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The Influence of El -Niño Southern Oscillation (ENSO) Phenomenon on Rainfall Variation in Kaduna Metropolis, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author AUS designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SAY and BAS managed the analyses of the study. Author ABA managed the literature searches in the study. All authors read and approved the final manuscript.

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ABSTRACT

Aim and Objectives: The aim of this study is to investigate the influence of El -Niño Southern Oscillation (ENSO) on rainfall variation in Kaduna metropolis from the year 1973-2013.

Study Design: Precipitation data was sourced from NIMET (Kaduna airport) while Sea Surface Temperature Anomaly and Southern Oscillation Index data was acquired from the National Oceanographic Atmospheric Administration (NOAA) climate prediction centre's website.

Methodology: These were analyzed to determine the extent of variation between ENSO and Sea Surface Temperature Anomaly (SSTA) and pattern of change in precipitation during El -Niño and non El -Niño years. Furthermore, the significant difference between rainfall amount of El -Niño and non El -Niño years was also determined.

Results: Results indicated that rainfall within the study area was highly varied during the period

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studied and there is no direct influence of SOI and SSTA on the rainfall variation in Kaduna metropolis as years considered to be El -Niño years brought about both surplus and deficit rainfall over the years. It was also discovered that the years within both El -Niño and non El -Niño were found to be associated with positive and negative anomalies which signifies surplus and deficit rainfall amounts respectively. The student τ-test indicates that there is no significant difference in rainfall amount of the El -Niño and non El -Niño years within the study period.

Conclusion: From the findings of this study, both the SSTA and ENSO can be inferred to have positive and negative impacts because they caused an increase as well as decrease in rainfall during El -Niño and non El -Niño years within the study area. It was therefore concluded that although ENSO is seen to have impacted on rainfall variability, it does not have direct influence on the total variation within the study area. However, both El -Niño and non El -Niño years show fluctuations in rainfall amount within the study area even though there was no significant difference in rainfall amount between the El -Niño and non El -Niño years within the period of the study.

Keywords: Rainfall anomaly; sea surface temperature anomaly; Southern Oscillation index; non El –Niño.

1. INTRODUCTION

Extreme weather and climate events have attracted considerable attention in recent years because of the loss of several lives as well as properties caused by the extreme events (Easterling et al. [1]). Evidence is emerging that climate change is increasing rainfall variability and the frequency of extreme events such as drought, floods, and hurricanes (IPCC, [2]). Fluctuations of climatic elements particularly rainfall in northern Nigeria is not new especially in the north western ecological zone which comprises of the northern Guinea, and Sudan/Sahel savanna of West Africa.

Studies have indicated that the Sudano-Sahelian Ecological Zone of Nigeria is suffering decreased rainfall in the range of about 3-4% per decade since the beginning of the 19th century (FRN, [3]).

There is now scientific consensus that the global climate is changing (Kandji, Verchot and Mackensen, [4]). Observations show that as climate changes, changes are occurring in the amount, intensity, frequency and type of precipitation (IPCC, [2]). These aspects of precipitation generally exhibit large natural variability, and El -Niño and changes in atmospheric circulation patterns such as the North Atlantic Oscillation have a substantial influence in the environment.

El -Niño is an unusual increase in sea surface temperature in the equatorial eastern pacific which is as a result of the weakening of trade winds (Kiladis and Diaz [5]). It is a recurrent weather phenomenon that takes place approximately every two to seven years and usually lasts between 12 and 18 months (CPC, [6]). An El -Niño event is defined by a high Oceanic Nino Index (ONI), which is based on Sea Surface Temperature (SST) departures from average in the region in central equatorial Pacific. An El -Niño episode is associated with persistent warmer than average sea surface temperatures and consistent changes in wind and rainfall patterns (Ropelewski and Halpert; [7]; IRI, [8]). Despite their periodic and recurrent manifestations, El -Niño episodes do not have a deterministic trend with fixed occurrence periods and a constant intensity.

El -Niño Southern Oscillation (ENSO) refers to the effect of a band of sea surface temperatures which are anomalously warm or cold for a long period of time that develops off the western coast of South America and causes climatic changes across the tropics and sub tropics. It is a phenomenon that has been known to characterize seasonal rainfall over East Africa for a long time (Camberlin, Janicot, and Poccard, [9]). Its importance lies in its ability to predict rainfall reasonably well during the seasons of October to December.

Consequently, (Anyamba, Tucker and Eastman, [10]) were able to show the Normalised Difference Vegetation Index (NDVI) anomaly patterns over Africa during the 1997/1998 ENSO warming event. It was reported to be one of the most severe in the 20th century both in terms of SST departure patterns and the associated magnitude of the climatic anomalies worldwide. The event was said to have the strongest SSTA (>2.0℃) because it affected most parts of the world during that period. ENSO therefore, comprised of the largest source of inter-annual variability in the troposphere and it is being invoked as a significant cause of rainfall variability over space and time in West Africa (Chang, [11]). Ati, Iguisi and Mohammed [12] studied the effects of El -Niño Southern Oscillation (ENSO) on rainfall characteristics in Katsina, Nigeria and they compared between the warm ENSO years, La Nina years and normal years over a period of 31 years (1972 - 2002). They found out that warm ENSO years has annual rainfall amount lower than the long term mean, onset is late and the termination of the rainy season is earlier than the normal years. Rainfall duration is shorter during warm ENSO years than other years and August rainfall is lowest in warm ENSO years.

Accordingly, Nicholson and Selato, [13], have shown that there is linkage between ENSO and African Rainfall. It is in the light of this that this analysis is undertaken so as to determine the extent of variation between SSTA which is used to investigate the strength and amplitude of ENSO events and SOI even though there are other determinants of rainfall variability and also observe the trend between El -Niño years and non El -Niño years in terms of precipitation within the period of 40 years. The El -Niño years (strong and moderate) considered for this study include the years: 1973, 1982, 1983, 1986, 1987, 1988, 1991, 1992, 1997, 1998, 2002, 2003, 2009, 2010 while the non El -Niño years include: 1974, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1984, 1985, 1989, 1990, 1993, 1994, 1995, 1996, 1999, 2000, 2001, 2004, 2005, 2006, 2007, 2008, 2011, 2012, 2013 (http://ggweather.com/enso/oni.htm)

It has been observed that the climate in Nigeria experiences lot of changes during El -Niño events but detail studies on the Influence of ENSO phenomenon on rainfall variation have not been adequately undertaken and reported in the study area. Besides existing literature concentrating their works outside Nigeria, the datasets ended in the 1990s. This study differs from others because it is focused on the linkage between ENSO and rainfall variability in a single station as opposed the regional approach of the previous studies.

2. MATERIALS AND METHODS

The dataset used for this study comprised of monthly precipitation data provided by Nigeria Metrological Station (NIMET) from Kaduna airport, covering the period from 1973 to 2013, Sea surface temperature anomaly (SSTA) and the southern oscillation indices (SOI) covering the same period. The SSTA and SOI were secondary data obtained from National Oceanographic Atmospheric Administration (NOAA) Climate Prediction Centre's website (htpp://www.cpc.noaa.gov/data/indices). The study area where analysis is being covered is Kaduna Metropolis located between latitude 10°20' and 10°40'N and between longitude 7°10' and 7°35' E. It covers an area over 43, 460 km^2 (Laah, [14]), and is made up of four local governments which include Kaduna North, Kaduna South, part of Igabi and part of Chikun LGA’s (Fig. 1).

Coefficient of Variation (CV) was used to determine the extent of variability between ENSO and SSTA. This is because ENSO and SSTA are on different scales of measurements and CV is known to have the ability to eliminate units of measurements (Abdi, [15]). It expresses the standard deviation as a fraction of the mean and is useful when interest is in the size of variation relative to the size of the observation. In comparing different years of rainfall with different means (μ), the coefficient of variation is therefore a more useful basis of comparison than the standard deviation (σ).

It is expressed as:

$$CV = \frac{\sigma}{\mu} x\ 100\%$$

The monthly rainfall data were averaged and converted to annual values. The data was subjected to time series analysis to determine the pattern of change in the annual rainfall amount over a 40-year period. However, El -Niño years were sorted into strong and moderate El -Niño years. To visualize this, a graph of the trend was plotted based on the rainfall anomaly values of the El -Niño and non El -Niño years. This gave the pattern of change of the rainfall within the El -Niño and non El -Niño periods. A student т-test was further conducted using the Statistical Package for Social Scientist (SPSS version 20) to see if there is any significant difference in rainfall amount in El -Niño and non El -Niño years within the study period.

Anomaly is calculated using the formula:

$$RA = \frac{x-y}{SD}$$

where

RA= rainfall anomaly
x = total annual rainfall of the year
y = mean annual rainfall of the study period
SD = standard deviation

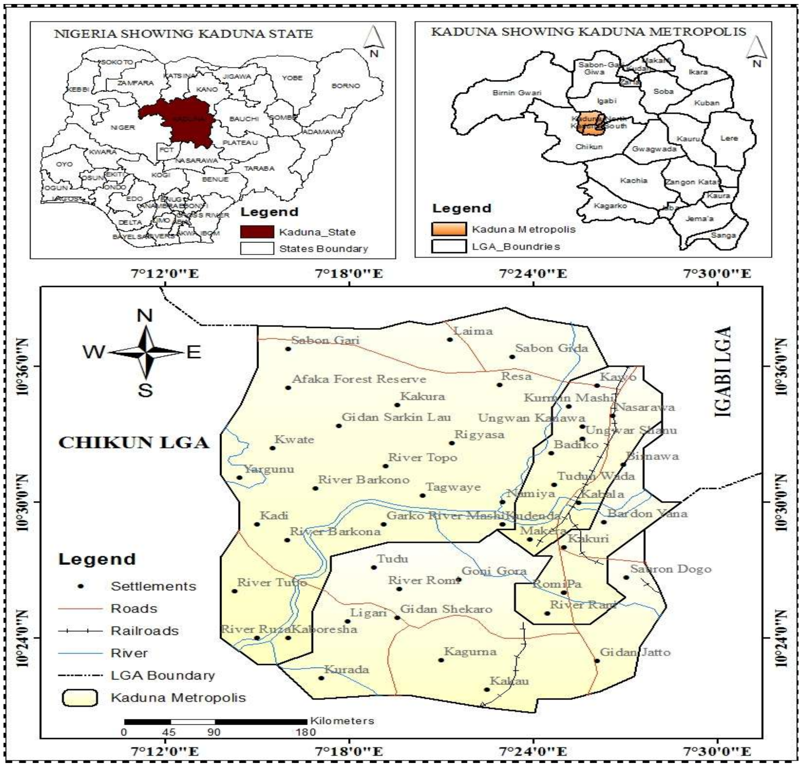

Fig. 1. Kaduna metropolis (Study Area)
Source: Ministry of Land and Physical Planning, Kaduna State, 2012

3. RESULTS AND DISCUSSION

3.1 Variation in Southern Oscillation Index (SOI)

Table 1 presents Extent of Variation in ENSO (SOI) and SSTA Data vs. rainfall variation for Kaduna metropolis and the computed coefficient of variation of SOI within the study period. The year 2005 has the highest CV (128.3%) followed by the year 1978 with a value of 126.53%, next to this is 120.9% in 1983. This is an indication that the years 2005 and 1978 were the most variable with respect to rainfall distribution. The lowest CV value of 38.4% was recorded in the year 1977 followed by a CV value of 39.1% in the year 1997. About 85% of the years indicated poorly distributed rainfall due to variation in SOI as suggested by Jagtap [16], who indicated that a CV of greater than 50% means rainfall is poorly distributed. The years 1977 and 2005 fall within the non El -Niño years with both having negative anomalies that suggest a deficit in rainfall amount during the periods. 1983 and 1997 were identified to be El -Niño years (strong) with 1983 having a negative anomaly while 1997 has a positive rainfall anomaly which indicates surplus of rainfall during the year. This shows that SOI do not clearly reveal the variations in rainfall distribution in Kaduna metropolis as both El -Niño and non El -Niño years shows variations in their rainfall distribution.

3.2 Variation in Sea Surface Temperature Anomaly (SSTA)

From Table 1, variation in SSTA within the study period shows that CV was highest in the year 1994 with a value of 104%. This indicates a very high variation in SSTA during the period of the study. The lowest CV value of 5.34% was noted in the year 1973. This means that there was stability in SST during the period. About 63% of the years indicated poorly distributed rainfall due to the effects of SSTA.

The year 1994 with a very high variation in SSTA was a non El -Niño year with a negative rainfall anomaly which means a deficit in rainfall. The year 1973 with lowest SSTA CV was an El -Niño year (strong) with a positive rainfall anomaly that suggests an increase in rainfall amount in the year. This result indicates that SSTA has no much influence in rainfall distribution in the region as it also shows variations within the El -Niño and non El -Niño years.

It was observed from the results that there is no direct influence of SOI and SSTA on the rainfall variation in Kaduna metropolis as years considered to be El -Niño years brought about both surplus and deficit rainfall over the years. This is in line with the findings of Bernard [17], who found a non-significant relationship between SOI/ENSO in rainfall variation in Makurdi, Nigeria. The distance of Kaduna from the coast is a major reason for the less influence between ENSO/SSTA and rainfall distribution as observed by Balas et al. [18]. In addition, Kaduna metropolis is too small in terms of Latitudinal and Longitudinal coverage for the effects of ENSO induced changes to be well felt.

Table 1. Extent of variation in ENSO and SSTA data vs. rainfall variation for Kaduna metropolis

Enso		Southern Oscillation Index (SOI)				Sea surface temperature anomaly (SSTA in ℃)				Rainfall (mm)	
Year	**Nature**	**SOI**	**Mean**	**SD**	**CV (%)**	**SSTA**	**Mean**	**SD**	**CV (%)**	**Amount**	**Anomaly**
1973	S	12.3	1.03	0.70	68.6	3.80	0.32	0.02	5.34	1221	0.090123
1974	N	13.4	1.12	0.79	70.7	3.69	0.31	0.02	5.50	1455	1.606305
1975	N	17.0	1.42	0.57	40.5	3.57	0.30	0.02	5.68	1307	0.798691
1976	N	10.0	0.83	0.53	64.2	3.46	0.29	0.02	5.87	1248	0.43692
1977	N	10.0	0.83	0.32	38.4	3.35	0.28	0.02	6.06	983	-2.04725
1978	N	7.20	0.60	0.76	126.5	3.23	0.27	0.02	6.28	1438	1.944954
1979	N	5.50	0.46	0.39	84.9	3.12	0.26	0.02	6.51	1481	1.936393
1980	N	3.00	0.25	0.22	87.8	3.01	0.25	0.02	6.75	1276	0.477454
1981	N	6.90	0.58	0.39	68.0	2.89	0.24	0.02	7.02	1231	0.177362
1982	S	14.9	1.24	0.80	64.3	12.35	1.03	0.88	85.1	1311.6	0.757245
1983	S	13.1	1.09	1.32	120.99	13.36	1.11	0.83	74.97	885	-3.47938
1984	N	3.50	0.29	0.21	72.3	8.08	0.67	0.40	59.7	1132	-0.7901
1985	N	6.20	0.52	0.42	82.1	8.43	0.70	0.28	40.0	1224	0.125503
1986	M	8.40	0.70	0.40	57.1	7.04	0.59	0.35	60.2	1096	-0.92357
1987	M	11.2	0.93	0.45	47.99	15.95	1.33	0.26	19.6	1201	-0.06572
1988	M	10.8	0.90	0.63	70.4	15.92	1.33	0.74	55.7	1188	-0.14661
1989	N	10.5	0.88	0.46	52.1	9.74	0.81	0.54	66.7	1003	-2.33559
1990	N	6.40	0.53	0.50	93.4	2.00	0.17	0.11	68.5	1037	-1.51682
1991	M	8.70	0.73	0.53	73.7	7.71	0.64	0.49	76.6	1359	0.998928
1992	M	11.5	0.96	0.80	83.2	9.61	0.80	0.71	88.9	1096	-0.94563
1993	N	8.20	0.68	0.35	50.6	4.46	0.37	0.29	77.7	1244	0.260828
1994	N	10.5	0.88	0.47	53.9	5.12	0.43	0.45	104.7	1067	-1.31626
1995	N	4.00	0.33	0.26	77.1	6.92	0.58	0.38	66.0	1151	-0.50203
1996	N	8.30	0.69	0.34	48.72	5.75	0.48	0.21	44.68	1218	0.073419
1997	S	13.2	1.10	0.43	39.2	17.28	1.44	0.98	68.2	1294	0.715352
1998	S	16.7	1.39	0.67	48.0	16.77	1.40	0.55	39.2	1110	-0.94447
1999	N	10.4	0.87	0.55	64.0	14.18	1.18	0.30	25.2	1286	0.580017
2000	N	11.0	0.92	0.53	57.5	10.67	0.89	0.45	50.8	1234	0.204403
2001	N	6.90	0.58	0.48	82.6	3.38	0.28	0.24	85.4	1185.8	-0.18979
2002	M	6.90	0.58	0.35	61.2	8.98	0.75	0.57	76.5	1317	0.890237
2003	M	4.10	0.34	0.31	92.1	4.93	0.41	0.33	80.6	1642	2.530806
2004	N	8.30	0.69	0.38	54.6	4.84	0.40	0.29	72.2	1380	1.168252
2005	N	7.80	0.65	0.83	128.30	3.59	0.30	0.18	61.8	1012	-2.01732
2006	N	9.30	0.78	0.60	77.3	6.87	0.57	0.38	66.5	898	-3.62539
2007	N	6.00	0.50	0.47	94.2	7.86	0.66	0.61	93.7	841	-4.3498
2008	N	13.7	1.14	0.68	59.3	8.88	0.74	0.63	85.3	752	-5.77162
2009	M	7.60	0.63	0.55	86.3	9.56	0.80	0.46	57.8	1186	-0.1696
2010	M	17.5	1.46	0.68	46.9	14.19	1.18	0.49	41.2	1220	0.092502
2011	N	16.8	1.40	0.92	65.96	9.96	0.83	0.42	50.61	1151	-0.54618
2012	N	4.60	0.38	0.31	80.9	5.63	0.47	0.28	60.7	1448	1.781887
2013	N	6.20	0.52	0.48	92.2	2.65	0.22	0.14	62.3	1753	3.476214

N : Normal year ; M : Moderate ENSO; S : Severe ENSO
Source: Authors computation, 2016

The result of the study suggests that rainfall variability in the study area may be related to other activities. The frequency, intensity and the contribution to total rainfall and storms in Nigeria increases inland from the coast as has been previously documented by Omotosho, [19] and Adelakan, [20].

From Fig. 2, the graph shows that rainfall anomaly index was highest in 1982 with a positive value of 0.76 while the least rainfall anomaly index of -3.48 was recorded in 1983. This indicates that there exist positive and negative anomalies across the strong El -Niño years under study. By implication therefore, the year 1982 recorded the maximum rainfall of 1311.6mm while a minimum amount of rainfall within the strong El -Niño years of 885mm was recorded in 1983 (Table 1).

Fig. 3 shows that there are more years of negative than the positive rainfall anomaly. For example, the years of surplus rainfall (positive anomaly) within the moderate El -Niño years fell in 1991, 2002, 2003 and 2010 are years with positive rainfall anomalies which indicate years of surplus rainfall within the moderate El -Niño years. It was reported that the flood as a result of the surplus rainfall in 2003 affected cultivable lands and human dwellings which rendered so many homeless (David and Aggarwal, [21]). On the other hand, the years with deficit amount of rainfall (indicative of negative anomaly) fell in 1986, 1987, 1988, 1992 and 2009.

Fig. 4 represents the non El -Niño rainfall anomaly graph. The year 2013 was observed to be the year with the highest positive anomaly while the least positive anomaly was recorded in 1996. Highest negative anomaly in rainfall recorded in 2008 while the least negative anomaly was recorded in the year 2001.

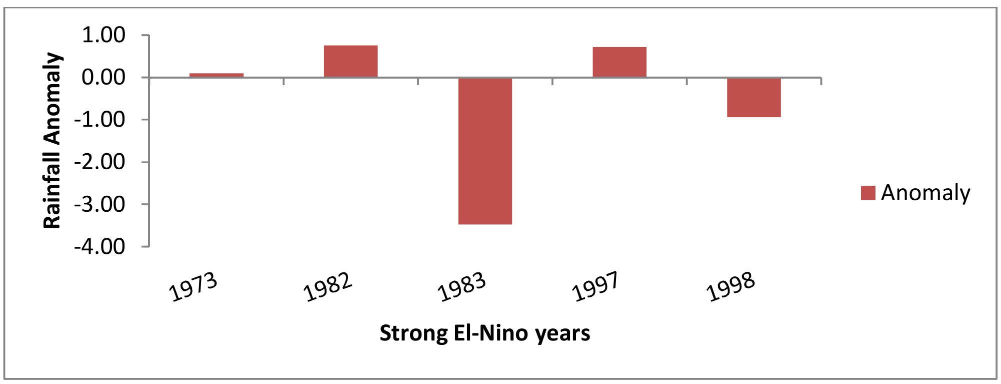

Fig. 2. Rainfall anomaly trend for strong El -Niño years

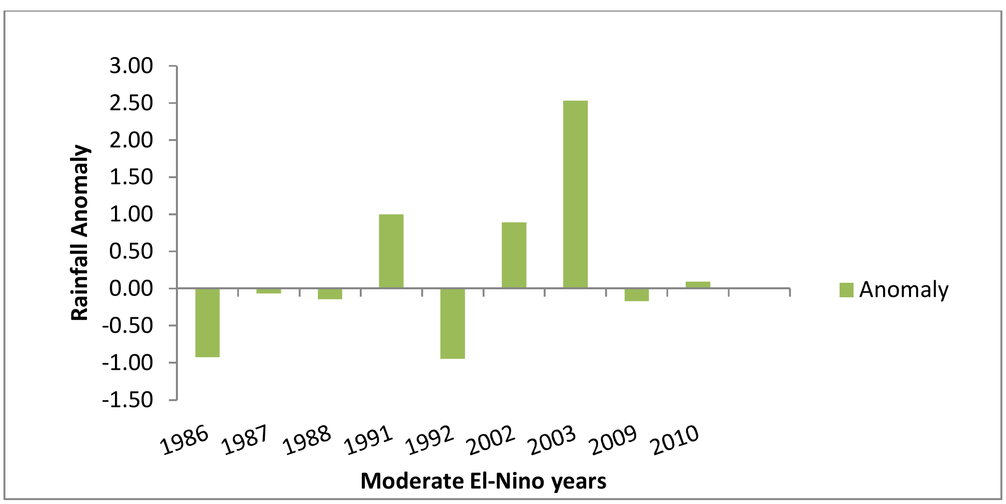

Fig. 3. Rainfall anomaly trend for moderate El -Niño years

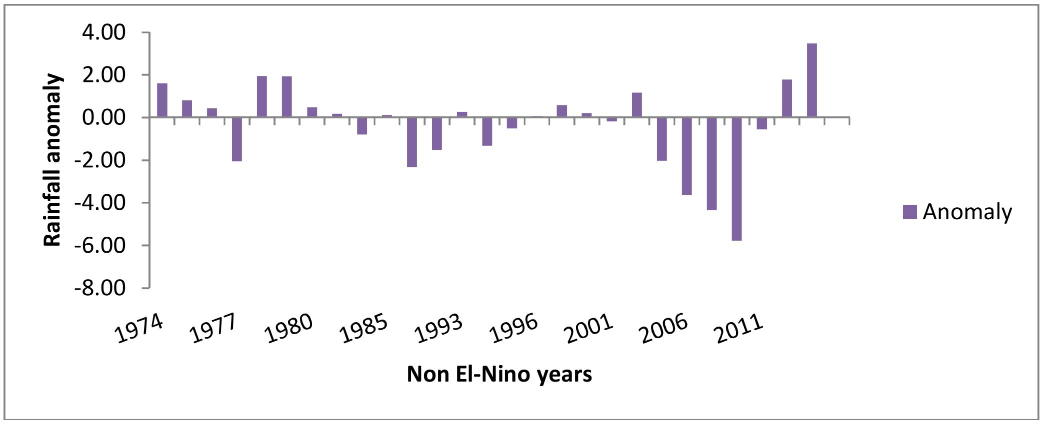

Fig. 4. Rainfall anomaly trend for non El -Niño years

Table 2. Paired sample t-test between rainfall amount for El -Niño and Non El -Niño years

	Paired samples test							
El -Niño years to Non El -Niño years	**Paired differences**					**t**	**df**	**Sig.(2-tailed)**
	Mean	**Std. deviation**	**Std. error mean**	**95% confidence interval of the difference**				
				Lower	**Upper**			
	-5.885	255.908	68.394	-153.643	141.871	-.086	13	.933

Source: SPSS Computation, 2016

3.3 Test for Significant Difference

Table 2 present the paired sample t-test result of El -Niño and non El -Niño years in terms of their precipitation.

Table 2 reveals the paired sample t-test result for rainfall of El -Niño and non El -Niño years. From this result it can be concluded that there is no significant difference in rainfall amount of the El -Niño and non El -Niño years in terms of their means at 95% level of significance. This is in line with the findings of Tarras-Wahlberg, Caudwell and Lane, [22] who examined the effect of El -Niño events on rainfall patterns and river flows for south-western Ecuador and northern Peru. They confirmed that high rainfall and extreme floods occur also in non El -Niño years and years following El -Niño events are found to be wetter than normal. This therefore suggests that El -Niño events are not always the cause of extreme floods and rainfall but that other climatic factors may at times have equal or greater importance.

4. CONCLUSION

Result was based on simple statistical analysis. It can therefore be concluded that although ENSO is seen to have impacted on rainfall variability, it does not show direct influence on the total variation within the study area. However, both El -Niño and non El -Niño years show fluctuations in rainfall amount within the study area even though there was no significant difference in rainfall amount between the El -Niño and non El -Niño years within the period of the study. This is a clear indication that El -Niño event is not the only factor causing rainfall variability in the study area. Several factors are therefore likely to cause such rainfall variability in the study area such as distance from the coast, trade wind force, storm frequencies amongst other although further research is required to ascertain this.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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