However, for this study, there is a need to determine the relationship between air temperature and rainfall in the Southwest of Nigeria due to rainfall drop in the region. Manatsa and Matarira [2] discovered that rainfall inconsistency in southern Africa can be allied to the Indo-Pacific Sea Surface Temperature. However, the study has shown that some west African countries are not situated beside the ocean; thus, leading to a little amount of rainfall and high temperature. For this study, there is a need to use air temperature and rainfall data to determine the anomalous experience on rainfall and air temperature values to explain the relationship between rainfall and air temperature in selected stations of Nigeria. The temperature has been observed to be one of the parameters that influence rainfall, either directly or indirectly [3]. Different researchers reported that temperature influences rainfall in many ways, which include high temperature leading to high evaporation and low precipitation. Those areas that are dominated by arid or semi-arid landscapes are one of the results of the high temperature [4]. Additionally, high temperature led to more evaporation [5]; therefore, leading to high rainfall across the globe. The characteristics of rainfall are of

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considerable interest to farmers, water resource managers and other user groups. As reported by different researchers, rainfall is a key factor in shaping the vegetation, hydrology, and water quality throughout the earth. Therefore, they lead to the effect of climate change globally. Furthermore, the trend of rainfall and air temperature over the sub-Sahara region of Africa is an important requirement for the planning and management of water resources and their use in agricultural irrigation farm practice. Irrigation in farming is one of the major activities of northern Nigeria owing to low rainfall in the sub-region, but in the southwest, two planting seasons are owing to a long duration of rainfall in the region. Management of water resources is an engineering activity that requires adequate knowledge of rainfall variation and its temporal pattern [6]. The recent change in climate which has intensified global variability of the hydrological cycle, creating uncertainties regarding the prediction of future climate conditions and the associated impact on the studies of long-term climate series, has become increasingly necessary [7]. The historical areas of Nigeria have a very important contribution to the planning, designing and operation of water reservoirs and availability of quality water as demanded by any community in the entire country [8, 9]. In a nutshell, there are different reports on the cases of flood in Nigeria the due to over-flow of rivers and ocean. It has been reported by different researchers that extreme rainfall causes floods across Nigeria [6]. Farming plays a major role in the economic development of Nigeria, thereby, increase agricultural production in the northern part of the country by contributing to the development of the nation. Meeting rising future demands for food and potable water requires more judicious use of water in both irrigation and rain-fed agriculture [10]. Numerous studies carried out on rainfall time series across the world revealed that the effect is positive and negative on the trends of rainfall [6]. Xu et al. [11], Wang et al. [12], Anghileri et al. [13] and Aweda et al. [14] expressed different analyses on the trend of rainfall and its fluctuations through diverse places across the entire world. Nevertheless, period sequence study of rain shown either reducing or accumulating rainfall, depending on the place [15]. Shahid [16] studied the trend of the annual rainfall of Bangladesh during the 1958 – 2007 periods and reported a significant increase in the average annual rainfall. Therefore, for this research, we studied the relationship between air temperature and rainfall variability across selected stations in sub-Sahara Africa (i.e Abeokuta, Akure, Ikeja, Iwo, Ado-Ekiti and Ibadan) located in the western part of Nigeria. In this study, we used monthly average data of rainfall and air temperature collected from the archive of the HelioClim website for 34 years (1985 – 2019) to investigate the relationship between rainfall trends and air temperature patterns across selected stations in Nigeria. However, as reported by Oloruntade et al. [6], there are reports on the study of variability and trend of rainfall at both spatial and temporal scales over Africa, particularly in the West Africa sub-region. Different rainfall trend has been reported across Nigeria [17–20]. However, Abaje et al. [18] observed that there are dry days in June and October over a study conducted in Kafanchan in the Guinea Savanna ecological belt of Nigeria from 1974 to 1983 and 1999 to 2008 research studies. Moreover, Abaje et al. [18] further revealed that there are significant dry conditions in June and October for the sub-period 1974 to 1983 and 1999 to 2008, respectively. The pattern and amount of rainfall are among the most important factors that affect agricultural systems. As reported by Lekalakala [21], a study in the Limpopo Basin has shown that increasing temperatures experienced over the years have a various effect on the impacts of agricultural products. The occurrence of increased temperature and its variability on rainfall alongside the precipitation also has a large extent on the determination of agricultural products grown in different regions throughout the world [22]. Some factors that contributed to the vulnerability of the water system in the Limpopo include seasonal and inter-annual variation in the rainfall, which are amplified by high runoff production and evaporation rates [23]. This study aims to investigate the relationship between air temperature and rainfall variability over selected stations in sub-Saharan Africa.

MATERIALS AND METHODS

The data used in this study consists of monthly rainfall and air temperature for six stations which were obtained from the archive of the HelioClim website of soda (http://www.soda-pro.com) of MERRA-2 meteorological re-analysis data as recommended by Gelaro et al. [24]. The data was evaluated on January 20th, 2020. In comma-separated value (CSV) data format, data for thirty-four (34) years covering 1985 to 2019 were retrieved as monthly averages for January to December of each year. The data was collected using the method described in literature [25–28]. Environmental running of statistical packages (i.e The Mann-Kendal statistics was used to analyze the trend in rainfall series while the normality of rainfall series was determined using the Kolmogorov-Smirnov test) was done for data plotting and curve fittings. The data obtained were analyzed using statistical packages to determine the relationship between rainfall trends and air temperature variability across selected stations in Nigeria. Descriptive statistics including means, minimum, maximum, skewness, kurtosis and coefficient of variation were computed for rainfall data in Abeokuta (7.1557° N, 3.3450° E), Ade-Ekiti (7.6232° N, 5.2209° E), Akure (7.2526° N, 5.1931° E), Ibadan (7.4020° N, 3.9173° E), Ikeja (6.6059° N, 3.3491° E) and Iwo (7.6292° N, 4.1872° E).

Furthermore, the comparison of the monthly rainfall in the six stations was carried out using the Mann-

Whitney test and a p-value less than 0.05 was considered statistically significant. Also, linear regression was used to estimate the trend in the rainfall data and data analysis was carried out using STATA, SPSS, and MS Excel. However, scattered graphs, line graphs and the autocorrelation function (ACF) were used to present some of the results graphically. The analysis was performed on the southwest region of Nigeria located in the coaster area of the country, which is known to be of rainforest and mangrove. The map of the stations for this research is shown in Figure 1.

RESULTS AND DISCUSSION

Table 1 presents the descriptive analysis of the rainfall in the six stations and the result revealed that the highest mean rainfall was recorded in Akure (198.91 mm) while the mean least rainfall was obtained in Ado- Ekiti. The maximum rainfall was obtained in Abeokuta (865.77 mm) with Iwo having the highest disparity in rainfall (SD = 148.81 mm) compared with other stations. The skewness values obtained in the six selected stations are greater than zero, meaning that rainfall increased more than it decreased within the period under study with rainfall increased more than it decreased in Abeokuta (Skewness= 0.92 mm) compared with Ado- Ekiti, Akure, Ibadan, Ikeja and Iwo with skewness values of 0.74 mm, 0.39 mm, 0.69 mm, 0.61 mm and 0.73 mm, respectively. The result of the coefficient of variation indicated that Ado – Ekiti (88.54%) followed by Iwo (84.17%) had the highest disparity in rainfall with the lowest disparity in rainfall reported in Ikeja (62.91%).

Table 2 shows the descriptive statistics for air temperature in the selected stations. The highest maximum air temperature was recorded in Iwo (301.70 K) and the least minimum air temperature observed in Ado- Ekiti (293.34 K). Ikeja (299.25 K) had the highest mean air temperature, while Ado - Ekiti had the lowest (297.76 K). The skewness values obtained in Akure (-0.24) and Ikeja (-0.26) were less than zero, indicating that air temperature decreased more than it increased in these areas; however, the skewness values obtained in Abeokuta (0.01), Ado – Ekiti (0.22), Ibadan (0.02), and Iwo (0.24) were greater than zero, indicating that air temperature increased more than it decreased in these areas. When compared to other stations, Ado – Ekiti had the largest coefficient of variation (0.41 %), indicating that the air temperature differential was greater in Ado – Ekiti than in Abeokuta, Akure, Ibadan, Ikeja, and Iwo.

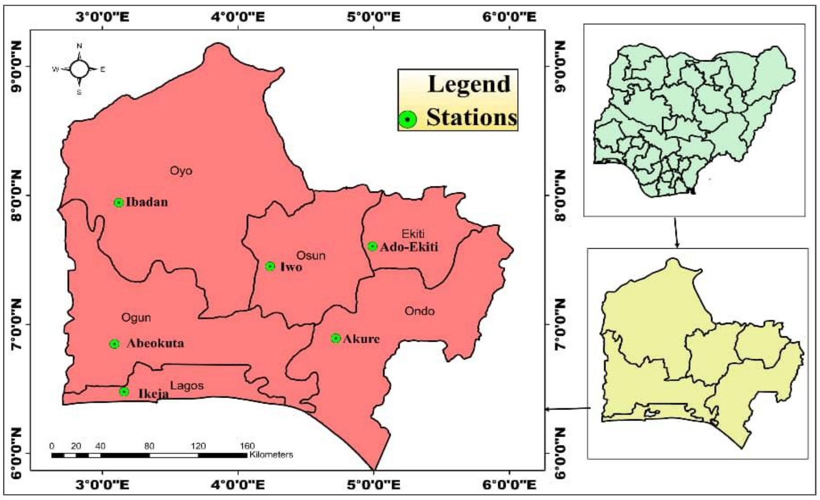

Figure 1. Southwest Nigeria showing the study stations

Table 1. Descriptive statistics for rainfall in six selected stations

Stations	n	Minimum	Maximum	Mean	SD	Skewness	Kurtosis	COV (%)
Abeokuta	480	0.1262	865.7734	163.4571	125.2857	0.9160	1.2730	76.6475
Ado – Ekiti	480	0.0016	619.1906	163.4049	144.6816	0.7380	-0.400	88.5418
Akure	480	0.0133	602.6252	198.9148	142.5710	0.3870	-0.889	71.6744
Ibadan	480	0.0107	638.3207	178.9636	141.6716	0.6870	-0.325	79.1622
Ikeja	480	0.2584	626.0036	164.5345	103.5082	0.6140	0.1200	62.9097
Iwo	480	0.0000	692.2735	176.7935	148.8110	0.7250	-0.2610	84.1722

Table 2. Descriptive statistics for air temperature in six selected stations

Stations	n	Minimum	Maximum	Mean	SD	Skewness	Kurtosis	COV (%)
Abeokuta	480	295.5000	301.4700	298.6313	0.9912	0.0130	-0.2390	0.3319
Ado – Ekiti	480	293.3400	300.9100	297.7566	1.2174	0.2170	-0.099	0.4089
Akure	480	293.6600	300.1800	297.8998	0.9667	-0.2350	0.3090	0.32451
Ibadan	480	295.0300	301.3900	298.2574	0.9748	0.0170	0.010	0.3268
Ikeja	480	296.2400	301.3900	299.2479	1.0179	-0.2560	-0.7300	0.3402
Iwo	480	294.8700	301.7000	298.0390	1.0629	0.2370	0.1050	0.35663

ND- normally distributed (P>0.05), NND- not normally distributed (P<0.05)

Table 3 presents the result of the normality test using Kolmogorov - Simonov test and the result show that air temperature was normally distributed in all the stations (P>0.05) except for Ado- Ekiti (P= 0.012, P<0.05) showing a departure from the normal distribution. Result also shows that rainfall data were not normally distributed in all the six stations as revealed by their p-values which were all less than 0.05 (P<0.05). Hence, the relationship between rainfall and air temperature in each of the six stations is determined using Spearman's rank correlation and the result obtained is presented in Table 4.

Result of the Bivariate Correlation presented in Table 4 indicates negative relationship between air temperature and rainfall in Abeokuta ($r = -0.408^{**}$, P= 0.0000, P<0.01), Ado- Ekiti (r = -0.255**, P= 0.0000, P<0.01), Akure (r = -0.233**, P = 0.0000, P<0.01), Ibadan (r =

Table 3. The result of Kolmogorov- Smirvov test for the normality of the air temperature and rainfall data

Stations	Temperature			Rainfall		
	Kolmogorov- Smirnov Z	P-value	Remarks	Kolmogorov- Smirnov Z	P-value	Remarks
Abeokuta	0.8230	0.507	ND	2.422	0.0000	NND
Ado – Ekiti	1.5980	0.012	NND	2.856	0.0000	NND
Akure	0.6850	0.735	ND	1.894	0.0020	NND
Ibadan	0.7830	0.572	ND	2.463	0.0000	NND
Ikeja	1.344	0.054	ND	1.778	0.0040	NND
Iwo	0.923	0.362	ND	2.771	0.0000	NND

Table 4. Rank correlation results summary of the relationship between temperature and rainfall

Stations	Variables	Mean	SD	r-coefficient	P-values	Remarks
Abeokuta	Temperature	298.6313	0.99120	-0.408^{**}	0.0000	Significant negative relationship
	Rainfall	163.4571	125.2857			
Ado – Ekiti	Temperature	297.7566	1.2174	-0.255**	0.0000	Significant negative relationship
	Rainfall	163.404857	144.6816			
Akure	Temperature	297.8999	0.9667	-0.233**	0.0000	Significant negative relationship
	Rainfall	198.9148	142.5709			
Ibadan	Temperature	298.2574	0.9748	-0.316**	0.0000	Significant negative relationship
	Rainfall	178.9636	141.6716			
Ikeja	Temperature	299.2479	1.0179	-0.4080**	0.0000	Significant negative relationship
	Rainfall	164.5345	103.5082			
Iwo	Temperature	298.0391	1.0629	-0.2930**	0.0000	Significant negative relationship
	Rainfall	176.7935	148.8110			

**significant at 1% (P<0.01)

-0.316**, P = 0.0000, P<0.01), Ikeja (r = -0.4080**, P= 0.0000, P<0.01) and Iwo (r = -0.2930**, P =0.0000, P<0.01). The significant negative relationship obtained between air temperature and rainfall in these stations implies that as the air temperature increases, there is a significant decrease in rainfall and as the rainfall increases significantly, air temperature decreases significantly. The scatter plots for this relationship with a line of best fit based on simple linear regression is presented in Figures 2, 3 and 4. These figures show that as the air temperature increases, rainfall decreases. From the figures, it can be deduced that air temperature only accounted for 17.2% of the variation in rainfall in Abeokuta and 12.3%, 5.9%, 12.8%, 15.4% and 12.9% of the variation in rainfall in Ado- Ekiti, Akure, Ibadan, Ikeja and Iwo, respectively Rainfall in Abeokuta reduces by 52.46 mm for every 1 K increase in air temperature, whereas rainfall in Ado-Ekiti, Akure, Ibadan, Ikeja, and Iwo decreases by 41.71 mm, 35.81 mm, 52.00 mm, 40.02 mm, and 50.43 mm.

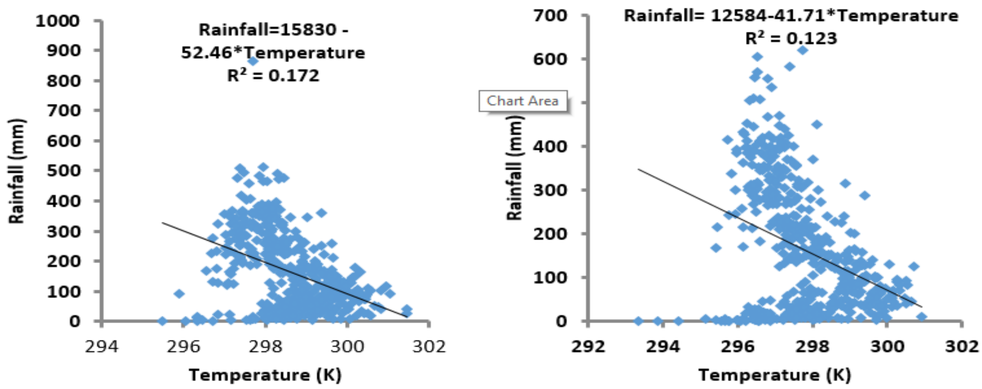

Figure 2. Relationship between rainfall and air temperature in Abeokuta and Ado Ekiti

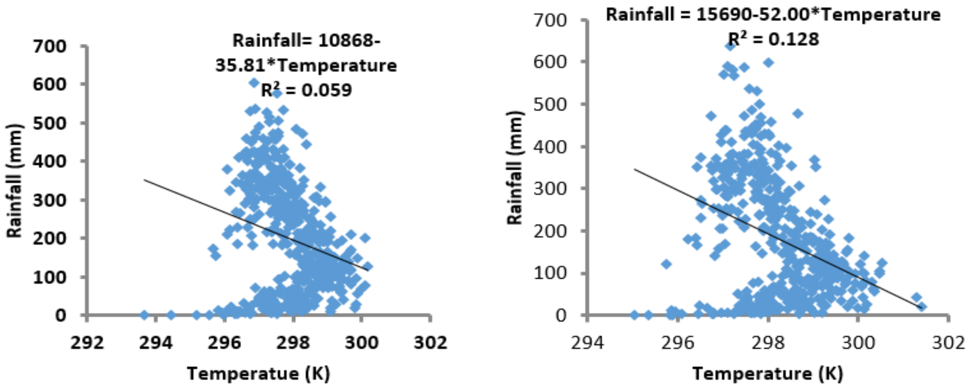

Figure 3. Relationship between and air temperature in Akure and Ibadan

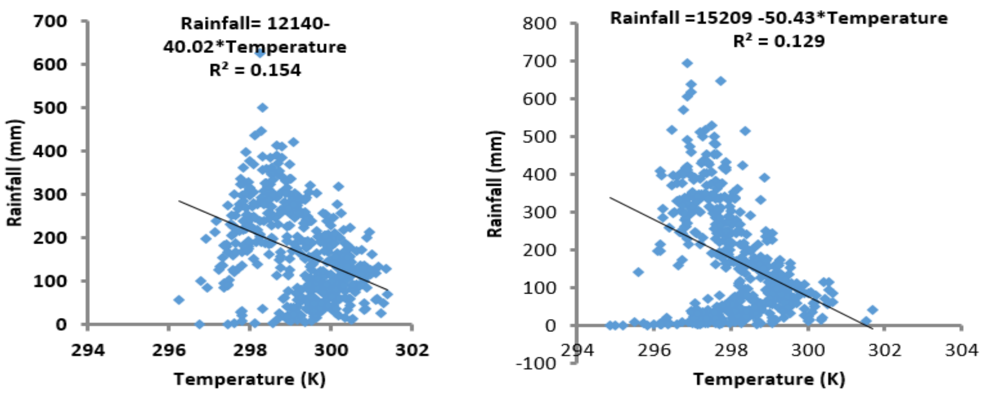

Figure 4. Relationship between and air temperature in Ikeja and Iwo

The result of the scattered plot for the stations under consideration revealed that Abeokuta has the highest R^2 (0.172), this was followed by Ikeja (0.154), Iwo (0.129), Ibadan (0.128), Ade-Ekiti (0.123) and the least was recorded in Akure (0.059) respectively. However, Abeokuta has almost the minimum temperature (163.4571 K), this may be due to the heavy and light industry located at the station and much of the high hills and mountains located in and around the stations. In another vein, Ikeja has the highest temperature (299.2479 K) due to more traffic congestion, ocean current and sea breeze, along the coast where the station was located, which may likely increase the temperature of the station. According to the literature, Lagos has 50% of the traffic congestion experienced in Nigeria. However, the Ikeja rainfall (164.5345 mm) was different in comparison with other stations. But Ibadan had the least temperature (298.2574 K), due to more vegetation in the climatic area of the city. The scattered plot shows that the regression line (R^2) across all the stations are significant, with a value less than 0.5.

The time series plot of the air temperature and rainfall in the selected stations are presented in Figures 5-10. The Autocorrelation Function plots as presented in Figures 5 - 10 revealed that at most of the lags, the autocorrelation coefficients were significant (outside the confidence limit) meaning that there was a significant correlation between air temperature at different lags. This implies that there is a similarity between the values of air temperature and rainfall over a successive time interval. These figures show that the values of air temperature and rainfall in the selected stations can be predicted based on the preceding values of air temperature and rainfall.

Figure 11 shows that air temperature was maximum in March and minimum in August while rainfall was at its peak between July and September and then started to be decreased towards the end of the year. It was observed that all the stations have an opposite relationship, that is, the higher the temperature the lower the rainfall vice versa. This signifies that temperature has a great influence on the increment of rainfall. It could be observed that Abeokuta, Akure, Ibadan, Ikeja and Iwo has a deep shape

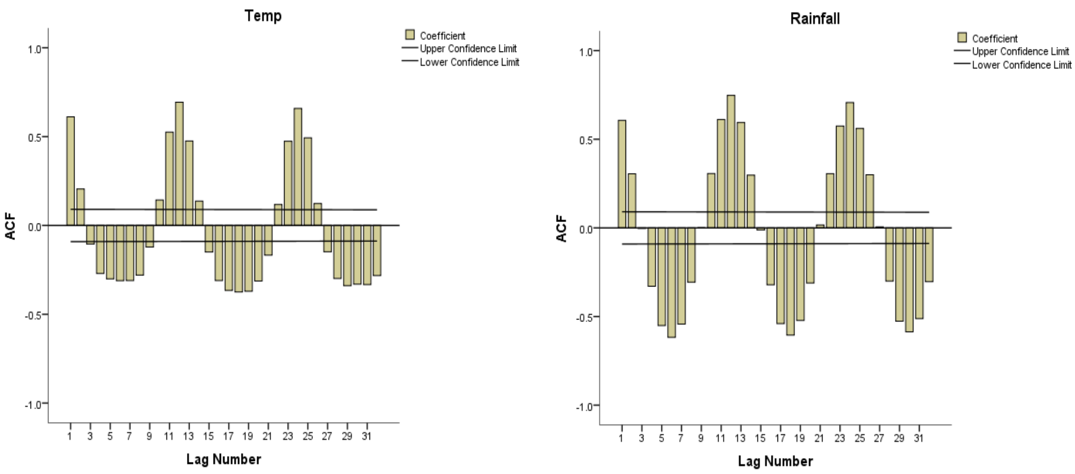

Figure 5. ACF plot for temperature and rainfall in Abeokuta

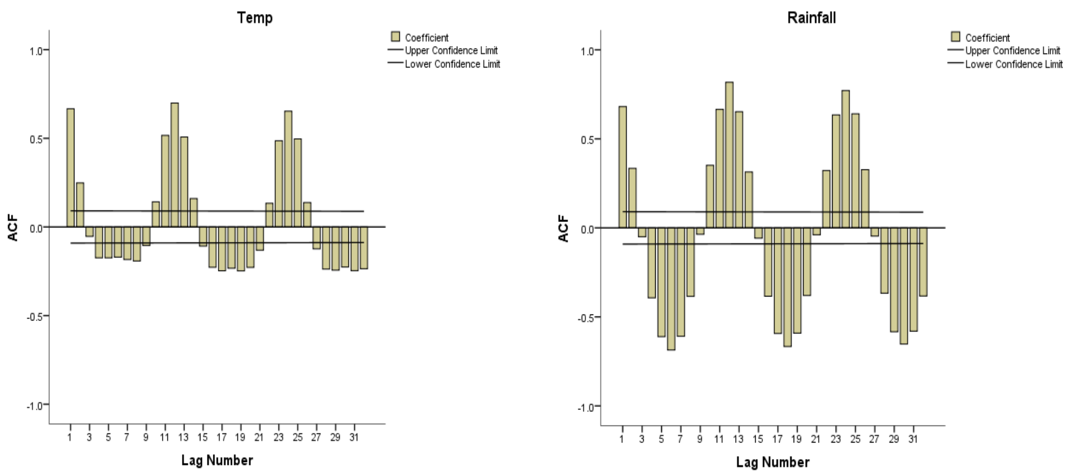

Figure 6. ACF plot for temperature and rainfall in Ado Ekiti

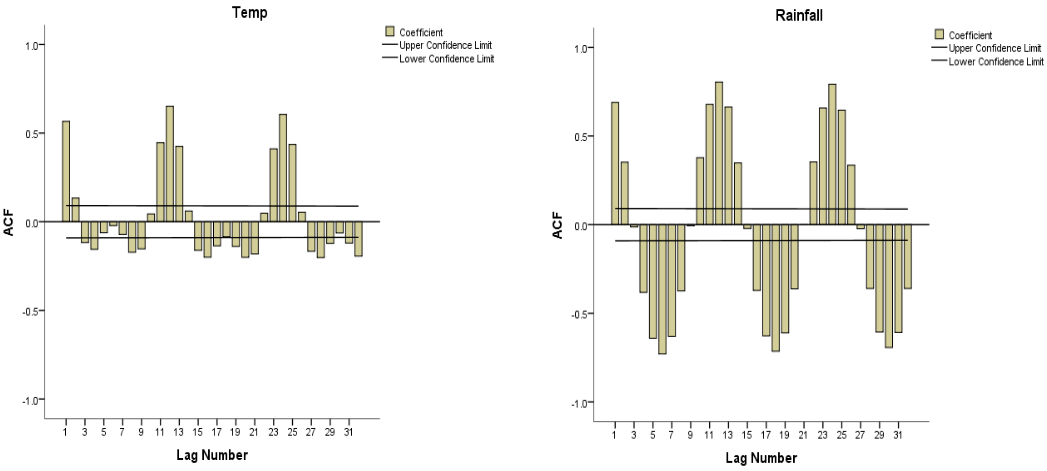

Figure 7. ACF plot for temperature and rainfall in Akure

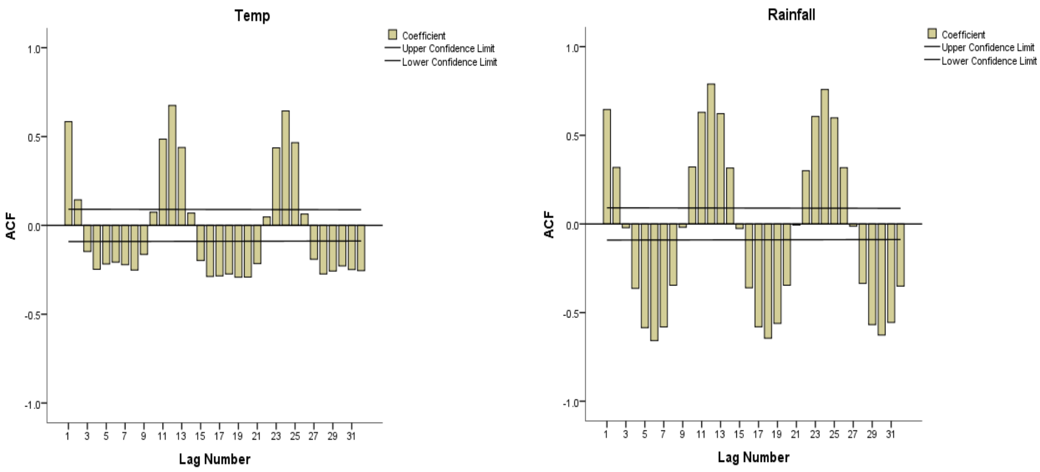

Figure 8. ACF plot for temperature and rainfall in Ibadan

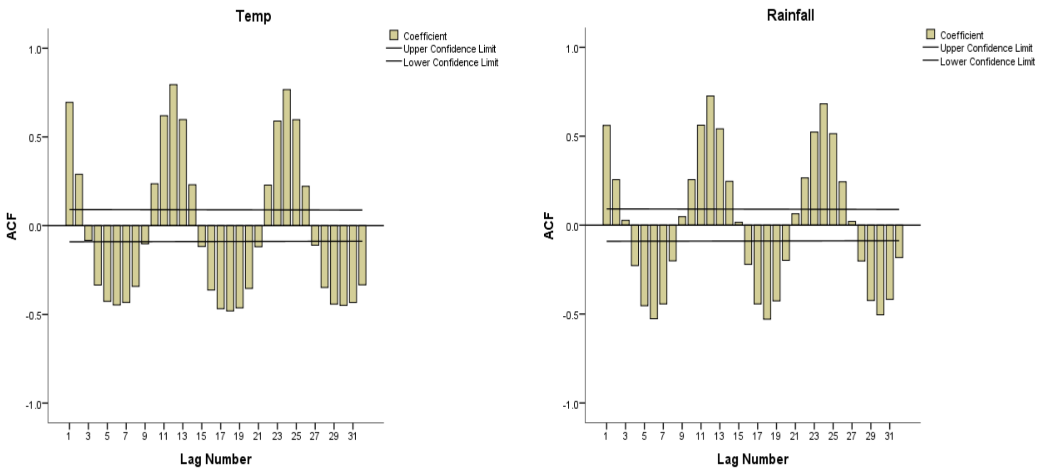

Figure 9. ACF plot for temperature and rainfall in Ikeja

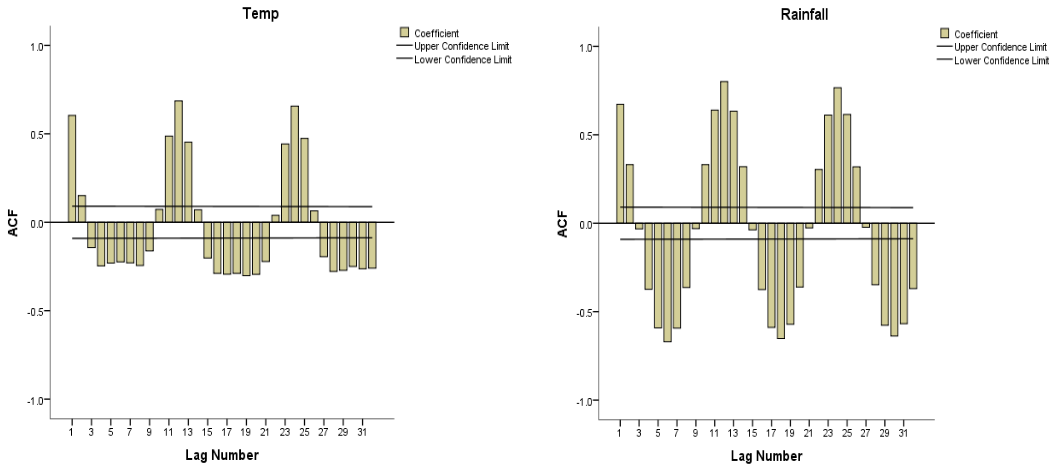

Figure 10. ACF plot for temperature and rainfall in Iwo

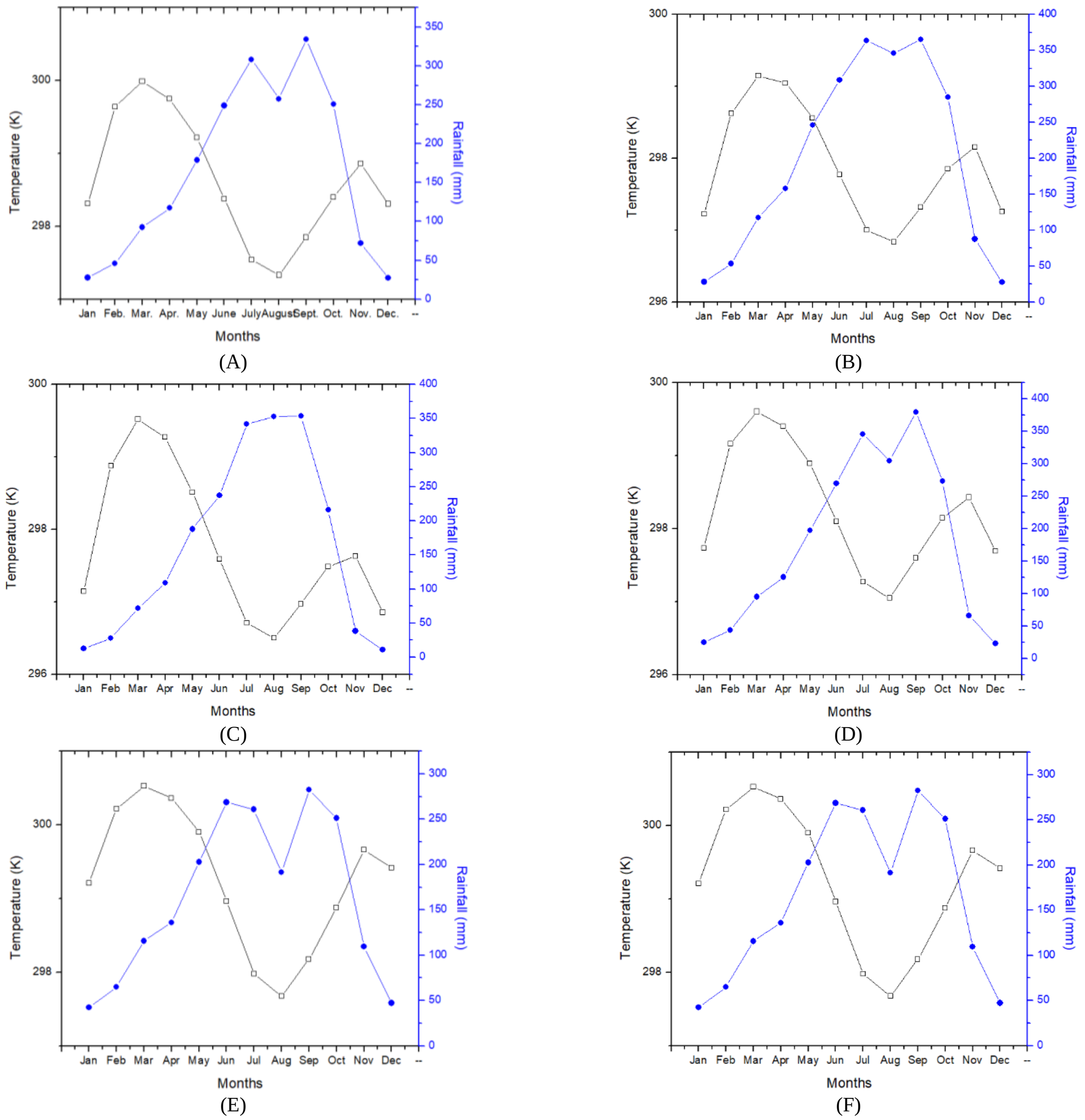

Figure 11. Monthly mean air temperature and rainfall (A- Abeokuta, B- Akure, C- Ado Ekiti, D- Ibadan, E- Ikeja, F- Iwo)

decrease in rainfall in August, this may be due to the August break experience in the entire country, while Ado – Ekiti has a stable increase in July, August, and September. This may be due to the vegetation of the station and some stream located in the station. Ado – Ekiti is one of the ancient cities in Nigeria, which experienced high humidity and rainfall.

CONCLUSIONS AND RECOMMENDATIONS

The present study suggested that the annual time correlation of rainfall and air temperature results shows that there is lack of negative correlation. This correlation explained the fact that during the wet period of the year, the standardized air temperature was low owing to the moisture in the air temperature which exceeded the long-term average, rainfall was high. For this reason, the average air temperature decreases as the rainfall increases, hence, a negative correlation is observed. A positive correlation was observed in the monthly long-term variation time series. More so, the monthly average air temperature and rainfall behave similarly. This shows that average air temperature is low in January and December, which correlates to a lack of rainfall owing to the harmattan dust in the period. However, the highest amount of rainfall was recorded in June, July, August and September across all stations in this present study. Therefore, the study shows that as air temperature increases, rainfall decreases. This may likely affect the availability of water resources in the Southwest of Nigeria.

As a result, the authors urge that the southwest government, as well as the federal government of Nigeria, take water storage seriously during periods of heavy rainfall so that farmers can benefit from the stored reservoirs and manage the use it for agricultural purposes. More importantly, the water storage for commercial and home use will help the community.

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Persian Abstract

چکیده

این مطالعه بر روی داده‌های بارندگی و دمای هوا به‌دست‌آمده از آرشیو وب‌سایت HelioClim برای تعیین ارتباط بین این دو پارامتر انجام شد. داده‌های سی و چهار سال از ۱۹۸۵ تا ۲۰۱۹ با استفاده از آمار Mann-Kendal بر روی روند سری بارندگی تجزیه و تحلیل شد در حالی که نرمال بودن سری بارندگی با استفاده از آزمون Kolmogorov-Smirnov در شش ایستگاه جنوب غربی نیجریه تعیین شد. نتایج نشان داد که بیشترین میانگین بارندگی در آکوره (۱۹۸/۹ میلی‌متر) و کمترین بارندگی در آدو-اکیتی (۱۶۳/۴ میلی‌متر) بود. بیشترین میزان بارندگی در آبئوکوتا (۸۶۵/۸ میلی‌متر) بود که Iwo دارای بیشترین اختلاف بارندگی (SD=148.8 میلی‌متر) در مقایسه با سایر ایستگاه‌ها بود. چولگی در آبئوکوتا (skewness = ۰/۹ میلی‌متر) در مقایسه با آدو-اکیتی، آکوره، ایبادان، ایکجا و Iwo با مقادیر skewness به ترتیب ۰/۷ میلی‌متر، ۰/۴ میلی‌متر، ۰/۷ میلی‌متر، ۰/۶ میلی‌متر و ۰/۷ میلی‌متر بیشتر بود. حداکثر دمای هوا در ایوو (۳۰۱/۷ کلوین) و کمینه دمای هوا در آدو-اکیتی (۲۹۳/۳ کلوین) ثبت شد. مقدار skewness به‌دست‌آمده در آکوره (۰/۲-) و ایکجا (۰/۳-) کمتر از صفر بود که نشان می‌دهد دمای هوا بیشتر از افزایش در این مناطق کاهش یافته است در حالی که در ایستگاه‌های دیگر آبئوکوتا (۰/۰۱)، آدو-اکیتی (۰/۲۲)، ایبادان (۰/۰۲) و Iwo (۰/۲۴)، skewness بیشتر از صفر بود به این معنی که دمای هوا در این ایستگاه‌ها بیشتر از کاهش آن افزایش یافت.