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On the use of Statistical Power in Examining Changes in Rainfall

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Abstract

The main objective of statistical analysis is to make inference. One way of doing this is through Hypothesis Testing and Post-hoc power analysis which can be applied to environmental phenomena such as rainfall. Rainfall is an important element in understanding the climatic condition of any environment.

In this work, tests of hypothesis and post-hoc power analysis are carried out using monthly rainfall series between 1971-2014 from Nigeria. Stratified sampling was done to choose the stations that were used for the analysis.

It can therefore be concluded that Nigeria is experiencing rainfall changes that can be more observed from the climatic zones. Thus, post-hoc power analysis proved efficient in examining change in rainfall series in this regard.

1. Introduction

In statistical analysis, one of the main objectives is to use information derived from the sample observations to make inferences about the population from which the sample is drawn.(Wackerly et al., 2008). These inferences are phrased in one of two ways: as estimates of the respective parameters or as tests of hypothesis about their values. Generally, in this study, focus will be on statistical tests of hypothesis.

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1.1. **Test of Hypothesis.** In many researches, questions are raised and attempts are made to answer these questions using suitable scientific methods. These questions are known as *research questions*. Often, in order to answer these questions, hypotheses have to be set up and tested. A statistical test of hypothesis has several components which are as follows:

- Null hypothesis, H_0
- Alternative hypothesis, H_1
- Significant level, α and Confidence level, $(1 - \alpha)$
- Test statistic and Critical Region
- Probability of type II error, β and Power, $(1 - \beta)$

In most statistical tests, the α level is set to be very low, but it has been observed, both theoretically and empirically, that there is an inverse relationship between the α level and the β level. That is, as the α level decreases, the β level increases and vice versa. This is not favourable, since in some cases, having a high β level may be more risky than having a high α level. This makes the examination of power of a statistical test very important.

The concept of statistical test of hypothesis can be applied to many areas of study. In Environmental Statistics, statistical methods are applied to solving environmental problems. One important environmental phenomenon is Rainfall. It is easy to examine the climate of a location in terms of annual or seasonal averages of precipitation, and rainfall is a type of precipitation (Akinsanola and Ogunjobi, 2014).

1.2. **Study Area.** The geographical area that will be examined in this study is Nigeria. Nigeria is a country in West Africa which shares land borders with the Republic of Benin in the west, Chad and Cameroon in the east, and Niger in the north. Nigeria is found in the Tropics, where the climate is seasonally damp and very humid. The Nigerian climate is characterized mainly by the interplay between the dry north-easterly (Tropical Continental) and the moist south-westerly (Tropical Maritime) winds, hence leading to three major climatic zones namely: Tropical Rainforest (Guinea), Savannah and Sahel. (Akinsanola and Ogunjobi, 2014) Nigerian States are also usually grouped into geopolitical zones namely: North East, North Central, North West, South West, South South, South East.

In many lands, due to concerns about climate change, many researches have been done and are being done to understand different aspects of climate and to suggest appropriate solutions to climatic problems. This is also the case with Nigeria, a country with over 160 million people. Due to the negative effect that adverse climatic conditions, such as heavy downpour of rain which could lead to flooding, could have on Nigeria's large population, it is very pertinent to regularly carry out climatic studies. When rainfall studies are carried out in Nigeria, it is a common to have a grouping of the states or meteorological stations into:

- The Geopolitical Zones and
- The Climatic Zones.

Figures 1 and 2 show how the regions of the country that fall under the geopolitical zones and climatic zones respectively.

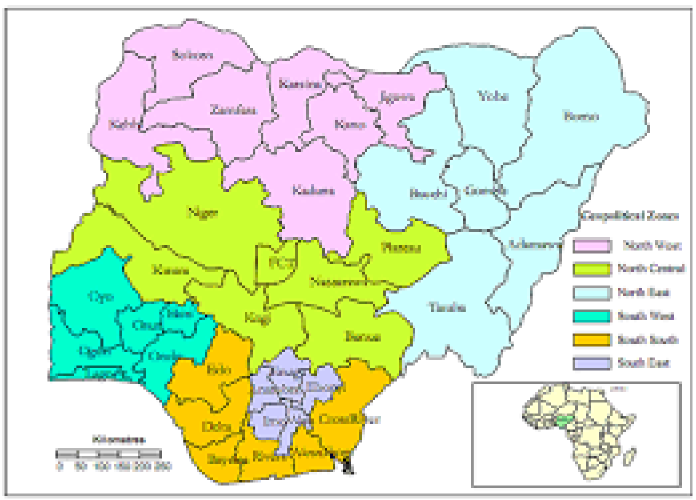

FIGURE 1. Map Showing the Geopolitical Zones in Nigeria

1.3. **Justification.** It is pertinent to test whether earlier assertions in literature about rainfall in Nigeria are at variance with current situations using current data. If there is variation, it is also of interest to know the direction of the change, that is, if rainfall is increasing or decreasing. These can be done through statistical tests of hypotheses. After carrying out these tests, it is very important to examine the power of these tests. This will help to examine the probability that there are changes in rainfall, since the power supports the alternative hypothesis which stipulates change in rainfall.

1.4. **Aim:** The aim of this research is to examine change in rainfall through tests of results of earlier research and to examine the effect of sample size on the power of these tests.

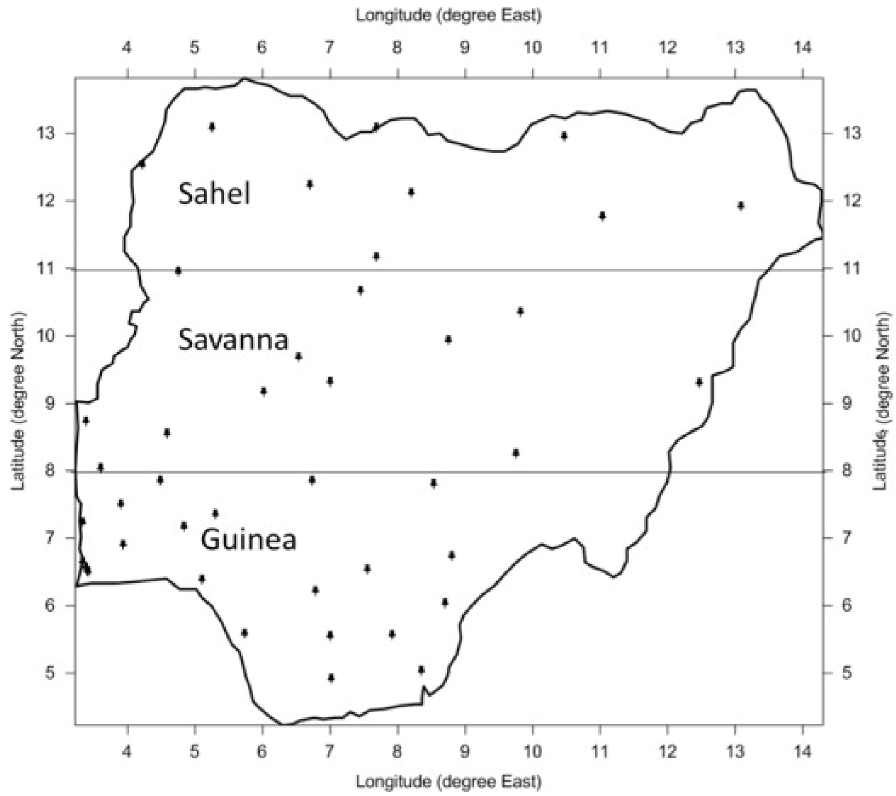

FIGURE 2. Map Showing the Climatic Zones of Nigeria (Omotosho and Abiodun, 2007)

2. Review of Literature

2.1. Review of Rainfall Studies of Nigeria.

2.1.1. *Geopolitical Zones.* Adefolalu (1986) studied rainfall trends for periods of 1911-1980 over 28 meteorological stations in Nigeria with 40 years moving average showing decline in rainfall. In that research, rainfall was noticed to have a negative trend, that is, it was decreasing. However, Eludoyin et al. (2009) studied monthly rainfall distribution in Nigeria between 1985-1994 and 1995-2004 and noticed some fluctuations in most months within decades. This research thus establishes the fact that rainfall is random and may not stick to a particular trend. It might be increasing at some point but later start decreasing or vice versa. This, however, does not render the study of rainfall trend useless. More recently, Akinsanola and Ogunjobi (2014) also carried out a research that investigated rainfall and temperature variabilities in Nigeria using observations of air temperature and rainfall from 25 synoptic stations from 1971-2000 (30 years).

The data were analysed for the occurrences of abrupt changes in temperature and rainfall values over Nigeria while temporal and spatial trends were also investigated. Their analysis showed that, though there have been rise and fall in the amount of rain in several decades, there is generally an increase in rainfall in the years of consideration. In other words, despite fluctuations in the amount of rainfall across the decades, rainfall is significantly increasing.

It is also important to know the average amounts of rainfall in these zones. These were shown in the preliminary analysis of the time series applied to rainfall data in Nigeria in the research carried out by Obot et al (2010). Using rainfall data from the year 1978 to 2007, the stipulated mean rainfall of the zones are: North East (580.5 mm), North West (1187.5 mm), North central (1228.7 mm), South West (1317.2 mm), South East (1753.8 mm) and South South (2925.6 mm). This study has provided valuable insight on rainfall pattern in Nigeria Geopolitical zones. The study showed that rainfall amount in South South, South East and South West was considerably higher than other zones and this might be one of the likely factors why dwellers of these zones were more vulnerable to flooding in comparison to other zones (Okunlola and Folorunsho, 2015).

Most of the researches discussed so far did not engage a probability distribution. Due to complexities in rainfall scenarios; stochastic modeling approaches have also been used by Obisesan and Yusuff(2015); Obisesan(2015) and Obisesan and Dosumun(2015). They used similar monthly rainfall series engaging different approaches from different angles. While Obisesan and Yussuff(2015) used generalized linear models for evaluating extreme rainfall; Obisesan and Dosumun(2015) compared various estimating procedures of maximum likelihood, method of moment and least square approach. Obisesan(2015) also used seasonalised time series models for evaluating rainfall data.

2.1.2. *Climatic Zones.* Ayansina and Ogunbo (2009) investigated the seasonal rainfall variability in Guinea savannah part of Nigeria, they concluded that rainfall variability, being in increase, is an element of climate change. A similar finding was discovered about northern Nigeria by Ati et al. (2009) from evidence from rainfall data of the years 1953-2002 for 9 stations. The data was used to determine the trend in annual rainfall for the region. Five-year running mean was calculated for annual rainfall for the selected stations. The means for each decade were compared with the long-term mean. They found out that there was significant increase in annual rainfall amount in the last decade of the study. According to Ati et al.(2009), 'It means, therefore, that we are experiencing wetter conditions in the sudano-sahelian zone of Nigeria. Increasing annual rainfall totals portend both good and ill. Good, because there is improvement in water supply to an otherwise marginal area. Ill, because flooding and dam collapse, as a result of excessive rainfall on an impervious terrain, could lead to damage to life and property.' This comment emphasizes the importance of continual study and monitoring of rainfall.

In a research carried out by Ogungbenro and Morakinyo (2014) entitled 'Rainfall distribution and change detection across climatic zones in Nigeria', Nigeria was subdivided latitudinally into three zones: Guinea (coast-8^0N), Savannah (8-11^0N) and Sahel(11-16^0N). Rainfall data was collected for a period of 90 years (1910-1999), while a sub-division was made to three non-overlapping climate period of 30 years i.e. 1910-1939, 1940-1969 and 1970-1999. The analysis from this data showed that annual rainfall ranges from 1400 to 2700 mm(Guinean zone), 950 to 1400 mm(Savannah zone)and 450 to 1050 mm(Sahelian zone) over the entire 90 years of study. This indicates that rainfall in Nigeria reduces as we move northward (Ogungbenro and Morakinyo, 2014), hence giving insight into the amount of rain expected in each climatic zone. That is, we expect more rainfall in the coastal areas than the sahelian areas.

2.2. **Review of Application of Post-hoc Power Analysis.**

2.2.1. *In random experiments.* Hogg and Craig (1978) applied the *post-hoc* power analysis to a random experiment. In their book, 'Introduction to Mathematical Statistics', they provided an example of a random experiment that has a random variable following the exponential distribution. Hypotheses on the parameter of the distribution were set up. A random sample of size 2 was assumed to be drawn and a critical region was established. Then, the power function of the test and the significant level were determined. In fact, the significant level was determined from the power function. (The power function could yield only two values since both the null and alternative hypothesis were simple.) The significant level is the value of the power function when H_0 is true. This shows how important the power function is. A difficult way and a simple way of obtaining the values of the power function were also shown. Therefore, power analysis proved quite helpful in this regard.

2.2.2. *In the manufacturing world.* In manufacturing companies, quality control is carried out regularly to ensure that products produced are not substandard. Allowable limits to variability in the quality of products are set, and production is monitored to ensure that the quality of products is within these limits. Even in this area, power analysis can be applied. Freund and Wilson (2003), in the book 'Statistical Methods', were able to plot the power curve of a statistical test on quality control on the amount of peanuts put in jars by one of the machines in a company that packages salted peanuts. The power curve was symmetric and approached α as the true value of the parameter approached that of the null hypothesis.

Evidently, these show that power analysis is a versatile tool in understanding the result of a statistical test no matter the area of study applied.

3. Methodology

3.1. **Sampling.** Stratified sampling is used in selecting the stations whose data would be used and that will be appropriate representation of the whole country. The tables show the stations selected from the geopolitical zones and the climatic zones.

Table 1. Selection of Stations from the Geopolitical Zones

Zone	Number of States	Number of Stations Selected	Name of Station
North East	6	1	Maiduguri
North West	7	1	Kaduna
North Central	6	1	Lokoja
South West	6	1	Ibadan
South East	5	1	Enugu
South South	6	1	Calabar
	36	6	

Table 2. Selection of Stations from the Climatic Zones

Zone	Number of Stations	Number Selected	Station Selected
Guinea	18	3	Enugu, Ikeja, Port Harcourt
Savanna	15	2	Bida, Yelwa
Sahel	9	1	Kano
	42	6	

3.2. **Exploratory Data Analysis.** Time plots, histograms and box plots were plotted in order to have good understanding of the data.

3.3. **Statistical Hypothesis Testing.** When carrying out a test of hypothesis, the steps below are followed:
Step 1: State H_0, H_1 and an acceptable level of α.
Step 2: Define the test statistic and the rejection region for the specified H_0.
Step 3: Calculate the test statistic using the sample data.
Step 4: Make a decision either to reject or to fail to reject H_0.
Step 5: Make a conclusion based on the decision.
Step 6: Examine the power curve of the test.

For the analyses on the geopolitical zones:

- The null hypothesis for the two-tailed tests:

$$H_0 : \mu_i = \mu_{0i} \tag{1}$$

where $i = 1, 2, 3, 4, 5, 6$ for the six geopolitical zones, μ_i represents the population mean annual rainfall for each geopolitical zone (i.e. the actual mean) and μ_{0i} is the hypothetical value of the mean annual rainfall for each geopolitical zone based on literature. The alternative hypothesis is stated as:

$$H_1 : \mu_i \neq \mu_{0i} \tag{2}$$

If the result of any of the two tailed tests shows that there is significant difference, one tailed test will be carried out to determine the direction of the difference. For the one tailed test, the H_0 remains the same while the H_1 states:

$$H_1 : \mu_i < \mu_{0i} \tag{3}$$

Or

$$H_1 : \mu_i > \mu_{0i} \tag{4}$$

Comparing the hypothetical mean and the calculated mean will aid in determining the H_1 to use. The significant level, α that will be used is 0.05

- The test statistic to be used for these analyses is the *t-statistic* given as

$$t = \frac{\bar{X}_i - \mu_{0i}}{\frac{s}{\sqrt{n}}} \tag{5}$$

where $i = 1, 2, 3, 4, 5, 6$ for the six geopolitical zones and

$$s = \sqrt{\frac{\sum_{j=1}^{n}(X_{ji} - \bar{X}_i)}{n-1}} \tag{6}$$

- The critical value to be used for the two tailed tests is $t_{\frac{\alpha}{2}}$ while the critical value for the one tailed tests is t_α. These are table values of the t distribution at the significance level, α and degrees of freedom $n - 1$.
- The decision rule
  - For the two tailed test is: Reject H_0 if $t_{calculated}$ ¡ $-t_{\frac{\alpha}{2}}$ or $t_{calculated}$ ¿ $t_{\frac{\alpha}{2}}$, otherwise fail to reject H_0.
  - For the one tailed test is: Reject H_0 if $t_{calculated}$ ¡ $-t_\alpha$ (for left tailed test) or $t_{calculated}$ ¿ t_α (for the right tailed test), Otherwise fail to reject H_0.

For the analyses on the climatic zones:

- The null hypothesis for the two tailed tests is

$$H_0 : \mu_i = \mu_{0i} \tag{7}$$

where $i = 1, 2, 3$ for the three climatic zones, μ_i represents the population mean annual rainfall for each climatic zone (i.e. the actual mean) and μ_{0i} is the hypothetical value of the mean annual rainfall for each climatic zone based on the research of Ogungbenro and Morakinyo (2014). The alternative hypothesis goes thus:

$$H_1 : \mu_i \neq \mu_{0i} \tag{8}$$

Like the analysis on the geopolitical zones, if the result of any of the two tailed tests shows that there is significant difference, one tailed test will be carried out to determine the direction of the difference. For the one tailed test, the H_0 remains the same while the H_1 states:

$$H_1 : \mu_i < \mu_{0i} \tag{9}$$

Or

$$H_1 : \mu_i > \mu_{0i} \tag{10}$$

In determining the H_1 to use for the one tailed test, the comparison of the hypothetical mean and the calculated mean will be used .The significant level, α that will also be used is 0.05

- The test statistic to be used for these analyses is still the *t-statistic* given as

$$t = \frac{\bar{X}_i - \mu_{0i}}{\frac{s}{\sqrt{n_i}}} \tag{11}$$

where $i = 1, 2, 3$ for the three climatic zones and

$$s = \sqrt{\frac{\sum_{j=1}^{n_i} (X_{ji} - \bar{X}_i)}{n_i - 1}} \tag{12}$$

n_i applies because different number of stations will be used for different climatic zones.

- The critical value to be used for the two tailed tests is $t_{\frac{\alpha}{2}}$ while the critical value for the one tailed tests is t_α.
- The decision rule is the same as the first case.

3.4. ***Post-hoc* Power Analysis.** Suppose that T is the test statistic and the critical region is C for a test of a hypothesis involving the value of a parameter μ. The power of the test, denoted by power(μ), is the probability that the test will lead to the rejection of the null hypothesis, that is

$$\text{Power}(\mu) = \text{P}(T \text{ in } C \text{ when the parameter value is } \mu)$$

Suppose that the null hypothesis to be tested is $H_0 : \mu = \mu_0$ and μ_1 is the particular value of μ chosen from H_1. The power of the test when $\mu = \mu_0$, power(μ_0), is equal to the probability of rejecting H_0 when it is true. That is, power(μ_0) = α, the probability of type I error. For any value of μ from H_1, the power of a test measures the test's ability to detect that the null hypothesis is false. That is, for $\mu = \mu_1$

$$\text{power}(\mu_1) = \text{P}(\text{rejecting } H_0 \text{ when } \mu = \mu_1).$$

Hence, power can be simply defined as the probability of *correctly* rejecting the null hypothesis when it is false. (Freund and Wilson, 2003)

A *post-hoc power analysis is any analysis on the power of a test done after the test has been carried out.* For this study, graphical analysis of the power curves for each test on annual rainfall of the geopolitical and climatic zones of Nigeria was carried out. Also, the power of each of the test was examined with different sample sizes based on a particular parametric value of the mean annual rainfall of each zone. This will help in observing how sample size affects the power of the tests. All of these were done using the **R** statistical package.

It is appropriate to show how power analysis can be used for the stated purpose. Suppose W is any critical region with sizeα i.e

$$Pr(W|H_0) = \alpha$$

Let W^* be the likelihood ratio critical region with size α i.e

$$W^* = \{x : f(x; \theta_1) \geq kf(x; \theta_0)\}$$

and

$$Pr(W^*|H_0) = \alpha$$

This implies that $\bar{W}^* = \{x : f(x; \theta_1) < kf(x; \theta_0)\}$. Then W^* has the maximum power in that

$$Pr(W^*|H_0) \geq Pr(W|H_1)$$

for a W. Now suppose A, B, C are also critical regions of size α we then have:

$$Pr(W^*|H_0) = Pr(W|H_0)$$

$$Pr(A|H_0) + Pr(C|H_O) = Pr(B|H_0) + Pr(C|H_O)$$

therefore; $Pr(A|H_0) = Pr(B|H_0)$ i.e

$$\int_A f(x; \theta_0)dx = \int_B f(x; \theta_0)dx$$

considering

$$Pr(W^*|H_1) - Pr(W|H_1)$$

which then means

$$Pr(A|H_1) + Pr(C|H_1) - Pr(B|H_1) - Pr(C|H_1) =$$

$$Pr(A|H_1) - Pr(B|H_1) =$$
$$\int_A f(x;\theta_1)dx - \int_B f(x;\theta_1)dx \geq$$
$$\int_A kf(x;\theta_0)dx - \int_B kf(x;\theta_0)dx = 0$$

since $A \subset W^*; B \subset \bar{W}^*$

3.5. **Data.** The secondary data to be used in this study is the monthly rainfall (mm) data from the Nigerian Meteorological Agency (NIMET). The data was collected from 42 stations nationwide and it spans a period of 44 years (1971-2014).

4. Results, Conclusion and Recommendation

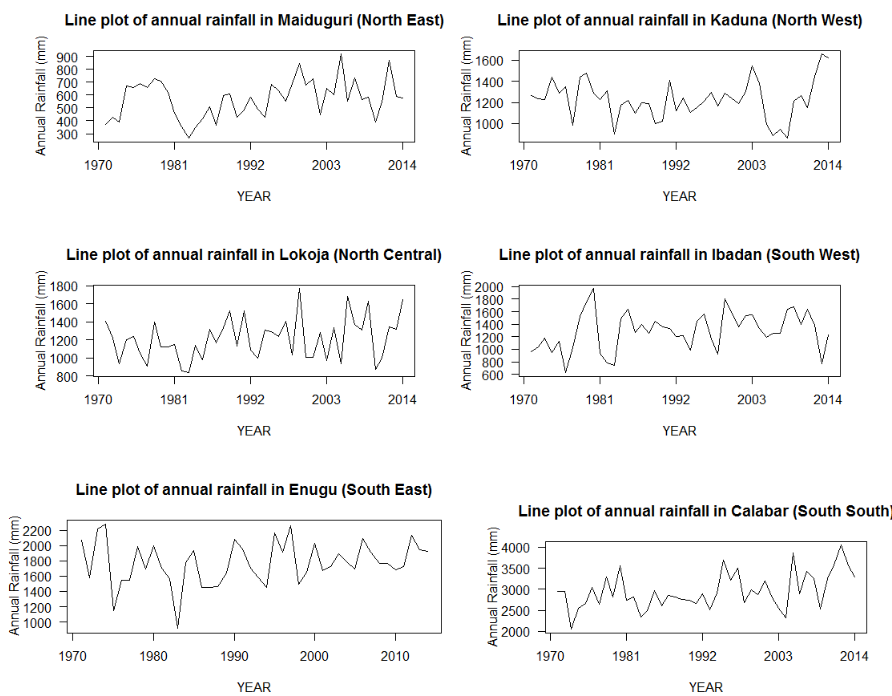

Figure 3. Time Plots of Rainfall Data for Each Geopolitical Zone

4.1. **Exploratory Data Analysis (Geopolitical Zones).** The time plots of figure 4.1 show abrupt changes in the amount of annual rainfall in each of the geopolitical zone. But, it is noticed that the line fall between a range of values.

In order to have insight into the distribution of the data, histograms and box plots were plotted for each zone.

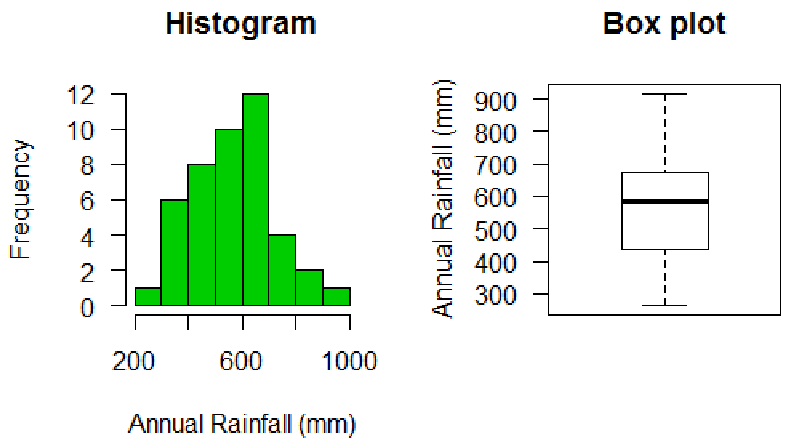

FIGURE 4. Histogram and Box Plot of Annual Rainfall in Maiduguri (North East)

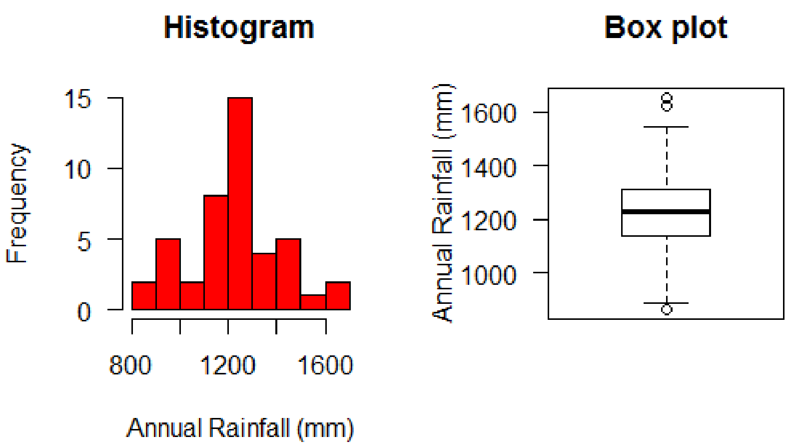

FIGURE 5. Histogram and Box Plot of Annual Rainfall in Kaduna (North West)

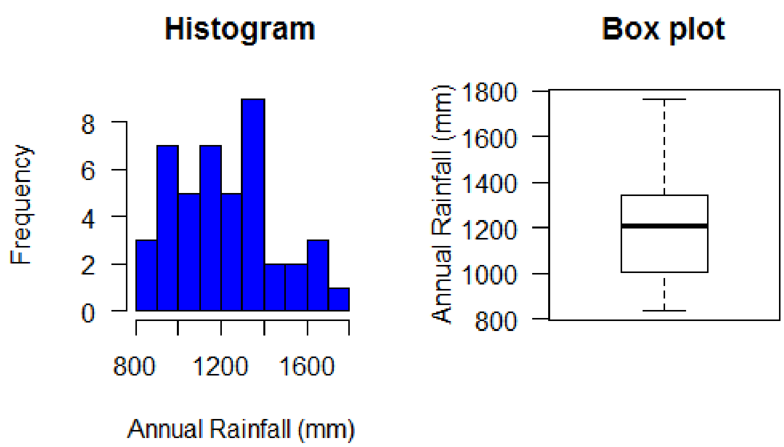

FIGURE 6. Histogram and Box Plot of Annual Rainfall in Lokoja (North Central)

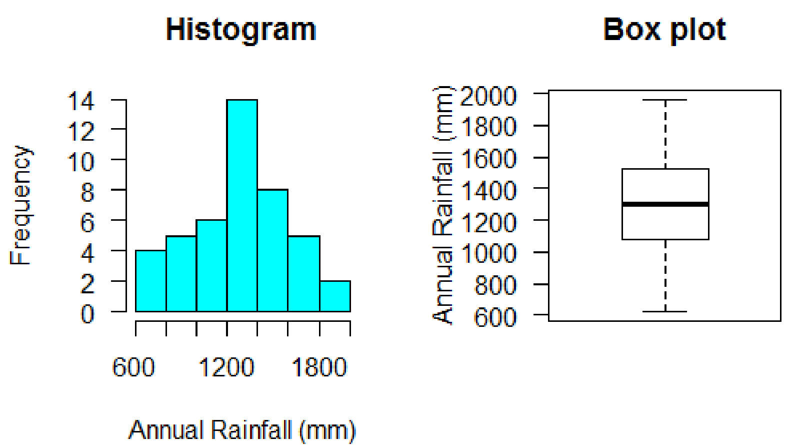

FIGURE 7. Histogram and Box Plot of Annual Rainfall in Ibadan (South West)

From the plots in figures 4-9, it can be observed that the distributions of the zones are skewed. This property of the distributions informs the decision to use the t-distribution for the tests that are carried out since the variance of the population annual rainfall is not known.

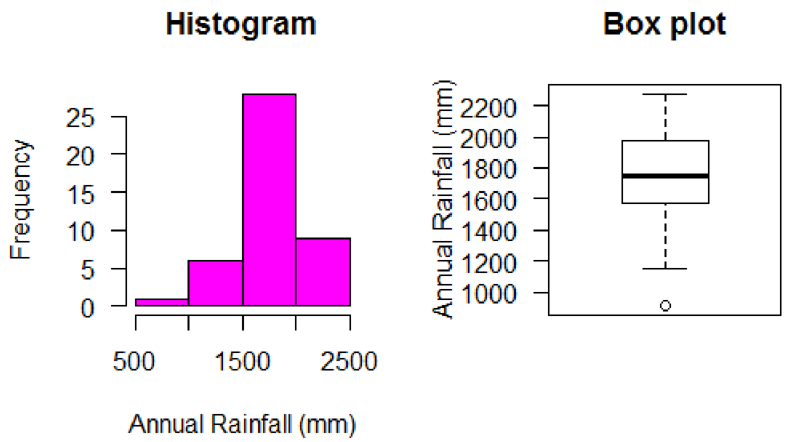

FIGURE 8. Histogram and Box Plot of Annual Rainfall in Enugu (South East)

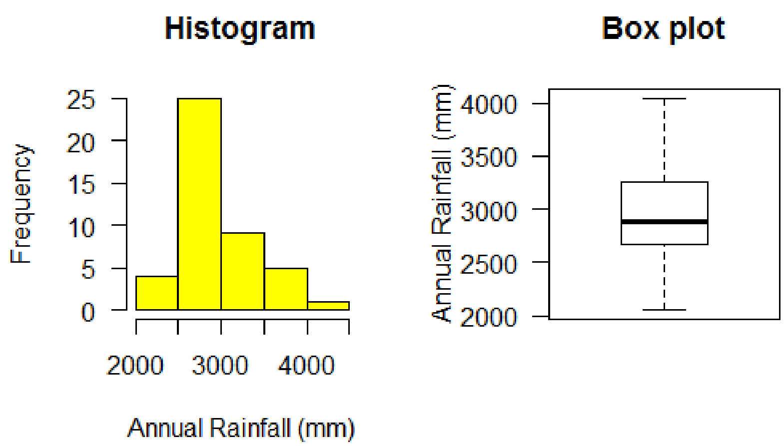

FIGURE 9. Histogram and Box Plot of Annual Rainfall in Calabar (South South)

4.2. **Result of Analysis on the Geopolitical Zones.**

4.2.1. *The Tests:* The null hypothesis values used for the Geopolitical Zones are derived from the research carried out by Obot et al (2010). The stipulated mean rainfall of the zones are: North East (580.5 mm), North West (1187.5 mm), North central (1228.7 mm), South West (1317.2 mm), South East (1753.8 mm) and South South (2925.6 mm).

Table 3. Table Showing the Result of the Two-tailed Tests

Zone	Hypothesis Value	t	p value
North East	580.5	-0.4491	0.6556
North West	1187.5	1.4471	0.1551
North Central	1228.7	-0.4403	0.6619
South West	1317.2	-0.5216	0.6046
South East	1753.8	0.4475	0.6567
South South	2925.6	0.5188	0.6066

Since all the p values are greater than α (0.05), hence we fail to reject the null hypotheses.

4.2.2. *The power curves:* The power curves of the tests are given in figure 10.

From the power curves (Figure 10), it can be noticed that the power of the test is low at the area around each of the null hypothesis value. This is so because if the true value of the mean annual rainfall of the respective geopolitical zone is not significantly different from the null hypothesis value (based on the result of the test), then the probability of rejecting the null hypothesis (power) should be low. Hence, since the power curves show low power at those points, then it is most probable that the mean annual rainfall of each of the geopolitical zone has not significantly changed from the hypothetical value from literature.

4.2.3. *Sample Size Effect On Power Curve:* A very important aspect of post-hoc analysis involves the examination of the power curve based on varying sample size. In this case, the power curve will be examined based on increasing sample size.

The figures below (Figure 11) show the effect of increasing sample size on the power curve of the tests on the mean annual rainfall in the geopolitical zones.

From figure 11, it can be observed that increase in the sample size leads to increase in the power. But, it is also noticed that the power curves still reveal low power at the area around the null hypotheses values, since according to the result from the test, we are 95 percent confident that the null hypotheses are true.

4.3. **Exploratory Analysis on the Climatic Zones.** We will be merging some of the stations for the analysis under the climatic zones. In the research by Ogungbenro and Morakinyo (2013), the range at which annual rainfall for each zone fall was given as 1400 to 2700 mm(Guinean zone), 950 to 1400 mm(Savannah zone)and 450 to 1050 mm (Sahelian zone). For the purpose of this study, the

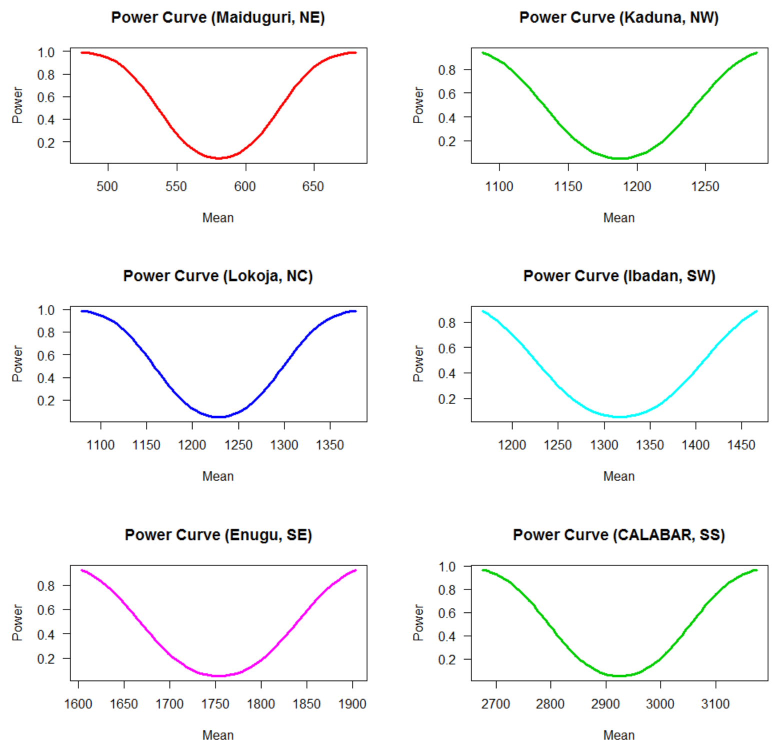

FIGURE 10. The Power Curve of the Two-tailed Test on Mean Annual Rainfall in the Geo-Political Zones

midpoint value of these ranges will be used as the null hypothesis value as shown in the table below:

TABLE 4. Midpoint Values Of the Climatic Zones

Zone	Range	Midpoint
Guinea	1400-2700	2050
Savanna	950-1400	1175
Sahel	450-1050	750

The figures below (Figures 12-14) show the histograms and box plots describing the distribution of rainfall amounts in the climatic zones.

From figures 12-14, it can be observed that the distribution of rainfall data of the Guinea and Sahel are skewed, and the distribution of rainfall data of Savannah is not perfectly symmetric. Since the population variances for these data are not

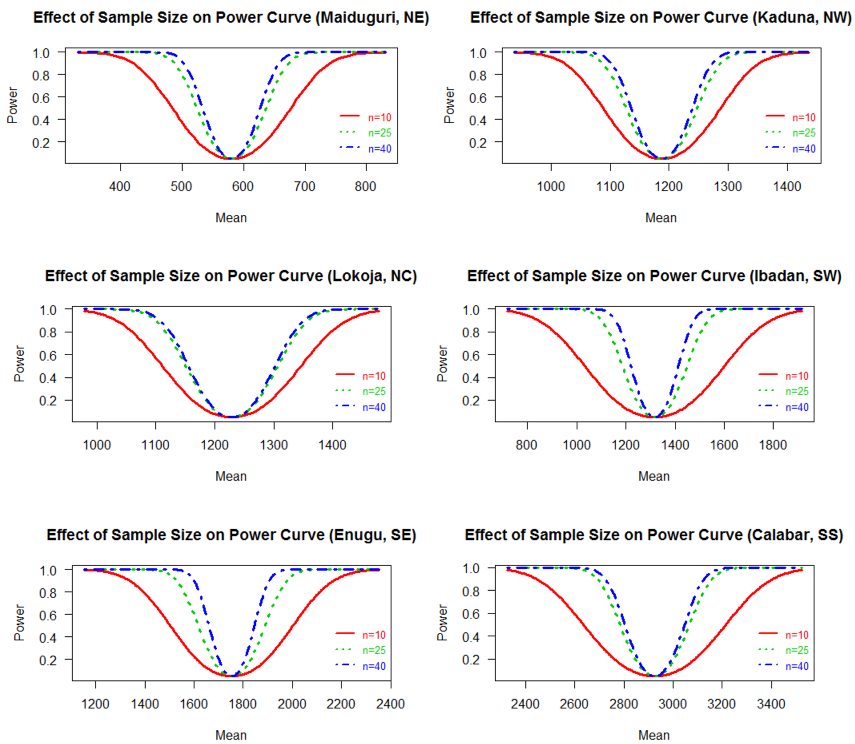

FIGURE 11. Sample Size Effect On Power Curve For the Geopolitical Zones

known, the t distribution (an approximation of the Normal distribution) will be used for the statistical tests.

4.4. **Result of Analysis on the Climatic Zones.**

TABLE 5. Table Showing the Result of the Two-tailed Tests

Zone	Hypothesis Value	t	p value
Guinea	2050	-5.519	1.757e-07
Savanna	1175	-5.3351	7.481e-07
Sahel	750	3.7314	0.0005537

4.4.1. *The Tests:* From the result in Table 4, all the p values are less than α (0.05), hence we reject the null hypotheses. This leads to the one tailed tests. The one tailed tests will help in detecting the direction of the change in the mean annual rainfall in the climatic zone. To determine whether to use a left-tailed or

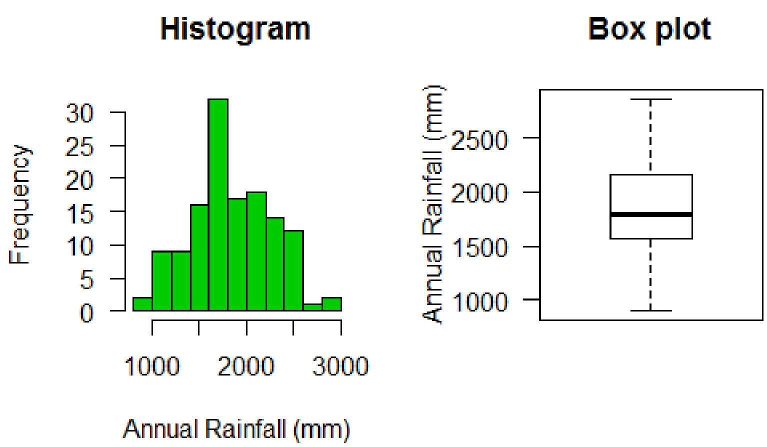

Figure 12. Histogram and Boxplot of Rainfall Data of Guinea Zone

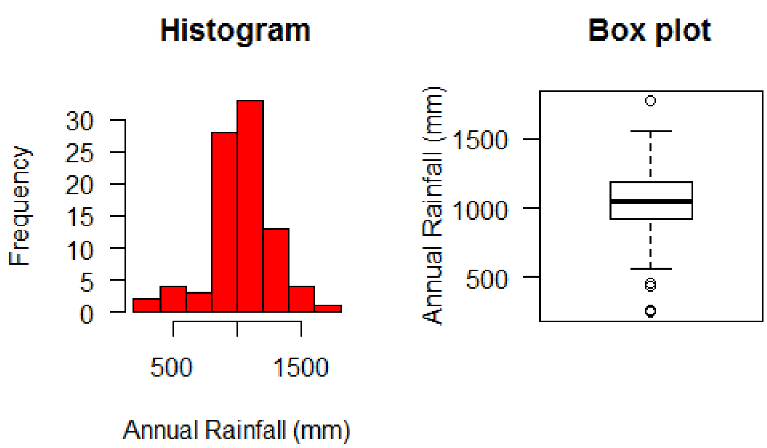

Figure 13. Histogram and Boxplot of Rainfall Data of Savanna Zone

right-tailed test, the sign of the difference between the calculated mean annual rainfall and the null hypothesis value was used. The table below shows the results of the one-tailed tests on the climatic zones:

From the table above, since all the p values are less than α (0.05), the null hypotheses are rejected. Therefore, it can be deduced from the result of the test

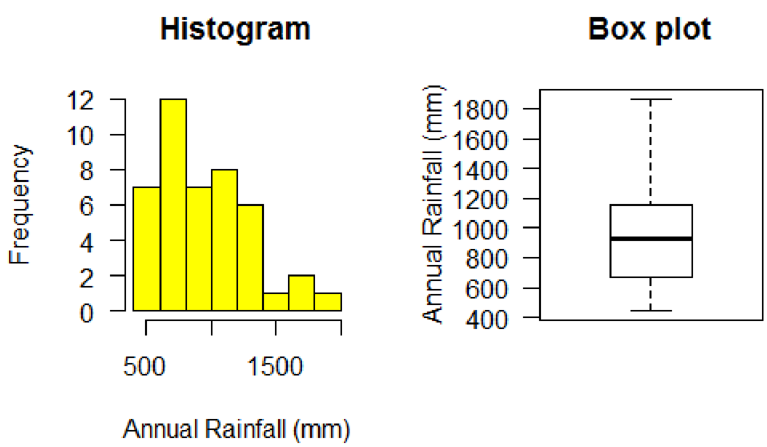

FIGURE 14. Histogram and Boxplot of Rainfall Data of Sahel Zone

TABLE 6. Table Showing the Result of the One-tailed Tests

Zone	Hypothesis Value	t	p value
Guinea	2050	-5.519	8.784e-08
Savanna	1175	-5.3351	3.741e-07
Sahel	750	3.7314	0.0002768

that the mean annual rainfall in the Guinea and Savannah zones have decreased significantly while the mean annual rainfall in the Sahel zone has increased significantly. This can be further proven by the power curves.

4.4.2. *The Power Curves:* The power curves of the one tailed tests above are thus given in figure 15:

From the power curves in Figure 15, it can be noticed that the power increases at the side that falls under the alternative hypothesis (which was accepted) of each of the tests. Hence, since the power is higher in these regions, then the null hypotheses are rejected.

4.4.3. *Sample Size Effect on Power Curve:* The power curves of the one-tailed tests will be examined based on increasing sample size.

- **Guinea Zone:** It can be noticed from figure 16 that the trough of the power curve decreases as the sample size increases.
- **Savannah Zone:** From figure 17, it can be noticed that the trough of the

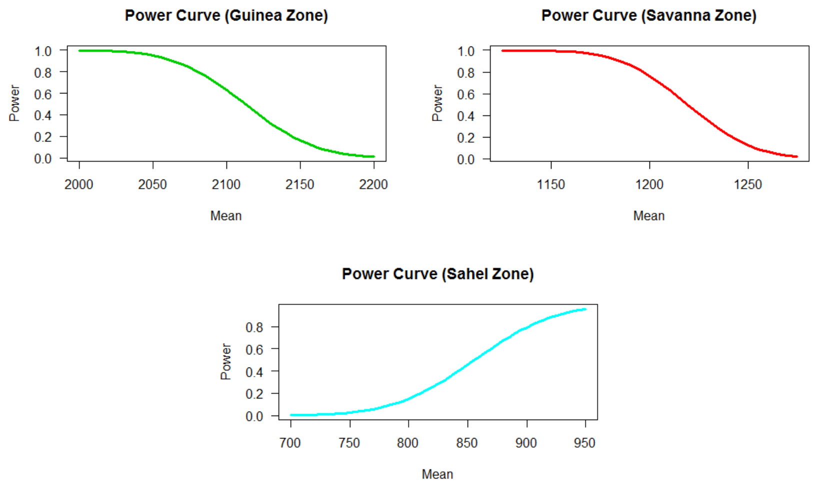

FIGURE 15. Power Curve of the One-tailed Test on Mean Annual Rainfall In Each Climatic Zones

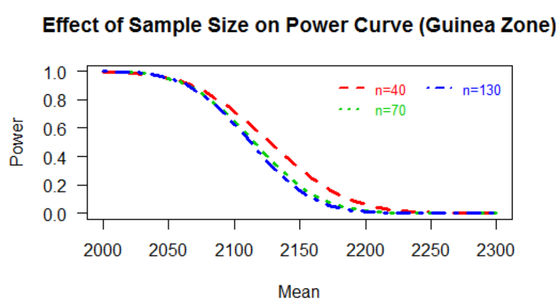

FIGURE 16. Sample Size Effect on Power Curve (Guinea Zone)

power curve increased when the sample size first increased, but decreased when the sample size was increased again.

- **Sahel Zone:** From the figure 18, it can be noticed that the trough of the power curve increased when the sample size first increased, but decreased when the sample size was increased again.

Despite the "irregularities" of the effect of sample size on the power curves on the one-tailed tests, it can still be noticed that the power curves still tended toward unity under the range of values of the alternative hypotheses, despite the sample size. This further proves that the null hypotheses should be rejected. Hence, the alternative hypotheses are accepted.

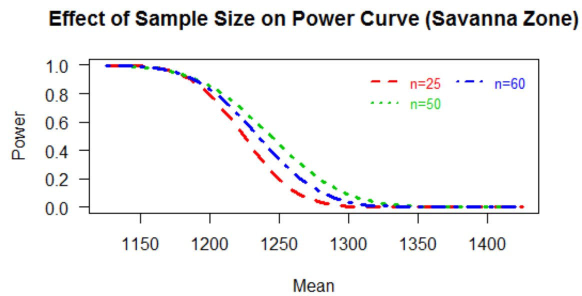

FIGURE 17. Sample Size Effect on Power Curve (Savanna Zone)

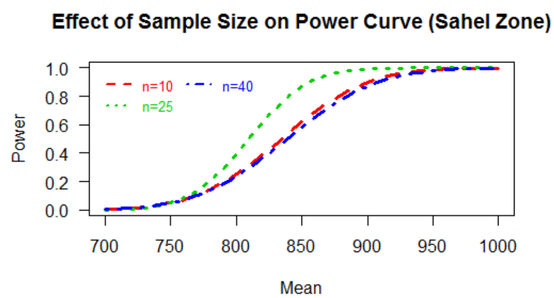

FIGURE 18. Sample Size Effect on Power Curve (Sahel Zone)

4.5. **Conclusion.** The results of the power analyses of the tests of hypothesis on the mean annual rainfall in the geopolitical zone show that there is no significant difference in the amount of rainfall in each of the geopolitical zone. Thus, we can conclude that the amount of rainfall in the geopolitical zones have not significantly changed over time.

On the other, the results of the power analysis on the tests done for the climatic zones show that there is significant difference in the amount of rainfall in each climatic zone. Hence, we can conclude that the amount of rainfall in each of the climatic zones have changed significantly. For the Guinea and Savannah zones, rainfall has decreased significantly, while in the Sahel zone, rainfall has increased significantly.

Since rainfall has not changed significantly in the geopolitical zones, this means that rainfall has not significantly changed when we consider smaller regions in Nigeria. But, since the climatic zones are larger regions of the country even comprising of some geopolitical zones together, it could therefore mean that when we consider rainfall of larger regions of the country, there may be significant changes in the amount of rain. Since the climatic zones represent different climatic conditions in the country, it could also be concluded that the country is experiencing slight changes in the climatic pattern of rainfall that could be noticed in the climatic zones but enough to be noticed in the smaller geopolitical zones.

It is important to note that post-hoc power analysis greatly help in giving evidences to support the results derived. Hence, it is a vital tool that have proved efficient in carrying out statistical tests.

4.6. **Recommendations.** Researchers should imbibe the habit of considering power analysis when carrying out statistical test. The common excuse that calculating power of a test is not straightforward or easy is no more valid since there are powerful statistical packages like **R** (a free statistical package) which can carry out power analysis efficiently.

It is also recommended, based on this research, that regular researches be done to ascertain trend of climate change in Nigeria since there is evidence that the country is experiencing some climatic change in rainfall. It is recommended that government should enforce environment-friendly laws that could help in improving climate conditions of the country.

Evidence exists that there is increase in the amount of rainfall in the Sahel zone, it is recommended that more agricultural activities should be encouraged in that region. Appropriate measures should be put in place to mitigate the negative effects of heavy rainfall.

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