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Sectional Investigation of Seasonal Variations of Surface Refractivity and Water Vapour Density over Nigeria

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Abstract

The accurate knowledge of radio refractive and water vapour density of the troposphere is important in the planning, budgeting and designing of transmission and reception of radiowave signals on earth-space path. Hence, there is the need to adopt more precise techniques to analyze the seasonal variation of refractivity and water vapour density over Nigeria. The seasonal variation of refractivity and water vapour density was studied using thirty-nine years meteorological data for forty-eight (48) stations over Nigeria. The forty-eight stations were grouped into nine vegetation and two major climates in Nigeria. Harmonic analysis approach was used in addition to the monthly mean computation. The results show that Forests zones values of refractivity and water vapour density are higher than Savannahs zones values. The refractivity value increases from about 281 N units at Sudarian Woodland in January to about 383.6 N units at Mangrove station in June. Water vapour density value increases from about 5.18 g/m^3 at Brush and Thicket station in November to maximum value of about 22.36 g/m^3 at Swamp Forest station in May. Results also show that over 80% variations in refractivity and over 70% variations in water vapour density are revealed in the first three harmonics at all the nine stations. The results indicate that the method of harmonic amplitudes and phases give a more analytical comparison between predictions model and observational data.

Keywords: radio refractivity, water vapour density, harmonic analysis, aerosol

INTRODUCTION

Radio wave propagations are affected by the properties of the atmosphere, that is, reflection, refraction, scattering, and absorption by different atmospheric constituents (Safdar, et al, 2012). Permanent dipole moments possess by atmospheric water vapour is of major concern in the propagation of the atmospheric refractive index for radio waves (Babalola, 1998). Oyedum (2008) have shown that variations of refractivity gradients are not strong enough to cause obvious effects at lower radio frequencies for which the ground wave and ionospheric propagation mechanisms dominate at transhorizon ranges. Kolawole (1983), Owonubi (1982), Willoughby et al. (2002), Adeyemi and Adedayo (2004) revealed in their studies that surface refractivity (N_s) and gradient of refractivity (ΔN) are well correlated in the African region.

One of the important gaseous constituent in the atmosphere that affects radio wave propagation is water vapour (Ojo, 1977). In the troposphere, water vapour is responsible for a major part of the radio refractivity fluctuations in the computation of radio refractivity index of air for radio meteorological studies (Kolawole, 1983). Water vapour and other atmospheric gases also affects radio satellite communication systems operating in the frequencies above 10 GHz range apart from rain (Bean and Dutton, 1968).

Surface refractivity (N_s) depends on meteorological parameters of pressure P (hPa), temperature T (K) and water vapour pressure e (hPa), as given by the relation (Smith and Weintraub, 1953; ITU, 2012):

$$N= \frac{77.6P}{T} + 3.73 \times 10^5 \frac{e}{T^2} = N_{dry} + N_{wet} \text{ (N units)} \quad (1)$$

N_{dry} and N_{wet} are usually referred to as dry and wet terms of radio refractivity, respectively. The first term on the right hand side of eq. (1) represents the dry component (N_{dry}) while the second term is the wet component (N_{wet}).

The vapour pressure is also related to the relative humidity (H) (%) as (ITU, 2012):

$$e = \frac{RHe_s}{100} \quad (2)$$

Where RH is the relative humidity (%), t the temperature (°C), e_s is the maximum or saturated vapour pressure (hPa) at the temperature t (°C) and may be derived from (ITU, 2012):

$$e_s = 6.1121\exp\left[\frac{17.502t}{(t+240.97)}\right] \quad (3)$$

Generally Pressure (P) and water vapour pressure (e) decrease rapidly with height while T decreases slowly with height. In the lower atmosphere, refractive index is a major factor for estimating the performance of radio links. Therefore, the knowledge of the refractivity is important in design of reliable and efficient radio communication (Isikwue et al., 2013). Refractive index variations of troposphere affect radio frequencies above 30MHz, although these effects become significant only at frequencies greater than 100MHz in the troposphere. The electromagnetic propagation of waves in the troposphere is greatly affected by the composition of the atmosphere (Korak, 2003). This is due to the fluctuations of atmospheric parameters like temperature, pressure and relative humidity primarily at the troposphere.

Several studies carried by many researchers at different locations in Nigeria, showed that the refractivity (N) and water vapour density (WVD) fluctuation in the lower troposphere is a function of atmospheric parameters such as temperature, pressure and relative humidity (Agbo, et al., 2013; Adeyemi, 2006; Willoughby et al., 2008).

Ayantunji, et al (2011), studied the diurnal and seasonal variation of surface refractivity over Nigeria and concluded that refractivity variation in dry season was caused by the dry term and wet term in the rainy season. However, looking at the meteorology and the influence of aerosols retention in the atmosphere of West Africa (Emetere et al., 2015 a & b), it may be difficult to draw specific conclusions on the radio refractivity and water vapour density of the troposphere over Nigeria. The importance of statistical techniques is enormous to scrutinize the properties of dataset, for example, harmonic analysis was used to investigate: the diurnal and semidiurnal of global positioning system (GPS)- derived zonal total delay (ZTD) dataset (Jin et al., 2009) with high success; and the monthly or seasonal sinusoidal precipitation patterns (Kristina, 1989). Many other successes on the use of harmonic analysis have been documented (Panofsky and Brier, 1960; Willoughby et al, 2002; Xie et al., 2010). In this paper, we adopted the harmonic analysis to further investigate on the radio refractivity and water vapour density over Nigeria.

CLIMATE AND VEGETATION CHARACTERISTICS OF NIGERIA

The Nigerian climate is characterized by hot and wet conditions associated with the movement of the Inter-Tropical Convergence Zone (ITCZ) north and south of the equator. Rainfall occurrence and distribution are however dependent on the Tropical maritime and the Tropical continental (air masses). Tropical maritime (TM) is linked with the south-west winds that blow from the Atlantic Ocean while tropical continental (TC) is associated with the dusty north-east winds which blow from the Sahara Desert. In the case when ITCZ is to the south of the equator, the north-east winds prevail over Nigeria thereby producing the dry-season conditions. Consequently, movement of the ITCZ into the Northern Hemisphere bring rain fall during the wet season. This implies that there is a prolonged rainy season in the far south, while the north experiences long dry periods annually (Sanusi, et al, 2013). Nigeria, therefore, has two major seasons, the dry season and the wet season, the lengths of which vary from north to south.

Nigeria has two broad belts of vegetation: forests zone (tree dominant) and savannahs zone (grassland area with no forest cover). Nigeria has a heavily forested coastal south where humid tropical conditions allow tree growth. Savannah vegetation in Nigeria consists of three major belts (i.e. Guinea Savannah, Sudan Savannah and Sahel Savannah), from south to north. The Guinea Savannah belt, located in the middle of the country and covering near half of the country, Sudan Savannah belt is found in the north-west of the country and Sahel Savannah belt located in the extreme north-eastern part of the country.

The focus of this study was chosen to cover the entire climatic and vegetation regions from the coastal zone in the south to the arid zone in the north of the country (Fig. 1).

DATA AND METHOD OF HARMONIC ANALYSIS

In this work, we investigate the monthly and seasonal variation of surface refractivity and water vapour density using meteorological data for at least 39 years (1973-2012) for forty-eight (48) stations within Nigeria. The forty-eight stations were grouped into nine vegetation and forest map of Nigeria; Brush and Thicket, Sudarian Undifferentiated Woodland, Montane, Jos Plateau Mosaic, Sudarian Woodland with aboundant Isobertinia, Forest and Woodland Mosaic, Rain Forest, Swamp Forest, and Mangrove as shown in Fig. 1.

Harmonic analysis was adopted in this study. The expression of its trigonometric functions is shown (Panofsky and Brier, 1960):

$$\text{X (t)} = X_o + \sum R_n \cos\left(\frac{2\pi nt}{P} + \Phi_n\right), \quad (4)$$

Where X_o is the mean of the data, X(t) is the variable data at time t i.e. N and WVD,

$$R_n = [A_n^2 + B_n^2]^{½}, \quad (5)$$

A_n and B_n are amplitudes of the harmonics and P is the period of observations, in our case, 12 months, Φ_n are the phase angles which determine the time of the year the maximum and minimum of a given harmonic occurs and n is the number of the harmonic (n= 1, 2, 3, 4, and 5). The amplitudes and the phases of the nth harmonic are averaged for each month for each year of the period.

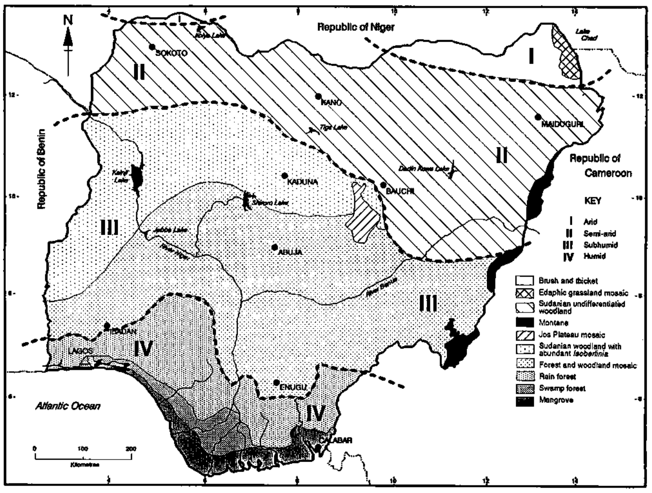


Figure: 1: Vegetation and Forest Map of Nigeria showing the study area.

RESULT AND DISCUSSION

Mean Refractivity with Standard Deviation

Fig. 2 illustrates plots of the monthly mean (N) and standard deviation (N-STD) variation of the refractivity average over 39 years period. It is evident from this study that there is seasonal variation of refractivity at all the stations. This result agrees with the work of Ayantunji et al, (2011), Owolabi and Williams (1970) and Oyedum et al. (2010). The results also showed an increase in the value of refractivity from minimum value of about 281 N units at Sudarian Woodland with Aboundant Isobertinia station in January (Fig. 2e) to maximum value of about 383.6 N units at Mangrove station in June (Fig. 2i). On the other hand, monthly standard deviations results obviously show a reduction in value from about 0.9 N units at Montane (Fig. 2c) and Mangrove (Fig. 2i) to about 51.3 N units Swamp Forest (Fig. 2h). The standard deviations at all locations reveal a close range of values and most importantly a dip during the rainy season.

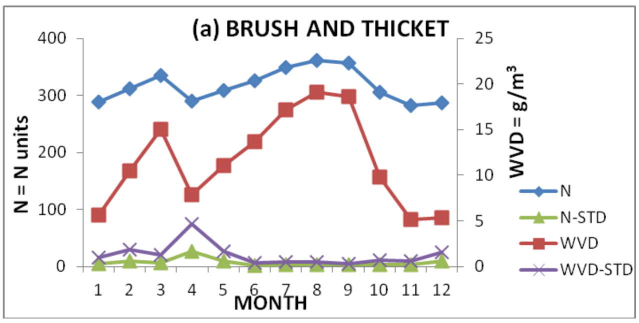
Fig. 2a, Brush and Thicket showed minimum value of about 282 N units in November and reach it maximum at about 361.4 N units for the month of August while the corresponding standard deviation only show a peak at about 26.8 N units. This pattern of variation can be attributed to rain pattern in Nguru and Birni Nkonni over the period under study where it normally rain in March with a little break from mid April to about early May and rained heavily in August before the unset of dry season between November and February.

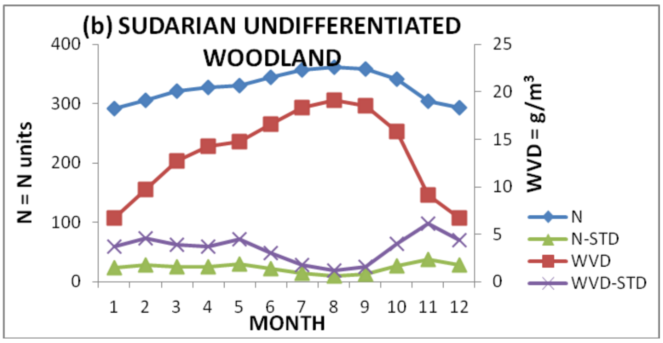
At Sudarian Undifferentiated Woodland, the variation of refractivity depicted in Fig. 2b shows a seasonal variability with gradual increase from minimum of about 292 N units in January and maximum of about 361.2 N units in August. Whereas, its standard deviation coincidentally dipping in August with a value of about 10.3 N units. Sudarian Undifferentiated Woodland is located in North-Eastern Nigeria and within Sahel Savannah. The value of refractivity in the rainy season is however found to be higher than that of Sudarian Woodland with Aboundant Isobertinia (see Fig. 2e) during the peak period because the rainfall at Sudarian Undifferentiated Woodland is usually heavy within the short rainy season.

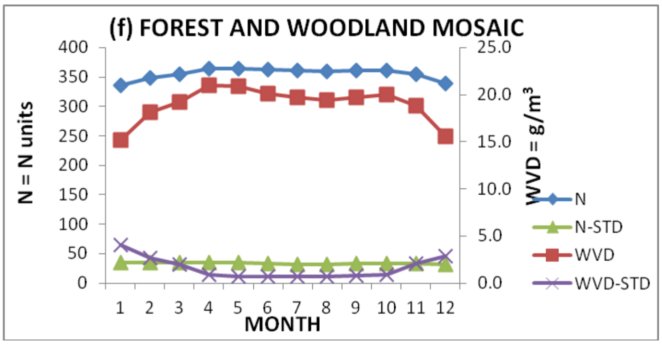
Montane in Fig. 2c depicted a very high refractivity mean values between April and August in the wet season months contrary to the picture of its standard deviation with a very low values particularly in March. This can be attributed to the fact that the rainfall pattern is intense in rainy season than the dry season in this region. The refractivity at Jos Plateau Mosaic (North Central) station increased from 336.5 N units in December to about 365.2 N units in May. Likewise, standard deviation increases from 14.3 N units in August to 26.8 in December as pictured in Fig. 2d. The low value of refractivity over Jos Plateau Mosaic is attributed to high altitude. The pressure in Jos Plateau Mosaic is low because of the high altitude and since the pressure is directly proportional to the dry component of the refractivity, the overall value of refractivity is affected.

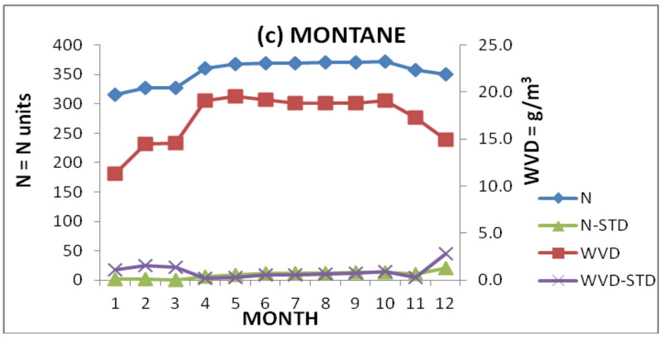
Forest and Woodland Mosaic, Commonly seen as savannah wood land (wood land savannah)- a transition between forest and savannah vegetations (Fig. 2f) shows a decrease from maximum of about 363.7 N units in April to minimum of about 336 N units in January.

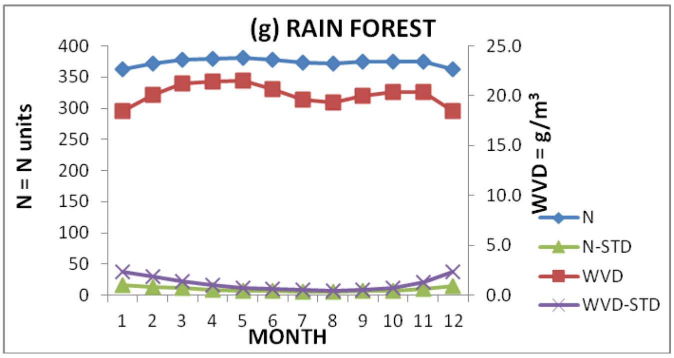
Seasonal variation of refractivity over Rain Forest, Swamp Forest and Mangrove is depicted in Figs. 2g, 2h and 2i respectively. These three stations fall within the same geographical and climatic region (Southern Nigeria/Forest Zone). The variation in these three stations follows the same pattern with almost constant value in the months of May to September which coincided with rainy season. The maximum value of refractivity was observed in June at Mangrove (383.6 N units), May in Rain Forest (380.4 N units) while Swamp Forest recorded maximum value in September (335.7 N units). The minimum value was recorded in January at all the three stations. Meanwhile, the standard deviations in these regions are also close in values and follow the same trend except for Swamp Forest that shows higher values (Fig. 2h).

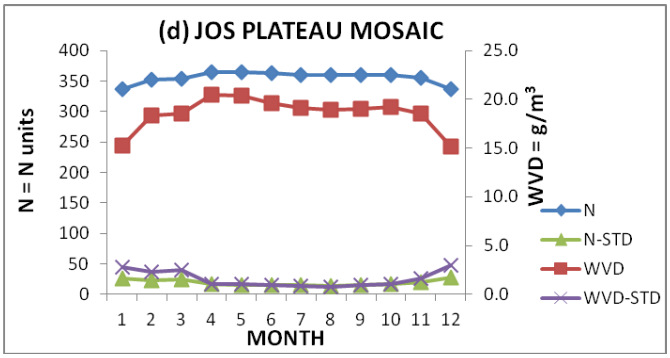


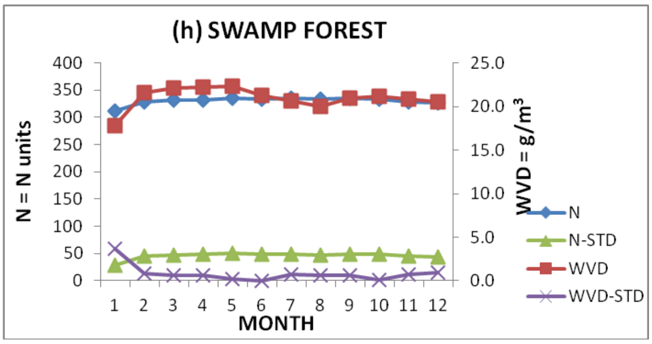


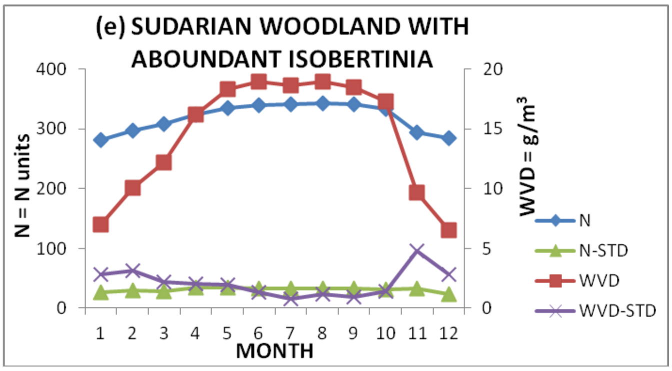












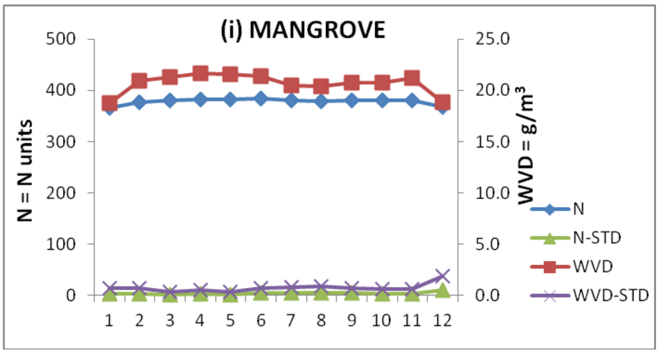


Figure 2: Monthly Mean refractivity and water vapour density and its standard deviations

Mean Water Vapour Density with Standard Deviation

Fig. 2 also represents the monthly mean variation of the WVD and its standard deviation average over 39 years period. It is also evident from the results that there is seasonal variation of WVD between the southern stations and the northern stations.

This result agrees with the work of Willoughby et al. (2008) and Adeyemi (2006). The results also showed an increase in the mean value of WVD from minimum value of about 5.18 g/m^3 at Brush and Thicket station in November (Fig. 2a) to maximum value of about 22.36 g/m^3 at Swamp Forest station in May (Fig. 2h). The variability in the standard deviation, on the other hand, increase from minimum value of about 0.03 g/m^3 in June at Swamp Forest (Fig. 2h) to maximum value of about 6.1 g/m^3 in November at Sudarian Undifferentiated Woodland contrary to the mean value.

At Brush and Thicket, Fig. 2a, show double peaks with a dip in April and the water vapour density is much higher in the wet season i.e. May to September. August had the highest mean value of about 19.09 g/m^3. Generally, the dry season has the lowest value of about 5.18 g/m^3 in November to January. Meanwhile, the standard deviation of water vapour density seems to maintain a low value during the wet season except for April notable for a peak value of 4.7 g/m^3. By comparison, all other stations in the savannah (Figs. 2b-f) have the same trends as that of Brush and Thicket, that is, the wet season months display higher mean values of WVD, while dry season months recorded lower values. Conversely, the standard deviation of water vapour density in Brush and Thicket is much lower in the rainy season.

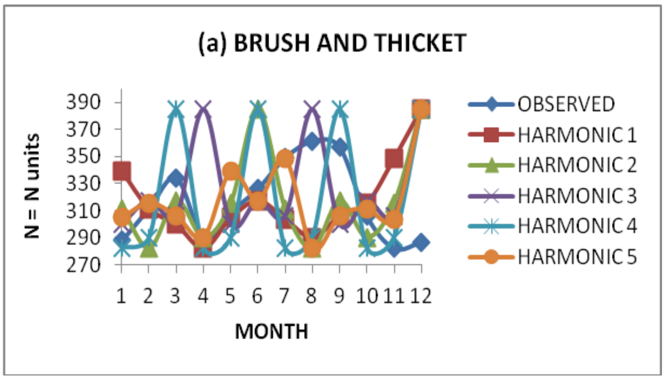
Seasonal variation plots of water vapour density over Sudarian Undifferentiated Woodland, (Fig. 2b), Montane (Fig. 2c), and Forest and Woodland Mosaic (Fig. 2f) shows a minimum mean values of about 6.70 g/m^3, 10.21 g/m^3 and 15.14 g/m^3 respectively, in January. While, Jos Plateau Mosaic and Sudarian Woodland with Aboundant Isobertinia (Figs. 2d and 2e) has minimum mean values in December of about 15.12 g/m^3 and 6.55 g/m^3 respectively. On the other hand, maximum values of WVD were observed in the months of August (19.06 g/m^3), October (20.08 g/m^3), April (20.44 g/m^3), June (18.97 g/m^3) and April (20.97 g/m^3) in Figs. 2b to 2f respectively. Also, figure 2b reveals highest standard deviation of water vapour density with three peaks values in February (4.5 g/m^3), May (4.5 g/m^3) and November (6.1 g/m^3) and a brief dip in August (1.2 g/m^3). It noted that the certain fluctuation in the WVD was due to the aerosol retention over the various region (Emetere et al., 2015b)

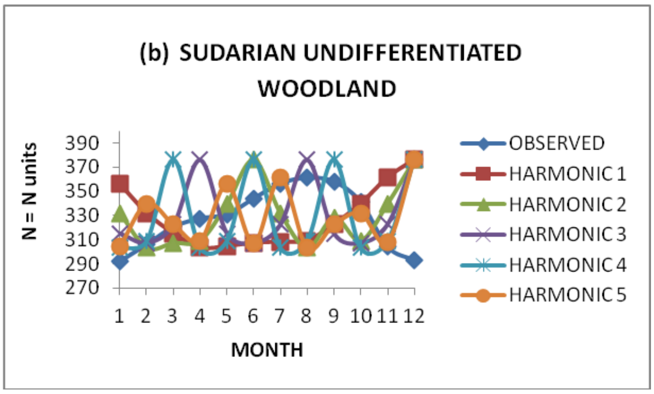
Figs 2g to 2i represents the southern and the forest region, WVD mean values is typified by double peaks with a unique dip in August at the three stations. Adeyemi and Aro, (2004) attributed the double maximum peaks at Rain Forest (Fig.3g) that occur in May with 21.52 g/m^3 as the primary maximum due to northward advance of the inter-tropical discontinuity (ITD) and also in November with 20.42 g/m^3 as the secondary maximum due to the southward recession of the ITD. Meanwhile, Swamp Forest, Fig. 3h, pictured maximum WVD value of about 22.36 g/m^3 in May and Mangrove (Fig. 3i) shows a maximum mean value of about 21.69 g/m^3 in April. The standard deviation exhibited in these three stations showed lower value in the rainy season than the dry season particularly at Swamp Forest displaying a dipper value of water vapour density.

Table 1: Values of X_o, A_n, B_n, Φ_n, R_n and R_x derived from harmonic analysis of surface refractivity

Station	q	X_o	A_n	B_n	Φ_n	R_n	R_x
Brush and Thicket	12	317.01	-22.08	-16.11	7.204	27.33	0.92
	6		-16.46	17.62	2.22	24.11	
	4		-1.07	-1.98	10.69	2.25	
	3		9.19	-4.55	11.78	10.26	
	2.4		3.35	2.83	0.27	4.38	
Sudarian Undifferentiated WoodLand	12	327.94	-25.24	-19.30	7.25	31.77	0.99
	6		-11.32	1.73	2.86	11.45	
	4		-1.62	-0.03	10.01	1.62	
	3		0.98	2.14	0.54	2.35	
	2.4		1.21	0.56	0.17	1.33	
Montane							
	12	354.95	-15.20	-18.44	7.68	23.90	0.97
	6		2.10	-10.68	10.69	10.39	
	4		2.32	-0.08	11.98	2.32	
	3		-0.35	-0.72	11.03	0.80	
	2.4		3.59	-3.05	11.73	4.71	
Jos Plateau Mosaic							0.93
	12	355.76	-10.02	-2.40	6.45	10.30	
	6		-4.16	-5.15	9.85	6.62	

	4		-2.42	-1.33	10.32	2.76	
	3		-2.51	-1.63	10.78	2.99	
Sudarian Woodland with Aboundant Isobertinia	2.4		-0.52	-1.88	11.30	1.95	
	12	318.83					
	6		-27.17	-14.99	6.96	31.03	0.99
Forest and Woodland Mosaic	4		-8.05	-3.41	9.38	8.74	
	3		-3.43	2.32	1.62	4.14	
	2.4		-0.10	1.53	0.78	1.53	
			2.36	0.40	0.06	2.39	
	12	355.35					
Rain Forest	6		-9.98	-3.28	6.61	10.50	0.98
	4		-4.18	-5.49	9.88	6.90	
	3		-1.70	-1.52	10.46	2.28	
	2.4		-1.27	-0.78	10.76	1.49	
			-0.07	-0.94	11.37	0.94	
	12	373.45					
	6		-4.85	0.82	5.68	4.92	0.97
Swamp Forest	4		-2.49	-4.46	10.01	5.11	
	3		-1.87	-1.13	10.35	2.18	
	2.4		-0.16	-1.11	11.18	1.13	
			-0.38	-0.51	11.15	0.63	
	12	330.76					0.82
Mangrove	6		-5.96	-3.17	6.94	6.75	
	4		-2.64	-3.16	9.84	4.12	
	3		-0.82	-2.37	10.79	2.50	
	2.4		1.14	-2.12	11.49	2.41	
			2.73	-1.44	11.81	3.09	
	12	378.45					0.91
	6		-5.14	-0.96	6.35	5.23	
	4		-2.31	-3.28	9.91	4.01	
	3		-2.05	-1.75	10.45	2.67	
	2.4		-0.63	-1.60	11.07	1.72	
			-0.96	-1.19	11.14	1.53	





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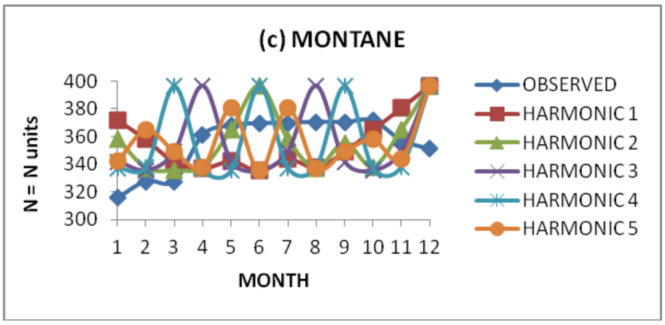
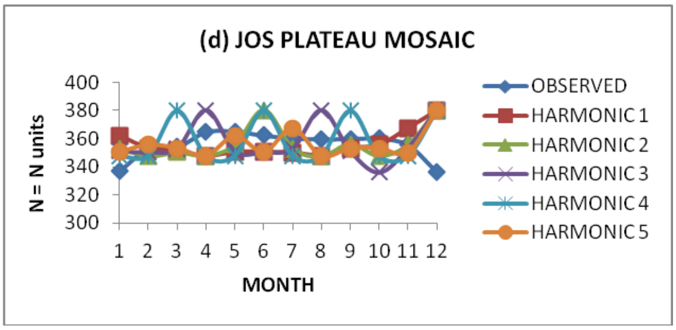
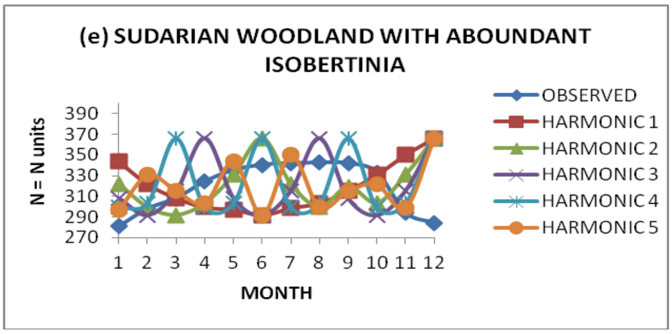
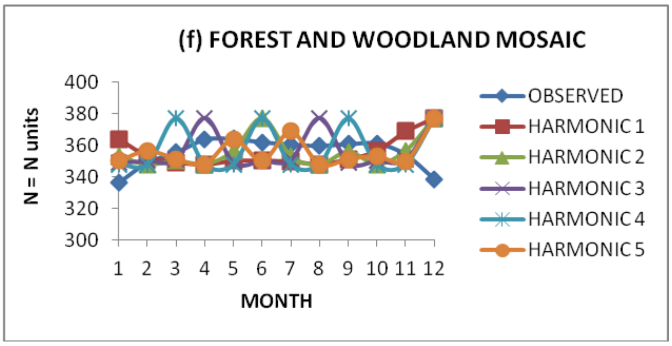
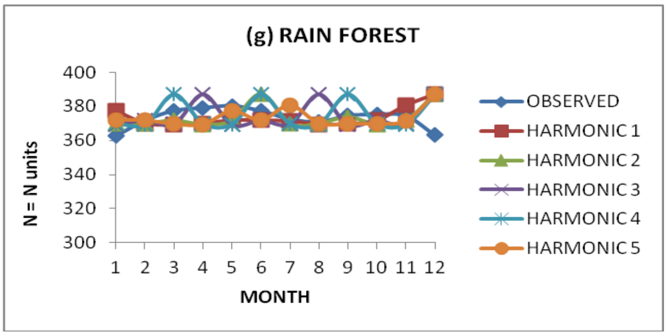
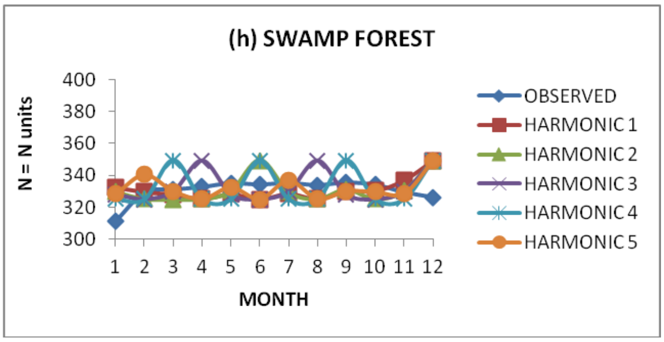












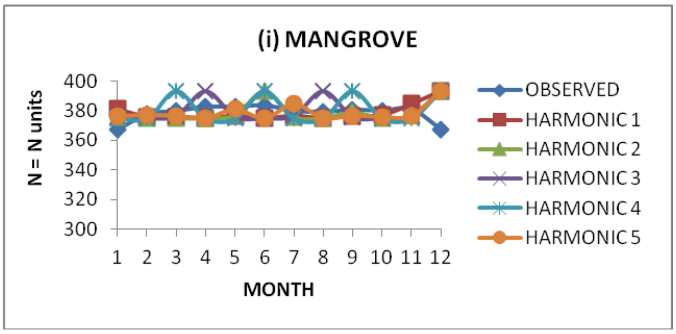


Figure 3: Monthly mean observed and amplitudes of first five harmonics of refractivity

Harmonic Analysis of Surface Refractivity

Amplitude Variation

Both Table 1 and Figure 3 shows the values of the mean, constants A_n and B_n (the amplitudes) and the phases for each harmonic computed from eqn. (4). In this study, monthly mean of surface refractivity have been subjected to harmonic analysis in order to predict the seasonal variation over thirty-nine years period. The data have been computed in terms of five harmonics with periods of q = 12 (1st harmonic), 6 (2nd harmonic), 4 (3rd harmonic), 3 (4th harmonic) and 2.4 (5th harmonic) months, respectively. The results of the first three harmonics have been deduced by the ratio of the sum of squares of their amplitudes to the sum of squares of the five amplitudes, denoted by R_x. Also, it was observed that when the ratio value is close to 1 (unity), the implication is that the first three harmonics increase/decrease as a result of greater/lesser percentage in the curve of the seasonal variation. Meanwhile, low fraction indicates larger amount of variation present in the higher harmonics. The highest harmonic of the 1st harmonic amplitude suggests a strong annual variation while the high amplitude of the 2nd harmonic indicates a strong semi-annual variation. Some certain harmonics may exert a dominating influence on the curve but the relative contribution of the first three harmonics is usually sufficient in explaining the seasonal variance of the parameter.

It is evident from table 1 that the fractions obtained from the contribution of the first three harmonics given in column 8 of the table exhibit high ratios, R_x, from 0.82 to 0.99. This implies that, at all the nine stations, the first three harmonics account for over 80% of the total variability. The major influence displayed by most stations of the annual component over the semi-annual component implies that the amplitudes of the annual component are higher than those of the semi-annual component, that is, $R_1 > R_2$ in most cases. This trend is an increase in annual amplitude when moving from moist climate of the Rain Forest (4.92) in southern coast to the dry regime of the Sudarian Undifferentiated Woodland (31.77) in the north. The high first harmonic amplitude computed for N at Sudarian Undifferentiated Woodland suggests a strong annual variation in the inland station.

At Brush and Thicket located in inland, strong semi-annual amplitude is present for N (24.11) and the lowest semi-annual amplitude is located at Mangrove N (4.01), these show a strong indication that northern part of the country still maintain lead in the semi-annual amplitude variation though semi-annual influences are smaller compared to the annual components. By comparison, high seasonal ranges arise from overlapping of the maritime (mT) and continental (cT) airmasses in the Northern stations because radiative heating are prominent in these areas. While, Southern stations shows low amplitudes because of small seasonal range in stations dominated by moist climate almost throughout the year. It may also be attributed to the continual onshore advection of cool moist (mT) air from the atlantic ocean that maintains uniform mean temperatures and humidity as noted by (Willoughby, et al, 2002).

Sudarian Woodland with Aboundant Isobertinia seems to be the only station that has the highest third harmonic amplitude for refractivity (4.14). The third harmonic describes those maxima having a tendency to occur four months apart. The outcome of the harmonic variations of the last two amplitudes values, that is, fourth (R_4) and fifth (R_5), to a large extent are not significant.

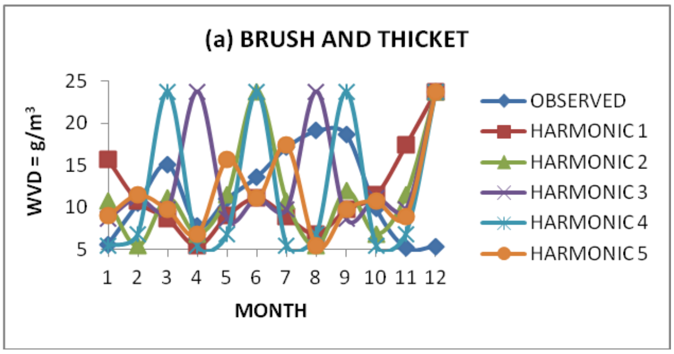
Phase Variation

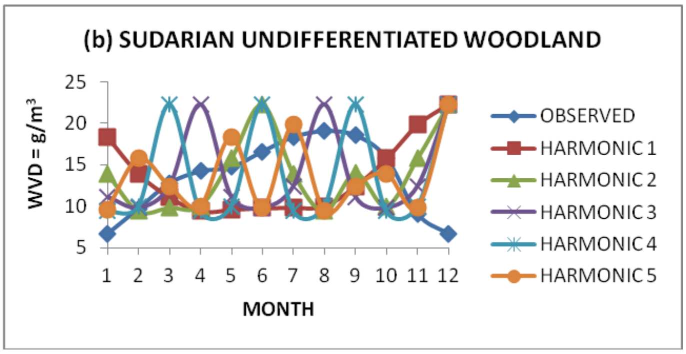
Observation of the phase data at the column 6 in table 1 for refractivity reveals that almost all stations experiences a first harmonic maximum between June and July, that is, $6.35 < \Phi_1 < 7.68$. These months coincide with the wet season which have the highest values in the country. Only Rain Forest station experience first harmonic peak in late May, that is, 5.68. The tendency of occurrence in six month apart, are describes by those maxima of the second harmonic phase. N reveal maxima occurrence in the second harmonic between September and October, that is, $9.38 < \Phi_1 < 10.69$ most stations except Brush and Thicket (Φ_2= 2.22) and Sudarian Undifferentiated Woodland (Φ_2 = 2.86). The third harmonic was observed mostly between October and November with exception at Sudarian Woodland with Aboundant Isobertinia in January.

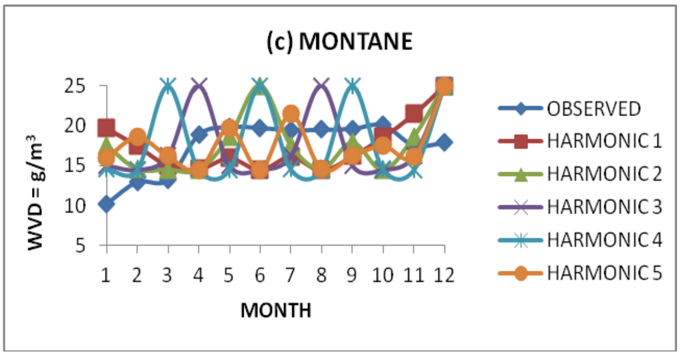
Table 2: Values of X_o, A_n, B_n, Φ_n, R_n and R_x derived from harmonic analysis of water vapour density

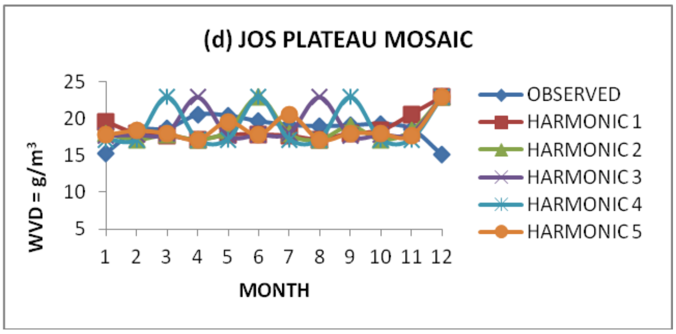
Station	q	X_o	A_n	B_n	Φ_n	R_n	R_x
Brush and Thicket	12	11.58	-4.44	-2.61	7.01	5.15	0.92
	6		-3.15	2.65	2.33	4.12	
	4		-0.28	-1.98	10.57	0.45	
	3		1.61	-4.55	11.78	1.79	
	2.4		0.58	2.83	0.26	0.75	
Sudarian Undifferentiated WoodLand	12	13.53	-4.78	-3.048	7.08	5.67	0.99
	6		-2.16	-0.01	9.01	2.16	
	4		-0.37	-0.04	10.08	0.37	
	3		0.12	0.36	0.59	0.38	
	2.4		0.2	0.11	0.19	0.23	
Montane							
	12	17.41	-2.42	-2.77	7.63	3.68	0.94
	6		0.44	-2.06	10.70	2.10	
	4		0.57	-0.09	11.90	0.58	
	3		0.19	-0.18	11.63	0.26	
	2.4		0.91	-0.53	11.8	1.05	
Jos Plateau Mosaic							
	12	18.55	-1.70	-0.15	6.17	1.71	0.92
	6		-0.79	-1.00	9.86	1.27	
	4		-0.45	-0.26	10.34	0.52	
	3		-0.47	-0.31	10.78	0.56	

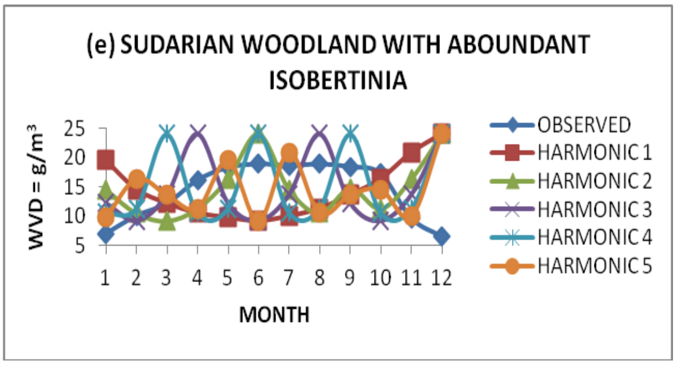
Sudarian Woodland with Aboundant Isobertinia	2.4		-0.09	-0.34	11.30	0.35	
	12	14.38					
	6		-5.65	-2.73	6.86	6.27	0.99
Forest and Woodland Mosaic	4		-1.60	-0.98	9.52	1.88	
	3		-0.78	0.55	1.61	0.96	
	2.4		-0.32	0.31	1.13	0.44	
			0.22	0.15	0.23	0.26	
	12	18.97					
	6		-1.89	-0.34	6.34	1.92	0.97
	4		-0.89	-1.20	9.89	1.49	
	3		-0.37	-0.34	10.46	0.50	
Rain Forest	2.4		-0.32	-0.23	10.80	0.39	
			-0.01	-0.25	11.39	0.25	
	12	20.13					0.97
Swamp Forest	6		-0.72	0.46	4.92	0.86	
	4		-0.45	-0.89	10.05	1.00	
	3		-0.33	-0.21	10.37	0.39	
	2.4		-0.04	-0.22	11.16	0.23	
			-0.06	-0.08	11.16	0.10	
	12	20.95					0.75
Mangrove	6		-0.70	0.46	4.88	0.84	
	4		-0.50	-0.94	10.03	1.07	
	3		-0.21	-0.42	10.69	0.47	
	2.4		0.25	-0.45	11.49	0.52	
			0.55	-0.32	11.80	0.64	
	12	20.68					0.88
	6		-0.74	0.19	5.51	5.23	
	4		-0.47	-0.66	9.91	4.01	
	3		-0.36	-0.33	10.47	2.67	
	2.4		-0.10	-0.34	11.11	1.72	
			-0.14	-0.23	11.19	1.53	

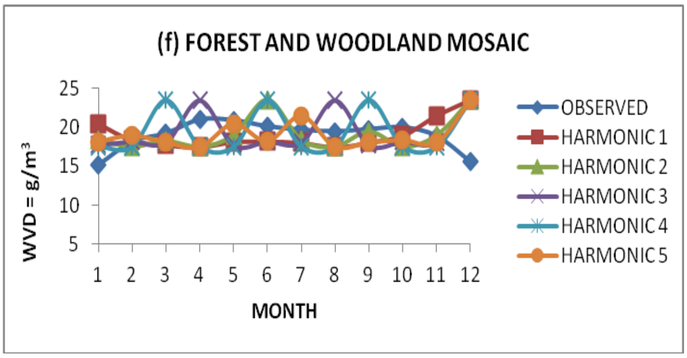


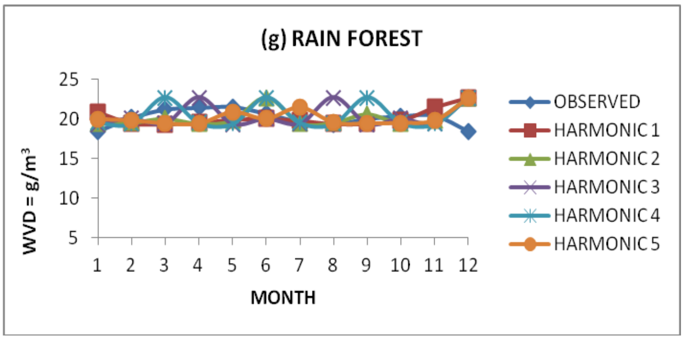


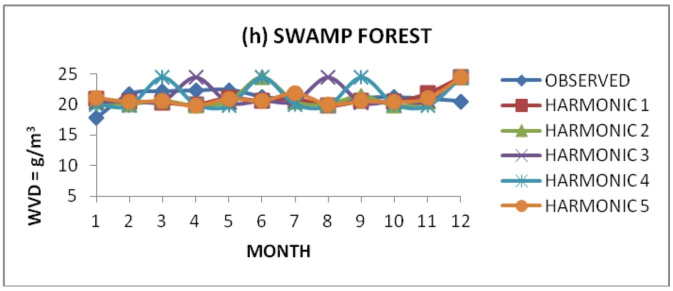












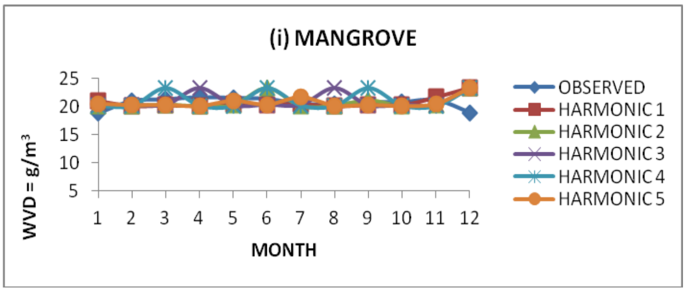


Figure 4: Monthly mean values and amplitudes of first five harmonics of water vapour density.

Harmonic Analysis of Water Vapour Density

Amplitude Variation

Water vapour density averaged over thirty-nine years period has also been subjected to harmonic analysis in order to predict the seasonal variation as shown in table 2 and figure 4.

The fractions obtained from the contribution of the first three harmonics shown in column 8 of the Table 2 exhibit high ratios, R_x, from 0.75 to 0.99. This means that, at all the nine stations, the first three harmonics account for over 75% of the total variability. As observed for refractivity, the trend also decreases in annual amplitude moving from Sudarian Woodland with Aboundant Isobertinia (6.27) in the northern part to Mangrove (0.77) in the south south zone of the country. The high first harmonic amplitudes computed at Sudarian Woodland with Aboundant Isobertinia suggest a strong annual variation in these inland stations for water vapour density.

At Brush and Thicket location, the strongest semi-annual amplitude is present for WVD (4.12) and the weakest semi-annual amplitude is located at Mangrove also for WVD (0.81) in southern part, as observed for refractivity. Sudarian Woodland with Aboundant Isobertinia seems to be the only station that has the highest third harmonic amplitude for WVD (0.96). Obviously from both the refractivity and water vapour density, the northern stations are more accountable for the total variability of the first three harmonics than the southern stations due to the strong amplitudes displayed.

Phase Variation

The phase data Observation at the column 6 in table 2 for water vapour density shows that shows that Montane, Sudarian undifferentiated Woodland and Brush and Thicket experiences a first harmonic maximum in July, that is, Φ_1 = 7.63, 7.08 and 7.01 respectively. Meanwhile, Sudarian Woodland with Aboundant Isobertinia, Forest and Woodland Mosaic and Jos Plateau Mosaic observed theirs peak in June, i.e, Φ_1 = 6.86, 6.34 and 6.17 respectively. Mangrove in May with phase data of 5.51 and both the Rain Forest and Swamp Forest occurrence of the first harmonic is in April with Φ_1= 4.88 and 4.92 respectively. The tendency of occurrence in six month apart are describes by those maxima of the second harmonic phase. N and WVD both reveals common maxima occurrence in the second harmonic between September and October in almost all the stations except Brush and Thicket (Φ_2= 2.22) and Sudarian Undifferentiated Woodland (Φ_2 = 2.86) in February. These anomalies presented in sections 4.4.1 and 4.4.2 may be adduced to the increased aerosols retention over the region (Emetere et al., 2015b). Table 3 illustrates the annual aerosols retention that was calculated over Sudarian Woodland and Jos Plateau Mosaic. Due to the increased anthropogenic pollution and the north-east winds, both the surface refractivity and the water vapour density are affected. The ratio of influence was not calculated in this work because of inadequate ground data set over most stations that were considered.

Table 3: Annual atmospheric aerosols retention over Sudarian Woodland and Jos Plateau Mosaic 2007-2013

	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Aerosol deposition	0.63	1.87	0.73	4.52	31.28	0.82	0.094

CONCLUSION

The observed features for both refractivity and water vapour density may be characterized by the prevailing weather conditions existing over the country. The results show that Forests zones values of refractivity and water vapour density are higher than Savannahs zones values and generally, show less variability. The atmospheric dynamics of the country is controlled by the dry tropical continental (cT) air originating from the sahara desert, tropical maritime (mT) air emanating from the Gulf of Guinea and moist monsoon. However, the dry tropical continental air is laden with north-east dust winds which also have influence on its variability.

The Savannahs region are attributed by high temperatures, both daily and seasonally, because the skies are on most occasion cloudless, thus aiding penetration of solar radiation through the troposphere and subsequently reducing the relative humidity. Therefore, the mean values obtained in these regions are influenced by precipitation, convection and thunderstorms. Down along the coastal and the Forests region, mean value are high because the tropical maritime (mT) air is sufficiently deep and humid. Hence, higher mean values of refractivity and water vapour value are experienced in this region.

The harmonic analysis results also revealed that the first three harmonics amplitudes were found to account for over 70% of the annual variation of both refractivity and water vapour density. The first harmonic amplitude increases in the south-north direction, the result suggest a strong annual variation in the inland stations than the coastal stations. There is also strong semi-annual variation, that is, second harmonic, which revealed second largest harmonic compared with the first. There are no strong harmonic in the last three harmonic amplitudes. The phase reveals that most of the stations experience a first harmonic maximum between June and July, these months coincide with the wet season recording its highest values in the country. The results obtained show that the model of the harmonic analysis agrees to a reasonable extent, with the measured data. Hence, this study suggests further work on the influence of annual aerosols retention on the seasonal variation of refractivity and water vapour density over Nigeria.

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