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ARTICLE

North Atlantic Oscillation and Rainfall Variability in Southeastern Nigeria: A Statistical Analysis of 30 Year Period

Okorie, Fidelis Chinazor

Department of Geography and Environmental Management, Imo State University Owerri, Nigeria

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ABSTRACT

This study analyzed rainfall variability in Southeast region of Nigeria using graphical models, as well as using statistical approach to investigate any significant relationship between the global North Atlantic Oscillation (NAO) Index and the regional rainfall variability in region. The study was conducted in three States of Southeastern Nigeria namely, Abia, Ebonyi and Imo States that lie between Latitudes 4^0 40' and 8^0 50'N and Longitudes 6^0 20' and 8^0 50'E. Data for the study included 30 years (1988 - 2017) archival time-series monthly rainfall values for the three study States, acquired from Nigerian Meteorological Agency (NIMET), offices in the states, and Standardized values of NAOI (North Atlantic Oscillation Index) for the same period, which were collected from a website, on the NOAA Data Center, USA. In the data analyses, the first method was adopted by using graphs to illustrate mean annual rainfall values for thirty years. Coefficient of variability was employed in evaluating the degree of variability of values from the mean rate. The second analysis was accomplished using correlation models to ascertain any relationship between NAOI and rainfall in Southeast Nigeria. The results showed a significant variability of rainfall in the region from January to December (mean monthly) within the study period. A negative correlation value of 0.7525 was obtained from the correlation analysis, showing that the global NAO index and rainfall variability deviate in the opposite direction. Coefficient of multiple determinations (CMD) subsequently showed value of 0.031%, being the variation in rainfall as influenced by the global teleconnectivity, and this means that the NAO index has zero or no influence on rainfall variability in Southeast region of Nigeria.

1. Introduction

In recent years, the incidence of unusual weather patterns as they affect wet and dry season regimes have been observed in West African sub-region, including Nigeria. Sometimes, heavier rainfall than usual may occur and the rain is prolonged and extends into the dry season [1].

*Corresponding Author:
Okorie, Fidelis Chinazor,
Department of Geography and Environmental Management, Imo State University Owerri, Nigeria;
Email: fidelisokorie@yahoo.co.uk

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The variability of rainfall is equally a necessary consideration in the tropics where rainfall is more eccentric than in temperate and also more seasonal in its occurrence within a year. The less eccentric, the more reliable rainfall is. Rainfall can vary in amount from one year, season, or month to month and may also show a downward or upward trend over a given period. According to [2], in the sub-Saharan region of Africa, climate variability has manifested essentially as rainfall variability.

The climate of Nigeria is however, a typical example of the climate of the West African sub-region. The variability of rainfall, defined as the average deviation from the mean, is enormous, sometimes up to 40-80% and increases with decreasing annual rainfall totals [3].

[4,5] reported the variations in rainfall intensified for different climatic regions and individual locations in Nigeria in the last century. [6], noted that climate variation generally occurs at different scales including local, regional, national and global scale.

[7], in a study ascertain there is variability in the weather and climate system of Imo State due to the observed shifts in rainfall within the 30 year climatic period. [8], indicates that shifts in rainfall and temperature regimes as well as evaporation and humidity conditions of southeastern Nigeria have been observed over time and the fluctuations however, are the atmospheric driving force that is responsible for the climate variations over the region. Another study [8], established that there is a variability and change in the weather and climate systems of Anambra state and entire southeastern Nigeria.

Increase in precipitation and changes in extremes, including floods would result to increased erosion and deterioration of groundwater quality, which would exacerbate many forms of water pollution [9]. This is because more sediment, nutrients, dissolved organic matter, pathogens, heavy metals, pesticides and salts are likely to infiltrate many aquifers more rapidly [10]. According to [11], rainfall variability can also affect agricultural productivity by decreasing outputs, which would negatively affect socio-economic wellbeing of the people. Hence, agriculture in the southeast region of Nigeria is adversely impacted by increasing variations in terms of timing and amount of rainfall.

Ever since, a variety of studies, more especially numerical modeling have been employed to analyze, as well as predict Sahel rainfall [12,13]. Although, these efforts have documented climate variations in West Africa, in recent times there has been little or no analysis of the forcing of climate trends particularly, in southeast region of Nigeria. For instance, what climatic factors control the nature and characteristics of the rain that falls in southeast Nigeria?

However, in this study the interest in the North Atlantic Oscillation and regional rainfall variability in southeast Nigeria. The North Atlantic Oscillation (NAO) index is based on the surface sea-level pressure difference between the Subtropical (Azores) High and the Sub-polar Low. The positive phase of the NAO reflects below-normal heights and pressure across the high latitudes of the North Atlantic and above-normal heights and pressure over the central North Atlantic, the eastern United States and Western Europe. The negative phase reflects an opposite pattern of height and pressure anomalies over these regions. Both phases of the NAO are associated with basin-wide changes in the intensity and location of the North Atlantic jet stream and storm track, and in large-scale modulations of the normal patterns of zonal and meridional heat and moisture transport, which in turn results in changes in temperature and precipitation patterns often extending from eastern North America to western and central Europe [14].

Strong positive phases of the NAO tend to be associated with above-normal temperatures in the eastern United States and across northern Europe and below-normal temperatures in Greenland and oftentimes across southern Europe and the Middle East. They are also associated with above-normal precipitation over northern Europe and Scandinavia and below-normal precipitation over southern and central Europe [15]. Opposite patterns of temperature and precipitation anomalies are typically observed during strong negative phases of the NAO. During particularly prolonged periods dominated by one particular phase of the NAO, abnormal height and temperature patterns are also often seen extending well into central Russia and north-central Siberia. The NAO exhibits considerable inter-seasonal and inter-annual variability, and prolonged periods (several months) of both positive and negative phases of the pattern are common. Studies indicate that the ENSO, which strength can be measured through an index, namely, the Southern Oscillation Index (SOI) influences West African rainfall [1,13]. The Southern Oscillation Index (SOI) is a standardized index based on the observed sea level pressure differences between Tahiti and Darwin, Australia [16].

Similarly, this study therefore, precisely intends to assess the influence of the North Atlantic Oscillation (NAO) on rainfall variability in southeast region of Nigeria. That means, trying to find out if there is any significant correlation between NAO and Rainfall variability in the region as the case in other countries for instance [17], used correlation analysis to study Relationship between the North Atlantic Oscillation Index and October- December Rainfall Variability over Kenya.

2. Area of Study

The study was conducted in three States of Southeastern Nigeria namely, Abia, Ebonyi and Imo States that lie between Latitudes 4^0 40' and 8^0 50'N and Longitudes 6^0 20' and 8^0 50'E (see Figure 1). These states cover about 16335.5 Km^2 in area. The study area lies in the humid tropical climate with annual rainfall ranging from 1500 mm in the northern part to 2500 mm in the southern part [18]. The mean annual temperature ranges from 24 ^0C to 30 ^0C [19].

However, the rainfall pattern is bimodal having peaks in July and September of the year with a short dry spell in August popularly referred to as 'August Break' or 'Little Dry Season'. Generally, the area has 8 months (March-October) of rainy season and 4 months (November- February) of dry season. Relative humidity of the area varies with seasons and a function of the prevailing air mass [20]. High relative humidity ranges from 80 to 90% at 10.00 am local time during rainy seasons when the westerly winds are prevalent. On the other hand, relative humidity ranges from 60 to 80% at 10.00 am local time during the dry season when northeast trade (Harmattan) winds prevail. Fluctuations in relative humidity exist on daily basis. In addition, mean monthly evapo-transpiration ranges from 4.0 to 4.5 mm/day during the dry periods of the year while values ranging from 2.5 to 3.5 mm/day characterize the evapo-transpiration of the rainy season. The drainage system is mainly influenced by Imo River, Ebonyi River, Aba River and their tributeries, and these influence soils, microclimate and land use activities. Most of these rivers move southwards to join larger bodies of water (see Figure 2).

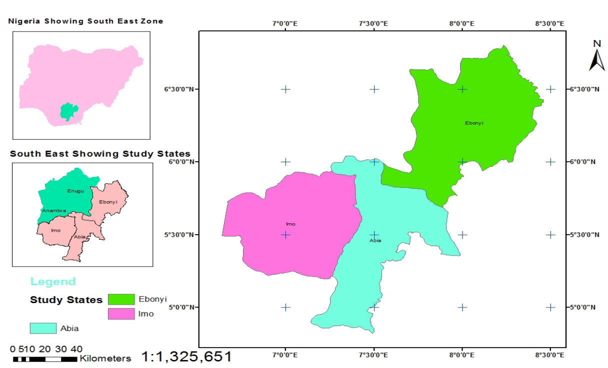

Figure 1. Location Map of the study area

Source: After Okorie 2021

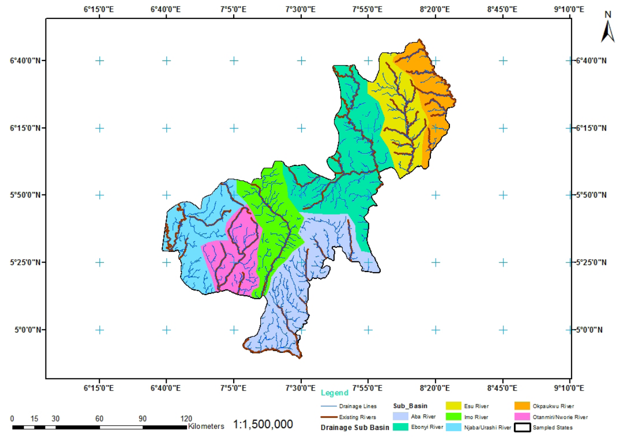

Figure 2. Drainage map of the study area showing the tributaries.

Source: Okorie, 2021.

3. Materials and Methods

The research activities comprised field studies for secondary data collection, and data analysis using statistical methods. The data therefore, included:

a. Archival time-series climatic data on monthly rainfall (in millimeters) for the three study states, acquired from Nigerian Meteorological Agency (NIMET), offices in the states.

b. Standardized values of NAOI (North Atlantic Oscillation Index), as complimentary data, which were collected from a website, on the climate database of NOAA, USA. Both the rainfall data and the NAOI values were for 30 years period, ranging from 1988 to 2017 (see Table 1 & Table 2).

The analysis for this study was approached in two main ways. First, rainfall variability patterns were analyzed and the second was the analysis linking Nigeria rainfall to the global North Atlantic Oscillation Index mode.

The first method was adopted by using line graphs modeling of annual values of rainfall, as well as their mean rate. Coefficient of variability was employed in evaluating the degree of variability of values from the mean rate. Meanwhile, the second analysis was accomplished using correlation models to ascertain any relationship between NAOI and rainfall in Southeast Nigeria.

4. Results and Discussions

Mean monthly rainfall in Southeastern Nigeria (1988-2017)

The results showed a significant variability of rainfall in the region from January to December (mean monthly) within the study period. December had the lowest with

Table 1. North Atlantic Oscillation (NAO) Index Values 1988 - 2017

S/N	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOT	Mean
1	1988	1.02	0.76	-0.17	-1.17	0.63	0.88	-0.35	0.04	-0.99	-1.08	-0.34	0.61	-0.16	0.013
2	1989	1.17	2.00	1.85	0.28	1.38	-0.27	0.97	0.01	2.05	-0.03	0.16	-1.15	8.42	0.702
3	1990	1.04	1.41	1.46	2.00	-1.53	-0.02	0.53	0.97	1.06	0.23	-0.24	0.22	7.13	0.594
4	1991	0.86	1.04	-0.20	0.29	0.08	-0.82	-0.49	1.23	0.48	-0.19	0.48	0.46	3.22	0.268
5	1992	-0.13	1.07	0.87	1.86	2.63	0.20	0.16	0.85	-0.44	-1.76	1.19	0.47	6.97	0.581
6	1993	1.60	0.50	0.67	0.97	-0.78	-0.59	-3.18	0.12	-0.57	-0.71	2.56	1.56	2.15	0.179
7	1994	1.04	0-46	1.26	1.14	-0.57	1.52	1.31	0.38	-1.32	-0.97	0.64	2.02	6.45	0.586
8	1995	0.93	1.14	1.25	-0.85	-1.49	0.13	-0.22	0.69	0.31	0.19	-1.38	-1.67	-0.97	-0.081
9	1996	-0.12	-0.07	-0.24	-0.17	-1.06	0.56	0.67	1.02	-0.86	-0.33	-0.56	-1.41	-2.57	-0.214
10	1997	-0.49	1.70	1.46	-1.02	-0.28	-1.47	0.34	0.83	0.61	-1.70	-0.90	-0.96	-1.88	-0.152
11	1998	0.39	-0.11	0.87	-0.68	-1.32	-2.72	-0.48	-0.02	-2.00	-0.29	-0.28	0.87	-5.77	-0.481
12	1999	0.77	0.29	0.23	-0.95	0.92	1.12	-0.90	0.39	0.36	0.20	0.65	1.61	4.69	0.391
13	2000	0.60	1.70	0.77	-0.03	1.58	-0.03	-1.03	-0.92	-0.21	0.92	-0.92	-0.58	1.85	0.154
14	2001	0.25	0.45	-1.26	0.00	-0.02	-0.20	-0.25	-0.07	-0.65	-0.24	0.63	-0.83	-2.19	-0.183
15	2002	0.44	1.10	0.69	1.18	-0.22	0.38	0.62	0.38	-0.70	-2.28	-0.18	-0.94	0.47	0.039
16	2003	0.16	0.62	0.32	-0.18	0.01	-0.07	0.13	-0.07	0.01	-1.26	0.86	0.64	1.17	0.098
17	2004	-0.29	-0.14	1.02	1.15	0.19	-0.89	1.13	-0.48	0.38	-1.10	0.73	1.21	2.91	0.243
18	2005	1.52	-0.06	-1.83	-0.30	-1.25	-0.05	-0.51	0.37	0.63	-0.98	-0.31	-0.44	-3.21	-0.268
19	2006	1.27	-0.51	-1.28	1.24	-1.14	0.84	0.90	-1.73	-1.62	-2.24	0.44	1.34	-2.49	-0.208
20	2007	0.22	-0.47	1.44	0.17	0.66	-1.31	-0.58	-0.14	0.72	0.45	0.58	0.34	2.08	0.173
21	2008	0.89	0.73	0.08	-1.07	-1.73	-1.39	-1.27	-1.16	1.02	-0.04	-0.32	-0.28	-4.54	-0.378
22	2009	-0.01	0.06	0.57	-0.20	1.68	-1.21	-2.15	-0.19	1.51	-1.03	-0.02	-1.93	-2.92	-0.243
23	2010	-1.11	-1.98	-0.88	-0.72	-1.49	-0.82	-0.42	-1.22	-0.79	-0.93	-1.62	-1.85	-13.83	-1.153
24	2011	-0.88	0.70	0.61	2.48	-0.06	-1.28	-1.51	-1.35	0.54	0.39	1.36	2.52	3.52	0.293
25	2012	1.17	0.42	1.27	0.47	-0.91	-2.53	-1.32	-0.98	-0.59	-2.06	-0.58	0.17	-5.47	-0.456
26	2013	0.35	-0.45	-1.61	0.69	0.57	0.52	0.67	0.97	0.24	-1.28	0.90	0.95	2.52	0.21
27	2014	0.29	1.34	0.80	0.31	-0.92	-0.97	0.18	-1.68	1.62	-1.27	0.68	1.86	2.24	0.187
28	2015	1.79	1.32	1.45	0.73	0.15	-0.07	-3.18	-0.76	-0.65	0.44	1.74	2.24	5.2	0.433
29	2016	0.12	1.58	0.73	0.38	-0.77	-0.43	-1.76	-1.65	0.61	0.41	-0.16	0.48	-0.46	-0.038
30	**2017**	0.48	1.00	0.74	1.73	-1.91	0.05	1.26	-1.10	-0.61	0.19	-0.00	0.88	2.71	0.226
	Total														

Source: Website of the National Climatic Data Center US

mean of 11.53 mm to highest in September with mean of 379.21 mm. Steady increase in rainfall was recorded in the months starting from January with mean of 14.18 mm, February with 34.01 mm, March with 88.03 mm, April 169.94 mm, May with 280.94 mm, June with 310.47 mm, July with 314.05 mm, August with 324.37mm and September (the highest) with 379.21 mm. Then, recession occurred in October with 265.68 mm and dropped significantly in November and December with mean of 56.11 mm and 11.53 mm, respectively. However, there was a decrease in mean monthly rainfall in the region following the downward rainfall trend line (see Figure 3).

Average Annual rainfall in Southeastern Nigeria (1988-2017)

Mean annual rainfall in the region showed a dramatic variability in the series. From the mean minimum (lowest) of 142.22 mm in the beginning of second decade, 1998 to the maximum (highest) of 235.13 mm in the middle of (last) third decade, 2012. Low mean annual rainfall in the series occurred in 2004 with 154.41 mm, 1993 with 159.49 mm, 2000 with 167.95 mm, 2010 with 168.18 mm, 2009 with 170.57 mm, 2001 with 171.92 mm, 2002 with 173.01 mm, 1994 with 175.34 mm, 1992 with 175.60 mm, 1988 with 177.38 mm, 1991 with 181.04 mm, 1989 with 181.16 mm, and 2005 and 2014 with 182.03mm and 185.99mm, respectively. High mean rainfall in the series as well occurred in 2006 with 224.50 mm, 2013 with 312.34 mm, 2003 with 208.47 mm, 2015 with 206.75 mm, 1996 with 206.55 mm, 1997 with 206.01, 1995 with 201.95 mm, 2008 with 196.83 mm, 1990 with 196.74 mm, 2011 with 193.97 mm, 2007 with 189.24 mm, 1999 with 186.73 mm and 2017 with 186.55 mm. However, the rainfall variability showed upward trend throughout the study period, which means there was generally increased rainfall in the region from 1988 to 2017 as shown in Figure 3.

Table 2. Values of the mean Rainfall (in mm) for the States in 30 years

S/N	Year	Abia	Ebonyi	Imo	Mean
1	1988	196.8	121.8	213.6	177.38
2	1989	191.4	137.0	215.1	181.16
3	1990	169.8	173.6	246.8	196.74
4	1991	165.7	163.4	214.0	181.04
5	1992	182.6	142.2	202.0	175.6
6	1993	165.1	131.5	181.9	159.49
7	1994	185.9	121.3	218.8	175.34
8	1995	206.7	180.7	218.5	201.95
9	1996	234.2	160.0	225.5	206.55
10	1997	188.5	188.5	241.0	206.01
11	1998	165.2	124.8	136.7	142.22
12	1999	224.9	125.7	209.6	186.73
13	2000	140.9	168.2	194.8	167.95
14	2001	184.0	139.8	192.0	171.92
15	2002	204.4	143.5	171.1	173.01
16	2003	186.8	240.1	198.5	208.47
17	2004	159.3	157.0	146.9	154.41
18	2005	171.0	188.7	186.4	182.03
19	2006	169.9	236.2	267.4	224.5
20	2007	201.7	169.2	196.8	189.24
21	2008	199.7	184.9	205.9	196.83
22	2009	169.2	168.1	174.4	170.57
23	2010	192.3	136.0	176.2	168.18
24	2011	181.5	199.3	201.1	193.97
25	2012	174.3	294.9	236.2	235.13
26	2013	181.4	294.0	164.6	213.34
27	2014	178.5	210.8	168.7	185.99
28	2015	173.5	235.2	211.6	206.75
29	2016	171.2	254.8	180.6	202.19
30	2017	151.3	236.6	171.7	186.55
TOTAL		**5467.7**	**5427.8**	**5968.4**	**5621.24**

Source of data: NIMET, 2018

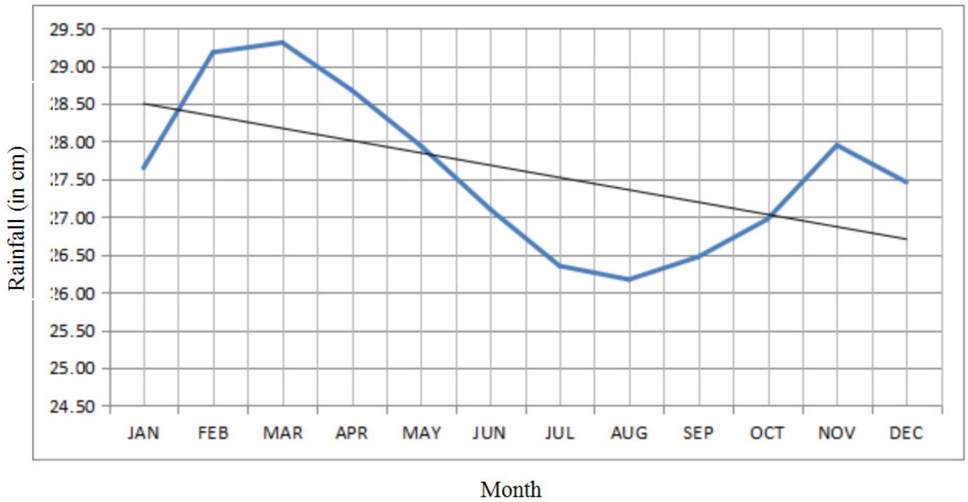

Figure 3. Mean monthly rainfall (in cm) for Southeastern Nigeria

Table 3. Values for Correlation of Rainfall with North Atlantic Oscillation Index

S/N	Year	NAO (X)	RF (Y)	NAO2 (X2)	RF2 (Y2)	NAO x RF (XY)
1	1988	0.013	177.38	0.000167	31463.66	2.30594
2	1989	0.702	181.16	0.4928	32818.95	127.17432
3	1990	0.594	196.74	0.3528	38706.63	116.86356
4	1991	0.268	181.04	0.0718	32775.48	48.51872
5	1992	0.581	175.6	0.3376	30835.36	102.0236
6	1993	0.179	159.49	0.0320	25437.06	28.54871
7	1994	0.586	175.34	0.3434	30744.12	102.74924
8	1995	-0.081	201.95	0.00656	40783.80	-16.35795
9	1996	-0.214	206.55	0.0458	42662.90	-44.2017
10	1997	-0.152	206.01	0.0231	42440.12	-31.31352
11	1998	-0.481	142.22	0.2314	20226.53	-68.40782
12	1999	0.391	186.73	0.1529	34868.09	73.01143
13	2000	0.154	167.95	0.0237	28207.20	25.8643
14	2001	-0.183	171.92	0.0335	29556.49	-31.46136
15	2002	0.039	173.01	0.0015	29932.46	6.74739
16	2003	0.098	208.47	0.0096	43459.74	20.43006
17	2004	0.243	154.41	0.0590	23842.45	37.52163
18	2005	-0.268	182.03	0.0718	33134.92	-48.78404
19	2006	-0.208	224.5	0.0433	50400.25	-46.696
20	2007	0.173	189.24	0.0230	35811.78	32.73852
21	2008	-0.378	196.83	0.1429	38742.05	-74.40174
22	2009	-0.243	170.57	0.0590	29094.12	-41.44851
23	2010	-1.153	168.18	1.3294	28284.51	-193.91154
24	2011	0.293	193.97	0.0858	37624.36	56.83321
25	2012	-0.456	235.13	0.2079	55286.12	-107.21928
26	2013	0.21	213.34	0.0441	45513.96	44.8014
27	2014	0.187	185.99	0.0350	34592.28	34.78013
28	2015	0.433	206.75	0.1875	42745.56	89.52275
29	2016	-0.038	202.19	0.0144	40880.80	-7.68322
30	2017	0.226	186.55	0.0511	34800.90	42.1603
TOTAL		**1.515**	**5621.24**	**4.512827**	**1065672.65**	**280.70853**

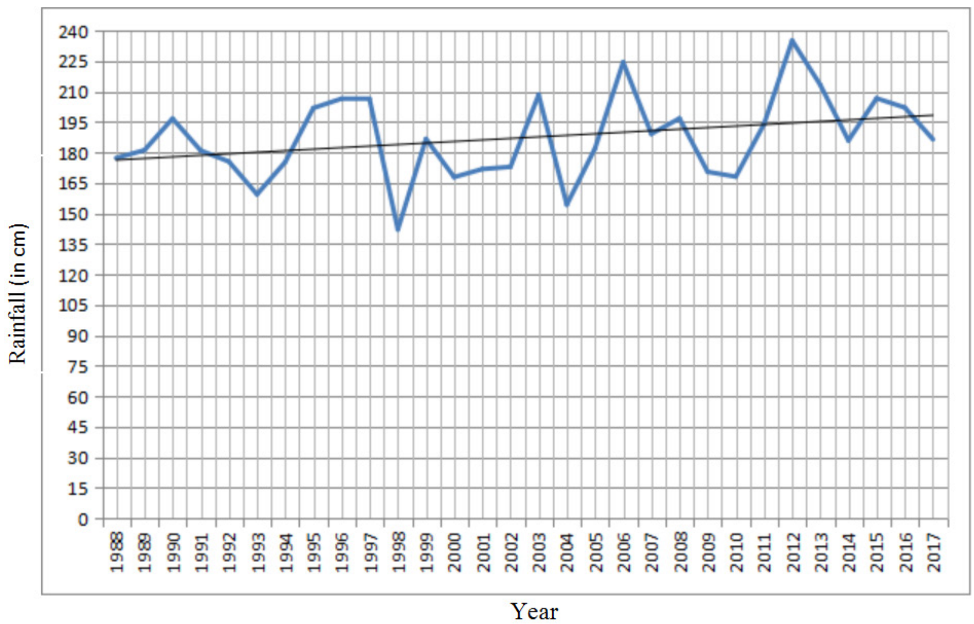

Figure 4. Mean Annual rainfall (in cm) for Southeast Nigeria

Relationship between NAO and Rainfall Variability

The correlation of Rainfall with NAOI is given as:

$$rNR\ (rxy) = \frac{n\sum NR - \sum N\sum R}{\sqrt{(n\sum N^2 - (\sum N)^2)(n\sum R^2 - (\sum R)^2)}} \text{ or } r = \frac{n\sum xy - \sum x\sum y}{\sqrt{(n\sum x - (\sum x)^2)\ x\ (n\sum y^2 - (\sum y)^2)}}$$

Where, n = 30 (number of years)

R = Rainfall values (mm) = Y = dependent variable

N = NAO index values = X = independent variable

i.e.

n =30,

$\sum x = 1.515$,

$\sum y = 5621.24$,

$\sum x^2 = 4.51$,

$\sum y^2 = 1065672.65$, and

$\sum xy = 280.71$

Therefore, r =

$$\frac{30x280.71 - 1.52\ x\ 5621.24}{\sqrt{(30\ x\ 4.51 - 1.52^2)\ x\ (30\ x\ 1065672.65 - 5621.24^2)}} = \frac{-122.99}{\sqrt{7032.13}}$$

r = -0.0175

The correlation value of 0.7525 is a negative one, showing that the two variables (x and y) deviate in the opposite direction i.e., the increase in the values of x (variable) results, on an average, in a corresponding decrease in the values of y (variable), and the decrease in the values of x (variable) results, on an average, in a corresponding increase in the values of y (variable).

Coefficient of Multiple Determinants (CMD)

CMD is given as $100r^2$ (i.e., 100 x -0.0175^2) = 0.031%

This shows that about 0.031% of the changes or variations in y (variable) can be attributed to the influences of x (variable).

Test for significance with Student's T-Test model

To test for the significance level of the influences of x on y, we employ the student's t-test model. This is given a;

$$tc = \frac{r\sqrt{n-2}}{1-r^2}$$

Where;

tc is the calculated table (t-value), n-2 is the degree of freedom (DF), r is the correlation value of x against y, and n is 30 years (duration under investigation).

$$\text{Therefore, } tc = \frac{0.0175\sqrt{30-2}}{1-0.0175^2} = 0.093$$

At DF of 28, the probability for a t-value of 0.093 lies below 0.5 (i.e., 50%) This reveals a very low significance level of the influences x on y.

Since the coefficient of multiple determinations (CMD) is 0.031%, it shows that about 0.031% of the variation in rainfall can be attributed to North Atlantic Oscillation Index, which means that the NAO index has no influence on rainfall variability in Southeast region of Nigeria.

5. Conclusions

This study indicates that southeast region of Nigeria has over time been experiencing high rainfall variability. The results generally, indicate that rainfall variability showed upward trend throughout the study period, which means increased rainfall in the region from 1988 to 2017. This study is in consonance with results of some studies such as [21], which stated that in Nigeria generally; there is high variability of rainfall characterized by pronounced variability from year to year and place to place. The work also reported that onset of effective rainy season seems to have been delayed in an unpredictable manner in recent years without delay in cessation. Other studies by [22,12,23] indicated that rainfall in Nigeria is showing some discrepancies and swings, and these studies report that the late onset of rains has been showing persistent downward annual rainfall trends. From the statistical analysis, the study shows that there is no relationship between global NAO index and Nigerian rainfall. In other words, NAO does not have any influence or control on the rainfall variability in southeastern Nigeria.

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