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Effect of Climate Variability on Relative Humidity Anomaly over Nigeria

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Abstract- Earth science data consist of a strong seasonality component as indicated by the cycles of repeated patterns in climate variables such as relative humidity. Since the raw meteorological data are constantly being generated with the help of satellite observations, the climate scientists usually use a moving reference base interval of some years of raw data to calculate the mean in order to generate the anomaly time series and study the changes with respect to seasons.

In this paper, the temporal trends in Surface Refractivity Humidity (SRH) anomaly was investigated using meteorological data (1983–2005; 2008 - 2013) from 17 gridded stations located in different climatic zones across Nigeria. Departure of recent values of relative humidity in 2008 – 2013 from 22-year mean value was graduated into 5 classes namely – extremely dry (-29.43 - -19.39); very dry (-19.38 - -10.40); dry (-10.39 – 0.74); wet (0.75 – 10.93) and very wet (10.94 – 20.17). A total of 4 maps were generated to show the spatial distribution and magnitude of SRH anomaly over Nigeria.

Surface relative humidity anomaly over Nigeria generally revealed negative trend in most of the stations under investigation. Each selected month had its peculiar characteristic along latitudinal belt. Intensive irrigation in northern Nigeria also contributed significantly to climate variability as wetness was sustained even in the peak of dry season. April, July and October had prevalence of drier phenomena in recent years (2008 – 2013) more than 22-year (1983 – 2005) averages while January was a slight exception.

Index Terms- Surface relative humidity anomaly, climate variability, surface moisture, satellite meteorological data

I. Introduction

An important component of meteorological data is the seasonal and temporal variation of the surface relative humidity (SRH). Seasons occur due to the revolution of the earth around the sun and the tilt of the earth's axis. The change in seasons brings about annual changes in the climate of the earth such as increase in relative humidity in wet season and decrease in relative humidity in the dry season. The seasonality component is the most dominant component in the earth science data.

The seasonal patterns even though important are generally known and hence uninteresting to study. Mostly, scientists are interested in finding non-seasonal patterns and long term variations in the data. As a result of the effect of seasonal patterns, other signals in the data like long term decadal oscillations, trends, etc., are suppressed and hence it is necessary to remove them. Climate scientists usually aim at studying deviations beyond the normal in the data and this is referred to as anomaly.

Often, climate scientists only take 30 years as a reference interval and construct anomalies with respect to that interval. There are several important results and implications derived from the anomalies constructed using a short reference base. In general, climate data has complex structures due to spatial and temporal autocorrelation (Wright *et al*, 2010).

In this research, SRH is regarded as an important factor in determining the distribution and occurrence of clouds (Sundqvist, 1978; Price and Wood, 2002). An increase in the fraction of optically thin high clouds with warming would represent a positive feedback; as such clouds are relatively transmissive to sunlight, largely opaque to outgoing longwave radiation, and have a substantially different emission temperature than the surface. The converse is true for low clouds, as the increase in solar albedo that they provide outweighs their effect as longwave absorbers

A greater understanding of the underlying causes of simulated SRH changes and their plausibility may therefore be helpful in constraining cloud feedbacks, which currently represent the largest source of intermodel spread in climate sensitivity (Randall *et al.*, 2007). Inhomogeneity in SRH changes also impacts the distribution of both latent and radiative heating, which may then project onto the atmospheric circulation (Schneider *et al*., 2010), large-scale convective organization (Gray and Jacobson, 1977), and the level at which deep convection detrains (Hartmann and Larson, 2002). Regional shifts of the climatological distribution of SRH thus have the potential to influence climate on a wide range of scales.

Relative humidity is defined in this analysis as the ratio of specific humidity to saturation specific humidity. Saturation specific humidity is a function of local temperature as expressed by the Clausius–Clapeyron equation (Galewsky *et al*., 2005). Free tropospheric specific humidity is in turn determined from temperature and circulation fields, where the latter includes the distribution of convective transport, with condensate evaporation playing a minor role (Wright *et al*. 2009).

In spite of current interest in analyzing atmospheric humidity for detecting global warming, there is lack of sufficient studies on the trends of SRH anomalies over Nigeria. This paper details the work performed to detect the temporal trends in SRH anomaly using meteorological data (1983–2005; 2008 - 2013) from 17 gridded stations located in different climatic zones across Nigeria. This study was therefore carried out to determine 22-year (1983 – 2005) monthly mean of relative humidity; to determine monthly and annual relative humidity anomalies for six consecutive years (2008 – 2013); to determine the range and trend of climate variability from estimated anomalies and to predict future trend of climate variability phenomenon over Nigeria.

II. Literature Review

In the study conducted by Oyewole et al, (2014) on the relationship between relative humidity and rainfall in Nigeria as indices for climate variability in Lagos, Port-Harcourt and Calabar respectively showed a long rainy season that begins in March and lasts to the end of July, with a peak period in June or July. It is a period of thick clouds and is excessively wet particularly in the Niger Delta and the coastal lowlands. It is marked by humidity with average values hardly below 82 % across the stations. It is also observed that there is a short dry season experienced in August in these locations and is commonly referred to as the "August Spell". This is followed by wet period from early September to mid-October, with a peak period at the end of September.

In the up-north stations, surface relative humidity is relatively low throughout the year, with average relative humidity values varying between 40% and 70%. The dry period extends from October to mid-May. With the Inter-tropical Continental Zone (ITCZ) in the Southern Hemisphere, the north-east winds and their associated easterlies over the Sahara prevail over the country which is responsible for the dry conditions. The harmattan period during December - January is more intense and longer in the north than in the south. Wet season in this part of Nigeria covers a relatively short period, from June to September. Both the number of rain days and total annual rainfall also decrease progressively from the south to the north. The rains are generally convectional, heavy and short in duration, often characterized by frequent storm (Ogbonna *et al.*, 2007). The results showed that there is a direct relationship between rainfall and relative humidity throughout the months of the year. Relative humidity increases as rainfall increases. Yearly correlation between the rainfall and relative humidity of the study area from (1979-2010) was confirmed.

In another study carried out by Ahmed et al., (2007) in Jordan, the analysis indicated an increasing trend in relative humidity at different stations. The analysis showed significant increasing trend at Amman Airport Meteorological station (AAM) station with a rate of increase 0.13% per year. These increasing trends are statistically significant during summer and autumn seasons. Also, it was observed that a major change point in the annual relative humidity occurred in 1979 at Amman Airport Meteorological station.

III. Materials and Method

3.1 Study Area

Nigeria is a Federal Republic situated in the Western part of Africa. Its coastal boundary is delineated by Mangrove swamp forest in the south; Guinea and Sudan Savannah in the East and West borders; and Sahel Savannah in the North. Nigeria covers a total area of 923,768 sq. km. making it the thirty second largest country of the world. It has a small coastline of 853 km in comparison to its total land boundary of 4047 km. The latitudinal and longitudinal extent of the country is between latitude 4^0N and 14^0N and longitude 2^0E and 15^0E respectively.

The climate of the country varies from equatorial in the south to arid in the north and tropical in the centre. The topography of the country has valley, plateaus and hilly areas. Nigeria's location in the tropics has given her a tropical hot climate. Temperatures in Nigeria vary according to the seasons of the year as with other lands found in the tropics. Nigeria's seasons are determined by rainfall with rainy season and dry season being the major seasons in Nigeria.

The study area contains 17 gridded locations randomly selected and spreading across different climatic zones over Nigeria as shown in figure 1. The coastal area – in the Mangrove Rain Forest has 5 locations namely, Port-Harcort, Carlabar, Enugu, Lagos, and Benin. There 7 inland stations – in the Tropical Rain Forest namely, Makurdi, Osogbo, Abuja, Bida, Yola, Minna, and Jos. There are 5 stations in the up north – in the Sudan Sahel - namely, Kaduna, Maiduguri, Kano, Katsina, and Sokoto.

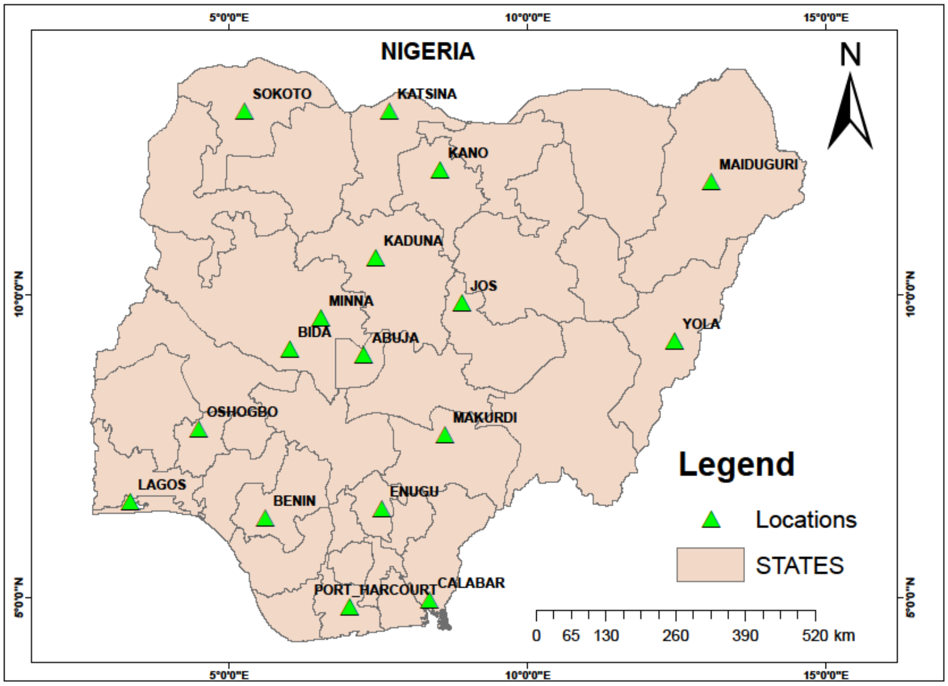

Figure 1: Map of Nigeria showing 17 Selected Locations across different Climatic Zones

3.2 Data Structure

In general, Prediction of Worldwide Energy Resource (POWER); Surface meteorology and Solar Energy (SSE) experiment for POWER/SSE Release 6.0 were obtained from the NASA science mission directorate's satellite and re-analysis research programs. Release 6.0 extends the temporal coverage of the solar and meteorological data from approximately 11 years to 22 years (e.g. July 1983 through June 2005) with improved NASA data, and includes new parameters and validation studies (FCM-H1-, 2005). It is generally considered that quality ground-measured data are more accurate than satellite-derived values. However, measurement uncertainties from calibration drift, operational uncertainties, or data gaps are unknown or unreported for most ground site data sets. In 1989, the World Climate Research Program estimated that most routine-operation solar-radiation ground sites had "end-to-end" uncertainties from 6 to 12%. Specialized high quality research sites are hopefully more accurate by a factor of two (Briggs et al., 2003).

Satellite meteorological point data from Goddard Earth Observing Satellite Model, version 5, (GEOS-5) comprising relative humidity averaged monthly within 10 m height for a period of 22 years 1983 – 2005 and 2008 – 2013 were obtained from NASA databank as shown in Table A.1 (see Appendix 1 for sample data). The data were gridded data covering 17 geo-referenced locations across Nigeria. The data was arranged in Microsoft EXCEL spreadsheet for further manipulation.

3.3 Data Analysis and Map Generation

The central idea behind anomaly construction is to split the data into two parts: (a) data with expected behavior – which is represented by 22-year mean, and (b) data that shows the variability from the expected, which is generally used for understanding climate variability phenomenon (Kawale *et al*., 2011). For a given location i, its anomaly times series $f_{0\ i}$ is constructed from the raw time series $f_{\ i}$ by removing a base vector b_i from it (Kumar *et al.*, 2007).

For a given location i, its anomaly in time series $f^{'}$ is calculated using the mean measure. In this measure, the long-time monthly mean values are considered as the base b_i and the recent measurements are classified as raw data (Wei *et al.*, 2005). Anomaly is therefore estimated using:

$$f' = f_i - b_i \qquad 1.0$$

where,

f' = anomaly in time series
f_i = raw data (recent dataset)
b_i = base data (long-time average)

A simple measure of computing the base b_i is by taking the mean of all data (f_i) present for location i. However the sample mean would not be a good measure as the earth science data is associated with a large amount of seasonality. In order to account for this the base b_i is computed by taking a monthly mean for each month separately.

The diagram showing procedure for data analysis is presented in the Appendix (Figure A.1). Mean value of monthly relative humidity for a period of 1983 – 2005 for 17 stations across Nigeria was estimated and stored as base data while the mean monthly value of relative humidity for each year within the period of 2008 – 2013 was also estimated and stored as raw data with a view to calculate monthly relative humidity anomaly using equation 1.0. All the calculations were carried out in Microsoft EXCEL spreadsheet.

The anomaly results were exported into Geographic Information System (GIS) environment to generate anomaly map for some critical months namely January, April, July and

October. The months were selected in accordance with seasonal rainfall regimes over Nigeria. January is usually the peak of dry season; April is the on-set of rainy season; July is the peak of rainy season and October is the period of latter rain. According to FCM-H1, (2005), departure of recent values of relative humidity in 2008 – 2013 from 22 year mean value was graduated into 5 classes namely – extremely dry (-29.43 - -19.39); very dry (-19.38 - -10.40); dry (-10.39 – 0.74); wet (0.75 – 10.93) and very wet (10.94 – 20.17). A total of 4 maps were generated to show the spatial distribution and magnitude of the anomaly over Nigeria.

IV. Results and Discussion

4.1 Monthly Mean Variations of Relative Humidity Anomalies over Nigeria

The monthly mean variations of relative humidity anomalies in 2008, 2010, 2012 and 2013 for some selected stations across Nigeria are shown in figures 2, 3, 4, 5, 6, 7 and 8. Figures 2 and 3 showed the plots for Nigerian coastal stations with significant increase in surface wetness from 2008 to 2013 most especially during the rainy season. The slight increase was one of the factors responsible for flooding observed most especially in 2012 and 2013. In January 2008 and 2013, Lagos had SRH anomalies of -34.35 and 7.35 while in July, 0.13 and 7.33 were estimated. Surface relative humidity anomalies for Port Harcourt in January were -40.39 and -3.69 for 2008 and 2013 respectively. In July for the same years and location, 0.99 and 5.79 were estimated.

The plots for inland stations in figures 4 to 6 showed a significant decrease in surface relative humidity coinciding with the onset of rainfall between March and May. The onset of rainfall across inland stations which is usually characterized by windy heavy rainfall with extremely sunny afternoon had experienced a drastic decrease in surface relative humidity in recent years which had resulted in a shift of early planting period. However, the severity of the dryness was reduced from 2008 to 2013 most especially in Minna and Abuja. Surface relative humidity anomalies for Osogbo in January were -3.77 and 1.83 for 2008 and 2013 respectively. In July for the same years and location, 2.97 and 14.00 were estimated. Minna had -2.55 and 10.05 in January 2008 and 2013 while -4.81 and 14.80 were estimated for the same years in July. In January 2008 and 2013, Abuja had SRH anomalies of 8.89 and 19.59 while in July, -3.49 and 22.03 were estimated.

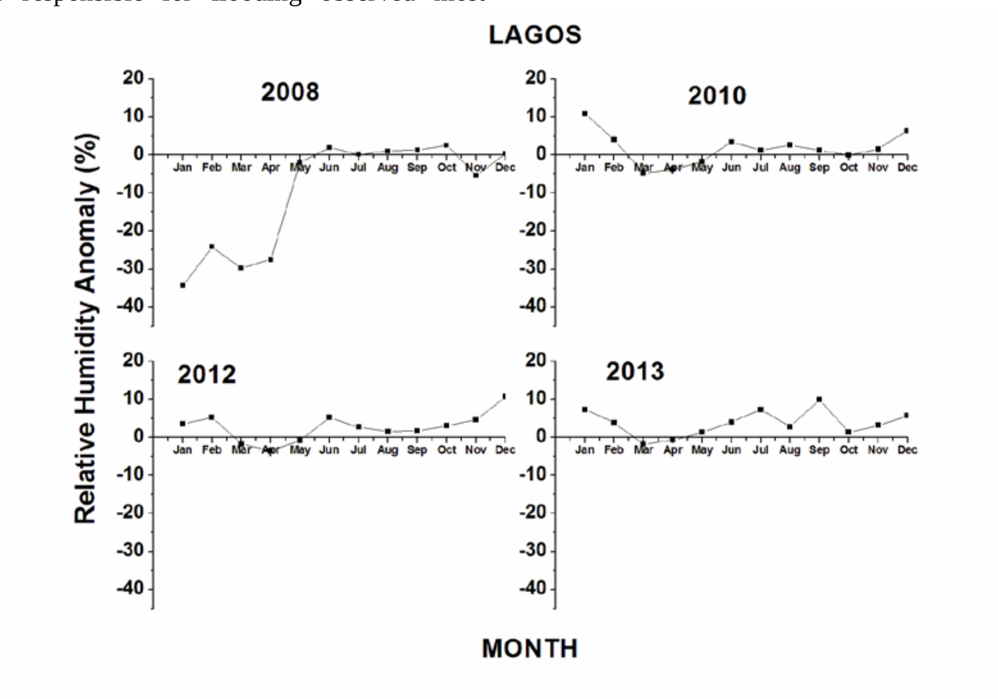

Figure 2: Monthly Mean Variation of Relative Humidity Anomaly in Lagos

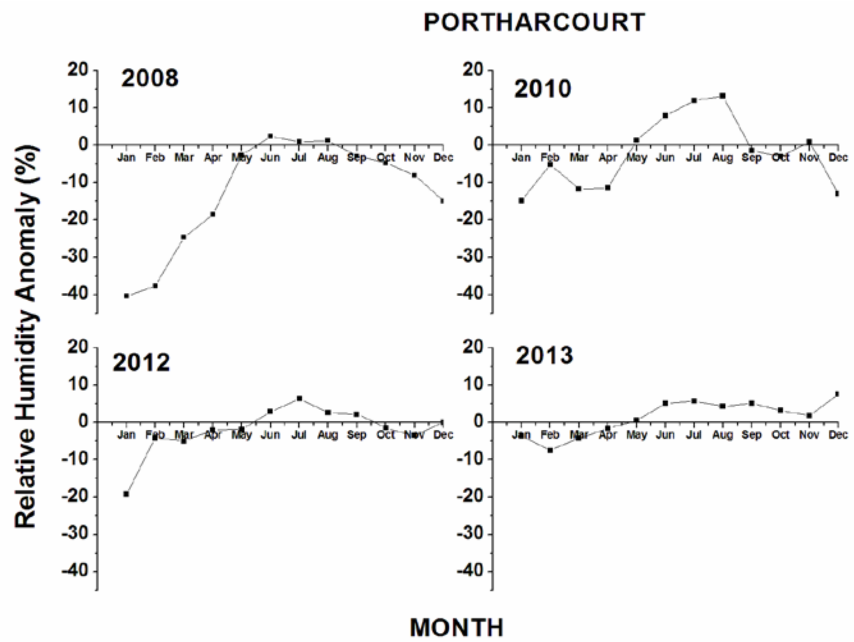

Figure 3: Monthly Mean Variation of Relative Humidity Anomaly in Port Harcourt

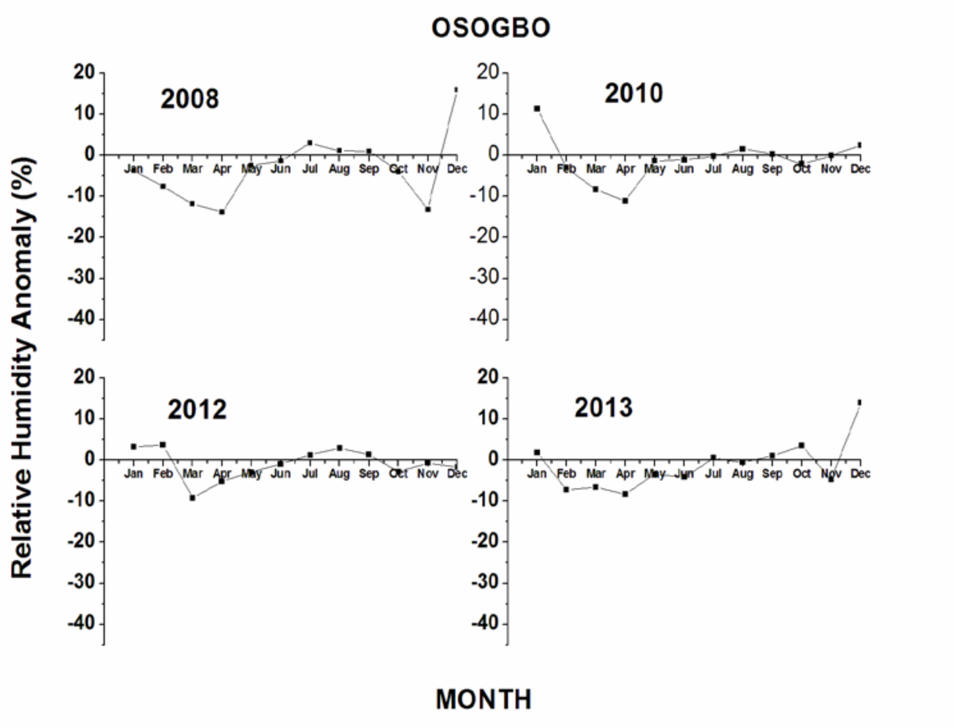

Figure 4: Monthly Mean Variation of Relative Humidity Anomaly in Osogbo

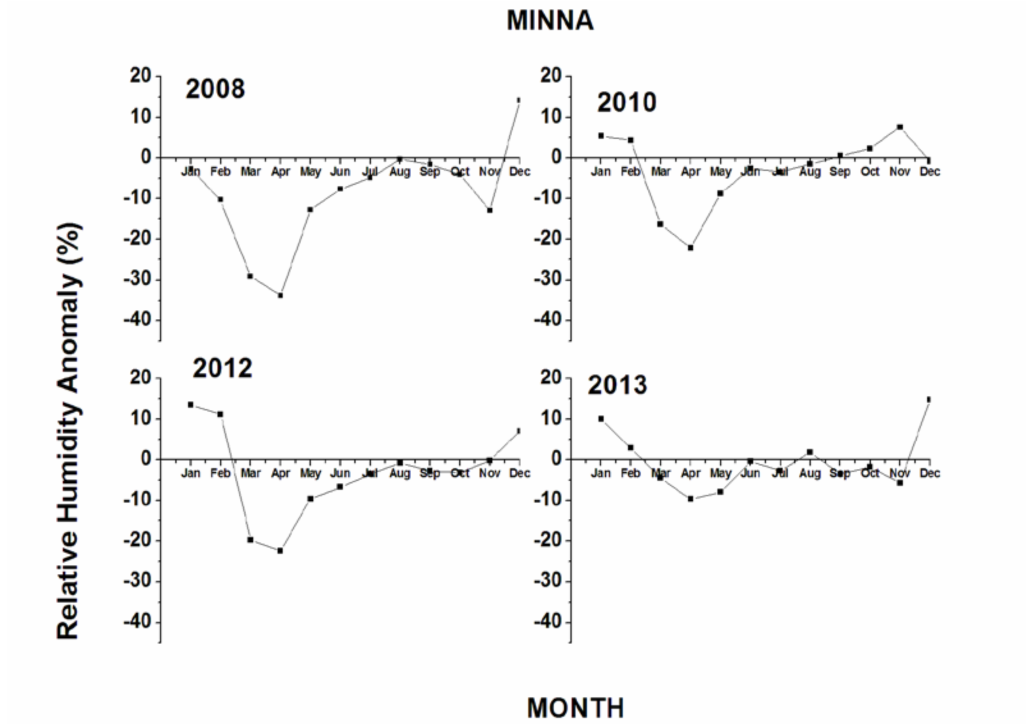

Figure 5: Monthly Mean Variation of Relative Humidity Anomaly in Minna

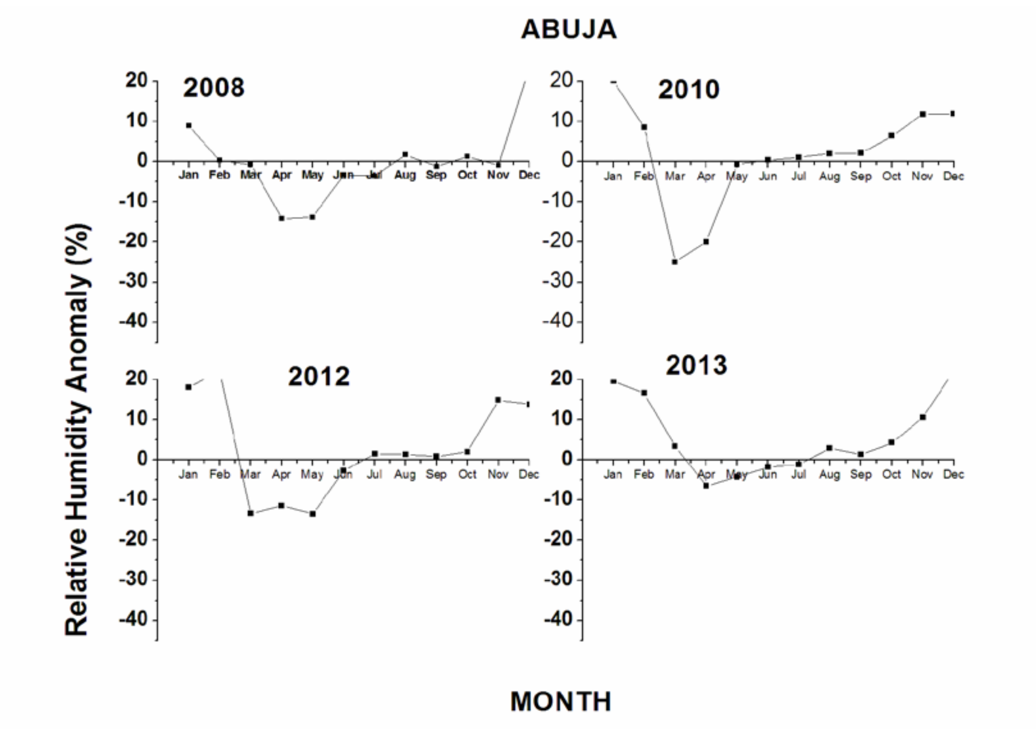

Figure 6: Monthly Mean Variation of Relative Humidity Anomaly in Abuja

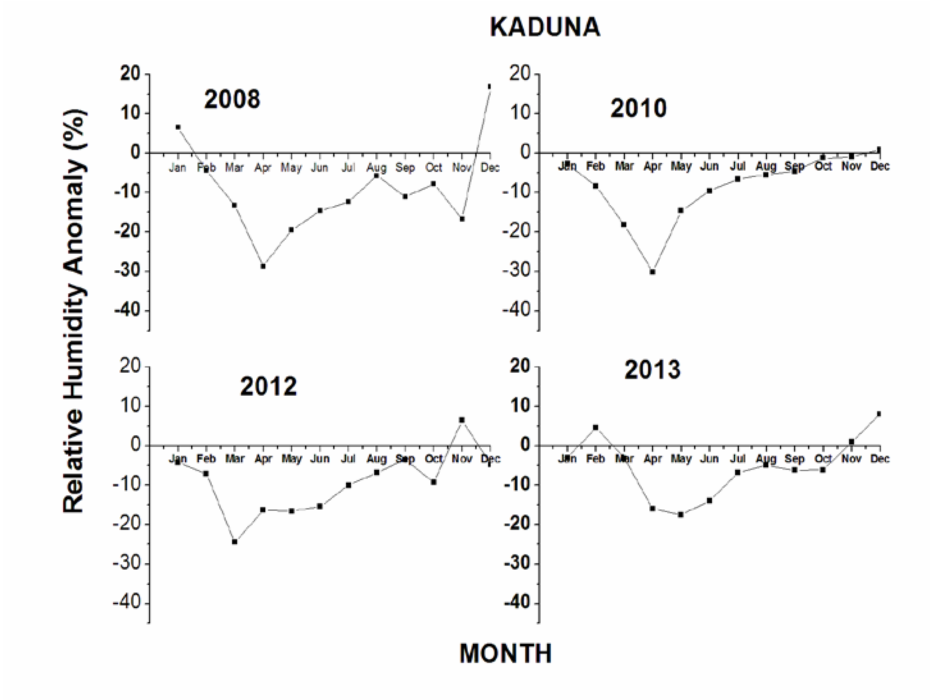

Figure 7: Monthly Mean Variation of Relative Humidity Anomaly in Kaduna

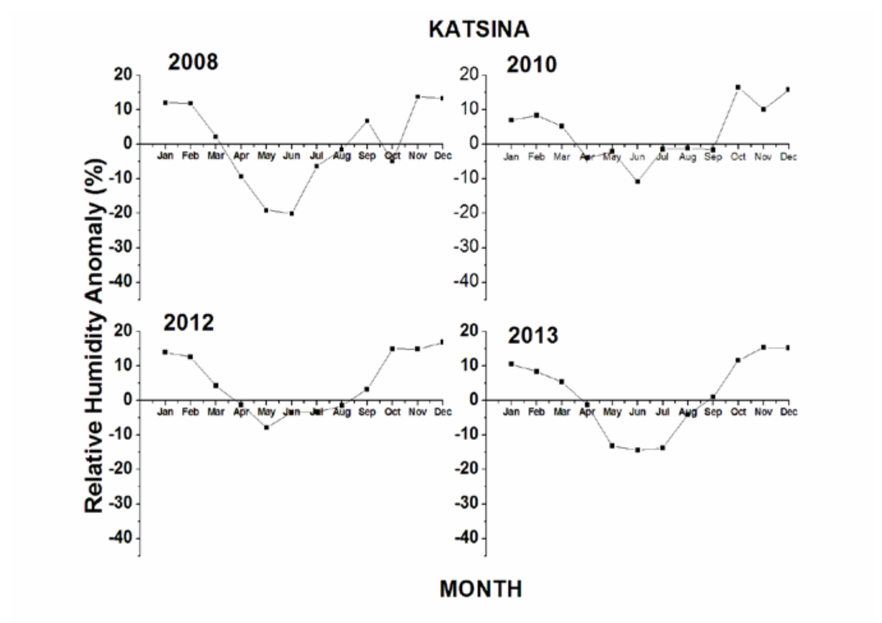

Figure 8: Monthly Mean Variation of Relative Humidity Anomaly in Katsina

The stations in the extreme north of Nigeria – Kaduna and Katsina – were plotted in figures 7 and 8. There is a significant increase in surface wetness in Kaduna though with a slight decreasing trends in magnitude from 2008 to 2013. Similar trend was also observed in Katsina with extreme scenario in 2012. On comparing surface relative humidity anomalies in January 2008 with January 2013, Kaduna had 6.57 and -2.93 respectively while in July, -12.35 and 8.15 were estimated for 2008 and 2013. In January 2008 and 2013, Katsina had 12.04 and 10.54 while -6.31 and 15.25 were estimated for July 2008 and 2013.

4.2 Spatial Distribution of Relative Humidity Anomalies over Nigeria (2008 – 2013)

The data for this work was analysed using descriptive statistics (mean measure). Figures 9, 10, 11, and 12 showed the dispersion of relative humidity anomalies in the months of

January, April, July, and October respectively across the study area for a period of six consecutive years (2008 – 2013).

In figure 9, the relative humidity anomaly in January, representing peak of dry season, was positive in northern Nigeria while coastal areas had negative trends. Increase in relative humidity in the month of January in the north can be attributed to intensive irrigation activities in the region. The negative trend observed in January along Nigerian coast confirmed a gradual shift in climatic features in the area. The result showed that Port Harcourt, Calabar and Enugu experienced more severe reduction in surface moisture in January (2008 – 2013) than the past 25 years. Kano had positive anomaly even in January due to intensive irrigation made possible by Watari dam and rehabilitation of Tomas dam for rice farming and other agricultural purposes. Inland stations such as Bida, Abuja, Makurdi maintained highly positive anomalies with likely probability for flooding occurrence as it was recorded in 2011 and 2012. The results also showed that Osogbo, Jos, Sokoto and Katsina had relative climatic stability in January when compared to what had been in the past 25 years. Maiduguri, Yola and Kaduna had a slight downward trend in the month of January. Severity of relative humidity anomaly in January (2008 – 2013) was more pronounced in the coastal areas and North East region of Nigeria.

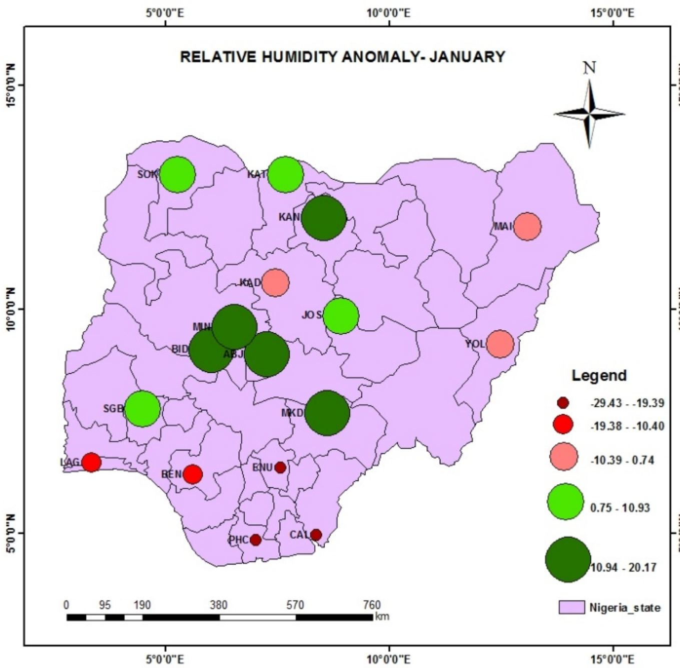

Figure 9: Relative Humidity Anomalies in January (2008 – 2013) across Nigeria

Figure 10 showed the spatial distribution of relative humidity anomaly in the month of April which represents the onset of rainy season in Nigeria. Inland station had been experiencing drier April of recent most especially in Bida, Minna, Kaduna, Makurdi, Jos and Yola. Coastal stations had a slight increase in surface moisture most especially in Benin, Lagos and Port Harcourt. Relative humidity anomaly is a very strong index for detecting surface moisture and this was sustained in Sokoto, Katsina and Kano while Maiduguri continued to experience drier April of greater magnitude than that of January. The result in figure 10 showed that Nigeria is currently experiencing drier April across all the inland stations which will eventually alter planting time table for the region if the trend persists.

In the month of July, as shown in figure 11, the relative humidity anomaly was intensively negative across northern Nigeria making it the driest July ever for the period under consideration. This is a clear pattern of climate variability showing significant departure from 25 years mean values. From Sokoto to Maiduguri and from Katsina to Yola, the severity was highly pronounced. Surface moisture had suffered great reduction with attendant characteristic of increase in surface temperature in the month of July. Consistent increase in rainfall amount and rainy days between 2008 and 2013 had significantly influenced relative humidity anomalies positively in southern stations of Lagos, Benin, Port Harcourt, Calabar and Enugu. Inland station comprising Osogbo, Makurdi and Bida had slight reduction while Abuja and Jos had a slight increase. Relative humidity anomalies in the month of July significantly reduced from south to north which was an indication of rainfall amount and intensity regimes over Nigeria.

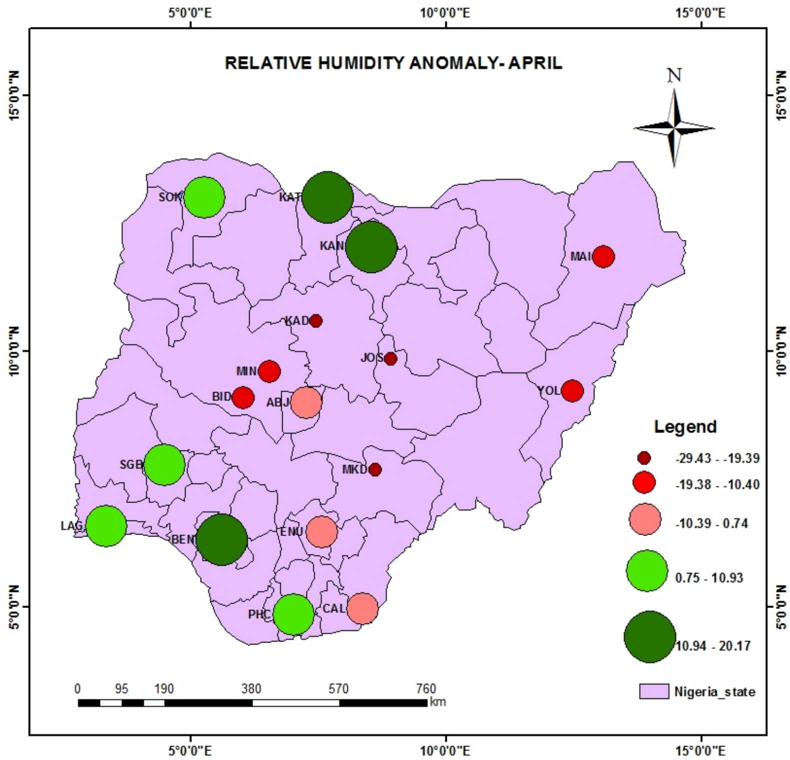

Figure 10 Relative Humidity Anomalies in April (2008 – 2013) across Nigeria

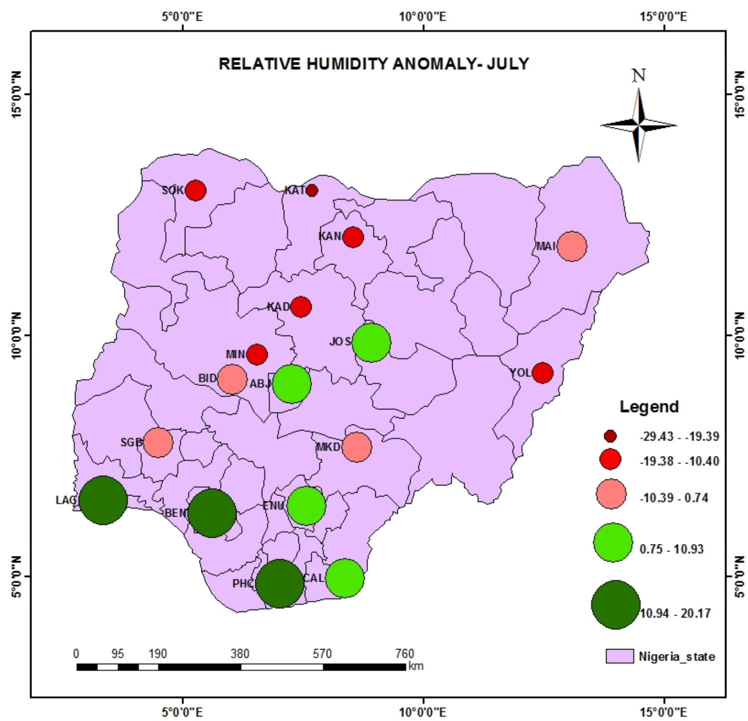

Figure 11 Relative Humidity Anomalies in July (2008 – 2013) across Nigeria

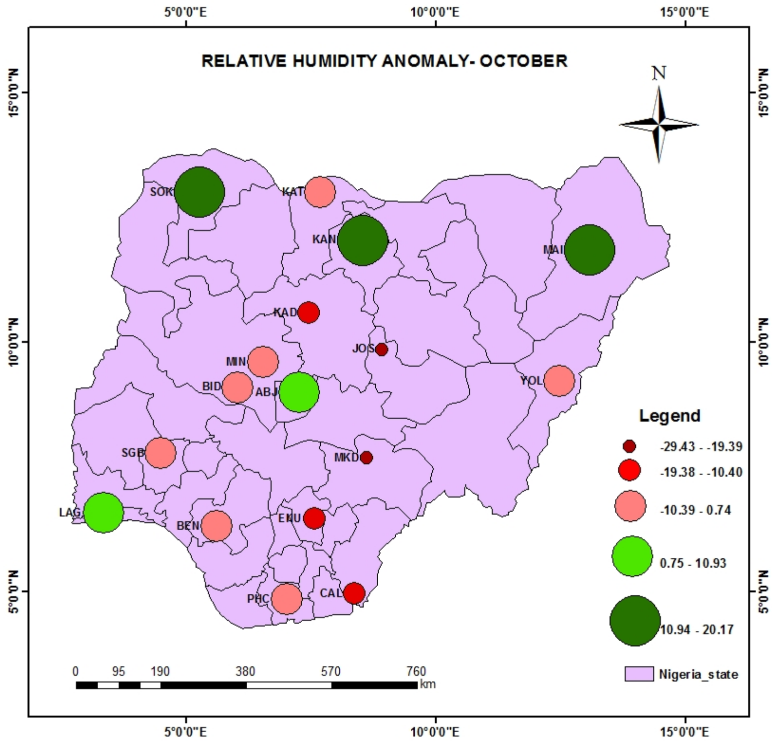

Figure 12 Relative Humidity Anomalies in October (2008 – 2013) across Nigeria

It is also observed in the month of October as shown in figure 12 that there was substantial increase in surface moisture in the north corresponding to a time of heavy showers most specially in Sokoto, Kano and Maiduguri. The inter-tropical discontinuity is just retreating from its northern most position bringing about heavy rainfall in the up north. However, the month of October showed a general decline in relative humidity except in Lagos and Abuja. Severe situation of negative trend were observed in Kaduna, Jos, Makurdi, Enugu and Calabar. This was an indication that the month of October was relatively dry compared to 22-year average.

V. Conclusion

Surface relative humidity anomaly over Nigeria generally revealed negative trend in most of the stations under investigation. Each selected month had its peculiar characteristic along latitudinal belt. Intensive irrigation in northern Nigeria also contributed significantly to climate variability as wetness was sustained even in the peak of dry season. April, July and October had prevalence of drier phenomena in recent years (2008 – 2013) more than 22 years (1983 – 2005) averages while January was a slight exception.

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APPENDIX

Table A1: SAMPLE OF RELATIVE HUMIDITY DATA FOR SOME SELECTED LOCATIONS ACROSS NIGERIA

Year	Month	LAGOS		PORT HARCOURT		ABUJA	
		Monthly Mean	22-year Mean	Monthly Mean	22-year Mean	Monthly Mean	22-year Mean
2008	1	35.30	69.65	35.30	75.69	32.80	23.91
	2	49.80	74.00	40.50	78.22	28.40	28.08
	3	51.40	81.09	57.40	82.08	52.30	52.97
	4	55.80	83.32	65.20	83.74	61.70	75.85
	5	81.80	83.79	81.80	84.34	67.60	81.41
	6	85.90	83.93	85.90	83.53	80.90	84.20
	7	83.60	83.47	83.60	82.61	81.80	85.29
	8	84.70	83.65	84.70	83.46	86.90	85.14
	9	86.40	85.07	82.50	85.38	82.80	83.97
	10	87.90	85.30	81.20	85.95	80.30	78.93
	11	76.90	82.30	76.90	84.97	52.70	53.62
	12	75.70	75.33	65.80	80.72	53.40	29.67
2010	1	80.60	69.65	60.90	75.69	36.70	28.08
	2	78.00	74.00	73.00	78.22	28.00	52.97
	3	76.30	81.09	70.40	82.08	55.90	75.85
	4	79.50	83.32	72.30	83.74	80.80	81.41
	5	82.10	83.79	85.70	84.34	84.60	84.20
	6	87.40	83.93	91.40	83.53	86.40	85.29

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	7	84.70	83.47	94.60	82.61	87.20	85.14
	8	86.20	83.65	96.70	83.46	86.10	83.97
	9	86.30	85.07	84.00	85.38	85.40	78.93
	10	85.30	85.30	83.00	85.95	65.50	53.62
	11	83.90	82.30	85.80	84.97	41.60	29.67
	12	81.70	75.33	67.70	80.72	24.00	23.91
2013	1	77.00	69.65	72.00	75.69	43.50	23.91
	2	77.90	74.00	70.70	78.22	44.80	28.08
	3	79.30	81.09	77.90	82.08	56.30	52.97
	4	82.70	83.32	82.20	83.74	69.40	75.85
	5	85.10	83.79	84.90	84.34	77.20	81.41
	6	88.00	83.93	88.70	83.53	82.40	84.20
	7	90.80	83.47	88.40	82.61	84.20	85.29
	8	86.50	83.65	87.80	83.46	88.00	85.14
	9	95.00	85.07	90.50	85.38	85.30	83.97
	10	86.60	85.30	89.20	85.95	83.20	78.93
	11	85.50	82.30	86.80	84.97	64.20	53.62
	12	81.10	75.33	88.40	80.72	51.70	29.67

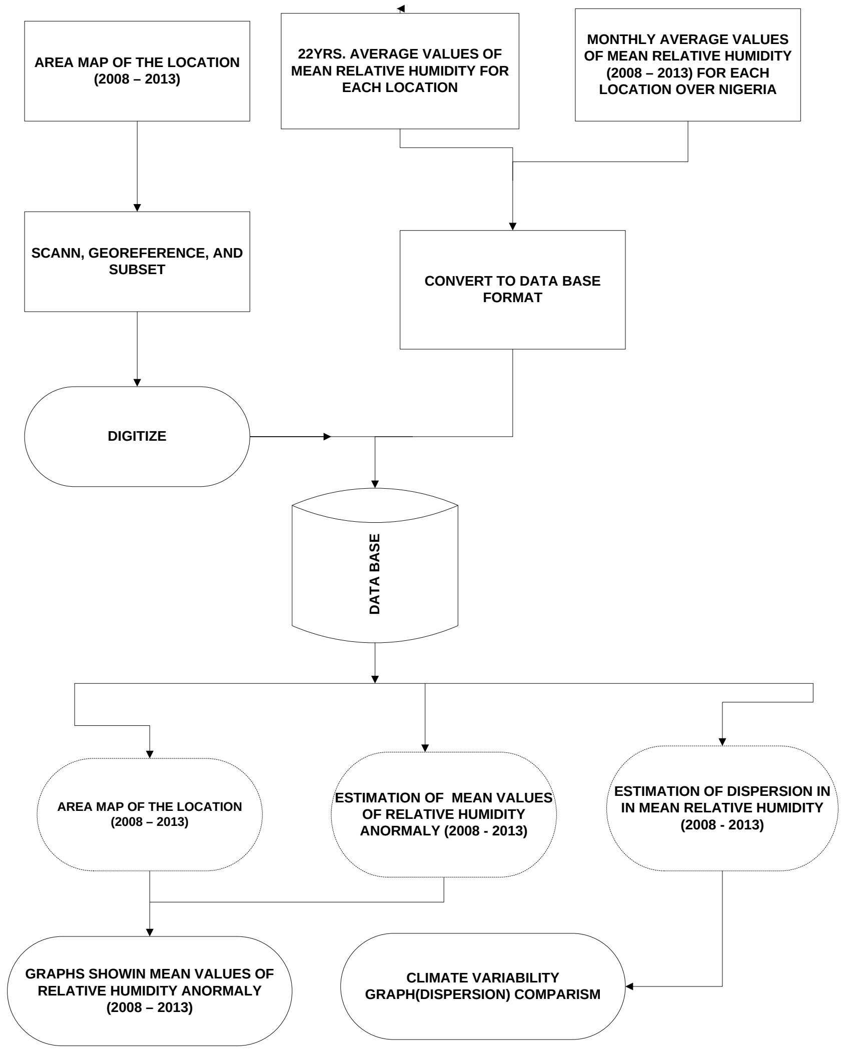

Figure A1: Data Analysis Procedure