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# The Links between Variations in Climate Patterns and ITCZ Position over Nigeria

**Opeyemi Rabiu Salau**

Department of Physics, Faculty of Science, Ekiti State University, Ado – Ekiti, Ekiti State, Nigeria

E-mail address: o.salau@t-online.de

Tel.: +2348163717664

**ABSTRACT**

The analysis of the observed 30 years data that include the monthly precipitation, wind speed and solar radiation from Maiduguri, Abuja, Ikeja and Port Harcourt is done to estimate the approximate shift in the Inter-Tropical Convergence Zone (ITCZ) mean position over Nigeria. The data are separated into three decades (1981-1990, 1991-2000 and 2001-2010) and their monthly mean values are compared with each other and with the corresponding magnitudes over the whole period (1981-2010). The results indicate that the overall precipitation increases southward across the country while the annual mean intensity rises over the decades in all the selected locations. Using the extreme decades, the magnitude of the rainfall in 2001-2010 is higher than the corresponding values in 1981-1990 by 20.84 mm, 9.87 mm, 18.40 mm and 6.89 mm in Maiduguri, Abuja, Ikeja (Lagos) and Port Harcourt respectively. Further investigation in all the locations showed periods of elevated monthly rainfall in the recent decades than other periods; the magnitudes compared to 1981-1990 are between 48.6mm-78.4mm which are much higher than the annual mean intensities while few months with very low rainfall are observed in Abuja and Port Harcourt. As expected, reverse pattern is seen in the wind speed which is generally lower in 2001-2010 than in 1981-1990. The rising magnitude of the precipitation over the decades imply that the ITCZ must have been shifting slightly over the periods to a more northern extreme in 2001-2010, causing northward spread of the rainfall which raises the overall intensity of the rainfall across Nigeria. A persistent northward shift in the ITCZ position with increasing magnitude of the associated rainfall could raise the current severity of soil erosion, frequency of flooding that might cause severe damages and paralyze businesses in Nigeria under such a future climate change. Hence, availability of data with advance technology for studying fluctuations in the ITCZ position might improve weather forecast that could favour farm yield and save lives and properties as climate changes in the future.

***Keywords*:** ITCZ, Rainfall, Wind Speed, Temperature, Solar Radiation, Flood, Climate

## 1. INTRODUCTION

Food production in most parts of the World and particularly in sub-Saharan Africa region is climate dependent such that crops are planted during the season with enough moisture for the crops to grow and produce maximum yield. However, research has shown that the spatial and temporal variability in rainfall patterns over Africa is very high. This is especially the case along the southern margins of the Sahara called the Sahel in the Western part of Africa where the variation in the mean annual rainfall over approximately 750 km could be above 1000 mm. The report further indicates that a climate induced small shift in the location of Inter-Tropical Convergence Zone (ITCZ) could have considerable effects on the intensity of rainfall and consequently on the economy and on the society of the region. According to *Philander et al*, the ITCZ position is characterized by low pressure and heavy rainfall formed by condensation from moist air that rises under the strong solar heating along the equator, before diverging poleward near the tropopause. The air later descends over subtropical regions (within 30°N and 30°S) and then travels equatorwards as dry and cool trade winds to complete what is known as Hadley Circulation. Thus, a few percent increase in the heating from solar radiation, might strongly raise atmospheric water vapour that migrates inland where it mixes with cloud to produce rainfall under favourable conditions [1-5].

Globally, the ITCZ position is sustained in a more northern location in the east by the enhanced heating from the larger land mass in northern part of the region compared to the west. Due to its sensitivity to solar heating, the ITCZ follows the north-south movement of the sun, leading to seasonal distribution of the rainfall and the length of the net season in the tropical region. In Africa and in Nigeria for example, the ITCZ is the interface between the cool, moisture bearing south-western wind from the Atlantic Ocean and the hot, dry north-easterlies continental air mass (CAM) from the Sahara desert; it is a band of clouds and rainfall with occasional thunderstorms. The ITCZ is in the southernmost position in Nigeria around January-February (Fig. 1a) during which dry season prevails under the influence of the north-east winds while rainy season begins in March, reaching the southern peak in July as the ITCZ moves to a more northern position. The precipitation reduces (increases) thereafter in the south (north) where there is what is called August break (rainfall peak) during which the ITCZ is in the northern-most position (Fig. 1b) [6-8].

Furthermore, the northern precipitation declines in September while it simultaneously rises to a secondary peak in the south due to southward migration of the ITCZ around September-October after which there is long dry season between November-February (October-April) in the southern (northern) Nigeria. Under the influence of rainfall, the temperature is lower in the south which is near the Atlantic Ocean than in the North where dry and cloud free conditions persist in most periods of the year. Hence, an ITCZ induced shift in the intensity of the precipitation and the associated planting season, might have catastrophic impacts on the country's economy through drought or flooding during the respective time of reduced rainfall or increased downpour. It is therefore necessary to improve our understanding of the current forecasting capabilities in Nigeria so as to minimize the possible climate hazards.

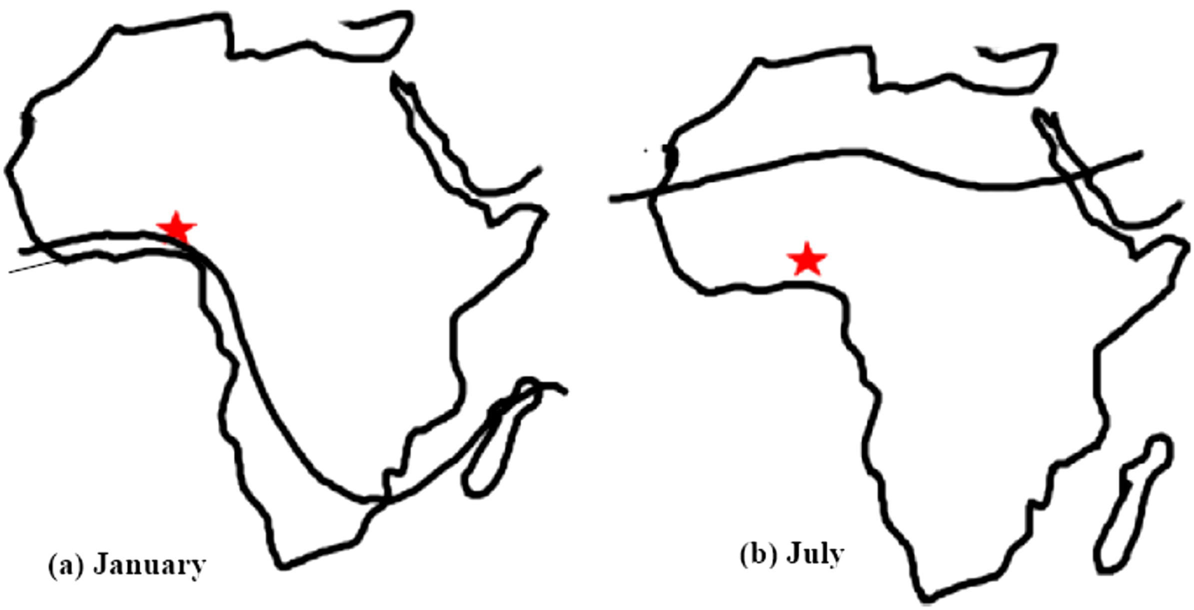



**Figure 1.** The maps of Africa showing the locations of the ITCZ in (a) January and (b) July. The approximate location of Nigeria is marked with red star.

## 2. THE STUDY AREA

The study area is Nigeria with focus on some selected regions as representative of the whole country; these areas include Maiduguri from the north, Abuja in the central part of the country while Ikeja and Port Harcourt represent the South and the far south respectively (Fig. 2). Nigeria is located in West Africa where it is positioned approximately between latitudes 4°N and 14°N and within longitudes 3°E and 14°E along its widest borders while it occupies total area of about 923,768 sq km (2012 estimate). The country is bounded in the North by Niger Republic, West by Benin Republic and shares boundary with Cameroon in the East while Atlantic Ocean occupies the south where the Ikeja port in Lagos State is located [6,7].

It is a strategic place for investors and businesses due to her abundant natural resources (led by petroleum) and population of over 174 million people (2012 estimate) which are mainly farmers that depend on weather.

Nigeria is located in the tropical region where the atmosphere is warm throughout the year. The daily temperature range could go beyond 35-38 °C depending on the location in Nigeria while the monthly mean value is about 27 °C. The temperature in Nigeria is slightly low in January before it rises as the Sun crosses the Equator and moves northward in March, thus leading to high temperature around March-April while there is ITCZ (rainfall) induced low magnitude in August. The warming diminishes when the Sun migrates southward, resulting in the secondary high peak in October-November. The mean temperature is higher in the north than in the wet and humid south where the temperature is damped under the influence of rainfall which reduces northward over the country. This atmospheric condition depends on the ITCZ induced seasonal changes in rainfall which in turn is important for farming activities in Nigeria. The dry season is between November-February (October-April) in the South (North) while the remaining months are in wet season; the seasonal patterns occur due to the north-south migration of the ITCZ location over the country.


**Figure 2.** Map of Nigeria showing the study areas (marked with red stars; Adapted from, [8]). Inserted is the map of Africa with location of Nigeria in green [6].

## 3. DATA DESCRIPTION AND ANALYSIS

The data used in this study include the observed monthly precipitation, average temperature, wind speed and solar radiation from the selected regions of the country based on the available records. Maiduguri is selected from the north, the capital town of Abuja in the middle, Ikeja in the south and Port Harcourt is picked because of its location in the far south where there is rainfall throughout the year (Fig. 2). The data is from the National Metrological Agency [NIMET] observational records of 1981-2010 with the exception of Abuja where values from 1983-2010 are available. The average temperature is estimated as the mean value $[\frac{1}{2}(maximum\ temperature + minimum\ temperature)]$ while the monthly mean magnitudes of all the variables are calculated over the 30 years. The monthly values are obtained over one decade as average figure for each month and are estimated for 1981-1990, 1991-2000 and 2001-2010 periods.

These records are compared for all locations while the overall monthly mean values for respective decades are obtained and compared for each variable; however, few months are without data.

## 4. THE RESULTS

### 4. 1. The Decadal Shifts in the ITCZ Position

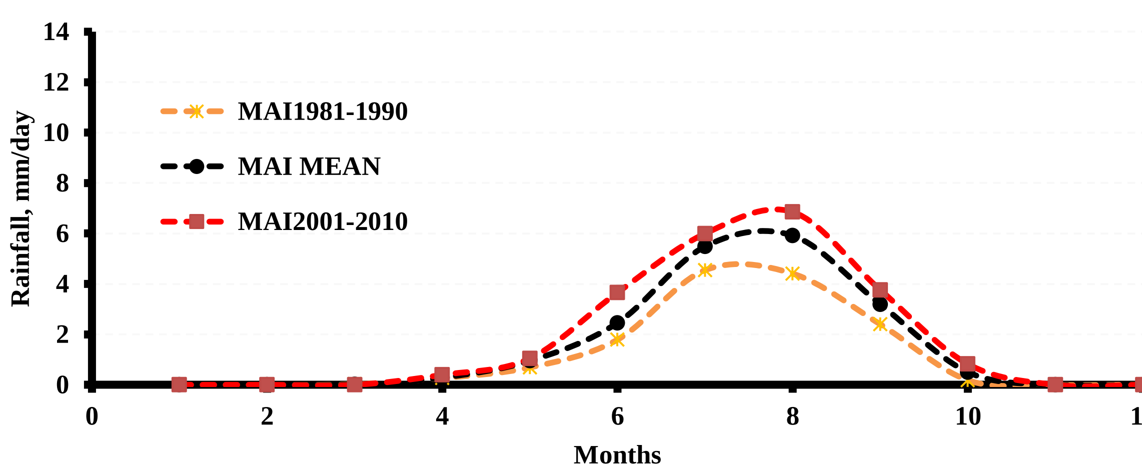
The decadal shift in the ITCZ position is mainly investigated using the variations in the rainfall intensity, wind speed and solar radiation since the ITCZ location in the thermal equator is usually characterized by deep, moist convection, weak wind and strong solar heating. The findings are explained under the following headings.

#### 4. 1. 1. Rainfall Patterns and the ITCZ Position

The monthly rainfall data, estimated as average values for each month over each decade (1981-1990, 1991-2000, 2001-2010) are investigated and compared with each other and with the corresponding values averaged over the whole study period (1981-2010). The aim is to use the monthly rainfall variations as a tracer of the ITCZ movement across the country.

Apart from the monthly values estimated over the three decades, only the precipitation changes for the first decades (1981-1990), the last decades (2001-2010) and the long term monthly magnitudes (1981-2010) are plotted for all the selected locations for clarity (Figs. 3a, b, c, d). According to the figure, the downpour that started early enough in the south, reaches the peak in June-July and has a secondary peak in September before a downward trend is seen.

The rainfall started around March (May) and rose to the peak in August before it declines to the minimum around November (October) in Abuja (Maiduguri). The rainfall is generally lower in 1981-1990 when compared with the long term mean values in 1981-2010 while the magnitude rises above the mean levels during 2001-2010 periods. This observation is more pronounced in the northern part of the country like in Maiduguri with broader curve in the recent decade than the mean intensity and far above the magnitude in 1981-1990; this is unlike the south where there is rainfall almost throughout the year.



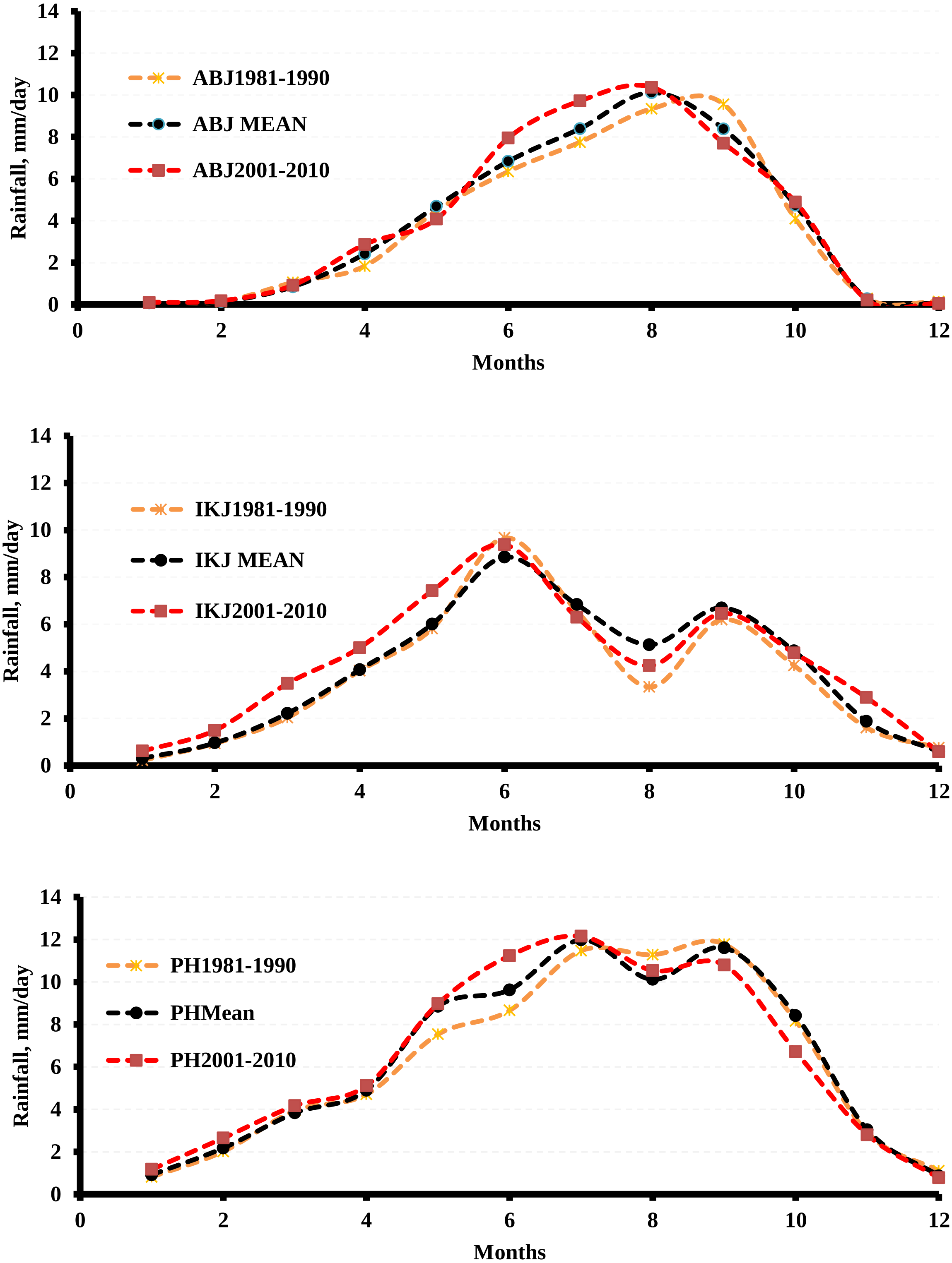



**Figure 3.** The changes in rainfall patterns as a measure of the shifts in the ITCZ position. The patterns are shown for Maiduguri (MAI), Abuja (ABJ), Ikeja (IKJ) and Port-Hacourt (PH). Note that the symbol used for each decade is the same in all locations.

The above patterns might be explained by the seasonal movement of the ITCZ position such that the rainfall is low in January-February during which the ITCZ is in the southernmost location due to the southward expansion of the influence of the dry, north-easterlies CAM over Nigeria. The rainfall later intensifies across the country as the ITCZ moves northward under a weak north-easterlies CAM, reaching the central-northern peak in August when the ITCZ gets to its northern-most location. This lead to the interruption of the southern peak rainfall by a period of low precipitation called August break which is followed by southward migration of the ITCZ and the gradual decline of the rainfall over Nigeria. These observations further explained the broader bases seen in Port Harcourt and Ikeja where the downpour started earlier and it also ended in the region when compared to the north where the onset of the rainfall is delayed. Thus, the overall intensity of the rainfall increases southward with magnitude of 1.57 mm/day (47.68 mm), 3.92 mm/day (119.22 mm), 4.03 mm/day (122.73 mm) and 6.43 mm/day (192.98 mm) in Maiduguri, Abuja, Ikeja-Lagos and Port-Harcourt respectively. The monthly equivalents which are shown in the brackets are obtained by multiplying the daily magnitudes by 30.4 which is the approximate average value of all the months. The second observation is the continuous increase in the overall mean values of the rainfall over the three decades (including 1991-2000). These are seen in the 2001-2010 curves that tend to be slightly broader than those in 1981-1990 in all cases with major noticeable exceptions in September over Abuja (Fig. 3b) and the slight decrease in the rainfall in August-November in Port Harcourt (Fig. 3d). The overall mean values from each decade show that the precipitation increases from south to the north. The mean values in all the locations slightly appreciate in 2001-2010 above the 30 years long term average and also rises over the decades such that the highest magnitudes are seen in 2001-2010, followed by 1991-2000 and the least intensities in 1981-1990 (Fig. 4). However, the intensity of the rainfall should be much greater in Ikeja than in Abuja, but the small difference between the two locations might be due to data problem or the concentration of heavy downpours in the few months of the rainy season in Abuja while rainfall might be weak in Ikeja during the study period.

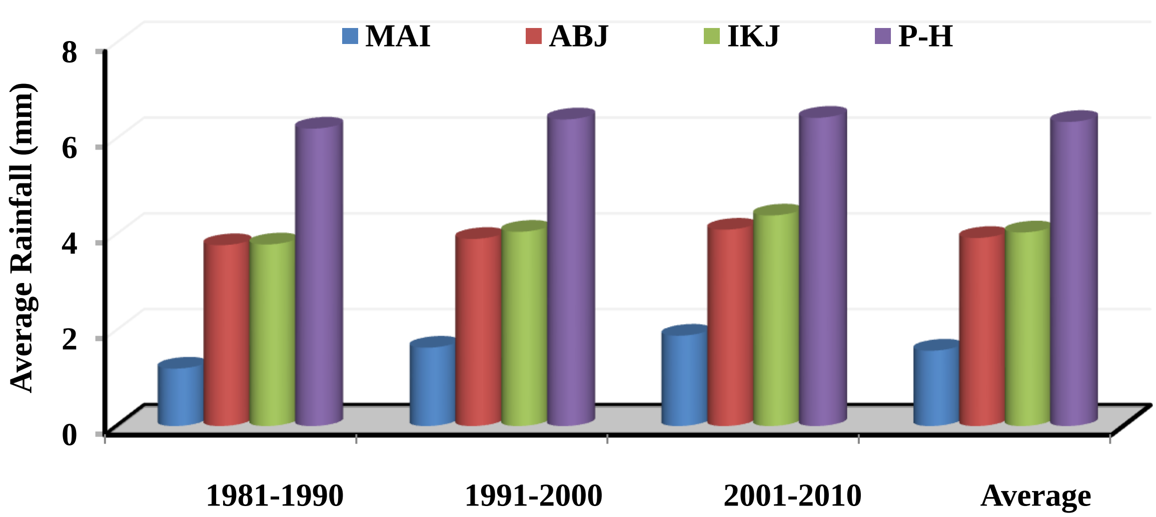



**Figure 4.** The overall mean values of the rainfall averaged over 1981-1990, 1991-2000, 2001-2010 and the 30 years for Maiduguri (MAI), Abuja (ABJ), Ikeja (IKJ) and Port-Hacourt (P-H).

Although the differences in the above values appear to be small across the decades, but a closer look revealed strong changes in the monthly intensities of the rainfall. This decadal changes in the monthly rainfall is investigated by subtracting the monthly average of 1981-1990 from 1991-2000 period, 1991-2000 from 2001-2010 and that of 1981-1990 from 2001-2010 for the extreme decades. All the results revealed positive values with few exceptions of negative magnitudes in some months (especially in Port Harcourt, Abuja) when the monthly differences are compared between all the decades (not shown); the outcome of the extreme decades is shown in Figure 5. In agreement with the observations in Figure 3(a, b, c, d), the curves indicate that the rainfall is generally higher in 2001-2010 when compared with that of 1981-1990 in each location; the exceptions are seen in the strong decrease of about 1.44 mm/day (43.8 mm) between August-November in Port Harcourt and the 1.86 mm/day (56.5 mm) in September within Abuja. In general, the 2001-2010 precipitation is above that of 1981-1990 by about 1.79 mm/day (54.4 mm) in August over Maiduguri while 1.96 mm/day (59.6 mm) is recorded in July at Abuja. Also, 2.58 mm/day (78.4 mm) is observed in June in Port Harcourt and Ikeja is characterized by several high intensities with the strongest value of 1.60 mm/day (48.6 mm) in May. The overall higher magnitudes of the precipitation in 2001-2010 compared to 1981-1990 suggest that the mean position of the ITCZ has slightly shifted more to the north in the recent decade, thus spreading the rainfall further north and raising the magnitude in the region and over Nigeria and her environments.

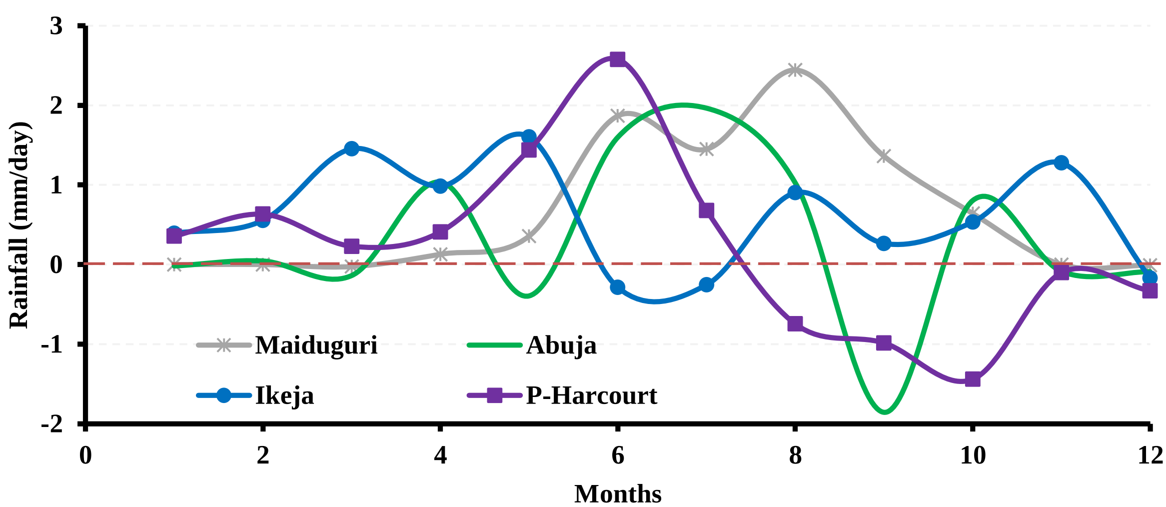



**Figure 5.** The differences in the monthly rainfall obtained for the extreme decades by subtracting the monthly values in 1981-1990 from the corresponding values in 2001-2010.

### 4. 1. 2. Wind Speed and the ITCZ Position

The ITCZ is called the doldrums because winds have weak strength within the area under the influence of the ITCZ; thus, this is investigated using the wind speed data from the selected areas. The first observation indicates that wind speed is higher in the northern parts of the country than in the southern locations and also revealed that periods with elevated downpours are characterized by reduced wind speed in the country (Fig. 6a, b, c).

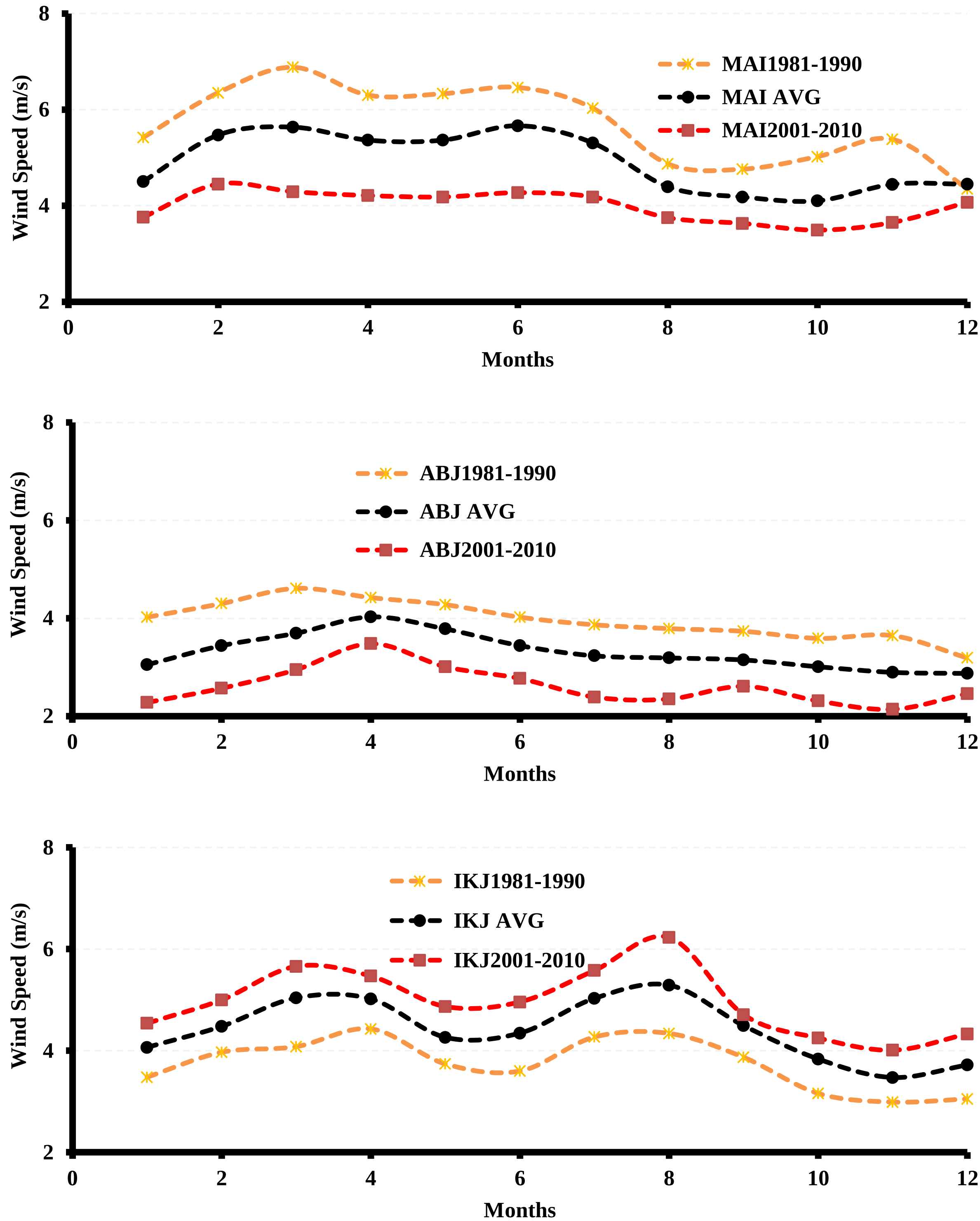



**Figure 6.** The decadal variations in the wind speed (m/s) from the study locations in Nigeria. The line colours and symbols are similar to those used in Figure 3.

There is no remarkable change in the wind speed in Port Harcourt where the speeds remain low throughout the year under the persistent heavy precipitation from the moisture bearing wind from the Atlantic Ocean (not shown). The result indicates that the high northern wind speed is very low during the strong rainfall in August (Fig. 6a, b) while the low speed in the south becomes strong within the southern parts in that month, this is followed by low speed as the rainfall increases (Fig. 6c). This result is in agreement with the northward migration of the ITCZ to the northernmost point in August with reduction in the wind strength and intensification of the rainfall while opposite pattern is seen in the south.

Secondly, the wind speed is generally low in the recent decades with increased rainfall (2001-2010) when compared to the 1981-1990 which is characterized by reduced rainfall. This is in support of a possible northward shift in the ITCZ position over the country. As expected, the speeds in Maiduguri are higher than the magnitudes observed in the corresponding periods in Abuja, but there is jump in the wind speed in the recent decade in Ikeja-Lagos, thus putting the mean value above that of 1981-1990 in the region and over the corresponding periods in Abuja (Fig. 6b, c). The irregular patterns in the wind speeds from these coastal regions might also be associated with local influences from the Atlantic Ocean.

#### 4. 1. 3. The Solar Radiation Patterns and the ITCZ Position

Also, investigation into the impacts of solar radiation on the ITCZ formation is done by comparing the solar radiation and the rainfall intensity. The Gunn-Bellani radiation data (in millimetres) that relates the volume of liquid distilled by solar radiation to the quantity of solar radiation reaching a horizontal surface is used for the comparison. The Gunn-Bellani data is converted to solar radiation intensity unit of $MJm^{-2}day^{-1}$ (Millijoules per metre square per day) by multiplying the values with a factor of 1.216 proposed by Ododo. In agreement with north-south movement of sun, the solar radiation is low in January; it rises to the peak in April and declines to the minimum in August under heavy rainfall before reaching the second maximum in October-November (not shown). Thus revealing an inverse variations between the rainfall and the solar radiation; this is further confirmed by the strong negative correlation between the two variables in Maiduguri, Abuja, Ikeja and Port Harcourt with values of -0.53, -0.93, -0.58 and -0.87 respectively. The strong correlation supports the importance of solar heating in the formation of the ITCZ; however, the negative values show that the solar radiation attenuates under the cloud formed during the heavy rainfall within the ITCZ. This observation also explained the reduction in the solar radiation in 2001-2010 during which the rainfall is higher than that of 1981-1990 in all locations with the exception of Abuja where the solar radiation rises in the recent decade (not shown).

Similarly, the findings indicate that the associated sunshine hours and the long-term mean temperature reduces southward as the rainfall increases while the magnitudes of both variables are generally lower in the recent decade due to increased rainfall when compared to 1981-1990. For instance, the long-term mean sunshine hours in Maiduguri, Ikeja and Port Harcourt is 8.26, 5.00 and 3.97 hours respectively; however, data representing the sunshine hours for Abuja is not available for this investigation. In accordance with the above results, strong negative correlation of -0.86, -0.54 and -0.83 is also obtained from Maiduguri, Ikeja and Port Harcourt respectively. The temperature over the country is lower in the South which is near the Atlantic Ocean than in the North where dry and cloud free days are common in most periods of the year. The observed long-term mean temperature (1980-2010) from the respective location is 27.73, 27.24, 27.21 and 26.96 °C for Maiduguri, Abuja, Ikeja and Port

Harcourt while strong negative correlations are also obtained between the rainfall and temperature. The temperature is generally low in December-February and in August in all the selected areas while the temperatures intensifies as the Sun crosses the Equator around March and moves northward, leading to the peak intensity in March from the southern regions which shift to April-May in the North with increased magnitudes (not shown). The secondary peak is seen in October-November as the Sun returns southward while low temperature is observed between July-September as the ITCZ spread the moisture bearing cool wind from Atlantic Ocean over the country [6-12].

### 4. 2. The comparison of the result with other data

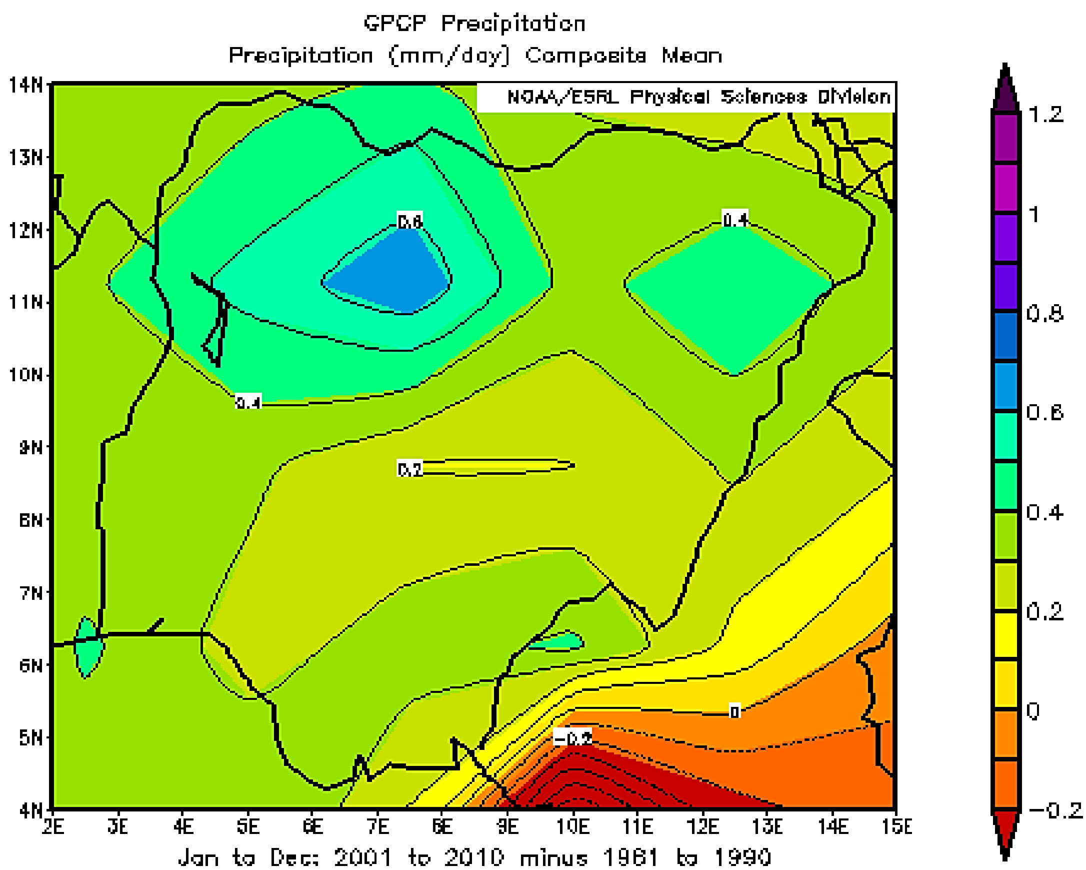



**Figure 6.** The observed difference between the rainfall data in 2001-2010 when compared to 1981-1990 using the Precipitation Climatology Project (GPCP) precipitation data.
(Data Source: https://www.esrl.noaa.gov/psd/cgi-bin/data/composites/printpage.pl)

The outcomes of this study are compared with other data to establish the authenticity of these results. For instance, the comparison with the Global Precipitation Climatology Project (GPCP) data is in support of a northward shift in the mean position of the ITCZ in the recent decade; this is confirmed by the higher intensity of the precipitation in 2001-2010 throughout Nigeria when compared to 1981-1990 (Fig. 7). This might be associated to a northward shift of the ITCZ and possible extension of the downpour to northern regions that are usually dry and hence causing an overall increase in the magnitude of the precipitation over the country. The anomalous increase in the magnitude of the GPCP rainfall is approximately 0.5 mm/day (15.22 mm), 0.3 mm/day (9.13 mm), 0.4 mm/day (12.18 mm), 0.2 mm/day (6.09 mm) in Maiduguri, Abuja, Ikeja and Port Harcourt respectively. This is in close agreement with this study where the value for each location is 0.68 mm/day (20.84 mm), 0.32mm/day (9.87 mm), 0.60 mm/day (18.40 mm) and 0.23 mm/day (6.89 mm) in Maiduguri, Abuja, Ikeja-Lagos and Port Harcourt respectively.

Similarly, the annual variations in the rainfall patterns and the observed movement of the ITCZ position across Nigeria with stronger rainfall in the south compare to the north is in agreement with the study reported by Udo and Okujagu. In accordance with this research, they observed peak rainfall in June-July (August) in the southern (northern) part of the country while a secondary peak is seen in the south in September after the rainfall declines as the ITCZ retreats southward over the country [11-19].

## 5. CONCLUSIONS

This study investigates the decadal shifts in the ITCZ mean position using 30 years long data that include rainfall, wind speed, solar radiation and sunshine hours from Maiduguri, Abuja, Ikeja-Lagos and Port Harcourt to estimate the approximate shift in the ITCZ mean position over Nigeria. The data are separated into three decades (1981-1990, 1991-2000 and 2001-2010) and their monthly mean values are compared with each other and with the corresponding magnitudes over the whole period (1981-2010) to examine the shift in the ITCZ location. The result indicates that the annual mean precipitation increases southward across the country while the intensity rises over the decades in all the locations; the magnitude tends to be higher in the northern locations than in the south. Using the extreme decades, the results revealed higher magnitudes of rainfall in 2001-2010 than in 1981-1990 with values of 20.84 mm, 9.87 mm, 18.4 mm and 6.89 mm in Maiduguri, Abuja, Ikeja (Lagos) and Port Harcourt respectively; the values are in good agreements with observation (GPCP). As expected, reverse pattern is seen in the wind speeds which are generally lower in 2001-2010 with heavier rainfall when compared to that of 1981-1990. Though the annual mean changes in the rainfall is low in each location (Fig. 4), but the observed elevated monthly rainfall of magnitudes between 48.6 – 78.4 mm and the months with extremely low precipitation in 1981-1990 when compared to the recent decade could cause environmental hazards (Fig. 5).

This investigation indicates that there is shift in the average position of the ITCZ to a more northern location over the thirty years studied. This imply that the ITCZ must have moved beyond its usual northern border in 1981 to a more northern extreme in 2010, causing northward spread of the rainfall that consequently raises the overall intensity of the precipitation across Nigeria. A persistent northward shift in the ITCZ position with increasing magnitude of the associated rainfall could raise the severity of soil erosion, spread of diseases like malaria and dengue, rise in frequency of flooding that might cause severe damages and paralyze businesses under a future climate change. Example might be seen in the flooding caused by intensification of rainfall between 1985 to 2014 that negatively touched the lives of over 11 million people in Nigeria, causing about 1100 deaths and damages worth more than US$17 billion.

Also, severe flooding in Kano (in north) claimed several lives, displaced thousands of people, damaged 180,000 houses and 14,000 farms in August, 1988 while 24 people died with about 100 houses destroyed and over 300 people displaced due to flooding in the area in July, 2011. The increased flooding and its damaging effects have been attributed to climate change with increase in rainfall and other factors like rapid population growth, poor urban planning during the current rising of urbanization. As part of the suggested solutions, availability of flood data with improved research and better technology for monitoring floods are necessary while strong political will, funding, public enlightenment and good environmental and physical planning are needed to combat the problem under a future climate change. Hence, proper monitoring of shifts in the ITCZ position might help to improve climate prediction that will raise farm yields and save lives and properties during the associated environmental hazards.

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## References

[1] B. Abaje, C. Ndabula, A. H. Garba, Is The Changing Rainfall Patterns Of Kano State And Its Adverse Impacts An Indication Of Climate Change? *European Scientific Journal*, vol. 10, No 2, Jan. 2014

[2] Philander, S. G. H., D. Gu, D. Halpern, G. Lambert, N.-C. Lau, T. Li, and R. C. Pacanowski, The role of low-level stratus clouds in keeping the ITCZ mostly north of the equator, *J. Clim.*, Vol. 9, 1996, No. 12, 2958-2972.

[3] Xie S.-P., Miyama, T., Wang Y., Xu H., deSzoeke S. P., Small R.J., Richards, K. J., Mochizuki T., and T. Awaji, A regional ocean-atmosphere model for eastern Pacific climate: towards reducing tropical biases, *J. Clim.*, 20, 1504-1522, 2007

[4] Hiremath, K. M. et al., Indian summer monsoon rainfall: dancing with the tunes of the sun, *New Astron.* 35, 8-19, 2015

[5] Okonkwo G. N., Nwokoye A. O. C., Estimating global solar radiation from temperature data in Minna location. *Eur. Sci. J.* 2014, 10, 255–264.

[6] Ododo, J. C., New models for the prediction of solar radiation in Nigeria, *in Proceedings of the 2nd OAU/STRC Conference on New, Renewable and Solar Energies*, Bamako, Mali, 16–20 May 1994.

[7] Adler, R. F., G. J. Huffman, A. Chang, R. Ferraro, P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, and P. Arkin, The Version 2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979-Present), 2003, *J. Hydrometeor.* 4, 1147-1167.

[8] Udo, I.A, Okujagu, C. U., "Assessment of Inter-Tropical Convergence Zone (ITCZ) Impact on Precipitation in Six Locations in Nigeria," *International Journal of Science and Research (IJSR)*, Vol. 3 Issue 6, June 2014

[9] Nkwunonwo U. C., Malcolm W., Brian B., Flooding and Flood Risk Reduction in Nigeria: Cardinal Gaps, *J Geogr Nat Disast* 5: 136, doi:10.4172/2167-0587.1000136

[10] Houston D., Werritty A., Bassett D., Geddes A., Hoolachan A., et al., Pluvial (rain-related) flooding in urban areas: the invincible hazard, York, UK: Joseph Rowntree Foundation, 2011

[11] Merz B., Thieken A. H., Gocht M., Flood risk mapping at the local scale: concepts and challenges, in Flood risk management in Europe, Springer, Netherlands, 2007.

[12] Kalnay Eugenia, Cai Ming. Impact of urbanization and land-use change on climate, *Nature* 423.6939 (May 29, 2003), 528-31.

[13] Virginia H. Dale. The relationship between land-use change and climate change. *Ecological Applications* Volume 7, Issue 3, August 1997 Pages 753–769, DOI:10.1890/1051-0761(1997)007[0753:TRBLUC]2.0.CO;2

[14] Urban Frank E., Cole Julia E., Overpeck Jonathan T., Influence of mean climate change on climate variability from a 155-year tropical Pacific coral record. *Nature* 407.6807 (Oct 26, 2000): 989-93

[15] Zhi Li, Wen-zhao Liu, Xun-chang Zhang, Fen-li Zheng. Impacts of land use change and climate variability on hydrology in an agricultural catchment on the Loess Plateau of China. *Journal of Hydrology* Volume 377, Issues 1–2, 20 October 2009, Pages 35-42 https://doi.org/10.1016/j.jhydrol.2009.08.007

[16] B. C. C. van der Zwaan, R. Gerlagh, G. Klaassen, L. Schrattenholzer. Endogenous technological change in climate change modeling. *Energy Economics*, Volume 24, Issue 1, January 2002, Pages 1-19, https://doi.org/10.1016/S0140-9883(01)00073-1

[17] Pytrik Reidsma, Frank Ewert, Alfons Oude Lansink, Rik Leemans, Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. *European Journal of Agronomy*, Volume 32, Issue 1, January 2010, Pages 91-102 https://doi.org/10.1016/j.eja.2009.06.003

[18] James E. Hansen. Sir John Houghton: Global Warming: The Complete Briefing, 2nd edition. *Journal of Atmospheric Chemistry*, July 1998, Volume 30, Issue 3, pp 409–412

[19] Lawrence H. Goulder, Koshy Mathai, Optimal $CO_2$ Abatement in the Presence of Induced Technological Change. *Journal of Environmental Economics and Management* Volume 39, Issue 1, January 2000, Pages 1-38 https://doi.org/10.1006/jeem.1999.1089

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