POSSIBLE TELECONNECTION BETWEEN THE INDIAN OCEAN DIPOLE (IOD) AND RAINFALL DISTRIBUTION OVER NIGERIA

The El Nino Southern Oscillation (ENSO) has some level of control over the weather of Nigeria and Africa seasonally but there has been enough debate as to the extent of the control. ENSO magnitudes do not necessarily translate into impacts in the same direction hence, attempt to investigate possible teleconnections with the Indian Ocean Dipole Mode Index (IODMI) phases over equatorial Indian Ocean that could explain the subsisting gaps in the knowledge of large scale controls on Nigerian Monsoon Seasonal Rainfall (NMSR) pattern is the basis of this paper. Daily rainfall data was obtained from Nigerian Meteorological Agency (NiMet) and Sea Surface Temperatures (SSTs) over the Indian Ocean and the Pacific Ocean were obtained from National Oceanic and Atmospheric Administration (NOAA) site for a period of 1983-2015. Pearson correlation coefficient method was used to assess the spatial and temporal relationship between the IODMI/NMSR and ENSO/NMSR while the test-of-significance of the correlation results were carried out using two methods- Critical r value and p-value. The results revealed that there is a significant correlation at alpha value 0.1 between the IODMI and NMSR over the selected stations with contrasting tendencies to increase rainfall at a certain period of the year or decrease it at another period. However, the comparison of the influence of IODMI and ENSO indices negates their effects on NMSR which is dependent on the strength of correlation, thus with both having a decreasing north to south spatial pattern. Hence, the study concluded that there is a teleconnection between the NMSR and IODMI over the stations considered in the study and it is recommended that the incorporation of IODMI for the climate prediction of the monsoon rainfall over Nigeria would improve the resilience of different specific sectors of the economy especially agriculture.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of Study

Despite the availability of oil revenues that form the backbone of the economy and foreign exchange earnings in Nigeria, agriculture still remains major source of livelihood in terms of food and employment for local communities. Therefore, no sustainable development can be Gachieved today and in the future without effectively addressing challenges associated with the threats of present and future rainfall variability and change. These include increased frequency and intensity of drought, floods, delayed onset, early cessation, and irregular distribution, leading to widespread impacts on infrastructure, agriculture, land degradation and soil erosion, livestock (including fisheries), loss of property, human health and life (Ukhurebor and Abiodun, 2018).

Rainfall variability and change impacts are already being felt in many parts of the world especially Africa, and are likely to worsen in the future, with clear evidences of changes in climate and weather patterns in many parts of the world based on Assessment Reports produced by the Working Groups of the Inter-Governmental Panel on Climate Change (IPCC, 2001b; 2012; 2013a).

However, the rainfall over the western region of Africa is directly affected by circulation over the Atlantic and indirectly by that over the Indian Ocean. (Preethi, 2015). Among the tropical indo-pacific climate drivers, the canonical El Niño/Southern Oscillation (ENSO), (Ramussen and Carpenter, 1983), is thought to play a dominant role in rainfall distribution over various parts of Africa during all the seasons (Janowiak, 1988; Janicot *et al.,* 1998).

ENSO has been recognized as an important manifestation of the tropical ocean-atmosphere-land coupled system. The more recently discovered Indian Ocean Dipole (IOD). (Saji *et al.,* 1999; Behera *et al.,* 1999; Webster *et al.,* 1999; Guanghan *et al.,* 2016) is another important manifestation of the tropical air-sea interaction.

IOD also known as the Indian Nino, is an irregular oscillation of Sea Surface Temperature (SST) in which the western Indian Ocean becomes alternately warmer and cooler than the eastern part of the ocean. This leads to a coupled ocean-atmosphere phenomenon in which convection, winds, SST and thermocline take part actively (Vinayachandran, *et al.,* 2007).

The IOD measured using a Dipole Mode Index (DMI) is calculated from the difference in SST anomaly between the tropical western Indian Ocean and the tropical south eastern Indian Ocean, (Saji *et al.,* 1999). It usually starts around May or June, peaks between August and October and then rapidly decays when the monsoon arrives in the southern hemisphere around the end of the spring. It involves an aperiodic oscillation of SST between "positive", "neutral" and "negative" phases. A positive phase has been shown to be associated with greater than average SST and greater precipitation in the western Indian Ocean region with a corresponding cooling of waters in the eastern Indian Ocean, which tends to cause droughts in adjacent land areas of Indonesia and Australia. The positive phase peaks is in September-October (Murtugadde *et al.,* 2000). The negative phase of the IOD brings about the opposite conditions with warmer water and greater precipitation in the eastern Indian Ocean and cooler and drier conditions in the west.

Hence, the negative phase of IOD can be considered as an intensification of the normal state whereas as a positive phase of the IOD represents conditions nearly opposite to the normal.

Thus, Positive IOD = Western Equatorial SST > Eastern Equatorial SST and Negative IOD = Eastern Equatorial SST > Western Equatorial SST. (Vinayachandran, *et al.,* 2007, Saji *et al.,* 1999).

The positive phase SST anomaly (SSTA) can be accompanied by above average rainfall in eastern Africa, Kavango-Zambezi Transfrontier Conservation Area (KAZA) in Southern Africa and the tropical western Indian Ocean but diminished rainfall over Indonesia and the tropical southeastern Indian Ocean (Saji *et al.,* 1999; Webster *et al.,* 1999; Black *et al.,* 2003; Gaughan *et al.,* 2016). It is understood that during the positive phase of IOD, unusually strong winds from the east push warm surface water towards Africa, allowing cold water to upwell along the Sumatran coast. Strong zonal wind anomalies trapped to the equatorial Indian Ocean are a characteristic atmospheric feature during such SSTA events (Reverdin *et al.,* 1986; Murtugudde *et al.,* 2000).

However, the perception that the Indian Ocean is passive and merely responds to the atmospheric forcing has been shown to be untrue. The discovery of the IOD and the studies that followed have demonstrated that the Indian Ocean can sustain its own intrinsic coupled ocean-atmosphere processes and is not merely a slave to the events happening over the Pacific Ocean in connection with ENSO. (Schott *et al.,* 2009; Cherchi and Navara 2013).

In addition, in March and April 2019 there were unprecedented atmospheric circulations over the Indian Ocean such as cyclones Idai and Kenneth that had devastating effects on the southern east African coast in Mozambique, Tanzania and Kenya ("Cyclones Idai and Kenneth", 2019 March 15th & April 25th), strongly indicating that independent active IOD-related SST influences exist east and south on the African continent.

El Niño and IOD events account for 30% and 12% of the tropical Indian Ocean SST variability respectively (Saji *et al.,* 1999). It means that both of the aforementioned phenomena explain a significant part of the tropical Indian Ocean variability. As alluded to earlier, the IOD events have a strong influence on the climate of the immediate neighboring regions such as East Africa, Indonesia and southern Africa (Saji *et al.,* 1999; Black *et al.,* 2003; Gaughan *et al.,* 2016), and also on the Indian summer monsoon region (Ashok *et al.,* 2001; Gouda *et al.,* 2017), East Asia (Saji and Yamagata, 2002b, Guan *et al.,* 2002), the Mediterranean, Australia, and Brazil (Saji and Yamagata, 2002b).

Significant increase in rainfall is seen in eastern Africa in association with canonical El Nino and positive IOD events. This significant positive correlation observed between the East African rainfall and IOD events during October-December season are in general agreement with the earlier studies (Ummenhofer *et al.,* 2009) which show that the East African short rains are predominantly driven by the warm SST anomalies in the western equatorial Indian Ocean. However, the IOD event has been observed to affect east African rainfall independent of ENSO especially during September and November period (Behera *et al.,* 2005) but have a weak influence on South Sudan rainfall pattern (Omay, 2015).

Over Nigeria, the seasonal cycle of rainfall is controlled by large scale monsoon circulations, the migration/oscillation of an Inter Tropical Discontinuity (ITD) and regional orography (Nicholson, 1996) as well as the African Easterly and Tropical Jet streams, and the weather-producing synoptic-scale wave disturbances (Sultan and Janicot, 2003), the westward-propagating mesoscale convective systems and African easterly waves (Kiladis *et al.,* 2006).

The West African Monsoon circulation is also known to combine with monsoonal circulation over the Indian sub-continent to define summer circulation features over Nigeria. Thus, good amount of warm waters over western Indian Ocean encourages good monsoon condition. As Oguntoyinbo (1986) puts it, there exists interaction between the atmosphere, land and ocean over large geographical scales, so that climatic anomalies tend to be extensive in space. Thus, it is common to find that an intensification in a feature in one area signifies an abatement in another feature in another region and *vice versa*. Such linkages are called teleconnections.

Many studies have established a correlation between SST and rainfall in Africa (Berte and Ward, 1998, Colma *et al.,* 2000). Rowell *et al.,* (1993), William and Hanan (2011), Okonkwo, (2014), Gaughan *et al.,* (2016) among others, established a significant empirical relationship between SSTAs and African precipitation variability. In addition, there are suggestions that there is a relationship between the strength and/or position of the African Easterly Jet and precipitation (Fontaine and Janicott 1992; Rowell *et al.*, 1993). Therefore, it is of interest to consider the dependence of the jet on structure in the SST field. Understanding this connection may help us to better understand the mechanisms that connect SST distributions and African rainfall. It is noteworthy that over Nigeria, the correlation between the tropical Indo-Pacific SSTA and East/South African rainfall has been established (Black *et al.,* 2003; Omogbai, 2010; Gaughan *et al.,* 2016).

Having established the facts that ENSO plays a huge role in the determination of the rainfall regime in Africa (Preethi *et al.,* 2015) this study is focused on investigating the unexplored influence of IOD SST anomalies on rainfall distribution over Nigeria.

1.2 Statement of the Research Problem

Rainfall patterns in Nigeria can be affected by a lot of factors which include; large scale monsoon circulation, the migration/oscillation of ITD, orography and other forcing functions, but the effects of IOD is yet to be investigated (specifically for Nigeria) even though established to have direct influence and impact on East and South African, and Sahelian rainfall patterns. (Black *et al.*, 2003; Behera *et al.*, 2005; Williams and Hannan, 2011; Preethi *et al.*, 2015; Gaughan *et al.*, 2016).

This gap is significant on the backdrop of the propagation of active mesoscale convective systems (line squalls) from the tropical western Indian ocean affecting both the Zonal (east-west) circulation and the meridional (north-south) circulation in the troposphere, as shown in the RGB satellite imagery in Figure 1.1.

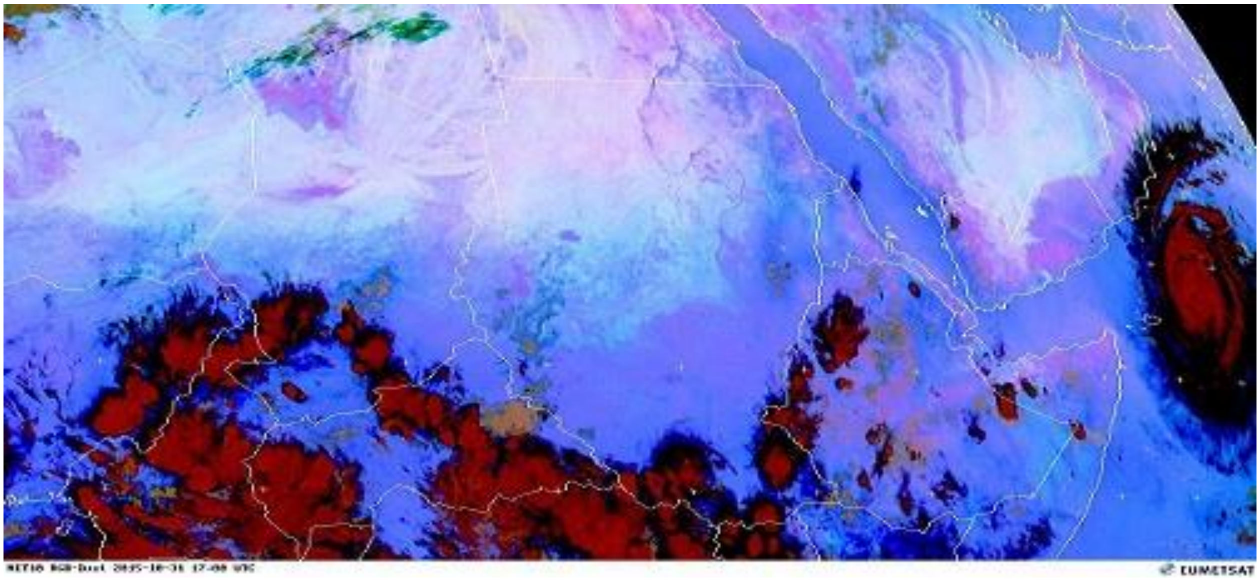


Figure. 1.1: Mesoscale convective clouds in RGB-Dust Meteosat imagery (saved on 2015-10-31 at 17:00 UTC). NIMET, 2015.

1.3 Justification for the Study

While it is a well-known fact that ENSO events exercise some control over the climate of Nigeria and West Africa at large and this knowledge has since been incorporated in the seasonal rainfall prediction for Nigeria. It is very imperative to investigate any possible interfaces with IODMI phases over equatorial Indian Ocean that could explain subsisting gaps in the Knowledge of large scale controls on rainfall over Nigeria.

This study seeks to answer the question as to whether there is a significant correlation between the SST anomalies over the tropical Indian ocean and the rainfall patterns over Nigeria. If this is proven, measures of Indian ocean SSTAs could be adopted, in addition to the ENSO already in use, to better improve the seasonal forecast of rainfall and for the better understanding of multi-decadal modulations of global interannual teleconnections.

For Nigeria to ensure food security through sustainable rainfed agriculture, there is need to understand the spatial and temporal characteristics of rainfall, and any teleconnection between these meteorological parameters and systems causing potential climate variability, such as Indian Ocean Dipole Mode Index (IODMI) and El Niño Southern Oscillation (ENSO). It will thus be the focus of this study to assess and fill the gaps and recommend possible means to better understand and forecast intra-seasonal and interannual variability in rainfall over Nigeria.

1.4 Aim and Objectives:

The aim of this research investigated the possible teleconnections between the Indian Ocean Dipole (IOD) phases and rainfall amount and distribution over Nigeria.

The specific objectives are to;

i. Examine the nature of the temporal relationship between IOD phases and intra-seasonal rainfall variability in parts of Nigeria.
ii. Assess the spatial distribution of rainfall across Nigeria in relation to IODMI phases.
iii. Compare the teleconnection between rainfall and IODMI and ENSO indices.

1.5 Research Questions

The following questions will be raised in order to achieve the above objectives;

i. How do IODMI phases affect the rainfall amount over selected stations in Nigeria?
ii. How do IODMI phases affect the spatial distribution of rainfall over Nigeria?
iii. How do the IODMI and ENSO indices compare in their influences on rainfall amount and distribution over Nigeria?

1.6 Research Hypothesis

Some hypotheses are put forth to wholly or partly address some of the objectives in this study. Hence,the following hypothesis;

i. **Null hypothesis (Ho)-** There is no significant relationship between Indian Ocean Dipole Mode Index (IODMI) and the Nigerian Monsoon Seasonal Rainfall (NMSR).
ii. **Alternative hypothesis (Hi)-** There is a significant relationship between Indian Ocean Dipole Mode Index (IODMI) and the Nigerian Monsoon Seasonal Rainfall (NMSR).

1.7 Scope and Limitations of the Study

The scope of this research focused on examining the temporal relationship between IOD phases and intra-seasonal rainfall variability in parts of Nigeria, was restricted to a domain delimited by Latitudes 4˚–14˚N and Longitudes 3˚–15˚E. Data utilised were daily rainfall data from NiMet and monthly IODMI/SOI indices from NOAA website covering a 33-year period (1983-2015). Synoptic stations included in the study, for which data were readily available, were; Sokoto, Maiduguri, Katsina, Kano, Yelwa, Yola, Ibi, Abuja, Ilorin, Jos, Ikeja, Benin, Enugu, Owerri, Portharcourt and Calabar, spread across the eco-climatic zones of the country.

1.8 Study Area

Nigeria is located between Latitudes 4˚–14˚N and Longitudes 3˚–15˚E and covers a total area of 923,768 km^2. It shares border with the Republics of Niger, Cameroon and Benin and the Gulf of Guinea, to the north, east, west and south respectively.

Due to its location just north of the equator, Nigeria enjoys a tropical climate characterized by the hot and wet conditions associated with the movement of the Inter-Tropical Convergence Zone (ITCZ) north and south of the equator. The climate of Nigeria is dominated by the influence of two major wind currents, namely: the south-westerly tropical maritime (mT) air mass which is prevalent during the wet season because it is moisture laden as a result of it has traversed through the Atlantic ocean where it acquired moisture and the north-easterly tropical continental (cT) air mass that prevails during the dry season because of its dryness since there is no ocean along its continental path (Adeniyi, 2014; Odekunle, 2004). Two main seasons; wet (April-October) and dry (November- March), result from the interplay of the aforementioned two major wind currents.

Rainfall in Nigeria falls within a distinct period (Adeniyi *et al*., 2009). These periods vary from the northern part to the southern part of the country because of their relative distances from the Atlantic Ocean. Rainfall starts earlier and ceases late in the southern parts while it starts later and ceases earlier in the north. The onset month in the south varies between March and April while the cessation month is October. In the North, however, rainfall starts in May and ends in September (Adeniyi, 2014). There is rainfall occurrence all over the country during June to September. However, in August, there is a period of little dry season in the southern part of the country (Odekunle, 2004). Overall two rainfall peaks occur in the south whereas only one rainfall peak occurs in the north. This makes the climate to be humid in the south with mean annual rainfall of over 2000 mm and semi-arid in the north with mean annual rainfall less than 600 mm (Ojo, 1977). However, topographic relief plays a significant role in the local climate only around the Jos Plateau and along the eastern border highland.

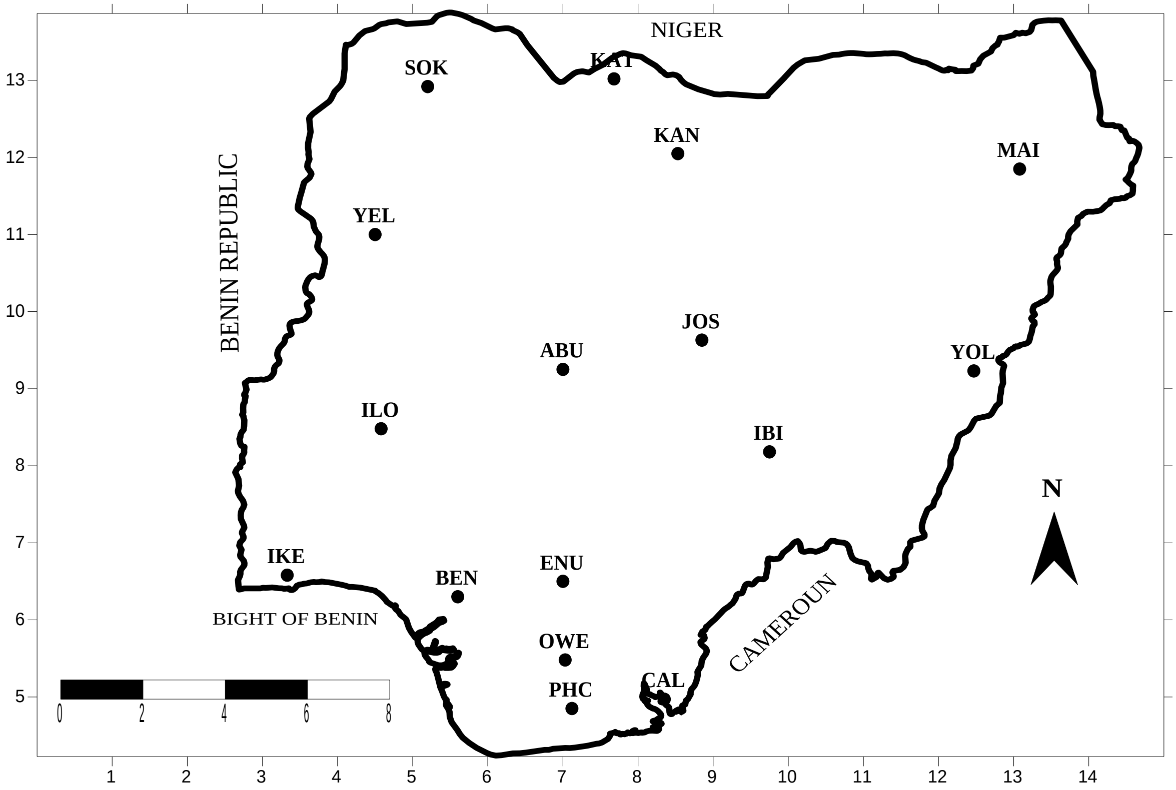


Figure. 1.2 The Study Areas (Location of selected synoptic stations in Nigeria) Source: (NIMET, 2018).

CHAPTER TWO

2.0 LITERATURE REVIEW

Preamble:

This chapter comprises of reviewed papers on the major air-sea climate forcing for rainfall occurrence and its variability including teleconnection of seasonal rainfall and El Nino Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) over Nigeria. However, the aim of this research work is to investigate the possible teleconnections of Indian Ocean dipole (IOD) events on rainfall distribution over Nigeria.

2.1 Rainfall in Nigeria

Rainfall has a profound impact on agriculture, air and road transports, hydroelectric power generation, construction, water resources, among others. Normal rainfall is beneficial for agriculture and other economic activities. However, when it is excessive, it may result in flooding and the associated negative impacts. Also the effects of below normal amount of rainfall are also not desirable. The past droughts over West Africa affected the economy, agriculture, livestock and human population (Shanahan *et al*., 2009).

Timely information in seasonal rainfall prediction is therefore vital for planning and decision making in these key sectors of the economy. Apart from its relevance to life, tropical rainfall is also important for global climate and weather. Over two thirds of global precipitation falls in the tropics (Simpson *et al*., 1988). A notable feature of tropical rainfall is its inter-annual variability, which on occasions can lead to prolonged dry (drought) and wet (flood) periods.

Due to its location just north of the equator, Nigeria enjoys a tropical climate characterized by the hot and wet conditions associated with the movement of the Inter-Tropical Convergence Zone (ITCZ) north and south of the equator. The climate of Nigeria is dominated by the influence of two major wind currents, namely: the southwesterly maritime tropical (mT) air mass which is prevalent during the wet season because it is moisture laden as a result of its traverse through the Atlantic ocean where it acquires moisture and the north easterly continental tropical (cT) air mass that prevails during the dry season because of its dryness since there is no ocean along its continental path (Adeniyi, 2014; Odekunle, 2004). Two main seasons; that is wet (April-October) and dry (November- March) result from the two major wind currents.

Rainfall in Nigeria falls within a distinct period (Adeniyi *et al*., 2009). These periods vary from the northern part to the southern part of the country because of their relative distance from the Atlantic Ocean. Rainfall starts earlier and ceases late in the southern parts while it starts late and ceases earlier in the north. The onset month in the south varies between March and April while the cessation month is October. In the North, however, rainfall starts in May and ends in September (Adeniyi, 2014). There is rainfall occurrence all over the country during June to September. However, in August, there is a period of little dry season in the southern part of the country (Odekunle, 2004). Overall two rainfall peaks occur in the south whereas only one rainfall peak occurs in the north. This makes the climate to be humid in the south with annual rainfall over 2000 mm and semi-arid in the north with annual rainfall less than 600 mm (Ojo, 1977).

2.2 Teleconnections- The major Ocean/Atmosphere vvariation phenomena in the Tropical Climate.

2.2.1 Concepts of IOD and ENSO;

According to Oguntoyinbo (1986), there exists interaction between the atmospheres over large geographical scales, so that climatic anomalies tend to be extensive in space. Thus it is common to find that the variation that is an increase in one element in a region may signify an increase in another element in another region and vice versa. Such linkages as these are called teleconnections.

According to Kucharski, *et al.*, (2010), atmospheric and oceanic teleconnections govern the variability in our climate system on a broad range of time and spatial scales, in both the tropics and extratropics. On inter-annual time scales, the connection between El Niño–Southern Oscillation and the Asian monsoon system influences rain amounts in regions particularly sensitive to floods/droughts. On inter-annual and decadal time scales, rainfall variability in the Sahel region of West Africa appears to be governed to a large extent by teleconnection patterns related to the Pacific Ocean, the Indian Ocean, and the Atlantic Ocean. The decadal behavior of the North Atlantic Oscillation (NAO), influencing climate in Europe, Asia, and northern Africa, is also likely to be connected to both tropical and extratropical sea surface temperatures in the Indo-Pacific and Atlantic regions.

As a consequence, enormous progress has been made in seasonal forecasting, which allows the estimation of climate anomalies for several months ahead and may have important implications for agriculture and economies. However, progress in seasonal forecasting is far from saturated and further improvements may be expected from better predictions of sea surface temperatures outside of the ENSO region.

2.2.2- El Niño/Southern Oscillation (ENSO):

The El Niño/Southern Oscillation (ENSO) is a naturally occurring phenomenon involving fluctuating ocean temperatures in the central and eastern equatorial Pacific, coupled with changes in the atmosphere. This phenomenon has a major influence on climate patterns in various parts of the world. Scientific progress on the understanding and modelling of ENSO has improved prediction skills within a range of one to nine months in advance, helping society to prepare for the associated hazards such as heavy rains, floods and drought. The value of these predictions can translate into hundreds of millions, if not billions, of dollars in potential savings. (WMO, 2014).

2.2.2.2 ENSO and its forecasting;

ENSO uses both the dynamical and statistical models that are based on the internal mode of oscillation of the coupled atmosphere-ocean system over the tropical Pacific Ocean, which is the continuous imbalance between the tightly coupled surface winds, temperature and thermocline. The positive/negative ENSO phase, called El Niño/ La Niña, was defined by the Scientific Committee for Ocean Research (SCOR) working group as "is the appearance of anomalously warm/cool water along the coast of Ecuador and Peru as far south as Lima (12°S).

This means a normalized sea surface temperature (SST) anomaly values exceeding one standard deviation for at least four (4) consecutive months to conform existence of El Niño or La Niña. This normalized SST anomaly should occur at least three (3) of five (5) Peruvian coastal stations," SCOR, (1983).

There are four Niño regions (indices) across the central Pacific namely Niño 1+2, Niño 3, Niño 3.4 and Niño 4. Niño Indices are computed as the area-averaged sea surface temperature of each of the four Niño regions. Niño 1+2 region covers the extreme eastern equatorial Pacific between 0°-10°S, 90°W-80°W. Niño 3 covers the eastern equatorial Pacific between 5°N-5°S, 150°W-90°W. Niño 3.4 region covers the east-central equatorial Pacific between 5°N-5°S, 170°W-120°W. Niño 4 region spans the date line and covers the area 5°N-5°S, 160°E-150°W (Reynolds and Smith, 1998).

More recently in 2003, National Oceanic and Atmospheric Administration (NOAA) has revisited the concept of El Niño and defined it as a phenomenon in the equatorial Pacific Ocean characterized by a positive sea surface temperature departure from normal (for the 1971–2000 base period) in the Niño 3.4 region greater than or equal in magnitude to 0.5° C, averaged over three consecutive months.'' The opposite phase, La Niña, also defined as "a phenomenon in the equatorial Pacific Ocean characterized by a negative sea surface temperature departure from normal (for the 1971-2000 base period) in the Niño 3.4 region greater than or equal in magnitude to 0.5° C, averaged over three consecutive months (NOAA, 2014).

El Niño and La Niña are the oceanic components while the Southern Oscillation is the atmospheric counterpart, thus giving rise to the term El Niño/Southern Oscillation. The El Niño/Southern Oscillation comprises three phases:- El Niño, La Niña and neutral.

El Nino: This phase is said to occur when there is temperatures (SST) rises above the normal in the central and eastern tropical Pacific Ocean (figure 2.1). The low-level surface winds, which normally blow from east to west along the equator (“easterly winds”), instead weaken or, in some cases, start blowing the other direction (from west to east or “westerly winds”). This is referred to as the Negative Phase (NOAA, 2014; WMO, 2014).

La Nina: This phase involves the cooling of the ocean surface, or decrease to below-average SST, in the central and eastern tropical Pacific Ocean. The normal easterly winds along the equator become even stronger. This is referred to as the Positive Phase. (NOAA, 2014; WMO, 2014). See also figure 2.1.

Neutral (neither El Nino nor La Nina): The ENSO is said to be in neutral phase when the tropical Pacific SSTs are close to average. However, there are some instances when the ocean can look like it’s in an El Nino or La Nina state, but the atmosphere is not playing along (or vice versa). (NOAA, 2014).Although ENSO has been shown to be one of the primary determinants of the inter-annual variability of rainfall in the low-latitudes, its influence over Africa remains controversial.

A number of studies have confirmed a relationship between rainfall and ENSO in parts of eastern and southern Africa (Lindesay *et al*., 1986; Farmer, 1988; Janowiak, 1988; van Heerden *et al*., 1988; Nicholson, 1996).

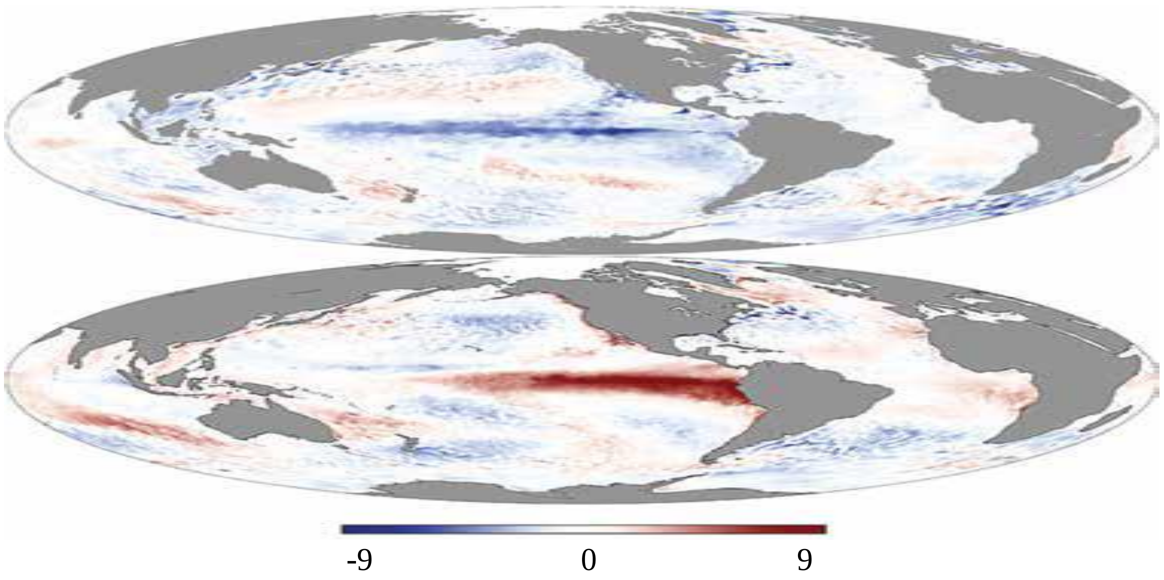


Figure 2.1- Maps of SSTA in the Pacific Ocean during a strong La Nina (top,December 1988) and El Nino (Bottom, December, 1997). Source: (NOAA, 2014).

Several studies have been done to establish the relationship between rainfall in Nigeria and the ENSO. While Adebayo, (1999) disclosed that ENSO has been shown to relate strongly to variations in Nigerian rainfall, analysis by Okere *et al.,* (2006) revealed some indication that rainfall in Nigeria is associated with El Nino- related circulation and rainfall anomalies. Data reported by Owen and Ward, (1990) and Adebayo, (1999) also confirmed the relationship between extra-tropical SST anomaly (for example, SSTAs over the North Atlantic, North Pacific and South Pacific) and rainfall fluctuations in Nigeria. However, the work done by Nnawuike, (2016) revealed there is a weak relationship between the ENSO phases and the rainfall over southwestern Nigeria.

ENSO forecast are societally revelant because the agrarian sector in tropical countries depends critically on water received during the rainy season. Precipitation and SST are tightly coupled in the tropics; hence useful precipitation information can be derived from forecasts of SST.

ENSO forecasts are a good example of a climate service that helps communities adapt to natural variations in the climate and to long-term climate change. The Global Framework for Climate Services, spearheaded by WMO, aims to improve such services and increase their outreach to the most vulnerable.

2.2.3 Indian Ocean Dipole:

Although ENSO was statistically effective in explaining several past droughts in India, in the recent decades the ENSO-Monsoon relationship seemed to weaken in the Indian subcontinent. For instance the 1997, strong ENSO failed to cause drought in India.

However, it was later discovered that just like ENSO was an event in the Pacific Ocean, a similar seesaw ocean-atmosphere system in the Indian Ocean was also at play, now known as the Indian Ocean Dipole (IOD). The IOD is defined by the **difference in sea surface temperature between two areas** (or poles, hence a dipole) – a western pole in the **Arabian Sea** (western Indian Ocean) and an eastern pole in the **eastern Indian Ocean** south of Indonesia. IOD develops in the equatorial region of Indian Ocean from April to May peaking in October. It was discovered in 1999 and named the **Indian Ocean Dipole (IOD;** Saji *et al.*, 1999).

The climate variability in the Indian Ocean is dominated by the Indian Ocean Dipole (IOD) during September–November, which is related to the inherent ocean and atmosphere coupling processes (Saji *et al.*, 1999; Yamagata *et al.*, 2004; Behera *et al.*, 2005).

During a positive IOD event, the sea surface temperature (SST) is colder (warmer) than normal off Sumatra (East Africa); winds over the Indian Ocean blow from east to west (from Bay of Bengal towards Arabian Sea). This results in the Arabian Sea (western Indian Ocean near African Coast), being much warmer and eastern Indian Ocean around Indonesia becoming colder and dry. The associated atmospheric teleconnections affect many parts of the world (Saji and Yamagata, 2003), especially Indian Ocean rim countries such as Australia, Maritime Continent, India, Sri Lanka and East Africa, where the IOD has a paramount impact (Behera *et al.*, 2005). Recent IOD events have caused huge impacts on the socio-economic conditions of those affected regions (Saji and Yamagata, 2003).

A negative IOD (the reverse) makes Indonesia much warmer and rainier. It usually follows a positive IOD giving rise to the quasi-biennial periodicity in the IOD variability (Saji *et al.*, 1999; Rao *et al.*, 2002*;* Behera *et al.*, 2005). However, the 2006 positive IOD event was succeeded by another positive IOD event in 2007.

The sea surface temperature anomalies (red shading denoting warming; blue cooling) during a positive Indian Ocean dipole (IOD) event (top) figure 2.2a. However, the white patches indicates increased convective activity with arrows indicating wind direction over India and East Africa . The negative IOD (bottom) figure 2.2b which is, in effect, the reversal of the positive IOD with increased convective activity over Australia, Indonesia and Japan (figure 2.2a and b).

Intensity of the IOD is represented by anomalous SST gradient between the western equatorial Indian Ocean (50^{o}E-70^{o}E and 10^{o}S-10^{o}N) and the south-eastern equatorial Indian Ocean (90^{o}E-110^{o}E and 10^{o}S-0^{o}N). This gradient is named as Dipole Mode Index (DMI).

When the DMI is positive, the phenomenon is referred to as the positive IOD and when it is negative, it is referred as negative IOD (Saji *et al.*, 1999).

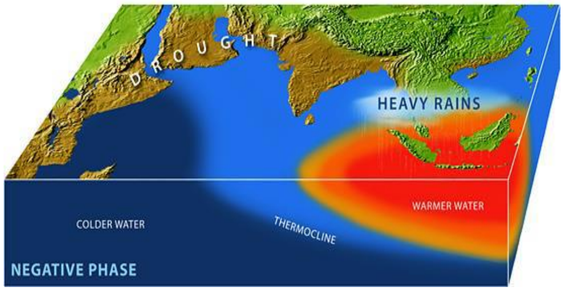
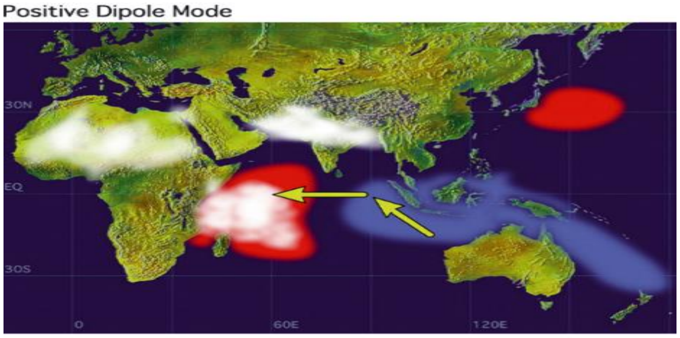


Figure 2.2a



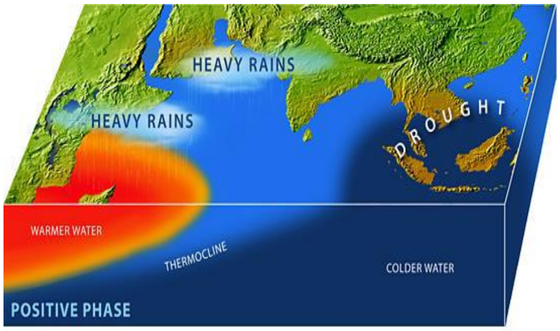


Figure 2.2b

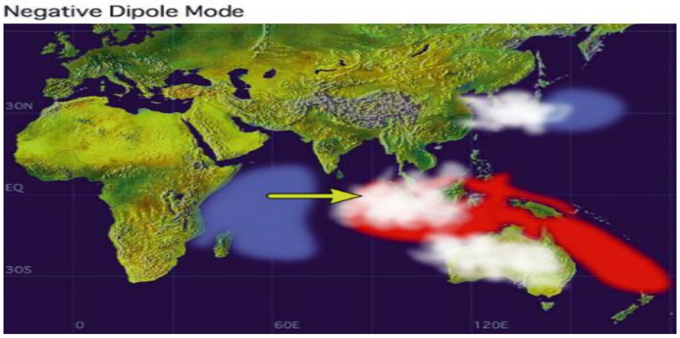


Figure 2.2a and b-- Schematic diagram of Sea Surface Temperature Anomalies. Source: (Rao, 2002)

2.3 Concepts of walker circulation

The term Walker Circulation was first introduced in 1969 by Professor Jacob Bjerknes, referring to the large-scale atmospheric circulation along the longitude–height plane over the equatorial Pacific Ocean. The Walker Circulation features low-level winds blowing from east to west across the central Pacific, rising motion over the warm waters of the western Pacific, returning flow from west to east in the upper troposphere, and sinking motion over the cold waters of the eastern Pacific.

The anomalous ocean warming in the central and eastern Pacific help to shift a rising branch of the Walker Circulation to east of 180°, while sinking branches shift to over the Maritime continent and northern South America. (NOAA, 2014).

Today, the Walker Circulation generally refers to the totality of the circulation cells as shown in figure 2.3.

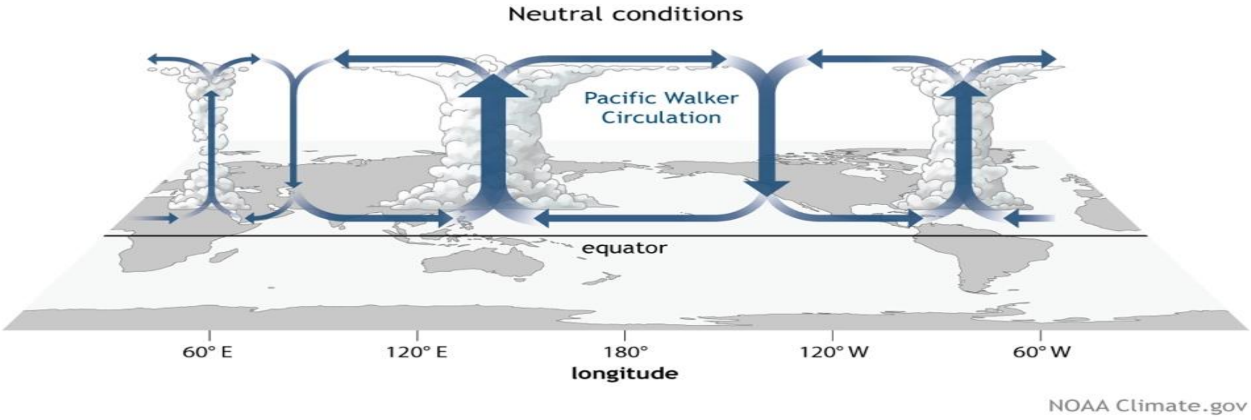


Figure. 2.3- Generalized Walker Circulation. Source: (NOAA, 2014).

According to Liu *and* Liu, (2014), Pacific Ocean atmospheric circulation, which he also calls the Pacific "overturning cell" of an atmospheric "loop", called the **Walker Circulation**. The lower part of the loop flows east to west across much of the tropics near the surface; the upper part flows west to east at higher altitudes. Rising air in the west and sinking air in the east connect the flow in one big, continuous loop which is driven by temperature and pressure gradients that is responsible for longitudinal air flow over the Indian Ocean and equatorial Atlantic Ocean. These oscillations can have significant effects on temperature and weather across the globe which forms the trade winds.

However, the continuous loop aforementioned is represents the neutral phase of the Walker cell functioning normally. The associated phase of the Walker circulation is such that it favors co-evolution of El Niño (La Niña) with positive (negative) IOD in the years of their co-occurrences.

The IOD is an inherent mode of variability in the Indian Ocean like El Niño/Southern Oscillation (ENSO) in the Pacific. However, in the incidence of co-occurrences those two modes modify their individual characteristics and also inherent conditions of both basins (Behera *et al.*, 2005). The co-occurrence of positive IOD and La Niña is therefore not commonly observed historically. It has happened only once in 1967 during recent history before the 2007 event. Because of such rarity in the evolution of two successive IOD events, one together with an El Niño and the other with a La Niña, it is important to investigate associated oceanic and atmospheric conditions for improving the predictability of those climate modes (Luo *et al.*, 2007; 2008).

In the paradigm of the atmospheric bridge (Alexander *et al.,* 2002; Shinoda *et al.,* 2003), ENSO affects the Indian ocean because the walker circulation shifts eastwards towards the dateline (Rassmusson and Carpenter 1983, Latif and Barnett 1995), resulting in anomalous easterlies and suppressed rainfall over Indonesia and eastern Indian ocean. On the other hand, a number of strong dipole events have developed in the absence of well-defined ENSO variations in the pacific (Reverdin *et al.*, 1986; Saji *et al.*, 1999), thus supporting the notion that ENSO maybe not a necessary stimulus.

Bjerknes feedback mechanism is a thermodynamic air-sea feedback in the Southeast Tropical Indian Ocean (SETIO) where for example, a drop in SST in the SETIO implies a corresponding drop in cloud amount in situ. A decrease in atmospheric convection leads to development of descending Rossby waves to the west (Han *et al.*, 2006), resulting in an anomalous anticyclonic circulation to the West of the decreased convection centre which enhances the wind speeds in the SETIO.

2.4 Madden Julian Oscillation (MJO)

The tropics is a key area of global climate variation. In fact, unique atmosphere-ocean coupled phenomena with various timescales are observed in the tropical Pacific and Indian Oceans, like El Niño, Indian Ocean Dipole mode phenomenon, the Monsoon, and the Madden-Julian Oscillation (MJO) (Yen *et al*., 2011; Zhou *et al.*, 2012). See figure 2.4.

MJO is the variability at time scale of 30-60 days in zonal winds and convection, where the anomalous convection first develops in western tropical Indian Ocean and propagates eastward across the Indian Ocean and maritime continent and finally decays east of 180^0E.

MJO is a large-scale disturbance of deep convection and winds that controls up to half of the variance of tropical convection in some regions now known to be a major propagator of weather systems. (Madden and Julian 1972; Maloney and Hartmann 2000).

MJO is an intra-seasonal event, prior to 1971, it was thought that virtually all variability in the weather conditions within a given season in the Tropics was random. There were indications of inter-seasonal variations, such as the Southern Oscillation. (Cassuo, 2008).

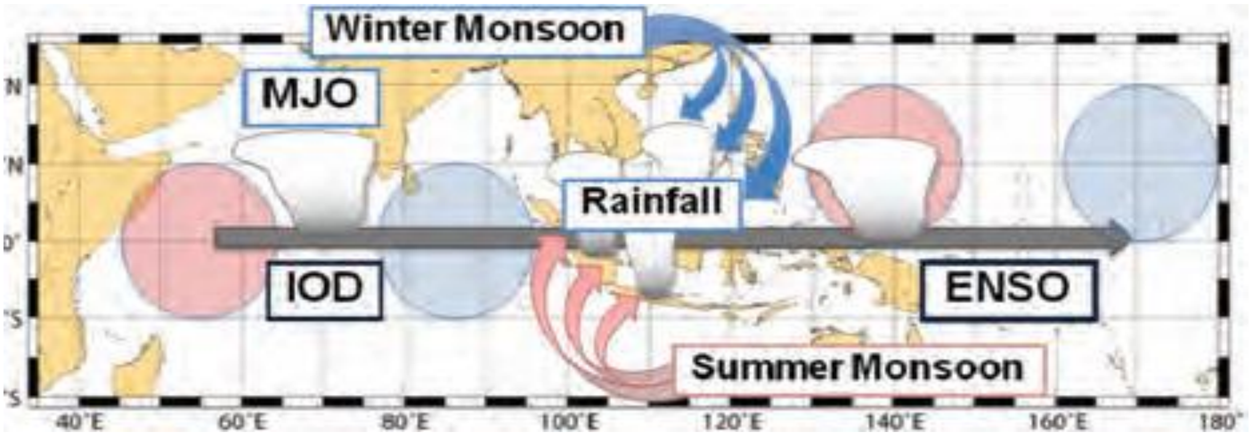


Figure 2.4- Sketch of the major ocean/atmosphere variation phenomena, which compose tropical climate. Source: (WMO, 2014).

It reveals a process of humidity accumulation by atmospheric mixed Rossby-gravity wave referred to as westward moving waves whose variance peaks off the equator along 10^0S near the dateline and along 10^0N near 135^0E over the West Pacific and also over the northern and southern Indian Ocean along 10^0N and 10^0S, which plays an important role in the initiation of the MJO, (Riddle *et al.,* 2013) and these phenomena sometimes bring anomalous weather not only to the tropical area but often worldwide with great impacts on human socio-economic activities.

Equatorial Rossby waves sometime impact the genesis of the MJO, (Roundy and Frank, 2004). The subsurface features of the Indian Ocean specifically, the sea surface height induces the equatorial Rossby wave that propagates towards the East African Coast. (Behera *et al.,* 2005).

2.5 Monsoon Winds

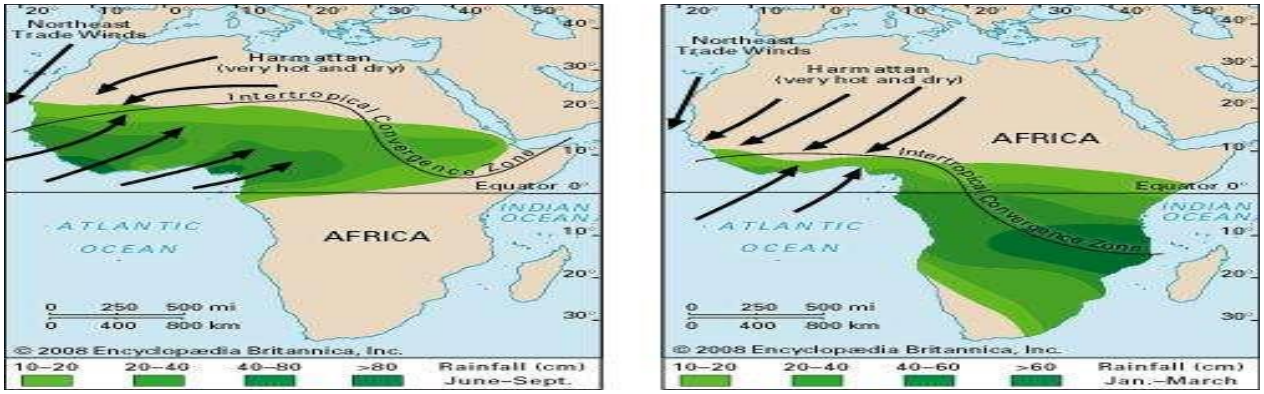


Figure 2.5a- The wind and rainfall patterns of West African Monsoon. Source: (NOAA, 2014)

Figure 2.5b- The wind pattern of the Indian Ocean Monsoon. Source: (NOAA, 2014)

Monsoons either the West African Monsoon (WAM) regime or the Indian Ocean Monsoon regime are seasonal winds which reverse their direction with season based on the thermodynamic difference in temperature between the Oceans and the Continents and it is associated with precipitation changes. However, they are seasonal (sometimes inter-hemispheric) wind systems that converge at the Intertropical Discontinuity (ITD). Hence, the major transporters of moisture inland for rain formation across continent. The main rainy seasons in Nigeria in general are largely associated with the alternating monsoonal wind currents with one receding while another one advancing. The monsoonal flows in the region are the south westerlies and the north easterlies, with its active phase of the monsoons as rain bearing systems in Nigeria occurring during June to September, (Mohammad *et al.,* 2018).

Unlike the Indian monsoon, the WAM is a very variable feature in terms of rainfall; throughout the twentieth century India never experienced more than two consecutive years of drought, whilst the Sahelian region has suffered from a long-lasting drought for the last twenty years, (Mote, 2003; Rosalind, 2012).

During the Northern Hemisphere winter (DJF), most parts of Nigeria are under the influence of the dry dusty northeast monsoonal wind currents that originate from the Azores Subtropical high pressure system, (Magami *et al.,* 2014). The southeast/southwest monsoonal wind currents are experienced during the Southern Hemisphere winter (June-September). These winds are cool and moist, and originate from the St. helena Anticyclone in the Atlantic Ocean. They are transported by the African Low Level Jet stream (ALLJ) that is fully developed in July and enhance rainfall amount and contributing in advancing the ITD northward over Nigeria in the rainy season, (Lavender and Mathews, 2009).

2.6 Easterly Winds and Weather over Equatorial Indian Ocean

The equatorial Indian Ocean, however, experiences a somewhat different seasonal wind forcing and hence has a different response than the Arabian Sea and Bay of Bengal. Winds over the equatorial Indian Ocean, particularly their zonal component, are weak during monsoons. Relatively strong westerly winds, however, appear during the transition between monsoons, first during April-May (spring) and then again during October-November (fall).

These winds drive strong eastward currents along the equator, attaining speeds exceeding 1 ms^{-1}, known as Wyrtki jets, (Wyrtki, 1973).

Wyrtki jets transport warmer upper layer water towards the east and accumulate near the boundary causing the thermocline in the east to be deeper than in the west. The thermocline slope becomes greater during spring and fall and the volume of warm water and the heat content of the Indian Ocean is larger on the eastern side than in the west. When the thermocline is shallow, winds have to do less work to bring cooler water into the mixed layer than when it is deep. That is, for the same wind strength, a shallower thermocline can facilitate cooling of the mixed layer and SST, whereas a deeper thermocline may not. Thus, Wyrtki jets dictate the shape of the thermocline in the equatorial Indian Ocean. (Wyrtki, 1973).

Modeling studies suggest that the evolution of this pattern is coupled to surface winds. When the surface wind is unusually easterly, the thermocline becomes shallower in the eastern and deeper in the western Indian Ocean. The air-sea interaction results in a positive feedback loop between the induced SST anomaly and the easterly surface winds. Thus, once an IOD event is triggered, the anomalies may maintain themselves or even amplify, (see figure 2.6). (Saji and Yamagata 2003).

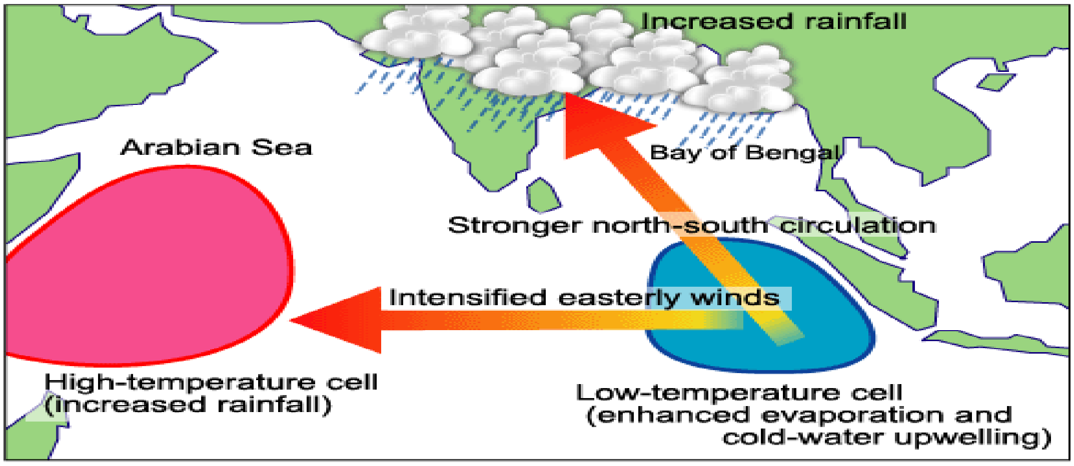


Figure 2.6 –Summer conditions during a positive IOD Event resulting to strong easterly winds. Source: (Saji and Yamagata 2003).

When the IOD index is positive, low temperatures occur off the west coast of Indonesia, causing the declining air mass to spread out from the lower troposphere. Part of this flow of air reaches the Bay of Bengal and India, strengthening the upward motion of the air leading to enhanced Indian monsoon rainfall.

2.7 Review of Related Studies

In a research work carried out on the relationship between IOD and ENSO using observed sea surface temperature data from 1871-1998; and observed wind data from 1958-1998, by Ashok *et al.*, (2001) and recent work done by Cherchi and Navara (2013), revealed that the Indian Ocean Dipole (IOD) is a physical entity.

Thus, many IOD events are shown to occur independent of the El Niño. By estimating the contribution from an appropriate El Niño index based on sea surface temperature anomaly in the eastern Pacific, has shown that the major fraction of the IOD Mode Index is due to the regional processes within the Indian Ocean.

The IOD events have been discovered to have a strong influence on the climate of not only the immediate neighboring regions such as East Africa and Indonesia (Saji *et al.,* 1999), but also the Indian summer monsoon region (Ashok *et al.,* 2001), East Asia (Saji and Yamagata, 2002b; Guan *et al.,* 2002), the Mediterranean, Australia, and Brazil (Saji and Yamagata, 2002b).

It has been demonstrated that a positive IOD index often negated the effect of ENSO, resulting in increased Monsoon rains in several ENSO years like the 1983, 1994 and 1997 (Behera *et al.,* 1999, Webster *et al.,* 1999) as shown in figure 2.7. Further, it has been shown that the two poles of the IOD – the eastern pole (around Indonesia) and the western pole (off the African coast) were independently and cumulatively affecting the quantity of rains for the Monsoon in the Indian sub-continent.

It is to be noted that ENSO, and therefore the degree to which there was interaction with the Indian Ocean, adjacent climate systems and resultant rainfall patterns, is known to be dynamic over the recent period (See Figure 2.7) and more broadly over the Holocene. The rainfall anomalies for the period 1958–1999 are derived from University of Delaware gridded precipitation analysis. The independent years used in the composites of pure IOD and pure ENSO (Yamagata *et al.,* 2004; Behera *et al.,* 2005).

Owiti, (2005) suggested that the Indian Ocean coupling is more crucial for the atmospheric variability in the tropical Pacific rather than the ENSO. It is also known that the IOD exhibits anomalous SST gradients in the tropical Indian Ocean regions that tend to be warmer (cooler) in the west and cooler (warmer) in the east. This generates strong zonal SST gradients that are considered to be the most important climatic phenomena to occur in the tropical Indian Ocean (Black *et al.*, 2003).

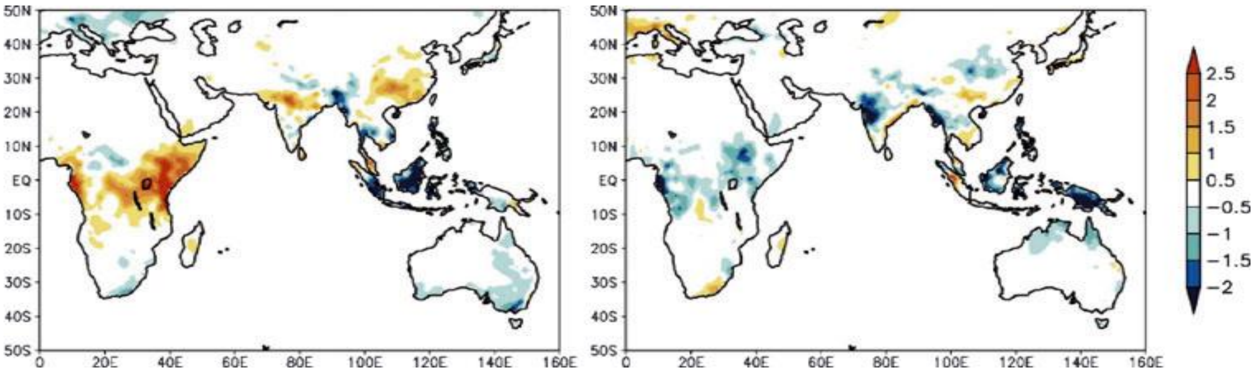


Figure 2.7 Composite rainfall anomalies (mm day)1) for September–November during (left) pure Indian Ocean dipole (IOD) and (right) pure El Nin˜o Southern Oscillation (ENSO) events. Source: (Behera *et al.*, 2005).

The IOD is known to occur at times of ENSO extreme and sometimes when the tropical Pacific does not display any anomalous SST behavior (Saji *et al.*, 1999; Webster *et al.*, 1999). Although this Indian Ocean phenomena had traditionally been viewed as an artifact of the ENSO system (Black *et al.*, 2003), evidence is increasingly amassing that it is a separate and distinct phenomenon (Saji and Yamagata, 2003; Ashok *et al.*, 2001).

Infact, the recent three (3) distinctive positive IOD events that evolved consecutively from 2006-2008 is seen to have settled all the speculation about its independence from ENSO. (Manatsa *et al.*, 2011). This rare occurrence provided ample evidence indicating that the dipole mode phenomenon is an independent atmosphere/ocean interaction in the Indian Ocean, with no causal relation to ENSO effect in the Pacific Ocean.

Therefore the self-sustainability of the IODMI and its impact on regional and global climate is still a matter of debate (Annamalai *et al.*, 1999; Murtugudde *et al.*, 2000). However, the explanation of the impact of the IODMI on the intraseasonal rainfall variability over Nigeria would be the major focus of this research work.

Rainfall pattern in Nigeria can be affected by a lot of factors – large scale monsoon circulation, the migration/oscillation of ITD and by regional orography but the effect of Indian Ocean Dipole (IOD) on rainfall pattern over Western Africa with Nigeria as a case study is the aspect this research was focused on since it has already been established to have direct influence on East African rainfall pattern (Black *et al.,* 2003*;* Behera *et al.*, 2005) though a weak influence on South Sudan rainfall pattern (Omay, 2015).

There is ample evidence in literature, some reviewed here, of a statistical relationship between both the IODMI and ENSO and spatial and temporal characteristics of rainfall variability over Africa, especially East Africa, South Africa and South Sudan, (Saji *et al.*, 1999; Gaughan *et al.*, 2016; Omay, 2015) respectively and the world, but gaps still persist with respect to Nigeria.

Therefore this study was designed to fill the gaps and to provide climate information needed in advance early warning systems. It will evaluate temporal and spatial characteristics of rainfall and the impacts of IOD events on variability of rainfall over Nigeria.

CHAPTER THREE

3.1 MATERIALS AND METHODS

This chapter presents the data and different methods that was used in this study to achieve the objectives.

3.2 Data source, collection and size

i) Daily rainfall data for 16 Synoptic Stations in Nigeria for 33years (1983-2015) were obtained from the archives of the Nigerian Meteorological Agency (NiMet.). The stations were selected from various parts of the country covering all eco-climatic zones to explore any possible teleconnections with the Indian Ocean Dipole Mode Index (IODMI).

ii) Monthly Indian-Pacific Ocean SSTAs/DMI for a period of 33years (1983-2015) were obtained from http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/DMI.

iii) Monthly NOAA ENSO/SOI data for a period of 33years (1983-2015) were obtained from http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino34/. This was to further compare with the IODMI phases to explore which has the statistically stronger influence on the mesoscale convective systems/monsoonal rainfall over Nigeria.

3.3 Data analysis techniques;

The following indices were used in carrying out the data analysis;

i) Monthly Moisture Quality Index

ii) Indian Ocean Dipole Mode Index

iii) El Nino Southern Oscillation Index

In order to compute an important index simply known as Moisture Quality Index (MQI), Usman (2000), a derivative of rainfall; weekly, monthly, three-month moving averages for each of the years of the study period, and the three-month moving average for the monsoon period beginning from the month of March was computed for each of the years in study period (1983-2015), thereafter, the monthly MQI was computed with the expression

$$MQI = \frac{r_{mm} \times Nbi}{{R_i}^2} \qquad 3.1$$

Where;

i= Year identifier

ɼmm= Highest weekly rainfall total for the month

R= Monthly rainfall total

Nb= Number of 'breaks' in rainfall per month. A break is taken as any pentad period with less than 5mm of rain.- The index is small if the annual amount is high and the rains are not concentrated in one month. Thus, the smaller the index, the better the season (and in this case, month) quality-wise. The index interpretation scheme is shown in Table 1.

Table 3.1. Moisture Quality Index (Usman, 2000)

Moisture Quality Index	**Interpretation**
>0.015	Very Poor
≥0.01< 0.015	Poor
≥0.0005< 0.01	Fair
≥ 0.001 < 0.005	Good
< 0.001	Very Good

The three-month moving averages of MQI and DMI (intra-seasonally and annually) beginning from the month of March, was computed for each of the years in study period (1983-2015). Expectedly, the monsoon period moving averages are for; **MAM** (March, April, May), **AMJ** (April, May, June), **MJJ** (May, June, July), **JJA** (June, July, August), **JAS** (July, August, September), **ASO** (August, September, October) and **SON** (September, October, November). So for any of the given period j, the moving average was calculated for MQI, DMI and SOI as follows respectively:

$$MQI_j = \frac{1}{3}\sum_{i=1}^{3} MQI_i \quad 3.2$$

$$DMI_j = \frac{1}{3}\sum_{i=1}^{3} DMI_i \quad 3.3$$

$$SOI_j = \frac{1}{3}\sum_{i=1}^{3} ENSO_i \quad 3.4$$

However, for the DMI and SOI thresholds it is shown in table 3.2.

Table 3.2 showing the thresholds for DMI and ENSO indices. (Omay, 2015)

Category	**Threshold of SST anomaly**	**Category**	**Threshold of SST anomaly**
Positive IOD	≥ 0.5	Negative IOD	≤ -0.5
Weak El Nino	0.5 to 0.9	Weak La Niña	-0.5 to - 0.9
Moderate El Nino	1.0 to 1.4	Moderate La Niña	-1.0 to -1.4
Strong El Niño	≥1.5	Strong La Niña	≤-1.5

3.2.1 Statistical methodologies for quantifying teleconnections

This section describes methodologies used to examine Teleconnections between observed rainfall and two different variables; IODMI and SOI using the Pearson correlation analysis.

3.2.2 Pearson correlation analysis

To assess possible intra-seasonal teleconnection effect of the Indian Ocean Dipole on the rainfall over the selected synoptic stations in Nigeria, the coefficient of correlation between DMI /MQI and SOI/MQI was calculated using the expression:

$$r_{xy} = \frac{{}^{1}/_{n}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{{}^{1}/_{n}\sum_{i=1}^{n}\{(x_i - \bar{x})^2 . {}^{1}/_{n}\sum_{i=1}^{n}\{(y_i - \bar{y})^2\}}} \qquad 3.5$$

‘x’ here represents DMI and SOI.

‘y’ here represents MQI

Additionally, the coefficient of correlation was computed between these variables based on monthly, three-monthly moving average on an annual basis and three-monthly moving averages over the monsoon period for the entire year.

3.2.3 Test of significance of correlation coefficient

The results of the computations was tabulated for the study period. This was done to efficiently test the significance of the correlation coefficients at the 10% level. The test to ascertain the significance of the correlation coefficients between the DMI and MQI over the stated time-scales was done only for the 3-month moving averages during the monsoon period throughout the study period.

However, this procedure was also carried out for the test of significance of the correlation coefficient at 10% level between the SOI and MQI in order to examine how significant is the influence of DMI and SOI on Nigerian Monsoon Seasonal Rainfall (NMSR) pattern using the same time scale. i.e. (the 3-month moving averages during the monsoon period throughout the study period).

Note: 10% level of significance was chosen because the test of significance of the ≥ 0.5 or ≤ -0.5 Pearson correlation coefficient (r) of the variables were widely statistically significant over the stations under study.

Hence, the formation of hypothesis for the test of significance;

i) The null hypothesis which states that "the correlation coefficients is not significant at the 10% significant level."

ii) The alternative hypothesis which states that "the correlation coefficients is significant at the 10% significant level."

This may be symbolically stated as:

$$\mathrm{H_0: r = 0, \quad the\ null\ hypothesis} \qquad 3.6$$

$$\mathrm{H_1: r \neq 0 \ \ the\ alternative\ hypothesis} \qquad 3.7$$

Two approaches were adopted for the test: they include the p-value approach and the critical r-value approach.

The first approach requires computing the p value of the correlation coefficient using equation 3.8 (in MS excel):

$$\boldsymbol{1 - F.DIST\left(\frac{df * r^2}{1 - r^2}, 1, df, TRUE\right)} \qquad 3.8$$

In the expression, df represents degrees of freedom, which is given as $n - 1$, with n as the number of periods within the monsoon season (MAM, AMJ, MJJ, JJA, JAS, ASO and SON) over the years, r is the coefficient of correlation and $\boldsymbol{F.DIST}$ is a function for f-distribution in MS excel. The computed p-value was then compared with a chosen level of significance of 10%. Where the computed p-value was found to be lower than the 10% level of significance, the null hypothesis was rejected in favor of the alternative hypothesis and it was concluded that the coefficient of correlation is significant. On the other hand if the coefficient of correlation is higher than the level of significance, it was concluded that coefficient of correlation is not significant.

The second approach requires computing a variable referred to as the critical r-value using equation 3.9:

$$\boldsymbol{r_{critical}} = \boldsymbol{T.}\frac{\boldsymbol{INV\left(1-\frac{\alpha}{2}, df\right)}}{\boldsymbol{SQRT\left(\left(T.INV\left(1-\frac{\alpha}{2}, df\right)^{2}+df\right)\right)}} \qquad 3.9$$

Here, $\boldsymbol{r_{critical}}$ represents the critical r-value, $\boldsymbol{\alpha}$ represents the level of significance which is 10%, df is the degrees of freedom as in above and $\boldsymbol{T.INV}$ is a function in MS excel. The computed critical r-value was then compared with the Absolute value of the Pearson correlation coefficient (r) at a chosen level of significance of 10%. Where the computed correlation coefficient (r) was found to be greater than the critical r-value, the null hypothesis was rejected in favor of the alternative hypothesis and it was concluded that the coefficient of correlation is significant at 10% level otherwise reject the alternative hypothesis and accept the null hypothesis, that the correlation coefficients is not significant at the 10% significant level.

Having found the test of significance of the correlation coefficient for each of the selected stations within the study period, the 'IF' command in MS excel was used to identify the 'Significant' and the 'Not Significant' years. Thereafter, the 'COUNTIF' command in MS excel was used to count the number of 'Significant' years and 'Not Significant' years. Finally, the percentage (%) of the 'Significant' years was also done and represented in a table.

3.3 Spatial presentation of result

The spatial display of spatio-temporal trend and pattern of correlation coefficient between the DMI/MQI and SOI/MQI over the study area was obtained using the Quantum GIS (QGIS) 2.18.9 software, as well as the Microsoft Excel 2013 software, using the following steps;

Step1: A database was created in Microsoft Excel which contained coordinates of each station and associated correlation coefficient values. The file was saved as delimited text, a format readable to QGIS 2.18.9

Step 2: The created database file was imported to the QGIS environment, then the coordinates system and the Map projection for the file were defined.

Step3: The event layer file was converted to ESRI shape file

Step4: The study area was clipped from Nigerian States shape file. Both files (ESRI shape file and study area shape file) were given the same coordinates system and projection (Spatial alignment).

Step5: Interpolation technique was used to interpolate the indices generated which included the coordinates and correlation coefficient values for each station.

Step6: The clipper was used to express spatial pattern. Maps were designed and produced in QGIS 2.18.9 layout environment (interphase) showing the spatio-temporal trends and pattern of correlation coefficient between the DMI/MQI and SOI/MQI in the study area.

3.4 Comparison of correlation analysis between the IODMI and SOI on NMSR

To compare the teleconnection of both the IOD and ENSO indices that influence rainfall, Bar Charts and Spatial pattern analysis was used.

i) The comparison analysis of MQI-DMI and MQI-SOI relationships was assessed during the IOD years, 1990 (Negative IOD year) and 2003 (Positive IOD year), using spatial patterns on a map.

ii) The comparison analysis of the correlation coefficient results between the MQI and DMI and MQI and SOI during the Monsoon seasons significant at 10% level, was done using spatial pattern analysis and bar charts.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

This chapter presents the discussion of the results obtained from the Pearson correlation coefficient analysis between the rainfall and IOD on different timescales and its comparison with the results of the Pearson correlation coefficient analysis between the rainfall and ENSO, for all the selected synoptic stations in Nigeria in order to achieve the overall and specific objectives of the study.

4.1 Assessment of the nature of the temporal relationship between IOD phases and intra-seasonal rainfall patterns over the selected stations in Nigeria.

This section presents the nature of possible teleconnection between intra-seasonal rainfall and IOD indices in order to achieve objective one of the study.

4.1.1Temporal patterns of SST anomalies over the Indian Ocean associated with the IOD Phases.

Figure 4.1 shows the inter-annual variability of the Dipole Mode Indices (DMI) during the initial Phases (MAM, JJA, JAS) and the peak phase (SON).

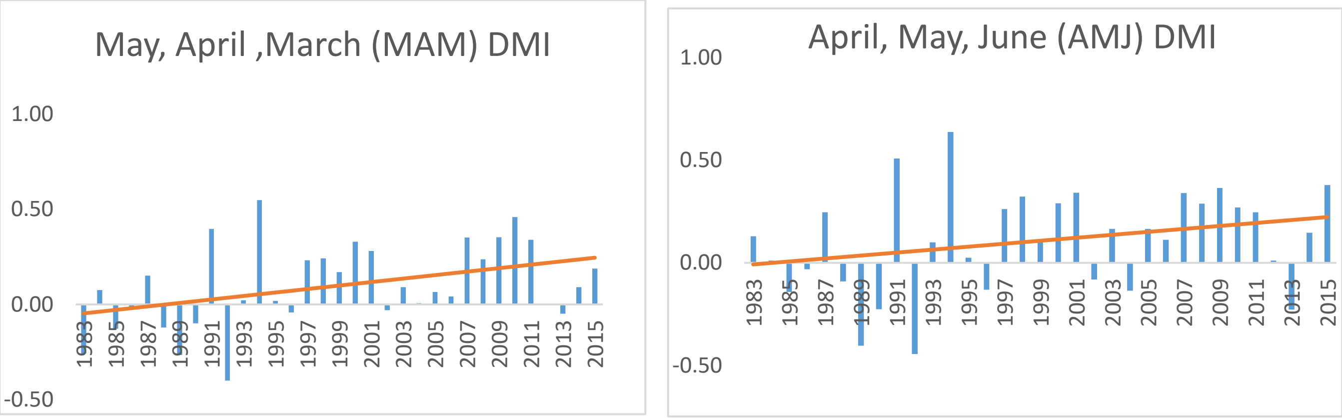


Figure 4.1- Inter-annual variability of the Dipole Mode Index (1983-2015).

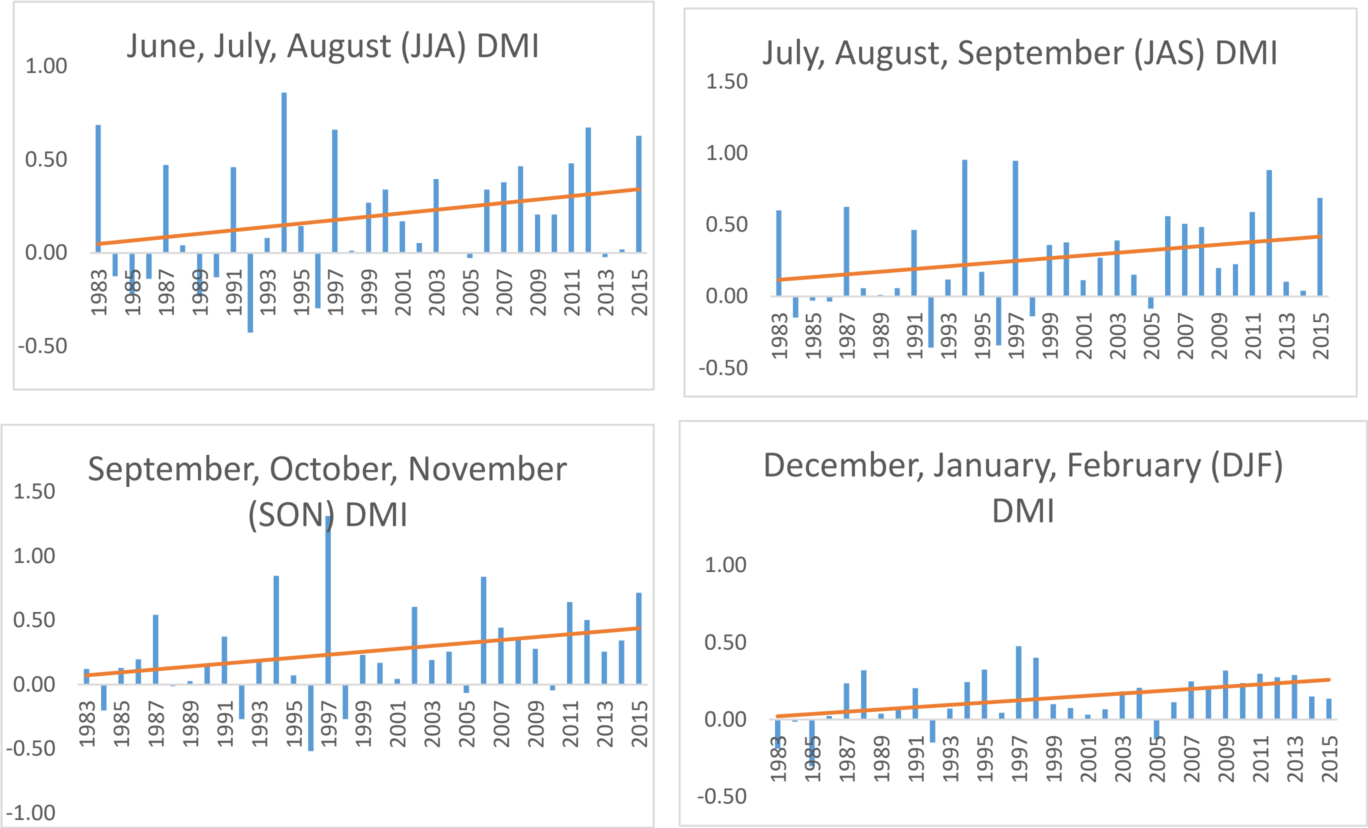


Figure 4.1- Inter-annual variability of the Dipole Mode Index (1983-2015).

It is observed that there are recurrences of more positive phases than negative phases of the IOD events from figure 4.1. It is also shown that the strength of DMI varies from year to year, season to season and event to event, hence the DMI trend increases from MAM, AMJ, JJA, JAS and peaks in SON, in agreement with the findings of Saji *et al.*, (1999) and Behera *et al.*, (2005).

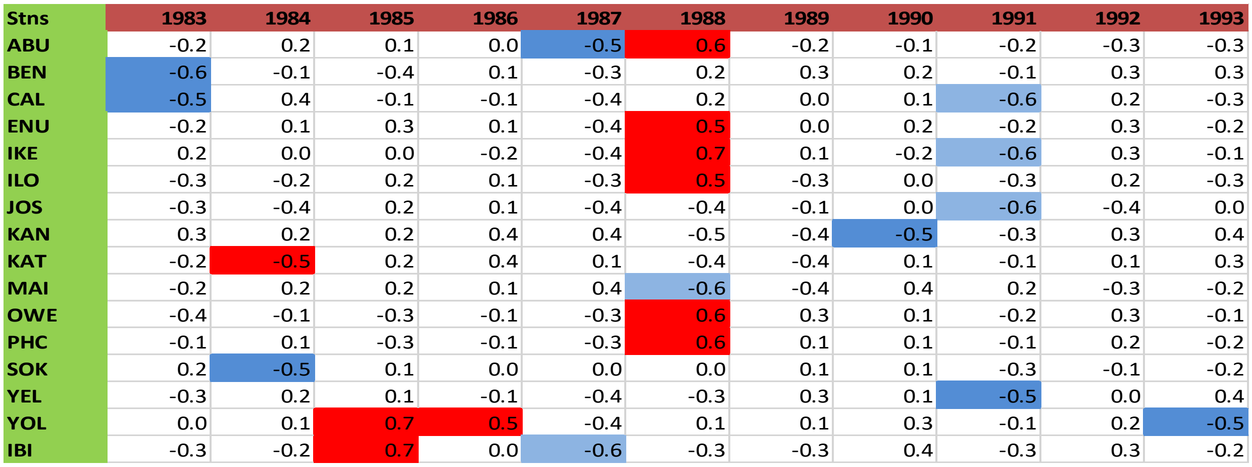
It is noteworthy that from the same figure 4.1, that there was intensification of the Sea Surface Temperature (SST) positve events in JJA, JAS and SON, during which the DMI exceded 0.5 standardized values. Hence, JJA season had five (5) positive years (1983, 1994, 1997, 2012, 2015), JAS season had eight (8) positive years (1983, 1987, 1994, 1997, 2006, 2011, 2012,

2015) and SON season had seven (7) positive years (1987, 1994, 1997, 2002, 2006, 2011, 2015). There was strong positive DMI in both JJA and JAS seasons in 1983 and 2012 but weakened in SON season. Meanwhile, the only negative event (defined as years during which the DMI exceeds -0.5 standardized values) occurred in SON season in 1996.

4.1.2 Pearson correlation coefficient analysis between the intraseasonal MQI and DMI over selected stations for a period of 33years (1983-2015)

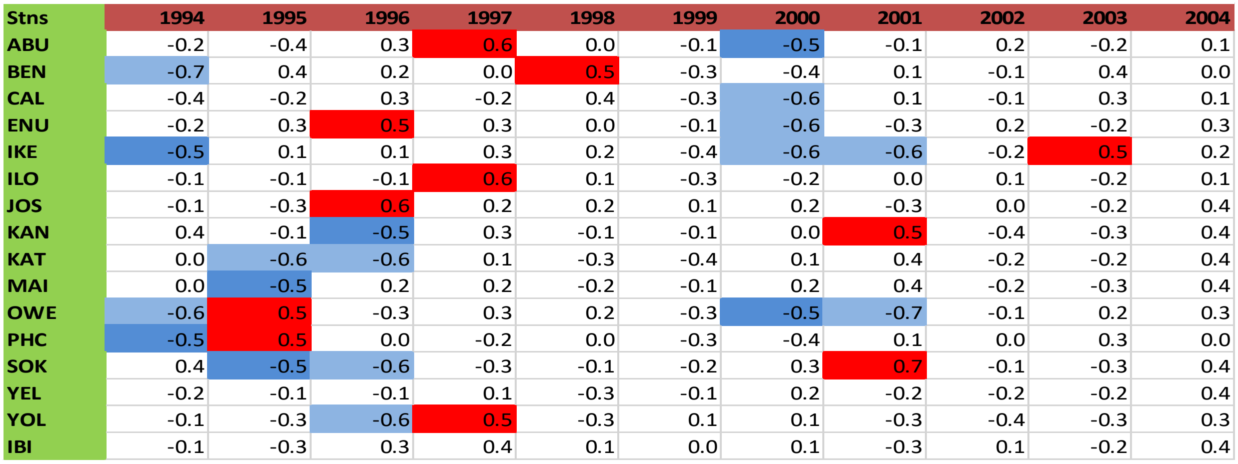
Pearson correlation coefficient analysis between the intraseasonal MQI and DMI is calculated using equation 5 and presented for three periods, 1983-1993, 1994-2004, 2005-2015, shown in Table 4.1-4.3. The red and blue coloured results show the correlation coefficients ≥ +0.5 or -0.5 respectively that have some significant relationship.

Table 4.1: Monthly correlation analysis results between MQI and DMI for 1983-1993



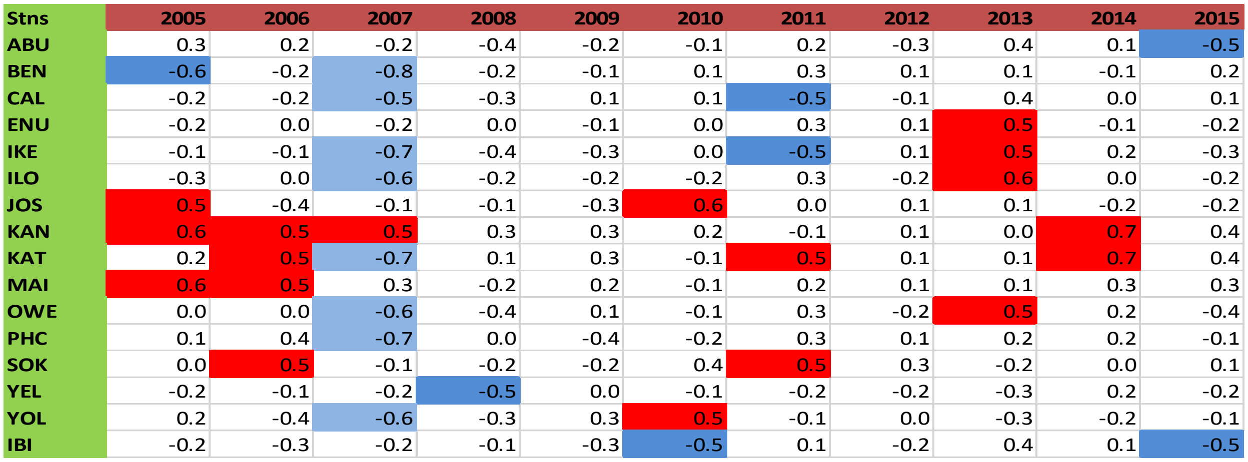
Stns	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
ABU	-0.2	0.2	0.1	0.0	-0.5	0.6	-0.2	-0.1	-0.2	-0.3	-0.3
BEN	-0.6	-0.1	-0.4	0.1	-0.3	0.2	0.3	0.2	-0.1	0.3	0.3
CAL	-0.5	0.4	-0.1	-0.1	-0.4	0.2	0.0	0.1	-0.6	0.2	-0.3
ENU	-0.2	0.1	0.3	0.1	-0.4	0.5	0.0	0.2	-0.2	0.3	-0.2
IKE	0.2	0.0	0.0	-0.2	-0.4	0.7	0.1	-0.2	-0.6	0.3	-0.1
ILO	-0.3	-0.2	0.2	0.1	-0.3	0.5	-0.3	0.0	-0.3	0.2	-0.3
JOS	-0.3	-0.4	0.2	0.1	-0.4	-0.4	-0.1	0.0	-0.6	-0.4	0.0
KAN	0.3	0.2	0.2	0.4	0.4	-0.5	-0.4	-0.5	-0.3	0.3	0.4
KAT	-0.2	-0.5	0.2	0.4	0.1	-0.4	-0.4	0.1	-0.1	0.1	0.3
MAI	-0.2	0.2	0.2	0.1	0.4	-0.6	-0.4	0.4	0.2	-0.3	-0.2
OWE	-0.4	-0.1	-0.3	-0.1	-0.3	0.6	0.3	0.1	-0.2	0.3	-0.1
PHC	-0.1	0.1	-0.3	-0.1	-0.3	0.6	0.1	0.1	-0.1	0.2	-0.2
SOK	0.2	-0.5	0.1	0.0	0.0	0.0	0.1	0.1	-0.3	-0.1	-0.2
YEL	-0.3	0.2	0.1	-0.1	-0.4	-0.3	0.3	0.1	-0.5	0.0	0.4
YOL	0.0	0.1	0.7	0.5	-0.4	0.1	0.1	0.3	-0.1	0.2	-0.5
IBI	-0.3	-0.2	0.7	0.0	-0.6	-0.3	-0.3	0.4	-0.3	0.3	-0.2

Table 4.2: Monthly correlation analysis results between MQI and DMI for 1994-2004



Stns	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
ABU	-0.2	-0.4	0.3	0.6	0.0	-0.1	-0.5	-0.1	0.2	-0.2	0.1
BEN	-0.7	0.4	0.2	0.0	0.5	-0.3	-0.4	0.1	-0.1	0.4	0.0
CAL	-0.4	-0.2	0.3	-0.2	0.4	-0.3	-0.6	0.1	-0.1	0.3	0.1
ENU	-0.2	0.3	0.5	0.3	0.0	-0.1	-0.6	-0.3	0.2	-0.2	0.3
IKE	-0.5	0.1	0.1	0.3	0.2	-0.4	-0.6	-0.6	-0.2	0.5	0.2
ILO	-0.1	-0.1	-0.1	0.6	0.1	-0.3	-0.2	0.0	0.1	-0.2	0.1
JOS	-0.1	-0.3	0.6	0.2	0.2	0.1	0.2	-0.3	0.0	-0.2	0.4
KAN	0.4	-0.1	-0.5	0.3	-0.1	-0.1	0.0	0.5	-0.4	-0.3	0.4
KAT	0.0	-0.6	-0.6	0.1	-0.3	-0.4	0.1	0.4	-0.2	-0.2	0.4
MAI	0.0	-0.5	0.2	0.2	-0.2	-0.1	0.2	0.4	-0.2	-0.3	0.4
OWE	-0.6	0.5	-0.3	0.3	0.2	-0.3	-0.5	-0.7	-0.1	0.2	0.3
PHC	-0.5	0.5	0.0	-0.2	0.0	-0.3	-0.4	0.1	0.0	0.3	0.0
SOK	0.4	-0.5	-0.6	-0.3	-0.1	-0.2	0.3	0.7	-0.1	-0.3	0.4
YEL	-0.2	-0.1	-0.1	0.1	-0.3	-0.1	0.2	-0.2	-0.2	-0.2	0.4
YOL	-0.1	-0.3	-0.6	0.5	-0.3	0.1	0.1	-0.3	-0.4	-0.3	0.3
IBI	-0.1	-0.3	0.3	0.4	0.1	0.0	0.1	-0.3	0.1	-0.2	0.4

Table 4.3: Monthly correlation analysis results between MQI and DMI for 2005-2015



Stns	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
ABU	0.3	0.2	-0.2	-0.4	-0.2	-0.1	0.2	-0.3	0.4	0.1	-0.5
BEN	-0.6	-0.2	-0.8	-0.2	-0.1	0.1	0.3	0.1	0.1	-0.1	0.2
CAL	-0.2	-0.2	-0.5	-0.3	0.1	0.1	-0.5	-0.1	0.4	0.0	0.1
ENU	-0.2	0.0	-0.2	0.0	-0.1	0.0	0.3	0.1	0.5	-0.1	-0.2
IKE	-0.1	-0.1	-0.7	-0.4	-0.3	0.0	-0.5	0.1	0.5	0.2	-0.3
ILO	-0.3	0.0	-0.6	-0.2	-0.2	-0.2	0.3	-0.2	0.6	0.0	-0.2
JOS	0.5	-0.4	-0.1	-0.1	-0.3	0.6	0.0	0.1	0.1	-0.2	-0.2
KAN	0.6	0.5	0.5	0.3	0.3	0.2	-0.1	0.1	0.0	0.7	0.4
KAT	0.2	0.5	-0.7	0.1	0.3	-0.1	0.5	0.1	0.1	0.7	0.4
MAI	0.6	0.5	0.3	-0.2	0.2	-0.1	0.2	0.1	0.1	0.3	0.3
OWE	0.0	0.0	-0.6	-0.4	0.1	-0.1	0.3	-0.2	0.5	0.2	-0.4
PHC	0.1	0.4	-0.7	0.0	-0.4	-0.2	0.3	0.1	0.2	0.2	-0.1
SOK	0.0	0.5	-0.1	-0.2	-0.2	0.4	0.5	0.3	-0.2	0.0	0.1
YEL	-0.2	-0.1	-0.2	-0.5	0.0	-0.1	-0.2	-0.2	-0.3	0.2	-0.2
YOL	0.2	-0.4	-0.6	-0.3	0.3	0.5	-0.1	0.0	-0.3	-0.2	-0.1
IBI	-0.2	-0.3	-0.2	-0.1	-0.3	-0.5	0.1	-0.2	0.4	0.1	-0.5

From these correlation analysis results, it is observed that there existed moderate-strong significant relationship between the MQI and DMI over some of the stations, with positive relationship in the following years; 1985, 1986, 1988, 1997, 1998, 2003, 2005, 2006, 2010, 2013, and 2014. In contrast, there were negative relationships in the following years; 1987, 1990, 1991, 1993, 1994, 1995, 1996, 2000, 2007, and 2015. Weak Pearson correlation coefficient values were observed for 1983, 1984, 1990, 1992, 1999, 2002, 2004, 2009, and 2012.

Table 4.4: The intra-seasonal Pearson correlation coefficient values between MQI and DMI for each station for 1983-2015 period

STATIONS	POSITIVE CORRELATION (≥ +0.5)	NEGATIVE CORRELATION (≤ -0.5)
ABUJA	1988, 1997	1987, 2000, 2015
BENIN	1998	1983, 1994, 2005, 2007
CALABAR	-	1983, 1991, 2000, 2007, 2011
ENUGU	1988, 1996, 2013	2000
IKEJA	1988, 2003, 2013	1991, 1994, 2000, 2001,2007, 2008
ILORIN	1988, 1997, 2013	2007
JOS	1996, 2005, 2010	1991
KANO	2001, 2005, 2006, 2007, 2014	1990, 1996
KATSINA	1984, 2006, 2011, 2014	1995, 1996
MAIDUGURI	2005, 2006	1988, 1995
OWERRI	1988, 1995, 2013	1994, 2000, 2001, 2007
PORTHARCOURT	1988, 1995	1994, 2007
SOKOTO	2001, 2006,2011	1984, 1995, 1996
YELWA	-	1991, 2008
YOLA	1985, 1986, 1997, 2010	1993, 1996, 2007
IBI	1985	1987, 2010, 2015

Table 4.4 shows that the occurrence of positive correlation values were higher over some stations in the north; Kano, Katsina, Yola, Jos, with some southern stations like Ilorin and Enugu, while Maiduguri and Sokoto had equal occurrence of positive and negative correlations. This could be deduced that the increase or decrease of rainfall amount has a direct relationship with the increase or decrease of positive DMI, hence this shows that the positive IODMI teleconnection with the rainfall pattern has moderate significant relationship with sub-continental region of the north.

However, the reverse seems to be the case where the occurrence of negative correlation values were higher over some stations in the south - Ikeja, Calabar, Benin, Owerri, and some northern stations- Abuja, Ibi, with Yelwa having only negative correlation. Hence, this shows that the increase or decrease of rainfall amount has an inverse relationship with the increase or decrease of negative DMI, hence this shows that the negative IODMI teleconnection with the rainfall pattern has moderate significant relationship with inland and coastal region of the south.

Although from table 4.4 there is no clear observed trend, however some stations had the impact of the IODMI in different years. During the Positive IOD years there seems to be a direct relationship with mostly rainfall in the stations over the north and an inverse relationship with the rainfall in southern stations. For instance, in 1997 and 2006, the following northern stations- Abuja, Ilorin, Yola, Kano, Katsina, Maiduguri and Sokoto had positive correlations while in 1983 and 1994, the following southern stations- Benin, Calabar, Ikeja, Owerri and Portharcourt had negative correlations. Hence, the influence of Positive IOD years showed a weak to moderate trend with the stations over north and south of the study area.

Meanwhile, during the Negative IOD years, the reverse is the case where some of the northern stations like Kano, Katsina, Sokoto in 1996 had negative correlations with positive correlations in Enugu and Jos, though not well defined as compared with its impact during Positive IOD years.

4.1.3 Pearson correlation coefficient analysis between the 3 months moving average of intra-seasonal MQI and DMI over selected stations for a period of 33years (1983-2015)

Pearson correlation coefficient analysis between the intra-seasonal MQI and DMI calculated using equation5 is presented in three periods (1983-1993), (1994-2004), (2005-2015) shown in Table 4.5-4.7. The red and blue colored results shows the correlation coefficient ≥ +0.5 or -0.5 respectively that have some significant relationship.

Table 4.5: Mean monthly moving average correlation analysis results between MQI and DMI for 1983-1993 over the selected stations

Stns	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**
ABU	-0.3	0.4	0.6	0.7	-0.9	0.7	-0.2	0.2	-0.2	0.1	0.0
BEN	-0.9	-0.4	-0.7	0.0	0.0	0.4	0.3	0.0	-0.2	0.4	-0.7
CAL	-0.9	0.5	0.3	0.3	-0.5	0.5	0.4	-0.2	-0.9	0.2	0.0
ENU	-0.5	0.0	0.1	0.1	-0.8	0.6	0.3	0.4	-0.3	0.8	0.0
IKE	0.3	-0.3	-0.5	-0.1	-0.5	0.6	0.4	0.1	-0.9	0.7	-0.3
ILO	-0.4	-0.4	0.1	0.6	-0.8	0.6	-0.4	0.4	-0.6	0.5	-0.1
JOS	-0.5	-0.6	-0.1	0.6	-0.7	0.1	0.0	0.7	-0.9	0.0	-0.8
KAN	0.2	0.6	-0.3	0.3	0.6	-0.6	-0.7	-0.7	-0.7	0.8	0.6
KAT	-0.3	-0.7	-0.3	-0.6	0.1	-0.8	-0.8	0.1	-0.4	0.6	-0.1
MAI	-0.3	0.1	-0.3	-0.4	0.6	-0.7	-0.6	0.7	0.0	-0.2	-0.5
OWE	-0.8	0.3	-0.2	0.3	-0.8	0.6	0.4	0.0	-0.3	0.3	0.0
PHC	-0.1	-0.2	-0.3	0.3	-0.4	0.6	0.4	0.0	-0.2	0.2	0.1
SOK	0.1	-0.7	0.0	-0.5	-0.4	-0.6	0.5	-0.6	-0.7	-0.5	-0.5
YEL	-0.5	0.7	0.4	0.4	-0.7	0.1	0.3	0.7	-0.7	-0.4	0.7
YOL	0.1	0.6	0.7	0.6	-0.8	0.3	0.5	0.7	-0.2	0.8	-0.7
IBI	-0.6	-0.5	0.4	0.7	-0.9	0.0	-0.5	0.7	-0.4	0.7	0.1

Table 4.6: Mean monthly moving average correlation analysis results between MQI and DMI for 1994-2004 over the selected stations

Stns	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
ABU	-0.6	-0.2	0.8	0.6	0.2	-0.2	-0.8	-0.2	0.7	-0.7	0.6
BEN	-0.9	0.0	0.0	-0.2	0.6	-0.4	-0.4	-0.4	0.3	-0.2	0.3
CAL	-0.6	-0.1	0.1	-0.4	0.4	-0.3	-0.7	-0.3	0.2	-0.1	0.3
ENU	-0.3	0.6	0.8	0.5	0.0	-0.3	-0.2	-0.6	0.2	-0.8	0.4
IKE	-0.7	0.2	-0.3	0.4	0.1	-0.3	-0.5	-0.3	-0.1	0.1	0.4
ILO	0.0	0.0	0.5	0.7	0.0	-0.4	-0.6	0.0	0.5	-0.1	0.6
JOS	0.2	-0.2	0.7	0.5	0.3	-0.4	-0.1	-0.5	-0.4	-0.1	0.7
KAN	0.0	0.0	-0.7	0.4	0.1	0.0	-0.5	0.7	-0.6	-0.5	-0.2
KAT	-0.4	-0.7	-0.8	0.5	-0.5	-0.6	0.3	0.7	-0.6	-0.6	0.6
MAI	-0.4	-0.7	0.8	0.6	-0.2	-0.2	-0.2	0.9	-0.5	-0.6	0.5
OWE	-0.8	0.4	-0.6	0.5	-0.1	-0.3	-0.8	-0.5	-0.5	0.4	0.4
PHC	-0.7	0.1	-0.4	0.1	0.1	-0.3	-0.4	-0.2	0.1	-0.1	0.4
SOK	0.5	-0.7	-0.8	-0.6	-0.3	-0.1	0.3	1.0	-0.1	-0.4	0.5
YEL	-0.5	0.2	0.5	-0.1	-0.7	-0.5	0.2	-0.6	-0.5	-0.2	0.7
YOL	0.2	0.0	-0.9	0.7	-0.7	-0.4	-0.5	-0.6	-0.6	-0.6	0.4
IBI	0.2	0.0	0.8	0.6	0.4	-0.5	-0.5	-0.5	-0.1	-0.1	0.6

Table 4.7: Mean monthly moving average correlation analysis results between MQI and DMI for 2005-2015 over the selected stations

Stns	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
ABU	0.1	0.4	-0.2	-0.7	0.0	0.3	0.3	-0.4	0.8	0.6	-0.7
BEN	-0.7	-0.2	-0.7	-0.4	0.0	0.3	0.2	0.0	0.4	-0.3	0.3
CAL	-0.3	-0.6	-0.6	-0.6	0.1	0.4	0.0	-0.6	0.5	0.2	0.2
ENU	-0.4	0.1	-0.4	-0.3	0.2	0.1	0.4	-0.2	0.7	-0.2	-0.6
IKE	-0.1	0.1	-0.7	-0.4	-0.4	0.1	-0.1	0.0	0.5	0.6	-0.6
ILO	-0.5	-0.5	-0.4	-0.5	0.2	-0.6	0.0	-0.6	0.8	0.4	-0.4
JOS	0.5	-0.7	0.0	-0.8	0.1	0.8	-0.1	0.4	0.5	-0.3	-0.6
KAN	0.5	0.9	0.6	0.1	0.2	0.2	-0.6	0.4	0.5	0.7	0.6
KAT	0.2	0.8	-0.7	-0.2	-0.2	0.2	0.7	0.4	0.6	0.9	0.6
MAI	0.5	-0.2	-0.2	-0.2	0.3	0.2	0.2	0.3	0.6	-0.2	0.3
OWE	-0.2	0.1	-0.7	-0.2	0.1	-0.1	0.1	-0.6	0.6	0.6	-0.6
PHC	-0.2	0.6	-0.6	-0.3	0.1	-0.5	0.2	0.0	0.4	0.5	0.0
SOK	-0.2	0.8	-0.3	-0.5	0.2	0.6	0.7	0.6	0.2	-0.2	-0.9
YEL	-0.2	-0.6	0.2	-0.7	0.4	-0.5	-0.7	0.0	-0.4	0.5	-0.6
YOL	0.3	-0.6	-0.6	-0.3	0.1	0.8	-0.6	0.2	-0.4	-0.3	-0.5
IBI	-0.3	-0.7	-0.3	-0.5	0.4	-0.8	-0.1	0.1	0.6	0.2	-0.6

From the correlation analysis results shown in Tables 4.5-4.7, the results showed better moderate- very strong significant relationship between the rainfall (MQI) and DMI over across the stations with dominant positive values in the following years- 1986, 1988, 1990, 1992, 1996, 1997, 2004, 2005, 2013, 2014, while there were dominant negative values in the following years- 1983, 1987, 1989, 1991, 1993, 1994, 1995, 1998, 1999, 2000, 2001,2002, 2003, 2006, 2007, 2008, 2010, 2011, 2012, 2015.

Table 4.8: The 3 months moving average of intra-seasonal Pearson correlation coefficient values between MQI and DMI for each station for 1983-2015 period

STATIONS	POSITIVE CORRELATION (≥ +0.5)	NEGATIVE CORRELATION (≤ -0.5)
ABUJA	1985,1986,1988,1996,1997,2002,2004,2013,2015	1994,1987, 2000,2003,2008, 2015
BENIN	1998	1983, 1994, 2005, 2007
CALABAR	1984,1988,2013	1983,1987, 1991,1994, 2000,2006, 2007,2008,2012
ENUGU	1988,1992,1995,1996, 1997,2013	2000
IKEJA	1988,1992,2013,2014	1985,1987,1991, 1994, 2000, 2001,2007, 2015
ILORIN	1986,1988,1992,1996 1997,2002,2004,2013	1987,1991,2000,2005,2006,2008,2010,2012
JOS	1986,1990,1996,1997,2004,2005, 2010,2013	1983,1984,1987,1991,1993,2001,2006,2008,2015
KANO	1984,1987,1992,1993,2001, 2005, 2006, 2007,2013, 2014,2015	1988,1989,1990,1991,1996,2000,2002,2003,2011
KATSINA	1992,1997,2001,2004,2006,2006,2011,2013 ,2014, 2015	1984,1986,1988,1989,1995, 1996,1998, 1999,2002,2003, 2007
MAIDUGURI	1987,1990,1996,1997,2001,2004,2005,2013	1988,1989,1993,1995,2002,2003
OWERRI	1988,2013,2014	1983,1987,1994,1996,2000,2001,2002,2007,2012,2015
PORTHARCOURT	1988,2006,2014	1994,2007,2010
SOKOTO	1989,1994,2006,2010,2011,2012	1984,1986,1988,1990,1991,1992,1993,2008,2015
YELWA	1984,1990,1993,1996,2004,2012,2014	1983,1987,1991,1994,1998,2001,2002,2006,2007,2011,2015
YOLA	1984,1985, 1986,1989,1990,1992,1997, 2010	1987,1993,1996,1998,2000,2001,2003,2006,2007,2011,2015
IBI	1986,1990,1992,1996,1997,2004,2013	1983,1984,1987,1989,1999,2000,2001,2006,2008,2010, 2015

From tables 4.5-4.7, it shows a stronger Pearson correlation coefficient with both contrasting positive and negative signs which indicates that there is a better correlation on a 3 months average basis as compared with the correlation coefficient values on a monthly basis as shown in table 4.4.

Although, there are contrasting strong positive and negative years, table 4.8 shows that there are much more positive correlation with the stations in the northern and southern fringes of the north of the country (Sokoto, Kano, Katsina, Maiduguri, Yola, Yelwa, Abuja, Jos, Ibi) though with exceptions of Ilorin and Enugu that had more positive correlations. In the contrary, most of the other southern part of the country (Benin, Calabar, Ikeja, Owerri) had negative correlations with portharcourt having same number positive and negative years as earlier seen in table 4.4.

Thus, table 4.8 shows that the rainfall pattern of stations in the northern part of the country have more positive correlations with the IODMI and conversely the rainfall pattern in the southern part of the country have more negative correlations with the IODMI.

4.1.4 Time series/graphical representation of monthly and 3 months moving average of correlation coefficient for each station for 1983-2015 period.

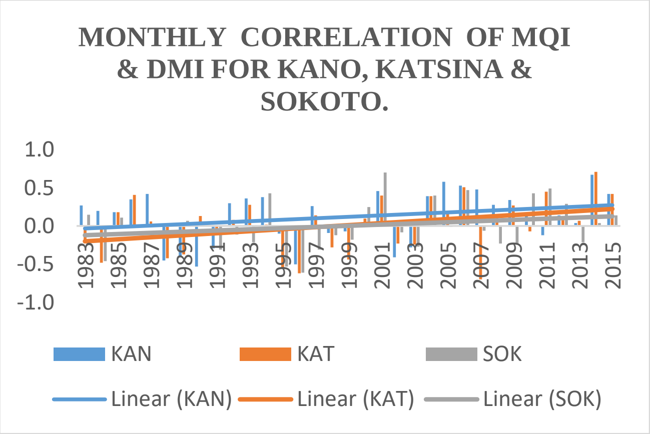
With a view of further investigating of possible teleconnections between rainfall in Nigeria and IOD/DMI, the monthly and 3 months running average correlation coefficient values for each stations for the period under study was done by combining three (3) stations over the north, inland of the south and four (4) stations over the coastal parts of the country as shown in figures 4.2(a, b, c, d & e).

This is to assess the spatio-temporal behavior of rainfall and DMI over the selected stations and it was observed that most of the stations over the north like Kano, Sokoto, Katsina, Maiduguri and Jos had moderate to strong positive trends in both monthly and 3-months basis as shown in figure

4.2b with exception of Abuja that showed negative trend on 3-months basis while Yelwa, Yola and Ibi had weak negative trends in both monthly and 3-months basis as shown in figure 4.2(c).

However, other stations in the south like Enugu, Ilorin, Owerri, also had negative trends as shown in figure 4.2(d). While the coastal stations - Benin, Calabar, Ikeja, Portharcourt showed no trend as shown in figure 4.2(e).

Hence, the results showed sufficient statistical evidence of a significant increasing and decreasing trends in the selected stations as aforementioned for all locations considered in study.



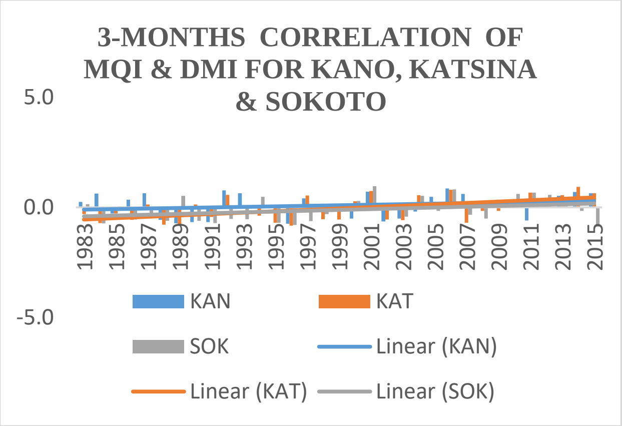


Figure 4.2a – Time series of monthly and 3-mont

Katsina and Sokoto from 1983-2015

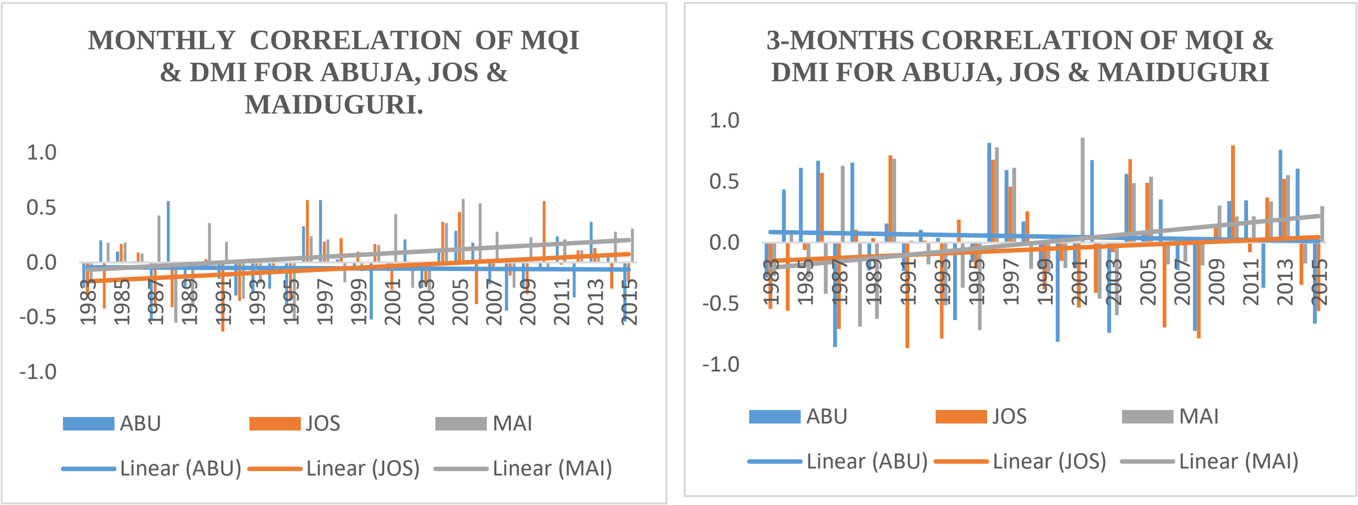


Figure 4.2b- Time series of monthly and 3-months correlation of MQI & DMI for Abuja, Jos and Maiduguri from 1983-2015

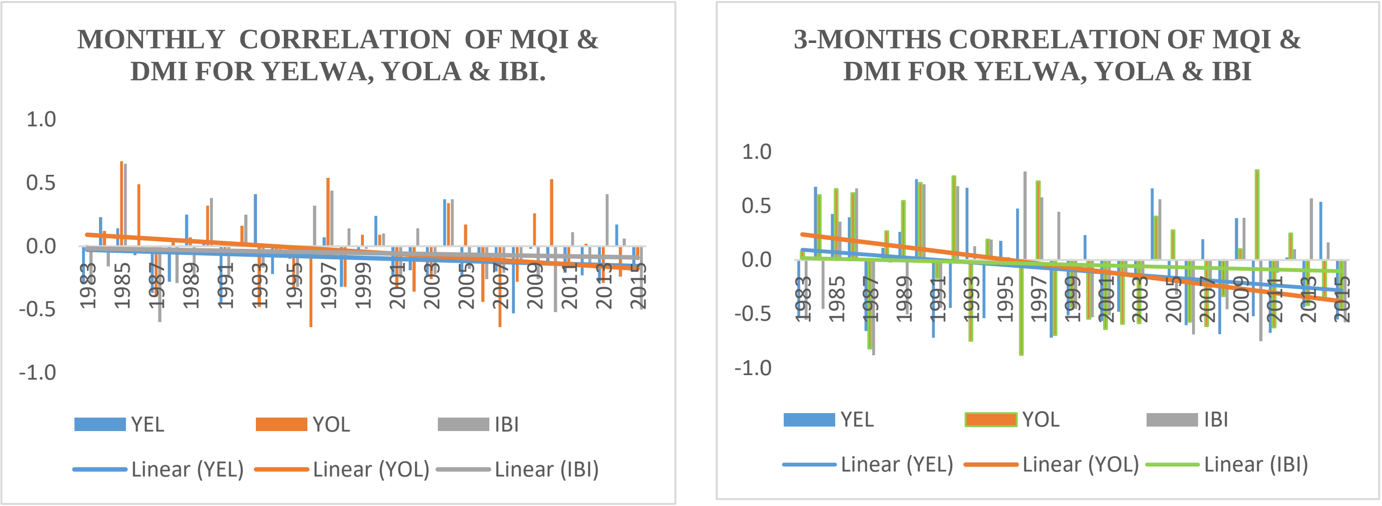


Figure 4.2c- Time series of monthly and 3-months correlation of MQI & DMI for Yelwa, Yola and Ibi from 1983-2015

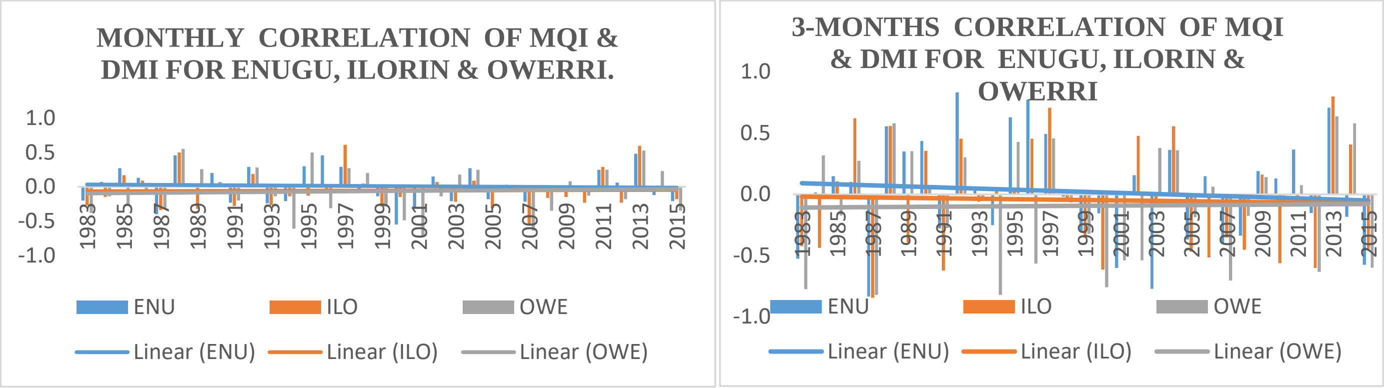


Figure 4.2d- Time series of monthly and 3-months correlation of MQI & DMI for Enugu, Ilorin and Owerri from 1983-2015

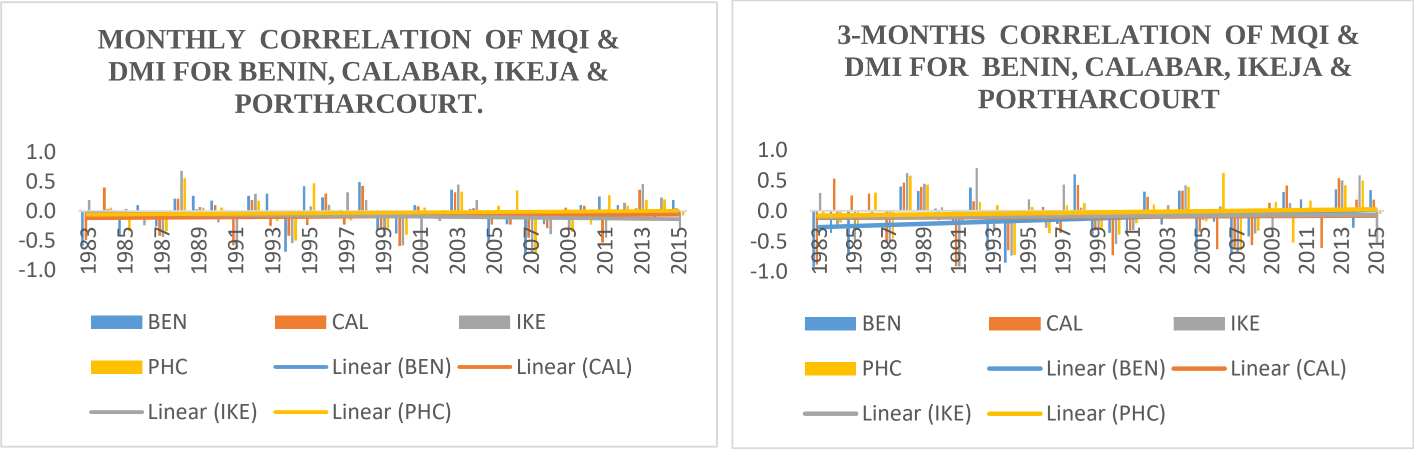


Figure 4.2e- Time series of monthly and 3-months correlation of MQI & DMI for Benin, Calabar, Ikeja and Portharcourt from 1983-2015

4.1.5 Pearson correlation coefficient analysis between the 3 months moving averages of intraseasonal MQI and DMI during monsoon seasons over selected stations for a period of 33years (1983-2015)

Further analysis was carried out to assess the relationship between DMI and rainfall during monsoon seasons starting with MAM, AMJ, MJJ, JJA, JAS, ASO and SON over each stations. The values of the Pearson correlation coefficient analysis was also computed using equation5 and presented in three periods (1983-1993), (1994-2004), (2005-2015) shown in Table 4.9-4.11. The red and blue colored results shows the correlation coefficient ≥ +0.5 or -0.5 respectively that have some significant relationship.

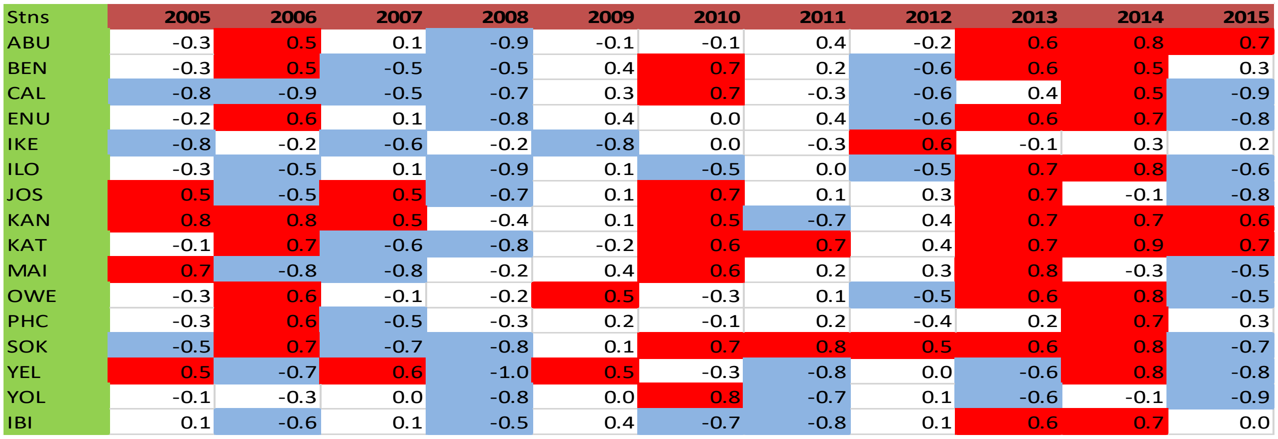
Table 4.9: Mean monthly moving average correlation analysis results between MQI and DMI during monsoon season for 1983-1993

Stns	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
ABU	-0.6	0.7	0.6	0.7	-0.8	-0.7	-0.4	0.6	-0.5	0.0	-0.8
BEN	-0.9	-0.4	-0.2	-0.3	0.1	0.1	0.4	0.0	-0.7	0.9	-0.4
CAL	-0.8	0.7	-0.2	0.0	-0.1	-0.6	0.3	-0.2	-0.6	0.9	-0.8
ENU	-0.9	-0.1	0.8	0.7	-0.7	-0.7	0.2	0.6	-0.5	0.9	-0.7
IKE	0.1	-0.4	-0.3	-0.1	-0.4	0.1	0.5	0.5	-0.7	-0.2	-0.1
ILO	-0.2	-0.4	0.9	0.7	-0.9	0.1	-0.5	0.7	-0.5	0.5	-0.8
JOS	-0.8	-0.6	-0.1	0.6	-0.9	-0.5	-0.2	0.7	-0.7	-0.1	-0.7
KAN	-0.4	0.7	-0.3	0.4	0.6	-0.8	-0.8	-0.8	-0.7	0.8	0.6
KAT	-0.7	-0.6	-0.3	-0.6	-0.2	-0.9	-0.8	0.7	-0.8	0.6	-0.4
MAI	-0.6	0.3	-0.3	-0.4	0.6	-0.9	-0.6	0.6	-0.7	-0.3	-0.7
OWE	-0.4	-0.4	0.8	0.5	-0.8	0.0	0.3	-0.1	-0.5	0.7	-0.1
PHC	-0.3	-0.1	0.7	0.4	-0.7	0.1	0.5	-0.1	-0.6	0.5	0.5
SOK	-0.4	-0.7	-0.6	-0.6	-0.9	-0.8	0.6	-0.9	-0.8	-0.5	-0.7
YEL	-0.8	0.5	0.4	0.4	-0.9	0.0	0.5	0.7	-0.4	-0.5	0.6
YOL	-0.1	0.4	0.6	0.8	-0.7	0.1	0.6	0.6	-0.6	0.7	-0.6
IBI	-0.8	-0.4	0.5	0.7	-0.8	-0.6	-0.6	0.6	-0.6	0.7	0.6

Table 4.10: Mean monthly moving average correlation analysis results between MQI and DMI during monsoon season for 1994-2004

Stns	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
ABU	-0.4	-0.3	0.6	0.5	-0.4	0.0	-0.9	-0.3	0.7	-0.8	0.5
BEN	0.0	-0.6	-0.3	0.0	-0.3	-0.4	-0.9	-0.5	0.4	-0.5	0.4
CAL	-0.1	-0.1	-0.6	-0.5	0.6	-0.9	-0.2	0.0	0.1	-0.4	0.3
ENU	-0.1	-0.2	0.8	0.5	-0.5	0.0	0.1	-0.6	0.2	-0.7	0.0
IKE	0.8	-0.2	-0.7	-0.4	-0.1	0.1	-0.9	0.0	-0.2	0.8	0.4
ILO	0.1	-0.6	0.6	0.6	-0.7	-0.1	-0.5	0.2	0.6	-0.2	0.5
JOS	0.1	0.0	0.1	0.6	0.6	-0.2	0.0	-0.6	-0.3	-0.2	0.7
KAN	-0.9	-0.6	-0.5	0.2	0.3	0.1	-0.7	0.7	-0.7	-0.8	0.4
KAT	-0.8	-0.7	-0.8	0.3	-0.3	-0.9	0.0	0.7	-0.7	-0.8	0.8
MAI	-0.8	-0.7	0.7	0.5	0.0	-0.4	-0.5	0.9	-0.5	-0.9	0.8
OWE	-0.5	-0.2	-0.6	0.1	-0.5	-0.4	-0.1	-0.5	-0.6	0.2	0.0
PHC	-0.3	-0.4	-0.3	-0.2	-0.3	-0.1	-0.7	-0.4	0.0	-0.3	0.0
SOK	0.5	-0.7	-0.8	-0.5	0.2	-0.2	-0.1	0.9	-0.2	-0.7	0.8
YEL	-0.4	-0.6	0.7	-0.4	-0.5	-0.8	0.0	-0.7	-0.5	-0.5	0.6
YOL	0.1	-0.6	-0.9	0.6	-0.5	-0.3	-0.7	-0.8	-0.6	-0.8	0.6
IBI	0.1	-0.5	0.6	0.3	0.8	-0.7	-0.6	-0.7	0.0	-0.3	0.8

Table 4.11: Mean monthly moving average correlation analysis results between MQI and DMI during monsoon season for 2005-2015



Stns	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
ABU	-0.3	0.5	0.1	-0.9	-0.1	-0.1	0.4	-0.2	0.6	0.8	0.7
BEN	-0.3	0.5	-0.5	-0.5	0.4	0.7	0.2	-0.6	0.6	0.5	0.3
CAL	-0.8	-0.9	-0.5	-0.7	0.3	0.7	-0.3	-0.6	0.4	0.5	-0.9
ENU	-0.2	0.6	0.1	-0.8	0.4	0.0	0.4	-0.6	0.6	0.7	-0.8
IKE	-0.8	-0.2	-0.6	-0.2	-0.8	0.0	-0.3	0.6	-0.1	0.3	0.2
ILO	-0.3	-0.5	0.1	-0.9	0.1	-0.5	0.0	-0.5	0.7	0.8	-0.6
JOS	0.5	-0.5	0.5	-0.7	0.1	0.7	0.1	0.3	0.7	-0.1	-0.8
KAN	0.8	0.8	0.5	-0.4	0.1	0.5	-0.7	0.4	0.7	0.7	0.6
KAT	-0.1	0.7	-0.6	-0.8	-0.2	0.6	0.7	0.4	0.7	0.9	0.7
MAI	0.7	-0.8	-0.8	-0.2	0.4	0.6	0.2	0.3	0.8	-0.3	-0.5
OWE	-0.3	0.6	-0.1	-0.2	0.5	-0.3	0.1	-0.5	0.6	0.8	-0.5
PHC	-0.3	0.6	-0.5	-0.3	0.2	-0.1	0.2	-0.4	0.2	0.7	0.3
SOK	-0.5	0.7	-0.7	-0.8	0.1	0.7	0.8	0.5	0.6	0.8	-0.7
YEL	0.5	-0.7	0.6	-1.0	0.5	-0.3	-0.8	0.0	-0.6	0.8	-0.8
YOL	-0.1	-0.3	0.0	-0.8	0.0	0.8	-0.7	0.1	-0.6	-0.1	-0.9
IBI	0.1	-0.6	0.1	-0.5	0.4	-0.7	-0.8	0.1	0.6	0.7	0.0

Tables 4.9-4.11 shows the Pearson correlation coefficient done on a 3 months moving average specifically to suit both the monsoon seasons experienced in the study area and the IODMI seasons (MAM, AMJ, MJJ, JJA, JAS, ASO, SON).

This is to better assess the level of relationship between the two variables and from the tables 4.9-4.11, it shows clearly of the years that majority of the stations had either purely or more positive or negative correlations for instance Years with positive correlation were 1984, 1985, 1986, 1990, 1992, 1996, 1997, 2004, 2006, 2010, 2013 and 2014 while years with negative correlation were 1983, 1987, 1988, 1991, 1993, 1995, 1998, 1999, 2000, 2001, 2002, 2003, 2007, 2008, 2011, 2012 and 2015.

Various researchers like Saji *et al.*, 1999, Yamagata *et al.*, 2004 and from Bureau of Meteorology (BOM) website-www.bom.gov.au/climate/iod/, agreed to some positive and negative IOD years as follows; Positive IOD years (1982, 1983, 1991, 1994, 1997, 2003, 2006, 2007, 2008, 2012, 2015) while Negative IOD years (1980 ,1981, 1985, 1989, 1990, 1992, 1996, 1998, 2005, 2010).

However, comparing the Pearson correlation during the monsoon seasons between the rainfall over the stations and DMI during the positive and negative IOD years, there seems to be significant negative correlations between the rainfall and DMI during some of the positive IOD (pIOD) years - (1983,1991, 2003,2007,2008, 2012 and 2015). Whereas, the reverse is the case during negative IOD (nIOD) years, having significant positive correlations between the rainfall and DMI for these years- (1985, 1986, 1990, 1992, 1996 and 2010), as shown in table 4.12.

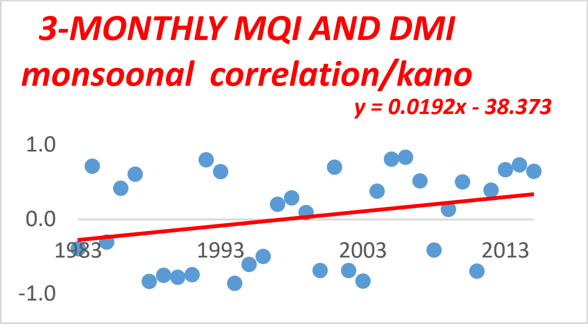
Furthermore, table 4.12 reveals that there is a negative correlation between NMSR and IODMI during some Positive IOD years while there is a positive correlation between NMSR and IODMI during some Negative IOD years, hence, the contrasting tendencies to increase rainfall at a certain period of the year or decrease it at another period.

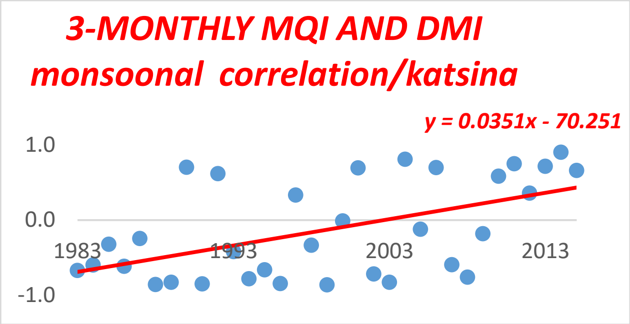
Table 4.12- Comparison of the (pIOD) years/negative correlation years and (nIOD) years/positive correlation years

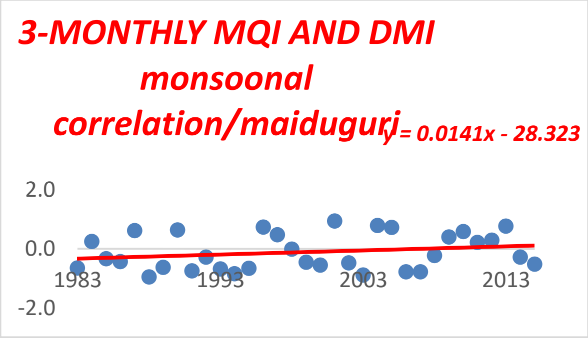
Positive (IOD) Years	Negative Correlation Yrs.	Negative (IOD) Years	Positive Correlation Yrs.
1983	1983	1985	1985
	1987		1986
	1988	1990	1990
1991	1991	1992	1992
	1995	1996	1996
	2000		1997
2003	2003		2004
2007	2007		2006
2008	2008	2010	2010
2012	2012		2013

4.1.6 Scatterplot showing the correlation coefficient between the 3 months moving averages of MQI and DMI during monsoon seasons for each station

This section shows the scatterplots of the 3-months running average for all monsoon seasons for each station and the results showed sufficient statistical evidence of a significant increasing trend at 10% level of significance for Sokoto, Kano, Katsina, Maiduguri, Jos, Abuja, Ibi in the north and Benin in the south as shown in figure 4.3a.

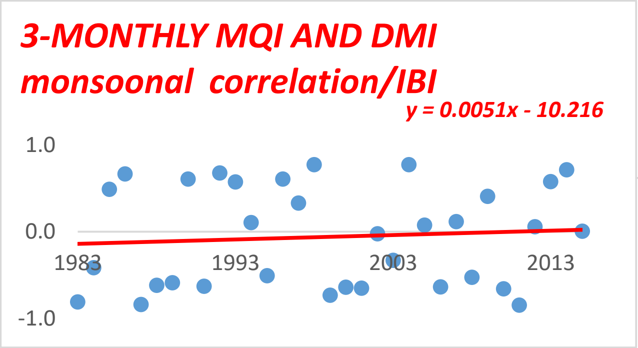






However, Yelwa and Yola in the north showed significant decreasing trends while the following stations in the south showed weak trends- Owerri, Enugu, Ilorin, Ikeja Portharcourt, Calabar as shown in figure 4.3b.

Furthermore, this supports the earlier observations in section 4.1.3 that the impacts of IODMI is perceived to be more over the selected stations in the northern parts of Nigeria.



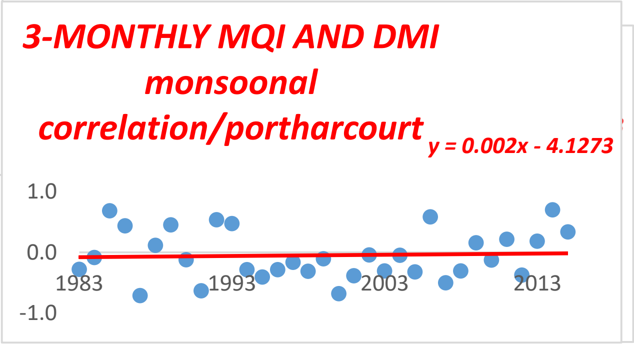


Figure 4.3a Stations with positive correlation trends during the monsoon season

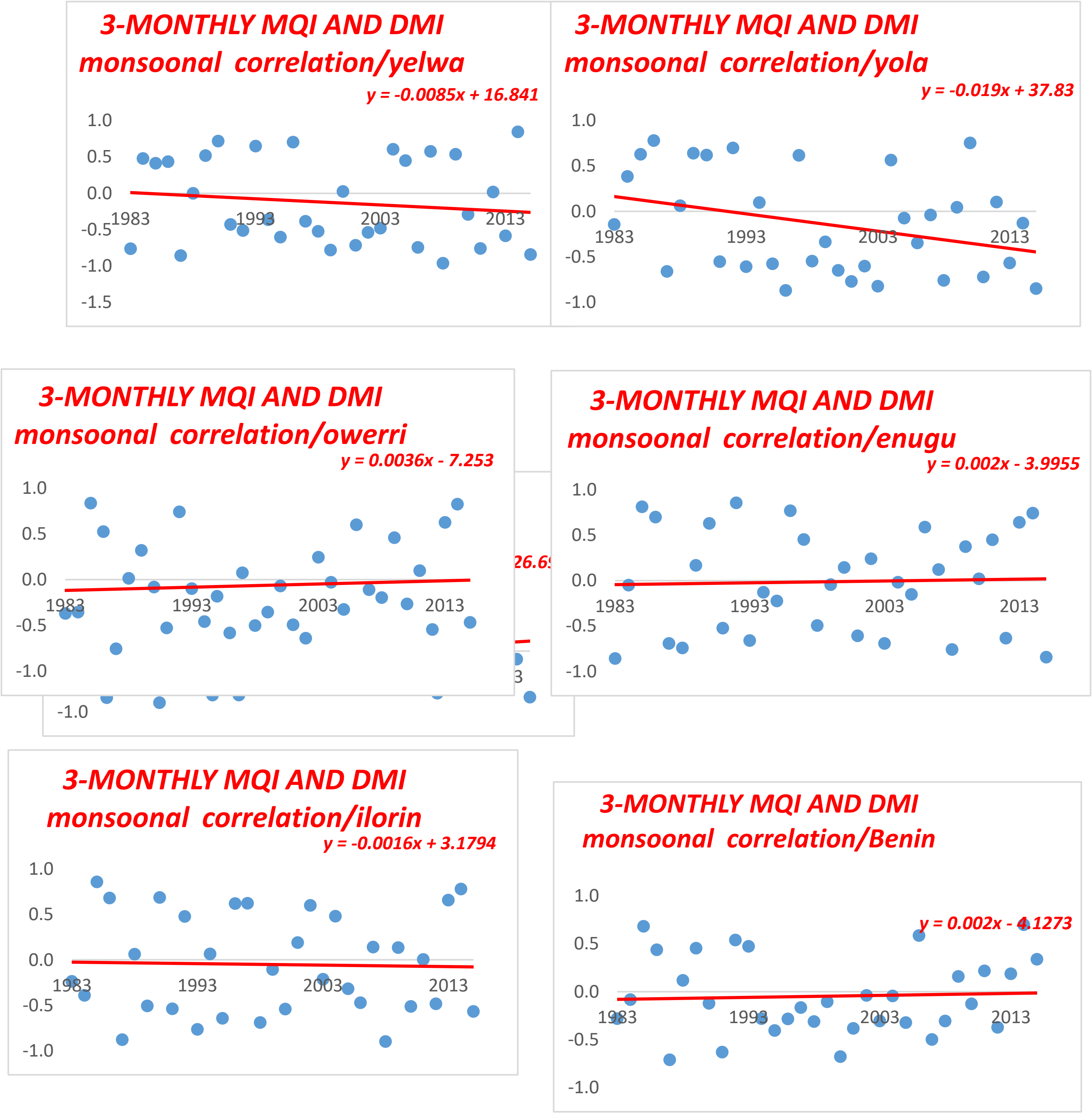


Figure 4.3b Stations with negative correlation trend during monsoon season

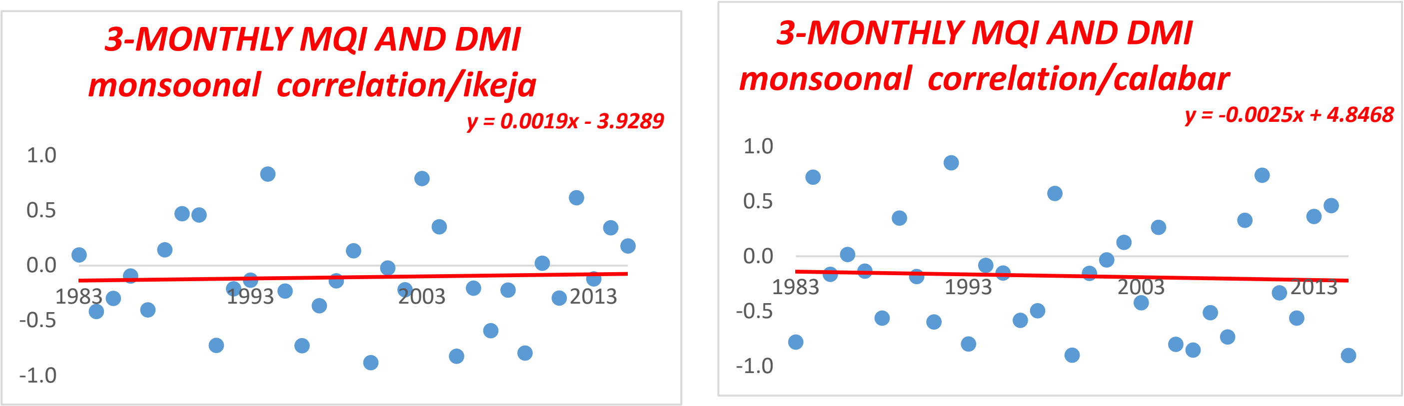


Figure 4.3b Stations with negative correlation trend during monsoon season

4.1.7 Test of significance of the Pearson correlation coefficient (r)

In other to determine whether the correlation values between MQI / DMI and MQI/ENSO were significant during the monsoon seasons, two methods were used;

a) Calculation of the p value and comparing it to the specified level of significance (α) at 0.1(10%) using equation 3.8.

b) Calculation of Critical r value and comparing it to Pearson correlation coefficient (r) using equation 3.9.

The results of test of significance of correlation coefficient between MQI / DMI is shown in table 4.13, shows that there is significant correlation in some years within the study period with most of the stations in the northern part of the country for instance, Sokoto, Katsina, Kano, Maiduguri, Yelwa, Yola, Jos, Abuja and Ibi while the stations like Enugu, Calabar, Ilorin, Ikeja, Benin, Owerri, Portharcourt, over the southern part of the country had fewer significant correlations. This could be as a result of the influence of the latitudinal fluctuation of Intertropical discontinuity zone

(ITD) on the rainfall patterns of Nigeria that leads to the influx of moisture farther the northern part than the southern part.

However, the results of the test of significant correlation coefficient between the MQI/ENSO was represented using a Bar chart shown in section 4.4, figure 4.7.

Table 4.13-Years with significant Pearson correlation between MQI and DMI during monsoon period at alpha value 0.1 (10%) level of significance

NORTHERN STATIONS	**POSITIVE CORRELATION YEARS**	**NEGATIVE CORRELATION YEARS**	**No. of Yrs. with non-Sig. r from 1983-2015**	**No. of Yrs. with Sig. r from 1983-2015**	**No. of Yrs. with Sig. r coefficient (%) from 1983-2015**
SOKOTO	2001,2004,2006,2010,2011, 2014	1984,1987,1988,1990,1991,1993,1995, 1996, 2003,2007, 2008,2015	15	18	54
KANO	1984,1992,2001,2005,2006, 2013, 2014	1988,1989,1990,1991,1994,2000,2002, 2003, 2011	17	16	48
KATSINA	1990,2001,2004,2006,2011, 2013, 2014	1988,1989,1991,1994,1996,1999,2002, 2003, 2008	17	16	48
MAIDUGURI	1996,2001,2004,2005,2013	1988,1991,1993,1994,2003,2006,2007	21	12	36
YELWA	1990,1996,2014	1983,1987,1999,2001,2006,2008,2011, 2015			33
JOS	1990,2004,2010,2013	1983,1987,1991,1993,2008,2015	23	10	30
YOLA	1986,1992,2010	1996,2001,2003,2008,2001,2015			27
IBI	1992,1998,2004,2014	1983,1987,1999,2011	25	8	24
SOUTHERN STATIONS	**POSITIVE CORRELATION YEARS**	**NEGATIVE CORRELATION YEARS**	**No. of Yrs. with non-Sig. r from 1983-2015**	**No. of Yrs. with Sig. r from 1983-2015**	**No. of Yrs. with Sig. r coefficient (%) from 1983-2015**
ENUGU	1985,1986,1992,1996,2014	1983,1986,1987,1988,2003.2008,2015	22	11	33
CALABAR	1984,1992,2010	1983,1993,1999,2005,2006,2008,2015	23	10	30
ILORIN	1985,1986,1990,2014	1987,1993,1998,2008	25	8	24
IKEJA	1994,2003	1991,1996,2000,2005,2009	26	7	21
BENIN	1992,2010	1983,1991,2000	28	5	15
OWERRI	1985,1992,2014	1987	29	4	13
PORTHARCOURT	1985,2014	1987,2000	29	4	12

Correlation is significant at alpha value 0.1 (10% level) (2-tailed).

However, the test of significance shown in table 4.13 suggests that there seem to exist a relationship (teleconnection) between the DMI and rainfall pattern over the selected stations. Hence, the contrasting strong negative and positive signs of correlations shown in tables 4.9-4.11 indicates the tendencies of IODMI to increase rainfall at a certain period of the year or decrease it at another period.

4.2 Spatial distribution of the correlation of rainfall pattern and IODMI phases.

This section would address the objective 2, which is to assess the spatio-temporal relationship between the rainfall pattern and the IODMI phases and how the latter affects the rainfall pattern over the selected synoptic stations in Nigeria.

It was observed from the NMSR and IODMI coefficient correlation analysis based on 3- month running average during monsoon season, that the Positive IOD years coincided with the years of negative Pearson correlation while the Negative IOD years coincided with positive Pearson correlation as seen in table 4.12.

Figure 4.4(a-g) and 4.5(a-f) shows the spatial pattern of the correlation coefficient between MQI and DMI significant at 10% level with positive IOD/ negative correlations and Negative IOD/ positive correlations during the 1983-2015 period.

However, this suggest that increase or decrease of sea surface temperatures (SSTs) during Positive IOD and Negative IOD years respectively over the Indian Ocean resulted to contrasting increase of rainfall in some station at a certain period of the year or decrease at another period during the Nigeria Monsoon seasons (MAM, AMJ, MJJ, JJA, JAS, ASO, SON), as shown in figure 4.4 and 4.5.

It was also observed that the tendency of IODMI to reduce rainfall were expected during Positive IOD years while its tendency to increase rainfall were expected during Negative IOD years as shown in table 4.12, however, this was also observed for all season (MAM, JJA and SON) in South Sudan (Omay, 2015).

Note-*The yellow –red color shows stations with increase rainfall while the green-blue color shows stations with decrease rainfall*.

4.2.1 Positive IOD years

It was observed that during the Positive IOD years that there are incidences of decreased rainfall though there are tendencies of the IODMI to reduce or increase in some stations at different period as earlier mentioned.

Importantly in 2003, the spatial pattern of the correlation between MQI and DMI showed widespread decreased rainfall as shown in figure 4.4c. However, there were drought incidences that supports the observation of widespread decreased rainfall for example during the rice growing period (June-October) in the north in the following years- 1982-1984, 1987-1988, 2003-2004 and 2009, (Mohammed *et al.*, 2018). Hence, supports the spatial patterns of significant negative correlation between rainfall and DMI during positive IOD in 1983 and 2003 of decreased rainfall amount and distribution shown in figures 4.4a and c.

Odjugo (2010), further supports that there was general decline of rainfall trend in Nigeria from 1901-2005 due to a sharp rise in air temperature of 26.6^0C at the rate of 1.1^0C. However, despite this period of drastic rainfall decline over Nigeria, the coastal areas had increasing rainfall. Odjugo, (2010).

Moreover, the negative correlation of MQI and IODMI during the positive IOD in 2003 that showed widespread rainfall decrease was also in agreement with the first quarter of Standardized Precipitation Index (SPI) hydrological bulletin produced by Nigerian Meteorological Agency, (NiMet) which indicated drought in most synoptic stations in 2003.

Perhaps, there is observed contrasting effect of Positive IOD to either increase or decrease rainfall at certain region and at different period. For instance the Positive IOD in year 2008 shown in figure 4.4e, cannot be unrelated to the high incidence of rainfall in Kano in August 2008 that resulted to a rainstorm described as one of the heaviest in a 90-years instrumental record and the rains lasted for a few days. The rain storm generated floods in various parts of Kano city. Consequently, the rain storm and flood water which it produced was caused by the Bagauda Dam near the city with a storage capacity of 34 million cubic liters of water to reach an unprecedented volume of 146 million cubic liters before it collapsed in august 17th, 2008. The havoc brought by the collapse of the dam and rainfall flood resulted in loss of 246 lives, destruction of 18 000 houses, washing away of 14,000 farms, displacement of 207,000 people and damage to residences and infrastructure worth about 650 million Naira (Kabiru, 2009).

More so, the flooding in year 2012 cannot be unrelated to the high incidence of rainfall that translated into a widespread flooding in 2012 amidst decreased rainfall in the southern Nigeria as shown in Figure 4.4f. However, 2012 was termed as the worst in 40yrs by National Emergency Management Agency, (NEMA) which affected 30 Nigeria’s 36 states that killed 363 people and displaced 2.1 million. (Reuter: November 5, 2012, retrieved November 26, 2012.).

In addition the increased rainfall in some parts of the northern stations (sokoto, Kano and Katsina) shown in Figure 4.4g agrees with the report of flooding incidence that occurred in September, 2015, where several states in the north was affected that claimed no fewer than 53 people, displaced more than 100,420 people, with thousands of houses, farmlands and property worth billions of Naira lost in many local government area in the following northern states- Kano, Katsina, and Sokoto. (Premium Times news, retrieved on 17th July, 2018).

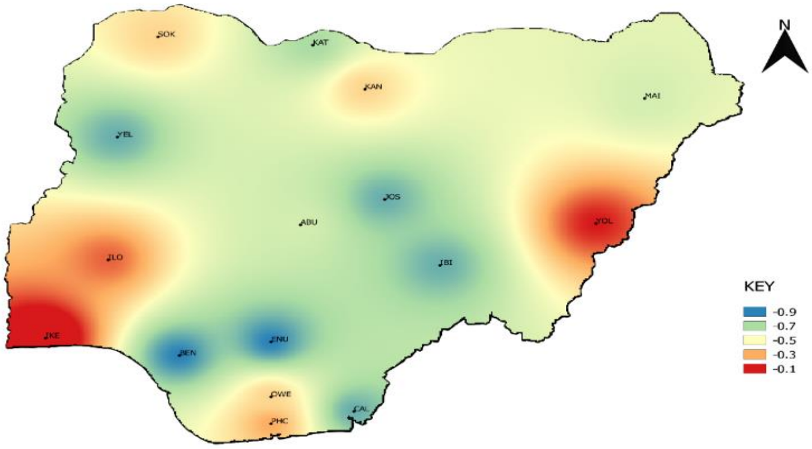


Figure-4.4a: Spatial pattern of contrasting decreased and increased rainfall during Positive IOD in 1983

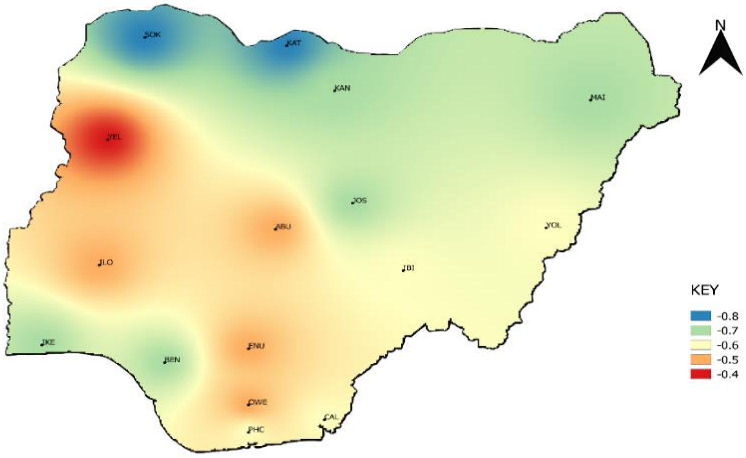


Figure-4.4b: Spatial pattern of contrasting decreased and increased rainfall during Positive IOD in 1991

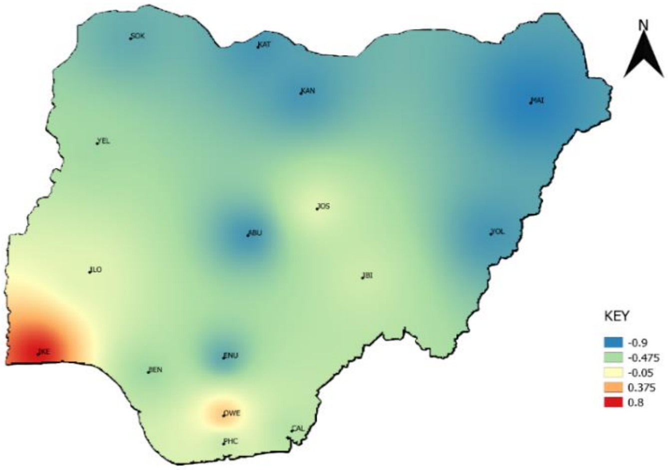


Figure- 4.4c: Spatial pattern of contrasting decreased and increased rainfall during Positive IOD in 2003

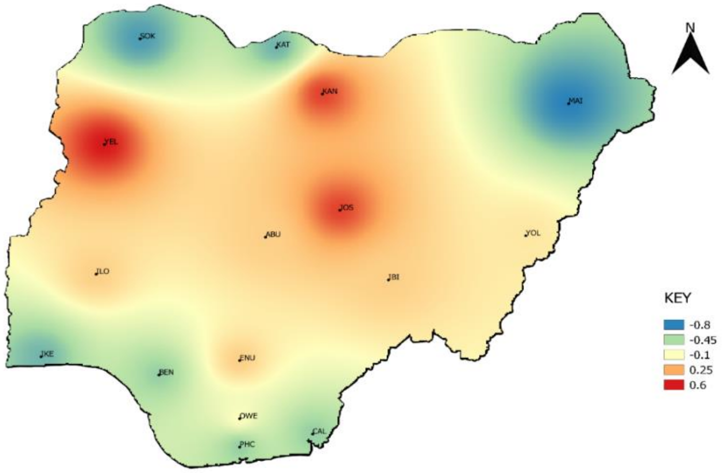


Figure-4.4d: Spatial pattern of contrasting decreased and increased rainfall during Positive IOD in 2007

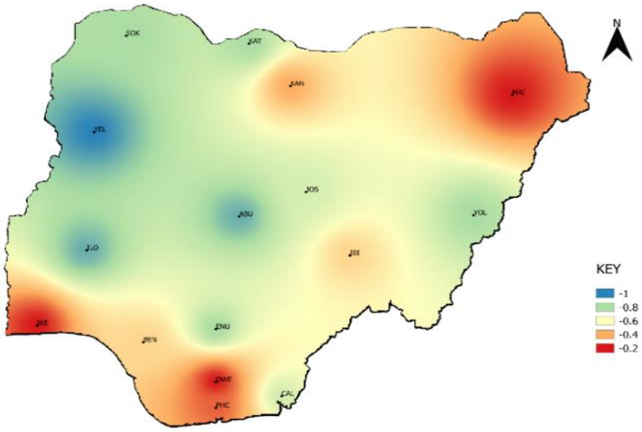


Figure-4.4e: Spatial pattern of contrasting decreased and increased rainfall during Positive IOD in 2008

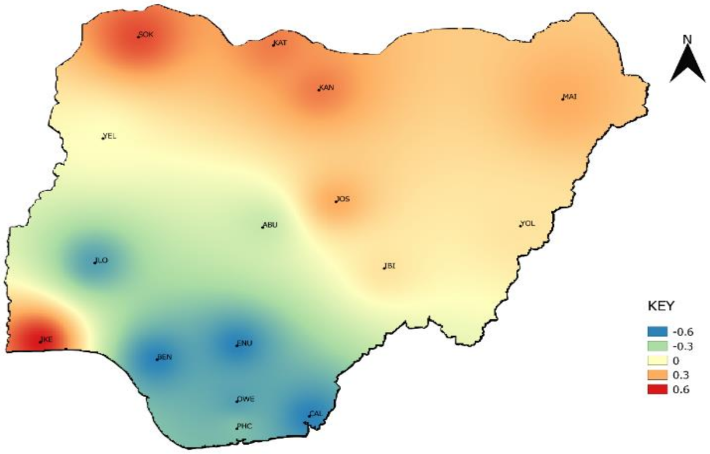


Figure- 4.4f: Spatial pattern of contrasting decreased and increased rainfall during Positive IOD in 2012

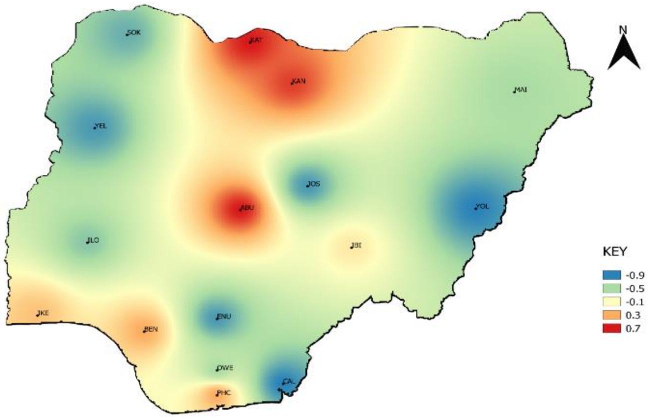


Figure-4.4g: Spatial pattern of contrasting decreased and increased rainfall during Positive IOD in 2015

4.2.2 Negative IOD years

It was observed that during the Negative IOD years that there are incidences of increasing rainfall though there are tendencies of the IODMI to reduce or increase rainfalls in some stations at different period as earlier mentioned as shown in figures 4.5 (a- f). However, amongst the negative IOD years, 1990 was observed to have been affected by a widespread increased rainfall as shown in figure- 4.5c.

Hence, there were reports of flood incidences in agreement with the observed 1990 flooding that took place in April 1990 which destroyed almost all the structures, worth over 2million naira and claimed more than 30 lives, damaged 100 houses, and over 15,000 rendered homeless near the major rivers in the city of Ibadan in the southwest region. Others floods in Ibadan were those of 1995, 1998, 2001, 2003, 2007, April 2010, August 26th 2012. However, the present findings has it that during Negative IOD in 1990 there seemed to be widespread increase rainfall.

Occurrences of floods disaster in the cities and towns of Nigeria in recent times have been great concern and challenge to the residents, Governments and researches, (Oriola, 2000 and Aderogba, 2012). For instance, reports have shown that devastating flood had occurred in Osogbo (1992, 1996, 2002 and 2010), Yobe (2000), Akure, (1996, 2000, 2002, 2004, and 2006) and the coastal cities of Ogun, Port-Harcourt, Calabar, Uyo, Warri 1986, 1994 and 2001.

In 2010 Usmanu Danfodiyo University Sokoto and other parts of the state was affected by flood, Magami et al. (2014) and also in Katsina which claimed 44 people with 20 missing and destroyed more than 500 houses. (Xinhua News Agency, retrieved on 17th July, 2017) as shown in figure 4.5f.

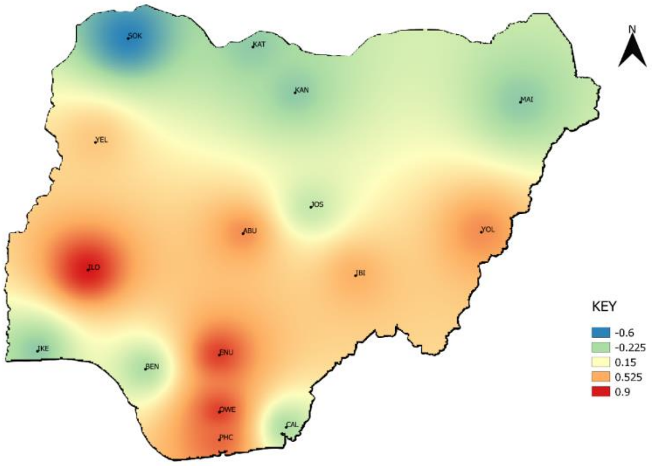


Figure- 4.5a: Spatial pattern of contrasting increased and decreased rainfall during Negative IOD in 1985

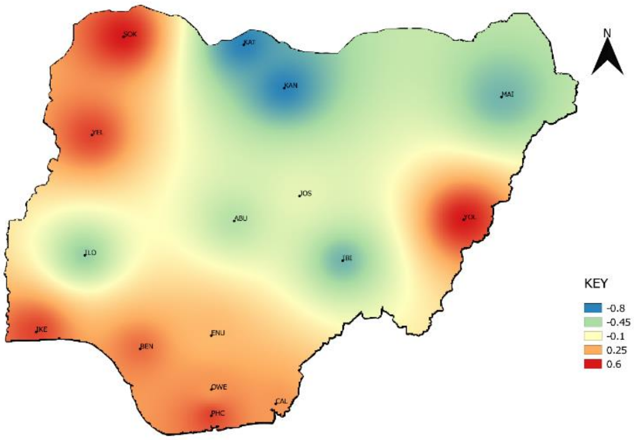


Figure-4.5b: Spatial pattern of contrasting increased and decreased rainfall during Negative IOD in 1989

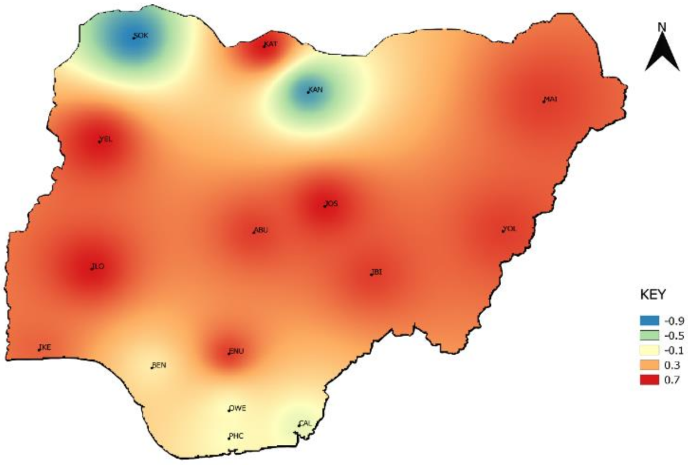


Figure- 4.5c: Spatial pattern of contrasting increased and decreased rainfall during Negative IOD in 1990

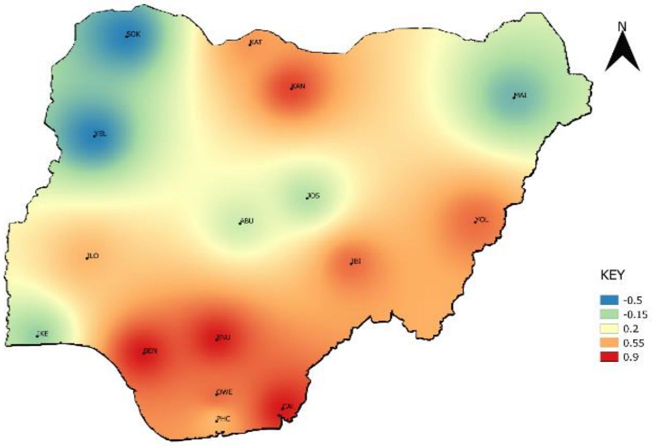


Figure- 4.5d: Spatial pattern of contrasting increased and decreased rainfall during Negative IOD in 1992

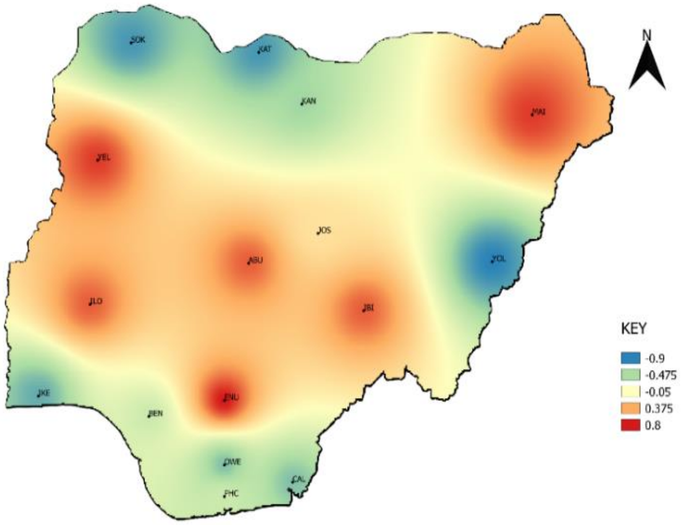


Figure- 4.5e: Spatial pattern of contrasting increased and decreased rainfall during Negative IOD in 1996

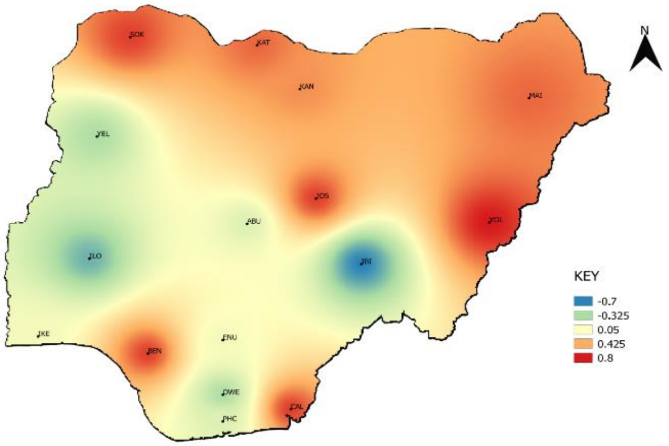


Figure- 4.5f: Spatial pattern of contrasting increased and decreased rainfall during Negative IOD in 2010

4.3. Comparison between the Indian Ocean Dipole and El Niño Southern Oscillation (ENSO) influence on the monsoon seasonal rainfall anomalies over the selected synoptic stations in Nigeria

This subsection examined the teleconnections between Nigeria monsoon seasonal rainfall and El Niño Southern Oscillation (ENSO) over the Nino 3.4 region during the Indian Ocean Dipole years. However, this is to achieve the objective 3 which is to ascertain how IODMI and ENSO influence monsoon seasonal rainfall pattern over the selected synoptic stations during IOD years.

4.3.1 Analysis of the comparison between the influence of the IODMI and ENSO on the monsoon seasonal rainfall pattern over Nigeria

For the purpose of the comparison of how the IODMI and ENSO indices influence the Nigerian Monsoon Seasonal Rainfall, (NMSR) pattern over the selected stations in Nigeria during IOD years, 1990 and 2003 which were positive and negative IOD years respectively were used.

In 2003 which is a Positive IOD year, it coincided with the Negative correlations between the NMSR/IODMI while in the same year the Pearson correlation coefficient between the NMSR/ENSO were positive. Hence, Positive IOD = Negative Correlation and ENSO of the same year = Positive Correlation as shown in table 4.14.

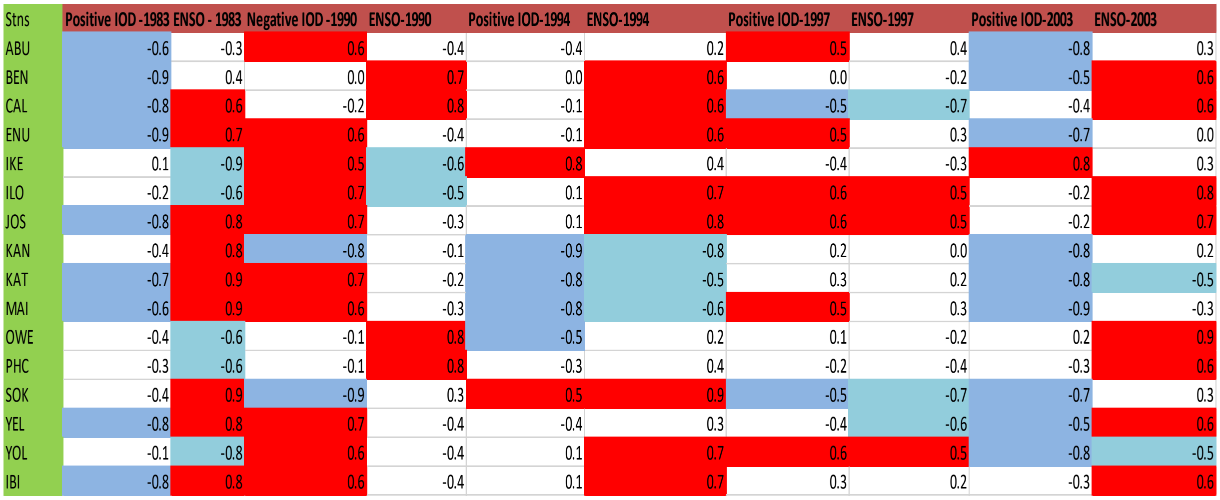
In contrast to the aforementioned, in 1990, a Negative IOD year, coincided with the Positive Correlations between the NMSR/IODMI while in the same year, the Pearson correlation coefficient between the NMSR/ENSO were weaker Positive correlations as shown in table 4.14.

Interestingly, this suggests that in 2003, the positive correlation between monsoon seasonal rainfall and ENSO resulted to negative correlation with the IODMI. Therefore, this indicate that the higher correlation between NMSR/ENSO was responsible for the reduced rainfall over the most parts of the selected synoptic stations during the 2003 Positive IOD year as shown in figure 4.6a and b. However, in 1990 the weaker positive correlation between the NMSR and ENSO resulted to positive correlation with the IODMI, hence the weaker positive correlations ENSO/MQI was responsible for the high rainfall on most parts of the selected synoptic stations as shown in figure 4.7a and b.

This is in agreement with the work by Ashok et al (2001), that whenever the ENSO- Indian Summer Monsoon rainfall (ISMR) correlation is low (high) the IOD-ISMR correlation is high (low) where in 1990 a weak correlation between the Indian Monsoon and ENSO resulted to an intense and frequent Dipole Mode events.

Furthermore, it was also observed that Positive IOD index negated the effects of ENSO that resulted in increased Nigerian Monsoon Seasonal Rains in 1983, 1994, 1997 and 2003 as shown in table -4.14. However, it agrees with what has been demonstrated in the works done by (Behera *et al.*, 1999, Webster *et al.*, 1999) where a Positive IOD index often negated the effect of ENSO which resulted to increased monsoon rains in several ENSO years like the 1983 and 1994 except 1997.

Table 4.14- How the positive IOD and ENSO negates their effects in 1983, 1994,



Stns	Positive IOD -1983	ENSO - 1983	Negative IOD -1990	ENSO-1990	Positive IOD-1994	ENSO-1994	Positive IOD-1997	ENSO-1997	Positive IOD-2003	ENSO-2003
ABU	-0.6	-0.3	0.6	-0.4	-0.4	0.2	0.5	0.4	-0.8	0.3
BEN	-0.9	0.4	0.0	0.7	0.0	0.6	0.0	-0.2	-0.5	0.6
CAL	-0.8	0.6	-0.2	0.8	-0.1	0.6	-0.5	-0.7	-0.4	0.6
ENU	-0.9	0.7	0.6	-0.4	-0.1	0.6	0.5	0.3	-0.7	0.0
IKE	0.1	-0.9	0.5	-0.6	0.8	0.4	-0.4	-0.3	0.8	0.3
ILO	-0.2	-0.6	0.7	-0.5	0.1	0.7	0.6	0.5	-0.2	0.8
JOS	-0.8	0.8	0.7	-0.3	0.1	0.8	0.6	0.5	-0.2	0.7
KAN	-0.4	0.8	-0.8	-0.1	-0.9	-0.8	0.2	0.0	-0.8	0.2
KAT	-0.7	0.9	0.7	-0.2	-0.8	-0.5	0.3	0.2	-0.8	-0.5
MAI	-0.6	0.9	0.6	-0.3	-0.8	-0.6	0.5	0.3	-0.9	-0.3
OWE	-0.4	-0.6	-0.1	0.8	-0.5	0.2	0.1	-0.2	0.2	0.9
PHC	-0.3	-0.6	-0.1	0.8	-0.3	0.4	-0.2	-0.4	-0.3	0.6
SOK	-0.4	0.9	-0.9	0.3	0.5	0.9	-0.5	-0.7	-0.7	0.3
YEL	-0.8	0.8	0.7	-0.4	-0.4	0.3	-0.4	-0.6	-0.5	0.6
YOL	-0.1	-0.8	0.6	-0.4	0.1	0.7	0.6	0.5	-0.8	-0.5
IBI	-0.8	0.8	0.6	-0.4	0.1	0.7	0.3	0.2	-0.3	0.6

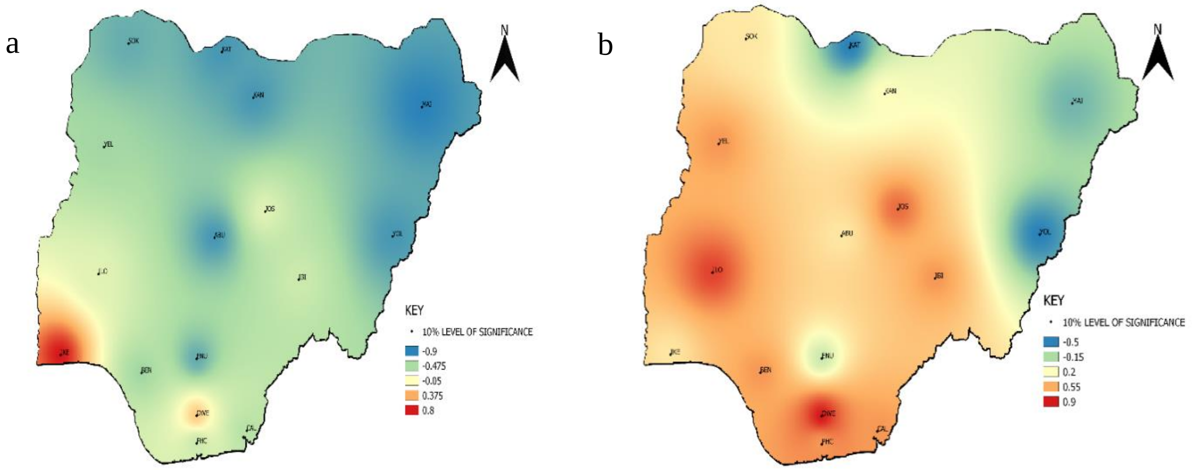


Figure 4.6: Spatial pattern of the reverse effects of relationship between Positive IOD (a) and ENSO (b) on NMSR in 2003

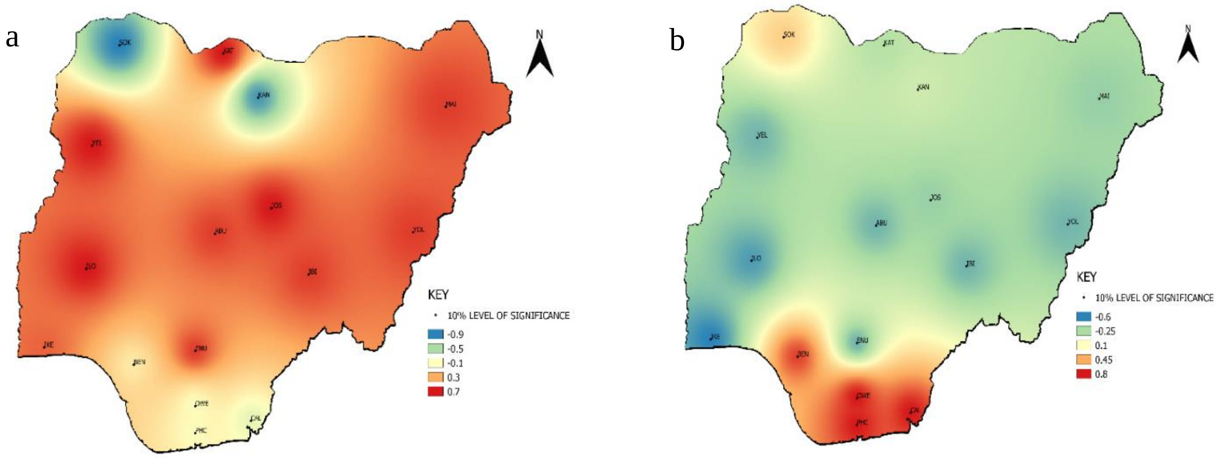


Figure 4.7: Spatial pattern of the reverse effects of relationship between Negative IOD (a) and ENSO (b) on NMSR in 1990

4.4 Summary of discussion

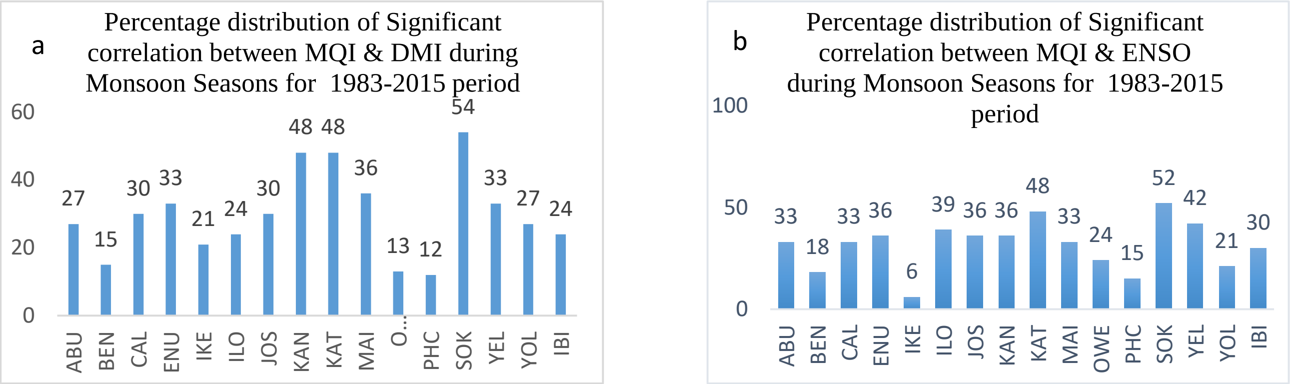
a) There is a great indication that Indian Ocean dipole indices could be a predictor of the rainfall anomalies over the selected stations in Nigeria as being studied to be a good predictor of East African short rains during OND season by Black *et al.,* (2003) and Owiti (2005) and over the African Sahel precipitation by Okonkwo (2014).

b) However, the results showed significant association between rainfall of the selected stations during the monsoon season with positive and negative Indian Ocean Dipole (IOD) phases that is indicative of the tendencies for IODMI to increase rainfall at a certain period of the year or decrease it at another period.

c) Furthermore, the research shows that Pearson correlation coefficient between IODMI and Nigerian Monsoon Seasonal Rainfall (NMSR) were significant at 10% level with more percentage of significance over the stations in the northern part compared to stations in the southern part of the country as seen in figure- 4.9a and b.

d) Conversely, the Pearson correlation coefficient between ENSO and Nigerian Monsoon Seasonal Rainfall (NMSR) were significant at 10% level with a strong and broad percentage of significance across all the stations except for Ikeja that had the lowest significant correlation as shown in figure-4.8a and b and figure 4.9a and b. The low significant correlation over Ikeja is in agreement with the work done by Nnawuike, (2016) that ENSO has no significant relationship with the rainfall over the southwestern Nigeria.

e) Therefore, we rejected the null hypothesis (Ho) that “the correlation coefficients is not significant at the 10% significant level” and accepted the alternative hypothesis (Hi) that “the coefficient of correlation is significant”.


a

Percentage distribution of Significant correlation between MQI & DMI during Monsoon Seasons for 1983-2015 period

b

Percentage distribution of Significant correlation between MQI & ENSO during Monsoon Seasons for 1983-2015 period

Figure 4.8- The percentage distribution of significant correlation between MQI&DMI (a) and MQI&ENSO (b) during the monsoon seasons for 1983-2015 period.

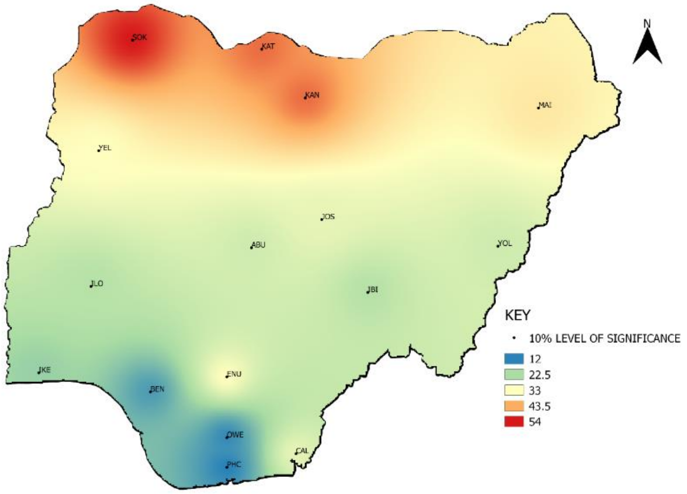


Figure 4.9a: Spatial correlation coefficient between the NMSR and IODMI significant at 10% level from 1983-2015

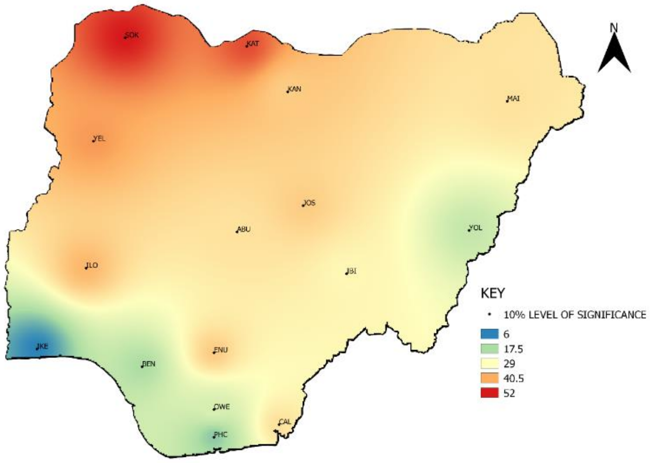


Figure 4.9b: Spatial correlation coefficient between the NMSR and ENSO significant at 10% level from 1983-2015

It is worthy to note that both the percentage of significance of ENSO and IODMI teleconnection affects the Sahel and guinea savanna regions of the country with lower influence over the south and the coastal regions of the country. Hence, both IODMI and ENSO influence decreases from north to south as shown in figures 4.9a and b

These findings indicated good prospective for improving monitoring, prediction and early warning of extreme rainfall events over selected stations of the study area, thereby reducing the vulnerability, and improving the resilience of the society of the region to negative impacts of extreme or below normal rainfall events that are common in the region.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion:

In conclusion, this research work has to a great extent found the existence of a teleconnection between the NMSR and the IOD based on the Pearson correlation coefficient results that was tested by two different tests of significance (Critical r and p-Value) and was found to be significant over the selected synoptic stations in Nigeria over the 33-yr period (1983-2015).

This research has also further proven that ENSO which is one of the major indices used by Nigerian Meteorological Agency (NiMet) for weather and climate predictions may not be the only feature that has teleconnection with the weather outcomes over Nigeria.

Therefore, the results and discussions have demonstrated that the IOD events affect NMSR on their own and do apparently weaken or strengthen the influence of the ENSO on the NMSR, depending on which phases of the two interface with NMSR. The analysis also showed that the impact of IODMI is felt more over the Sahel region of Nigeria, unlike the ENSO impact that appears a little more widespread, relatively. Hence, the results showed similar pattern of influence of IODMI and ENSO on NMSR to decrease from north to south over selected stations in Nigeria.

In view of the recent findings of significant north-south correlation between DMI and NMSR over the selected synoptic stations, it may be worthwhile to examine the possibility of using the IODMI for the climate prediction of the quality of monsoon rainfall over Nigeria.

5.2 Recommendations:

i. This study examined only the teleconnection between sea surface temperatures (SSTs) over Indian Ocean and equatorial Pacific Ocean with the NMSR. Hence, further research should consider examining the combined effects of DMI and SOI in forecasting the quality of NMSR over Nigeria. A logical further step would also be to explore other indices possibly affecting monsoon rainfall over Nigeria including but not limited to; Precipitable Water (PW), African Southwesterly Index (ASWI), the Atlantic Multi-decadal Oscillation (AMO), the Atlantic Meridional Mode (AMM), the South Atlantic Ocean Dipole Index (SAODI) etc.

ii. Government and relevant agencies like NiMet and Nigerian Hydrological Services Agency (NIHSA), should work harmoniously to enhance the resilience of Nigerian communities through mainstreaming and incorporating the Dipole Mode Index (DMI) over the Indian Ocean as part of the weather components in weather monitoring and forecasting especially for the seasonal rainfall prediction (SRP) to various weather-dependent sectors like agricultural production and food security sector and in prevention/ mitigation of weather related hazards like flooding, drought etc. especially in this era of climate change.

REFERENCES

Adebayo, W.O. (1999). The Spatial-Temporal Dynamics of Temperature and Rainfall Fluctuations in Nigeria Unpublished Ph.D thesis, Department of Geography, University of Ibadan.p. 196.

Adeniyi, M. O. (2014). Variability of daily precipitation over Nigeria.*Meteorology and Atmospheric Physics, 126(3-4):161-176.* DOI: 10.1007/s00703-014-0340-6.

Adeniyi, M. O., Ogunsola, O. E., Nymphas, E. F., & Oladiran, E. O. (2009). Food security measures during uncertain climatic conditions in Nigeria. *African Journal of Food, Agriculture, Nutrition and Development (AJFAND) 9(2):652–67.*

Adeyinka, S.A (2012). A Review of physical Planning Law in Nigeria. Adekunle et al (eds) being a paper Delivered at 11th annual national Conference on Environmental Sustainability in a Democratic Government Held at Federal University of Akure (FUTA).

Alexander, M. A., Blade, I., Newman, M., Lanzante, J., Lau, N.C., & Scott, J. (2002). The atmospheric bridge: the influence of ENSO teleconnections on air-sea interaction over the global oceans. *Journal of Climate*, 15, 2205-2231.

Annamalai, H., Slingo, J. M., Sperber, K. R., & Hodges, K. (1999). The mean evolution variability of the Asian summer monsoon: Comparison of ECMWF and NCEP–NCAR reanalyses. *Monthly Weather Review,* 127, 1157–1186.

Ashok, K., Guan, Z., & Yamagata, T. (2001). Impact of the Indian Ocean Dipole on the relationship between the Indian monsoon rainfall and ENSO, Geophysics Research Letter, 28, 4499–4502, doi:10.1029/2001GL013294.

Behera S. K., Krishnan, R., & Yamagata, T. (2005). Paramount impact of the Indian Ocean Dipole on the East African short rains: A CGCM Study. *Journal of Climate* 18, 4514–4530.

Behera S. K., Krishnan, R., & Yamagata, T. (1999). Unusual Ocean-Atmosphere conditions in the tropical Indian Ocean during 1994. Geophysics Research Letter 26, 3001-3004.

Berte, Y., & Ward, M. N. (1998). Experimental forecast of seasonal rainfall and crop index for July–September 1998 in Côte D'Ivoire. SODEXAM, Meteorologie Nationale de Côte D'Ivoire, Abidjan CIMMS, pp 59 –62.

Black, E., Slingo, J., & Sperber, K. R. (2003). An observational study of the relationship between excessively strong short-rains in coastal East Africa and Indian Ocean SST, *Monthly. Weather Review*, 131,74–94.

Cassou, C. (2008). Intraseasonal interaction between the Madden Julian Oscillation and the North Atlantic Oscillation. *Nature,* 455,523-527 doi:10.1038/nature07286 Letter

Cyclones Idai and Kenneth Retrieved from https://www.unocha.org/southern-and-eastern-africa-rosea/cyclones-idai-and-kenneth.

Cherchi, A., & Navara, A. (2013). Influence of ENSO and of the Indian Ocean Dipole on the Indian summer monsoon variability. *Climate Dynamics*. 41:81-103

Colman, A. W., Davey, M. K., Graham, R. & Clark, R. (2000). Experimental forecast of 2000 seasonal rainfall in the Sahel and other regions of tropical North Africa, Using Dynamical and Statistical Methods.Experimental Long-Lead Forecast Bulletin. http:// grads.iges.org/ellfb/Jun001colman. 6.00.htm

Farmer, G. (1988). Seasonal forecasting of the Kenya coast short rains, 1901–1984, *Journal of Climatology*, 8, 489–497.

Fontaine, B., & Janicott, S. (1992). Wind-field coherence and its variations over West Africa. *Journal of Climate,* 5, 512–524.

Guan, Z., Yamagata, T., & Ashok, K. (2002). Individual and Combined Influences of ENSO and the Indian Ocean Dipole on the Indian Summer Monsoon. *Journal of Climate,*17, 3141-3155

Guanghan, A., Stanb, C., Hoell, A., Weaver, A., & Waylen, P. (2016). Inter- and Intra-annual precipitation variability and relationships to ENSO and the IOD in the southern Africa. *International Journal of Climatology.* 36:1643-1656, doi:10.1002/joc.4448

Gouda, K., Sahoo, S., Samantray, P., & Shivappa, H. (2017). Comparative Study of Monsoon Rainfall Variability over India and the Odisha State. *Climate,* Vol.5,79 doi:10.3390/cli5040079

Han, W., Shinoda, T., Fu, L. L., & McCreary, J. P. (2006). Impact of atmospheric intraseasonal oscillations on the Indian Ocean dipole during the 1990s, *Journal of Physical Oceanography*, 111,679-690.

IPCC (2013a). Climate Change 20113a: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. (Stocker, T. F., Qin, D., Plattner, G. K., & Tignor, M. (eds)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC (2012). Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX), 2012, http://ipccwg.gov/SREX/ 40-43.

IPCC (2001b). Climate Change 2001: Synthesis Report. A contribution of Working Groups I, II and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Watson, R.T. and the Core Writing Team, Eds. Cambridge University Press, 398 pp.

Janicot, S., Harzallah, A., Fontaine, B., & Moron, V. (1998). West African monsoon dynamics and eastern equatorial Atlantic and Pacific SST anomalies (1970–1988). *Journal of Climatology*, 11, 1874–1882.

Janowiak, J. (1988). An investigation of interannual variability in Africa, *Journal of Climate*, 1, 240–255.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., *et al.* (1996), The NCEP/NCAR 40-year reanalysis project, *Bulletin of Atmospheric Meteorological Society*, 77, 437–471.

Kiladis, G., Thorncroft, C., & Hall, N. (2006). Three-dimensional structure and dynamics of African easterly waves. Part I: Observations. *Journal Atmospheric Science*, 63**,** 2212–2230.

Kucharski, F., Kang, I., Straus, D., & King, M. (2010). Teleconnections in the Atmosphere and Oceans.*International Centre for Theoretical Physics,* 381- 383*,* doi:10.1175/2009BAMS2834.1

Latif, M., & Barnett, T. P. (1995). Interactions of the Tropical Oceans. *Journal of Climate*,8, 952-964.

Lavender, S., & Mathews, A. (2009). Response of the West African monsoon to the Madden-Julian Oscillation, *Journal of Climate*, 22, 4097-4116.

Lindesay, J. A., Harrison, M. S. J. & Haffner, M. P. (1986). The Southern Oscillation and South African rainfall, *South African Journal of Science,* 82, 196–198.

Liu, W., & Liu, Z. (2014). A note on the stability indicator of the Atlantic Meridional Overturning Circulation, *Journal of Climatology, 27 (2), 969-975.*

Luo, J. J., Masson, S., Behera, S. & Yamagata, T. (2007). Experimental forecasts of the Indian Ocean Dipole using a coupled OAGCM, *Journal of Climatology*, 20, 2178–2190.

Luo, J. J., Behera, S., Masumoto, Y., Sakuma, H., & Yamagata, T. (2008). Successful prediction of the consecutive IOD in 2006 and 2007, *Geophysics Research Letter*, 35, L14S02,doi:10.1029/2007GL032793.Wiley Online Library | PubMed | Web of Science® Times Cited: 32

Madden R. & Julian, P. (1972). Description of global-scale circulation cells in the tropics with a 40-50 day period. *Journal of Atmospheric Sci*ence, 29, 1109-1123.

Magami, I., Yahaya, S., & Mohammed, K. (2014). Causes and Consequences of flooding in Nigeria: A Review. Biological and Environmental Sciences. *Journal for the Tropics* 11(2), June, 2014, ISSN 0794-9057, pp 154-162.

Maloney E. & Hartmann, D. (2000).Modulation of hurricane activity in the Gulf of Mexico by the Madden-Julian Oscillation. *Science*, 287, 2002-2004.

McKee, T. B., Doeskin, N.J., & Kleist, J. (1993). The relationship of drought frequency and duration to timescales, 8th Conference on applied climatology, American Meteorological Society, Anaheim, Canada, pp.179-184.

Mohammed, S., Shamsuddin, S., Noraliani, A., & Eun, S. (2018). Trend Analysis of Droughts during Crop Growing Seasons of Nigeria. Sustainability 2018, 10, 871; doi:10.3390, pp1-13.

Mote P. W., (2003). Trends in temperature and precipitation in the Pacific Northwest during the Twentieth century. University of Washington. *Washington. North West Science*, 77(4): 271-282.

Murtugudde, R. G., McCreary, J. P., & Busalacchi, A. J. (2000). Oceanic processes associated with anomalous events in the Indian Ocean with relevance to 1997–1998. *Journal of Geophysics Research*, 105, 3295–3306.

NOAA, (2014). Aglobal merged land, air and sea surface temperature reconstruction based on historical observations (1880-1997), *Journal of Climatology*, 18, 2021-2036.

Nicholson, S. E. (1996). A review of climate dynamics and climate variability in eastern Africa, in Johnson, T.C. and Odada, E. (eds), *The Limnology, Climatology and Paleoclimatology of the East African Lakes*, Gordon and Breach, in press.

Nigerian Meteorological Agency (NIMET), (2015). Monthly historical rainfall data, NiMet Archive. Retrieved July, 15, 2015.

Nnawuike, N. (2016). Assessment of the impact of El Nino- Southern Oscillation (ENSO) events on rainfall amount in South-Western Nigeria. *Journal of Physical Science and Environmental Studies*, Vol.2 (2) pp.23-29. ISSN 2467-8775.

Odekunle, T. O. (2004). Determining rainfall onset and retreat dates in Nigeria. *Journal of Human Ecology, 16(4):239–247*

Odjugo, P. (2010). General Overview of Climate Change Impacts in Nigeria. Journal of Human Ecology. 29(1):47-55 (2010).

Oguntoyinbo, J. S. (1986). Drought Prediction. *Climate Change*, 9:79-90.

Ojo, O. (1977). *Climates of West Africa:* Heine-man Publishers, Ibadan.

Okere, F. N., Marengo, J. A., & Nobre, C. (2006). Investigation of El Nino and La Nina Effects and impacts of Atlantic Sea Surface Temperatures (SSTs) on precipitation in Nigeria from 1950 to 1992. Surveys in Geophysics, 27 (5): 545-555.

Okonkwo, C. (2014). An Advanced Review of the Relationship between Sahel Precipitation and Climate Indices: A Wavelet Approach. *International Journal of Atmospheric Science* Vol. 2014, Arcticle ID 759067, 11pg. Doi.org/10.1155/2014/759067

Omay, P. O. (2015). Assessing the Temporal and Spatial Characteristics of Rainfall and Temperature over South Sudan. M.Sc thesis. Dept of Meteorology, University of Nairobi, Nairobi, Kenya.

Omogbai, B. E. (2010). An Empirical Prediction of Seasonal Rainfall in Nigeria. *Journal of Human Ecology*. 32(1), 23-27

Oriola, E. O. (2000). Strategies for Combating Urban Flooding in a Developing Nation: A case Study of Ondo, Nigeria. The Environmental, Vol. 14 No 157, Pp. 62-70.

Owen, J. A., & Ward, M. N. (1990).Forecasting Sahel Rainfall. Weather, 44 (2): 57-64.

Owiti Z. O (2005). Use of the Indian Ocean dipole indices as a predictor of east African rainfall Anomalies, MSc. Dissertation Thesis: Department of Meteorology, University of Nairobi ed. 2005.

Preethi, B., Sabin, T. P., Adedoyin, J. A., & Ashok, K. (2015). Impacts of the ENSO Modoki and other Tropical Indo-Pacific Climate-Drivers on African Rainfall. Science Rep. 5, 16653, doi:10.1038/srep16653

Rao, S. A., Behera, S. K., Masumoto,Y., &Yamagata, T. (2002). Inter-annual subsurface variability in the tropical Indian Ocean with a special emphasis on the Indian Ocean dipole. Deep Sea Res. II, 49, 1549-1572

Rasmussen E. M. & Carpenter T. H. (1983). The relationship between eastern equatorial Pacific sea surface temperatures and rainfall over India and Sri Lanka. Monthly Weather Review. 111, 517–528

Reverdin, G., Cadet, D. L., & Gutzler, D. (1986). Interannual displacements of convection and surface circulation over the equatorial Indian Ocean.*Quarterly Journal of Royal Meteorological Society,* 112, 43–67.

Reynolds, R. W, & Smith, T. M. (1998). A high-resolution global sea surface temperature climatology for the 1961-90 base period. *Journal of Climate*, 11, 3320-3323.Short rains over East Africa. *Journal of African Meteorological Society*, 3, 127-138.

Riddle, E. E., Stoner, M. B., Johnson, N. C., L'Heureux, M. L., Collins, D. C., & Feldstein, S. B. (2013). The impact of the MJO on clusters of wintertime circulation anomalies over the North American region. *Climate Dynamics*, 40, 1749–1766.

Rosalind, J. C. (2012). Overview of the West African Monsoon 2011. *Weather. Royal Meteorological Society* *https://doi.org/10.1002/weather.1896*. Volume 67, Issue 3, pp. 58-65.

Roundy, P. E., & Frank, W. M. (2004). A Climatological of waves in the equatorial Region. *Journal of Atmospheric Science, 61, 2105-2132.*

Rowell, D. P., & Milford, J. R. (1993). On the generation of African squall lines. *Journal of Climate*, 6, 1181–1193.

Saji N. H., Goswami B. N., Vinayachandran P. N. & Yamagata T. (1999). A dipole mode in the tropical Indian Ocean. *Nature* 401, 360–363. [PubMed].

Saji, N. H., & Yamagata, T. (2002b). Interference of teleconnection patterns from the tropical Indian and Pacific Oceans (revised for climate research).

Saji, N. H., & Yamagata, T. (2003). Structure of SST and surface wind variability during Indian Ocean Dipole mode events: COADS observations, *Journal of Climatology*, **16**, 2735–2751.

Schott, F., & McCreary, J. P. (2009). The monsoon circulation of the Indian Ocean, *Programme Oceanography*, 51, 1–123.

SCOR (Scientific Committee on Oceanic Research) (1983). Prediction of El Nino. Proceedings No. 19 Paris. Annex VI, SCOR WG 55, 47-51.

Shanahan, T., Overpeck, J. T., Anchukaitis, K. J., Beck, J. W., Cole, J. E., Dettman, D. *et al*. (2009). Atlantic Forcing of Persistent Drought in West Africa. *Science 324 (5925): 377–380.*

Shinoda, T., Alexander, M. A. & Hendon, H. H. (2003). Remote response of the Indian Ocean to inter-annual SST variations in the tropical Pacific. *Journal of Climate* (submitted).

Simpson, J., Adler, R. F. & North, G. R. (1988). A proposed Tropical Rainfall Measuring Mission (TRMM) satellite. *Bulletin of American Meteorological Society. 69, 278–295.*

Sultan, B. & Janicot, S. (2003). The West African Monsoon Dynamics. Part I: Documentation of Intraseasonal Variability, *Journal of Climate*, *https://doi.org/10.1175/1520-0442(2003)016*

Thorncroft, C., & Hodges, K. (2001). African easterly wave variability and its relationship to Atlantic tropical cyclone activity. *Journal of Climate*, 14, 1166–1179.

Ukhurebor, K. E., & Abiodun, I. C. (2018). Variation in Annual Rainfall data of forty years (1978-2017) for South-Souh, Nigeria. *Journal of Applied Sciences*. Environmental Management.22(4): 511-518.

Ummenhofer, C. C., Sen, G. A., England, M. H., & Reason C. J. C. (2009). Contributions of Indian Ocean Sea surface temperatures to enhanced East African rainfall. *Journal of Climate* 22, 993–1013.

Usman M. T. (2000). An instability index for monsoon onset characterization over Nigerian Sahel. *Environmental Rev*iew, 3(1):367-379.

Van Heerden, J., Terblanche, D. E. & Schulze, G. C. (1988). The Southern Oscillation and South African summer rainfall, *Journal of Climatology,* 8,577–597.

Vinayachandran, P. N., Kurian, J., & Neema, C. P. (2007). Indian Ocean response to anomalous conditions in 2006, *Geophysics Research Letter,* 34, L15602, doi:10.1029/2007GL030194.

Webster, P. J., Moore A. M., Loschnigg J. P., & Leben R. R. (1999). Coupled ocean–temperature dynamics in the Indian Ocean during 1997–98. *Nature,* 401, 356–360.

Williams, C. A., & Hanan, N. P. (2011). ENSO and IOD teleconnections for African ecosystems: evidence of destructive interference between climate oscillations, Biogeosciences, 8, 27–40, www.biogeosciences.net/8/27/2011/ doi:10.5194/bg-8-27-2011

World Meteorological Organization, (WMO), (2014). El Nino Southern Oscillation (ENSO); *Journal of Weather. Climate. Water*. ISBN 978-63-11145-6

Wyrtki, K. (1973). An equatorial jet in the Indian Ocean, Science, 1973 Jul. 20. 181(4096):262-4. DOI:10.1126/science.181.4096.262

Yamagata, T., Ashok, K., Guan, Z., & Saji, N. H. (2004). Individual and Combined Influences of ENSO and the Indian Ocean Dipole on the Indian Summer Monsoon. *Journal of Climate,*17, 3141-3155

Yen, M.C., Chen, T.C., Hu, H. L., Tzeng, R.Y., DinhDucTu, Nguyen, T.T.T *et al.* (2011). Interannual Variation of the Fall Rainfall in Central Vietnam, *Journal of Meteorological Society Japan, 89A,* 259-270.

Zhou S., L'Heureux, M., Weaver, S., & Kumar, A. (2012). A composite study of MJO influence on the surface air temperature and precipitation over the Continental United States. Climate Dynamics, 38, 1459-1471.