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Assessment of the Teleconnection Between El Nino Southern Oscillation (ENSO) and West African Rainfall

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Abstract

In this study, rainfall variability over Nigeria was analysed in relation to ocean-atmospheric interaction due to ENSO event. Monthly rainfall data were collected from Nigerian Meteorological Agency (NIMET) from six (6) synoptic stations selected across three (3) geographical regions in Nigeria for a period of 26 years (1988 - 2013). Cluster analysis grouped the rainfall data into three clusters namely Coastal South, Middle belt and Sahel North, while Southern Oscillation Index (SOI) data from 1988 to 2013 was retrieved from National Ocean Atmospheric Administration (NOAA) as updated by the National Centre for Environmental Prediction (NCEP). Rainfall Analysis Index (RAI) was computed for each of the three sub-regions and respective anomalies revealed in a time series. Additionally, linear correlation analysis between the RAI and SOI were computed at lag three months to determine any relationship between ENSO and Nigerian rainfall. The result shows that correlation between RAI and SOI were not uniformly significant, with Region 1 having a positive correlation and a negative correlation recorded for regions 2 and 3. Likewise, simple matrix confirm for region 1 the positive rainfall anomalies occurring during warm ENSO

phase. How forecast will be improved if ENSO indices are included as precursor variables in rainfall forecast for the region will be of interest.

Key Words: El Nino Southern Oscillation, Nigerian rainfall, Southern Oscillation Index (SOI)

Introduction

In the sub-Saharan region of Africa, which includes South-eastern Nigeria, Climate variability has manifested essentially as rainfall variability, meaning that the two types of variability observed for the region, namely decadal and inter-annual (Nicholson 1981) interact and interrelate. But for the most part, very high-level variability manifest on the inter-annual scale so much so that efforts at forecasting rainfall in the region is almost always hindered by high fluctuation. This is in addition to external factors that have teleconnected effects on rainfall formation in the region. As such, additional climate forces that control rainfall in the region have to be identified and included in any new forecast model. Efforts in this direction were made by Nnaji (2001), Gray et al. (1997) and, Landsea et al (1994). While these efforts moderately improved forecast, the challenge is how to further improve forecast window in the face of teleconnected events. One such event is the El Nino Southern Oscillation (ENSO) which is known to have influence on global weather conditions possibly including Nigeria.

El Nino southern Oscillation is a global event arising from large scale interactions between the ocean and the atmosphere. It is also said to be the see-saw atmospheric pressure between the eastern equatorial pacific and Indo Australian area (Glantz et al 1991). Ayodele (2004) referred to the ENSO as the see-saw relationship between pressure over the Indian Ocean in the west and that over the Southeast Pacific in the east such that when pressure rises in one of the two areas, it falls in the other. An above average rise in pacific sea surface temperature is known as El Nino and a below average value is known as La Nina. Teleconnection links the tropical Pacific with high latitude and mid latitude synoptic weather patterns. (Berlage and De Boer 1999). Knowledge of climate variability linked with global atmospheric forcing has become important to understanding the unprecedented complex nature of the climate system and their impact on the environment (Oguntunde et al., 2012). Nigeria is in no way far from the concerns of extreme irregular climate variations. This research therefore investigates the contributions of ENSO to rainfall variation across Nigeria. Nigeria, is a country with irregular annual and inter-annual pattern of rainfall, varying across its regions (fig 1).A typical climate in the southern region characterised by annual rainfall amount of about 1,200mm with an onset and retreat period in Mid-March and Mid-October respectively, have fallen short of the average value in the last three decades (Obodo 2008). Likewise, the northern region, shifting from its normal predictable pattern of short rainfall period between June and September with annual rainfall amount of between 500mm and 750mm as documented in the 2010 NIMET annual bulletin, has continued to witness high annual rainfall variability.

With unexpected flooding in the south and drought in the North, off season rains and dry spells has sent growing season out of range in a country much dependent on rain fed agriculture. The problem of extreme irregular climate variation in Nigeria is critical and should be proactively prepared for since no one can technically control climate. In a bid to protect livelihood against climate uncertainty, meteorological forecast has become paramount. To forecast rainfall effectively, an understanding of climate controls of rainfall is necessary. In Nigeria, rainfall variation is associated with the movement of the Inter-Tropical Convergent Zone (ITCZ) which in turn is an influence of two continental trade winds from of the Atlantic Ocean and the Sahara Desert, it is also sensible to mention that an oscillation in SST could be a factor to rainfall variations in Nigeria since SST controls the SLP which forces the trade wind system. (Obodo, 2008). It is therefore paramount to investigate the climate drivers of these abrupt changes in relation to other external forcing possibly driving these unprecedented variations. These could serve as key indicators to the impact of weather changes and improve weather forecasting for the region. ENSO has been shown to relate strongly to variations in climatic elements like rainfall across the tropical belt (Berlage and De Boer, 1999). Reports by Owen and Ward (1989) and Adebayo (1999) confirmed the relationship between extra-tropical SST (e.g. SSTs over the North Pacific and South Pacific) and weather fluctuations in East Africa. According to Owen and Ward (1989), when the El Nino pattern is strongly positive (i.e. positive SST pattern in the eastern tropical Pacific) there is a tendency for the Sahel to be dry, but wet when the pattern is strongly negative. Obodo, (2008) also hinted on a significant correlation between tropical east Pacific SST and weather events in Nigeria. This study aims at further investigating this relationship by determining the statistical correlation between ENSO and rainfall and obtaining timeline trends between rainfall amount in Nigeria and past records of ENSO events.

Ojo (2002) opined that weather variations in West Africa are predetermined by global atmospheric and oceanic interactions, thereby aligning with Maynard, *et al*. (2002), who noted that there is a link between African climate variations and major global modes of variability. This view is a hint that ENSO may be a candidate of influence on the subject.

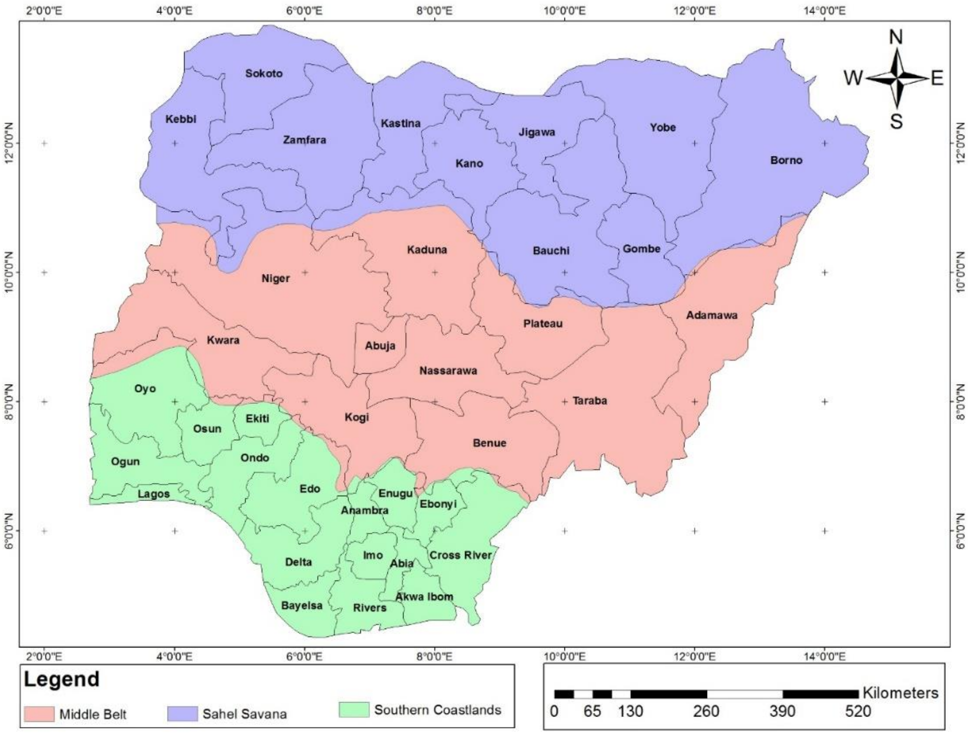

Fig 1: Climatic distribution pattern across Nigeria.

The characteristics of the Southern Oscillation in the tropics and subtropics of the southern Hemisphere have been presented by many researchers, for example, Walker and Bliss (1982), Berlage and De Boer (1959), Kidson (1975), etc. In fact, Nicholson and Palao (1993) hinted that precipitation variability in sub Saharan Africa may be related to the sea surface temperatures, and large-scale circulation features. However, it was Maynard et al. (2002) who noted that monsoon circulations influence the climate of tropical Africa over adjacent oceans and that, on the global scale, there is clear evidence of an interaction between East African climate drivers and major global modes of variability. For these regions, these global modes drive a large part of the inter-annual fluctuations in rainfall and possibly the tropical Atlantic Sea Surface Temperatures (SST) could have an impact and influence on the West Africa monsoon in the Gulf of Guinea. The tropical Atlantic itself appears to contain some lagged influence of the global ENSO signature. Thus, aligning with Janicot *et al*. (1997) that the positive/negative phases of this coupling could enhance the impact of ENSO warm (cold) events on West African monsoon dynamics.

Recently, there has been an increased scientific interest in linking the numerical measures of hydrologic variability to larger scale climate variation, such as the EL Nino Southern Oscillation phenomena, to demonstrate the impact of climatic condition on regional precipitation and stream-flow (Waylen and Caviedes 1986, 1990; Cayan and Webb 1992; Eltahir 1996). The practical importance of such endeavor is reflected in a variety of water resource-related issues, including hydraulic design, flood plan, land use decisions and evaluation of water supply (O'Brien & Motts 1980; Tobin 1986).

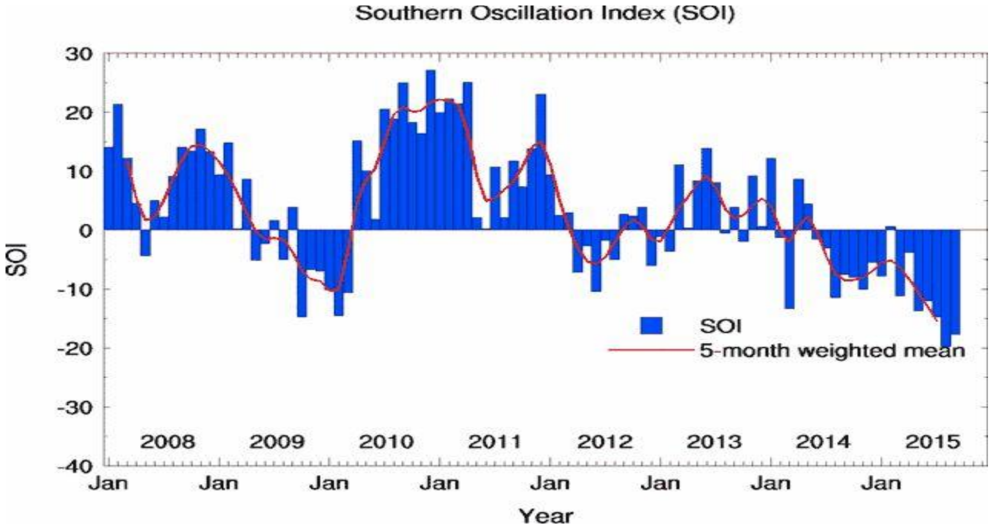

Fig 2: Graphical representation of SOI (2008-2015)

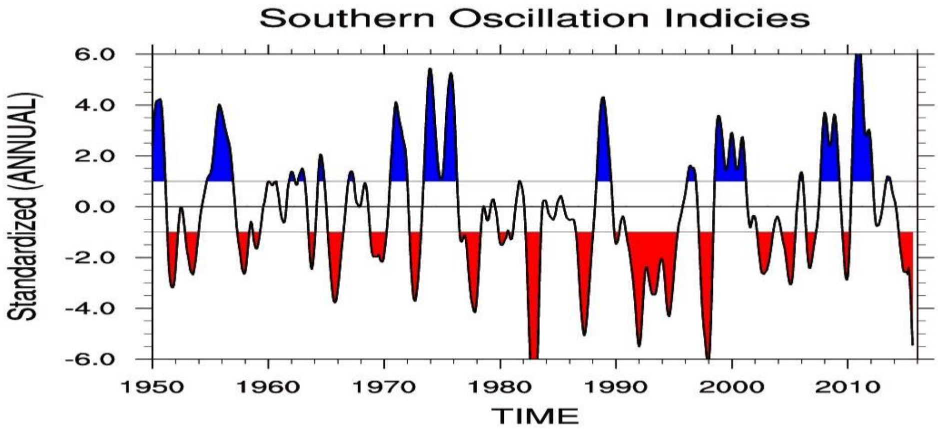

Fig 3: Standardised graphical representation of SOI showing El Nino/ La Nina Phase

In general, smoothed time series of the SOI correspond very well with changes in ocean temperatures across the eastern tropical Pacific (Fig 2). The negative phase of the SOI represents below-normal air pressure at Tahiti and above-normal air pressure at Darwin. Prolonged periods of negative (positive) SOI values (Fig 3) coincide with abnormally warm (cold) ocean waters across the eastern tropical Pacific typical of El Niño (La Niña) episodes.

Methodology

The data sets used in this work consist of the ENSO data represented by Southern Oscillation Index (SOI) covers a period of twenty-six years (1988-2013) and is based on quarterly record of occurrence of El Nino Southern Oscillation indicating their intensity (weak moderate and strong). Data records for rainfall precipitation was provided by the Nigerian Meteorological Agency (NIMET) covering a period of 26 historic climatological years, from 1988 to 2013. Rainfall data values was collected from six (6) meteorological stations across 3 geographical regions in Nigeria and clustered as two (2) stations from each region. These regions are namely Southern-Coastal belt (R1), the Middle belt (R2) and the Northern region (R3) of Nigeria. (see Table 1 below).

All meteorological stations were chosen taking into consideration the annual / seasonal variability of rainfall in their respective regions. Stations used in this study and their coordinates are given in Table below with positions and zones.

Table 1: Nigerian Synoptic Stations and their locations

Region	Stations	Longitude (degree)	Latitude (degree)	Elevation
Region 1	Lagos	3.3E	6.5N	38.0
	Port-Harcourt	7.0E	4.9N	18.0
Region 2	Kano	7.6E	6.5N	137.0
	Abuja	7.4E	6.8N	152.0
Region 3	Kaduna	.4E	10.5N	642.0
	Sokoto	5.3E	13.0N	287.0

Data Analysis and Result

To determine the relationship between El Nino Southern Oscillation on rainfall across Regions in Nigeria, time series analysis and statistical correlation analysis between standardised values of Southern Oscillation Index (SOI) data and Rainfall data was carried out.

Time Series Analysis

Graphical Time series analysis was carried out using a standardised calculated rainfall data computed as Rainfall Anomaly Index (RAI). This was computed for the 26 years study period over the three regional zones.

For region 1, the peak of the rainy season occurs during the months of May, June and July. Region 2 shows maximum rainfall during the same months. However, in region 3, the peak rainy season is during the months of July, August and September.

For the 26 years, under study, rainfall anomalies were computed for each region in the following way:

I. The yearly averages for every station in the region were calculated from the seasonal peak rainfall of 3 months for each region.
II. The regional averages of peak rainfall for each year from 1983 to 2013 were calculated by averaging the seasonal peaks from the two chosen stations in each region
III. A 26-year climatological mean was calculated for each region by averaging the 26 values for the three regions. All the stations were used.

IV. Finally, the rainfall anomaly indices (RAI) were calculated by standardizing the yearly mean precipitation value for each region from its respective climatological mean.

These anomalies are represented in a time series anomaly graph for each the three regions (Figs 4, 5 and 6)

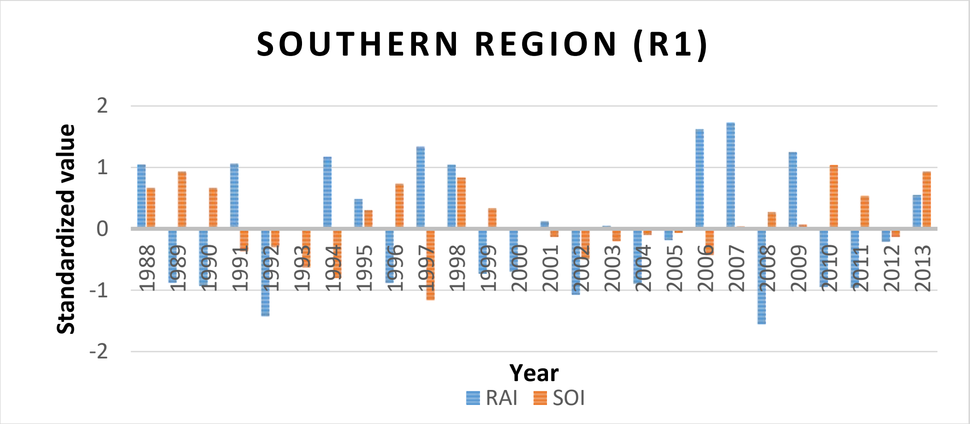

Fig 4: Time series of Precipitation Anomaly in Region 1

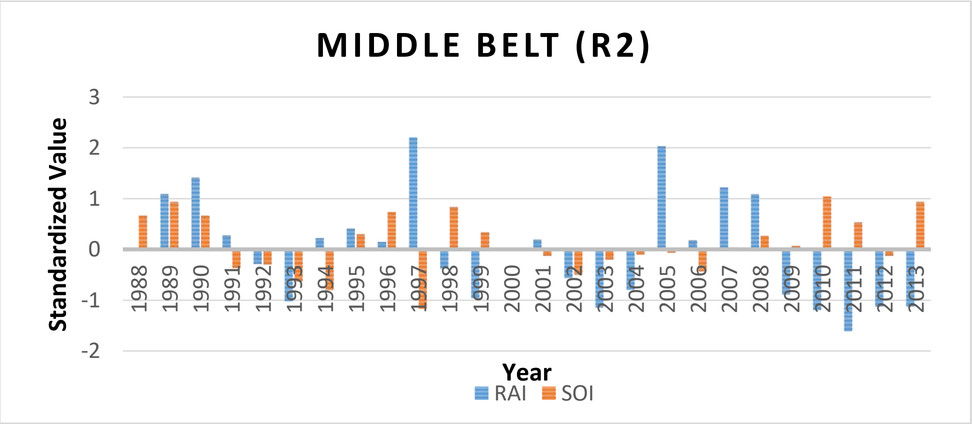

Fig 5: Time series of Precipitation Anomaly in Region 2

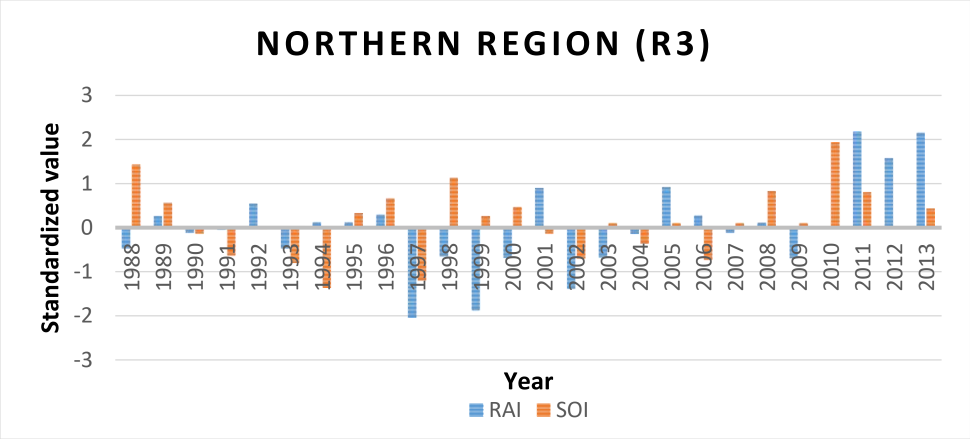

Fig 6: Time series of Precipitation Anomaly in Region 3

Correlation Analysis and Data Preparation

In region 1, correlation analysis was carried out starting with the month of May Similarly in region 2 it was also performed starting with the month of May, while, in region 3, it was carried out from the month of June. This choice of lag correlation analysis was employed for plausible lead–lag relationships between the two variables (Maynard 2002). The result is shown on Table 2.

Table 2: Result of Correlation analysis

Regions	Months	Correlation Coefficient (r)	% mean coefficient
R1	May June July	-0.160 0.005 -0.150	10
R2	May June July	-0.133 0.087 0.027	8
R3	July August September	0.014 -0.172 0.000	6

In Region One (R1), the month of May over the 26-year study period shows a slight negative correlation relationship, June showed an almost no correlation relationship. While July shows a rather less negative correlation relationship. R1 totally showed a 10 percent significant level of confidence.

In region two (R2), the month of May over the 26-year study period shows a more negative correlation relationship, June showed an almost no correlation relationship.

While July shows a slight positive correlation relationship. R2 totally showed an 8 percent significant level of confidence.

In region three (R3), where peak rainfall season begins from the month of July over the 26-year study period shows the slightest positive correlation relationship, August showed a negative correlation relationship and September shows a no correlation relationship. R3 totally showed a 6 percent significant level of confidence. Tables 3 to 5 show the result of simple matrix computed for the regions

Table 3. Simple matrix showing annual +ve and –ve rainfall anomaly in R1

	1988	1989	1990	1991	1992	1993	1994	1995	1996
El Nino					+	-	+		
Normal				+				+	
La Nina	+	-	-						-

	1997	1998	1999	2000	2001	2002	2003	2004	2005
El Nino	+					-			
Normal			-	-	+		+	-	-
La Nina		+							

	2006	2007	2008	2009	2010	2011	2012	2013
El Nino	+							
Normal		+	-	+			+	
La Nina					-	-		+

Table 4: Simple matrix showing annual +ve and –ve rainfall anomaly in R2

	1988	1989	1990	1991	1992	1993	1994	1995	1996
El Nino						-	+		
Normal	-				-			+	
La Nina		+	+	+					+

	1997	1998	1999	2000	2001	2002	2003	2004	2005
El Nino	+					-			
Normal			-		+		-	-	+
La Nina		-							

	2006	2007	2008	2009	2010	2011	2012	2013
El Nino	+							
Normal		+	+	-			-	
La Nina					-	-		-

Table 5. Simple matrix showing annual +ve and –ve rainfall anomaly in R3

	1988	1989	1990	1991	1992	1993	1994	1995	1996
El Nino				-		-	+		
Normal			-		+			+	
La Nina	-	+							+

	1997	1998	1999	2000	2001	2002	2003	2004	2005
El Nino	-								
Normal			-	-	+	-	-	-	+
La Nina		-							

	2006	2007	2008	2009	2010	2011	2012	2013
El Nino	+							
Normal		-		-			+	+
La Nina			+			+		

The graphs above clearly show that there are positive as well as negative anomalies in all the regions 1, 2 and 3. Although region 1 shows a more positive anomaly than region 2, this may be attributed to less rainfall in region 2 and more rainfall in region 1. While region 3 reveals very different pattern, with a negative anomaly persisting for most years and highlighting the low rainfall in this region compared with the other two regions under study.

Observing the time series anomaly plot, one might be tempted to assume some association between ENSO and rainfall in Nigeria. This is because the positive anomalies occurred particularly near and around most of the strong ENSO years, for example, 1991, 1993, 1997, 2002, 2005, and 2012, these are more pronounced in regions 1 and 2.

Conclusion and Recommendations

Rainfall anomalies in Region 1, show a pattern of strong positive correlation with SST anomalies in the tropical pacific. This suggests abundant rainfall in this region from May to July when the surface waters become warm. In region 2, rainfall anomalies are negatively correlated with SST anomalies in the tropical East- pacific, suggesting that warm surface water in this part of the pacific moves the ITCZ southward and away from region 2 such that less rainfall is observed. The field of correlations in region 2 differs substantially from that of region 1, and no physical mechanism has been provided for the explanation.

In northern Nigeria (region 3), the field of correlations shows negative values over the eastern tropical Pacific. The lower correlation is due to the continentality of region 3, which is away from the influence of the sea surface conditions in the Gulf of Guinea and tropical Atlantic. Though the graphical relationship between RAI and SOI investigated do not correlate spatially or temporally in any consistent manner, the study does show some slight indications that rainfall variation in Nigeria is associated with ENSO related circulation, as suggested by positive correlation coefficients between rainfall values of the region and the Southern Oscillation Indices (SOI),

The trend in the occurrence of El Nino Southern Oscillation originate at both the Indian and the Pacific Ocean respectively affect regional climate of Nigeria. This confirms that the occurrence of this global phenomenon does affect weather condition globally and indeed parts of Nigeria. For instance, the effect of those global phenomenon within the last twenty-six years correspond with high variability of rainfall, flooding, drought, intensified Haematin Haze in Nigeria (see Table 6).

Table 6: Significant Historical Weather Events in Nigeria Linked with Enso Extremes

Year	ENSO Phase	Recorded Disaster
1982 – 1988	Strong ENSO years	Drought in Northern Nigeria (Borno, Katsina, Kano)
1990 – 1993	EL Nino year with slight occurrence of La Nino phase	Intense Harmattan Haze in Northern Nigeria
1996	El Nino Phase	One-week heavy rainfall at Ilorin leading to flooding
1998	Strong Enso year	Ogunpa flooding
2001 – 2003	Strong Enso phase with slight la Nina years	Intense Harmattan Haze
2005	Slight Nino occurrence	Coastal Flooding
2012	El Nino year	Coastal Flooding
2013	Normal	No Significantly recorded weather event
2014	Normal	No Significantly recorded weather event
2015	Strong El Nino Year	Intensive dust haze in southern Nigeria

(Obodo, 2008) updated by the authors of this paper

These disasters are amongst many other environmental hazards ("Odukpani" flooding disaster, "Nanka" erosion, "Amucha" gully erosion) that occurred in Nigeria during the period under study. Conclusively, ENSO events are linked to rainfall variability in Nigeria.

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