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Spatial and Seasonal Estimation of Tropospheric Radio Refractivity in Nigeria

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Abstract

The spatial and seasonal variation of tropospheric radio refractivity of Nigeria has been studied using meteorological variables (temperature, relative humidity and pressure) retrieved from the archive of the United States' National Aeronautics for Space Administration (NASA). This work established a seasonal variation. The results also revealed an increase in radio refractivity from minimum of about 270N-units at Abadam to maximum of about 415N-units at Warri. The variation of radio refractivity is synchronous with rainfall in most of the stations especially those in the Guinea Savannah, Tropical Rainforest and Coastal areas where the effects of august break manifest vividly on the curves. Intense refractivity was measured mostly in the tropical rainforest and coastal areas. This could be attributed to the intensity of rain and the length of the wet season in those locations. The Sahel, Sudan and Guinea savannah which experience less rain with short period of wet season recorded reduced refractivity. Just like rainfall, the movement of Inter Tropical Discontinuity (ITD) is also found to be linked to the variation of the radio refractivity. The northward movement of the ITD brings with it elevated refractivity while the southward movement leads to reduced refractivity. This is because the ITD is an element of two high pressure cells which influences its motion. Majorly, the seasonal variation is found to be the product of climate except in some high ground areas where the topography was found to be majorly responsible.

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1. Introduction

Propagation of signal and data transmission through a certain channel determines the quality of wireless communication system that is why users around the world enjoy the mobility of wireless communication [1]. The transmission channel of radio wave signal is the atmosphere which is largely non-homogenous. This property of the atmosphere give rise to the distortion of the signal as it travel in the medium. This distortion can be in form of reflection, refraction and scattering.

Refraction is the most important effects of the earth's atmosphere on the propagation of radio wave, particularly at frequencies of 30 MHz and above [2]. Because of changes in refractivity, radio waves may bend as they travel through different atmospheric layers. Meteorological parameters, primarily temperature and humidity, which are highly variable depending on geographical location and time of year, determine this variation. The troposphere's radio refractive index is crucial in predicting the scale of performance of terrestrial radio communications. Variations in the tropospheric radio refractive index have a considerable impact on frequencies above 100 MHz in the troposphere. Even at lower frequencies above 30 MHz, this impact can be seen [3].

The temporal and spatial variation of radio refractivity has been observed, this can be season to season, day to night, hour to hour, as well as location to location [4]. The outcomes of random spatial fluctuations in radio refractive index in the troposphere include absorption and scattering of radio signals, amplitude and phase scintillations, and other complex phenomena that can cause transmission losses and interference between channels. Because of the presence of high-intensity tropical rainfall, the influence of interference owing to tropospheric fluctuation of refractivity is significantly more widespread in the tropics than in the temperate environments [5].

The influence of earth's and atmosphere's properties on radio wave propagation in the atmosphere is highly significant [6]. The "curvature of the earth and the condition of the atmosphere" are responsible for the multi-directional refraction of electromagnetic waves. The refractive index of the medium of oscillation of the radio wave determines the clearing of the microwave route.

2. Data and Methods

Meteorological data comprising of relative humidity (%), temperature (^oC), pressure (hPa) and rainfall (mm) was retrieved from the NASA at 2-meter height for the period of five years (2016-2020). These data is however obtained daily.

The analysis of the surface radio refractivity depends on air temperature, relative humidity and pressure. The propagation of electromagnetic in the air depends largely on the moisture in the atmosphere. The computation of radio refractivity N (N-units) is done as proposed by Smith & Weintraub [7]:

$$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right), \tag{1}$$

where P is atmospheric pressure (hpa), T is absolute temperature (K), and e is the atmospheric water vapour pressure (hpa). The water vapour pressure is calculated as follows [8]:

$$e = \frac{He_s}{100}, \tag{2}$$

where H is the relative humidity and e_s is the saturated vapor pressure which can be obtained from equation (3).

$$e_s = H \times \frac{6.1121exp\left(\frac{17.50t}{t+240.97}\right)}{100}, \tag{3}$$

where H is the relative humidity and t is temperature in Celsius (° C).

3. Study Area

The study is undertaken from the 61 stations within Nigeria. These stations were sampled from the five geo-climatic in the country using the definition of Ogunjobi *et al*. [9]. These stations are:

3.1. Sahel

Gusau, Sokoto, Maiduguri, Katsina, B/Kebbi, Damaturu, Nguru, and Abadam.

3.2. Sudan Savannah

Yelwa, Maru, Zaria, Giade, Dutse and Potiskum and Kano.

3.3. Guinea Savannah

Abuja, Bida, Jalingo, Kaiama, Wase, Ilorin, Jos, Lafia, Lokoja, Makurdi, Minna, Ibi, M/Plateau, Yola, Kaduna, Bauchi, Gombe, Shaki,.

3.4. Tropical Rainforest

Abeokuta, Ado-Ekiti, Akure, Ibadan, Iseyin, Ondo, Oshogbo, Benin, UsiEki, Abakaliki, Asaba, Umuahia, Owerri, Awka, Enugu, Ogoja, Obudu, and Ikom.

3.5. Coastal

Ijebu-Ode, Ikeja, KokaMarine, Calabar, Eket, Onne, Port Harcourt, Uyo, Yenagoa, and Warri.

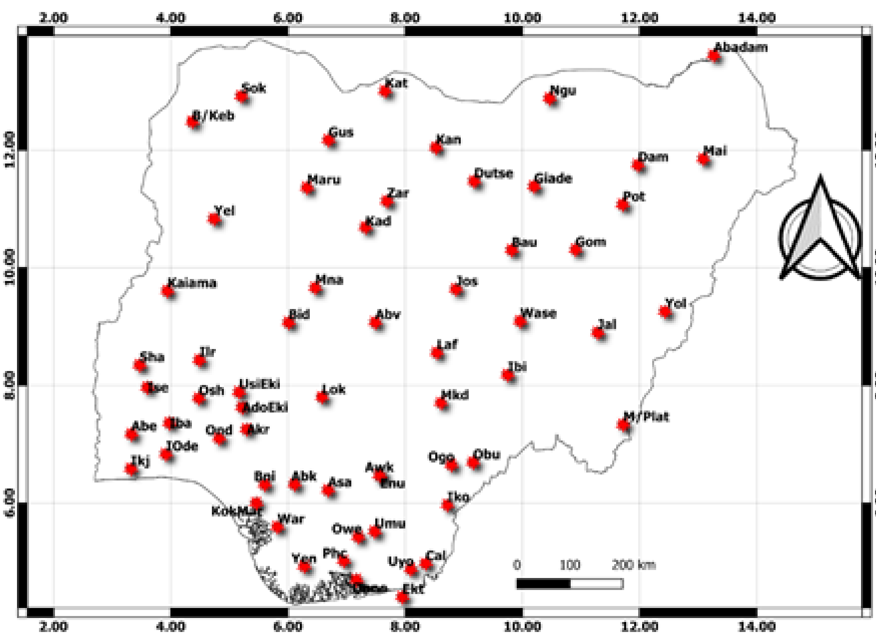

Figure 1: Map of the study area.

4. Result

The radio refractivity variation from the satellite data for each of the sixty one (61) locations was obtained after carrying out the analysis. The analysis was done by computing the daily radio refractivity of each station. This was followed by monthly mean and seasonal mean culminating with the station, geo-climatic zone mean and study mean. Rainfall data was introduce into the analysis in order to confirm the relation between the refractivity and rainfall pattern.

Table 1: Radio Refractivity (N-unit) of the study area (2016-2020).

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sahel	283	278	282	304	347	366	379	385	386	359	316	299
Sudan	291	287	296	330	369	374	378	381	383	366	328	308
Guinea	315	315	347	372	386	385	383	382	384	381	360	334
T/Rainforest	371	384	402	403	402	398	395	394	395	397	395	381
Coastal	391	401	407	407	405	401	398	397	399	401	403	396

4.1. Seasonal Variation of Radio Refractivity across Nigeria

This study has observed a seasonal variation of radio refractivity for the area under study as shown from Fig. 2 to Fig. 7. This work reveals a seasonal variation. This is in agreement with the work in Refs [3, 10-13] [10]. The results also revealed an increase in radio refractivity from minimum of about 270N-units at Abadam to maximum of about 415N-units at Warri. This is in agreement with Ref. [10].

Due to the large number of stations involve in the study we narrowed the discussion of the result to geo-climatic zones of the country. Using the definition of Ogunjobi *et al.* [9] and considering the meteorological factors we have five geo-climatic zones in the country (Sahel, Sudan Savannah, Guinea Savannah, Tropical Rainforest and Coastal).

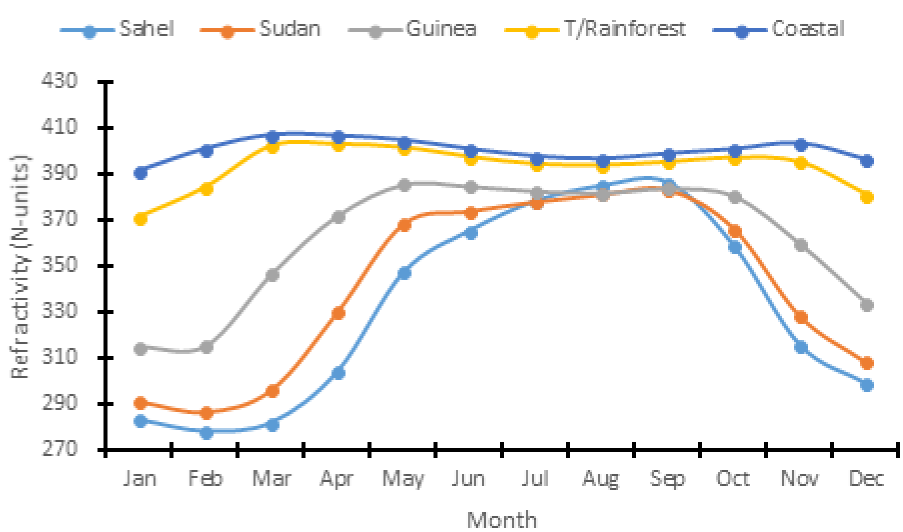

Figure 2(a): Seasonal variation of radio refractivity over the climatic zones of Nigeria.

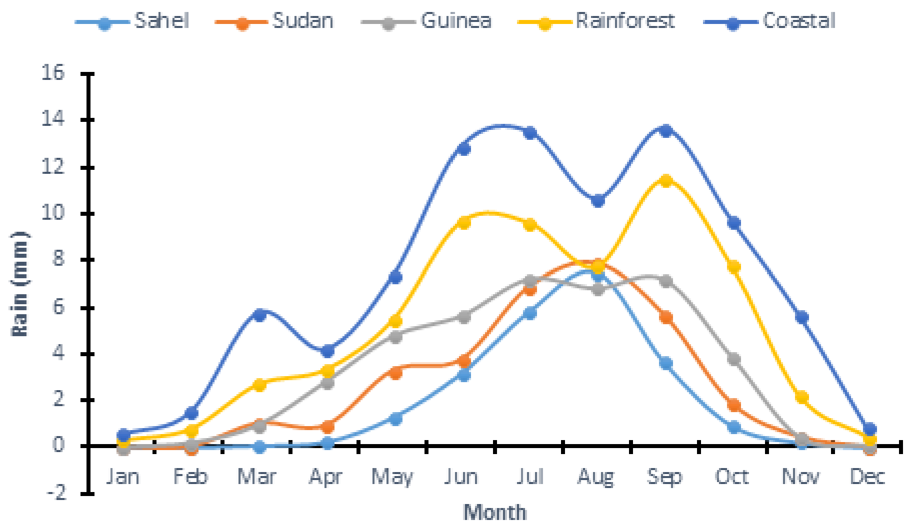

Figure 2(b): Rainfall curve over the climatic zones of Nigeria.

The seasonal refractivity variation at the Sahel zone showed an increase from the minimum of about 273N-units for February until it reached a peak of about 397N-units for September. Looking at Fig.3 (a), you will observe that there is sudden increase between March and May, after which a steady increase is observed until a peak in September followed by a steady decease to December. This followed the pattern of the rain in the zone as shown in Fig. 3(b). The maximum refractivity was measured at Birnin-Kebbi while the minimum was measured at Katsina. The result obtained from the analysis revealed that all the maximum values of refractivity during the study period in Sahel were measured in Birnin-Kebbi, while the minimum values were measured in Katsina and Abadam. This clearly validate the fact that the stations covered in this study, Katsina and Abadam are the stations with shortest rainy season. For about half of the year the stations in Sahel are above the Inter Tropical Discontinuity (ITD). This further explains why lower values of refractivity are prevalent in the zone. The rainfall curve in Fig. 3(b) shows a single peak in the month of August while the peak in the seasonal variation of refractivity is in September. This is because refractivity doesn't directly depends on the amount of rainfall but the relative humidity which always high during the rainy season. The average refractivity recorded for this zone is about 331.99N-unit.

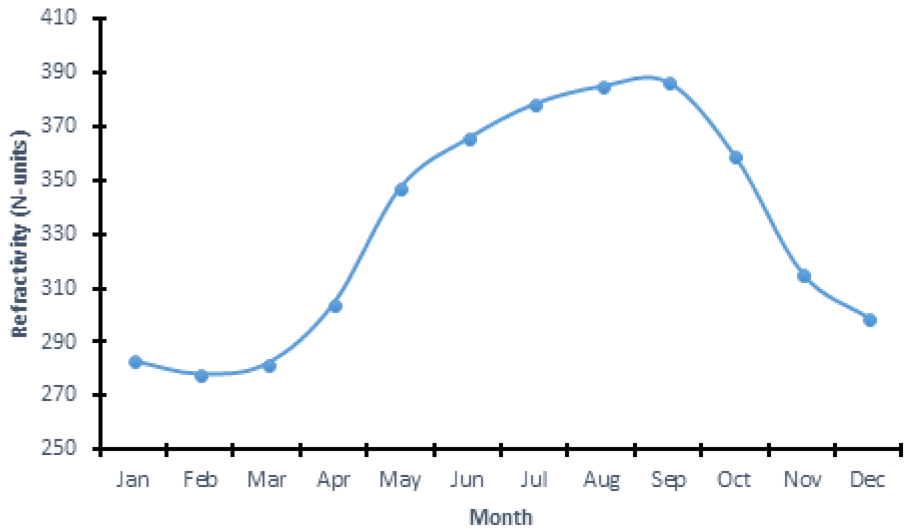

Figure 3(a): Seasonal variation of radio refractivity of over the Sahel zone of Nigeria.

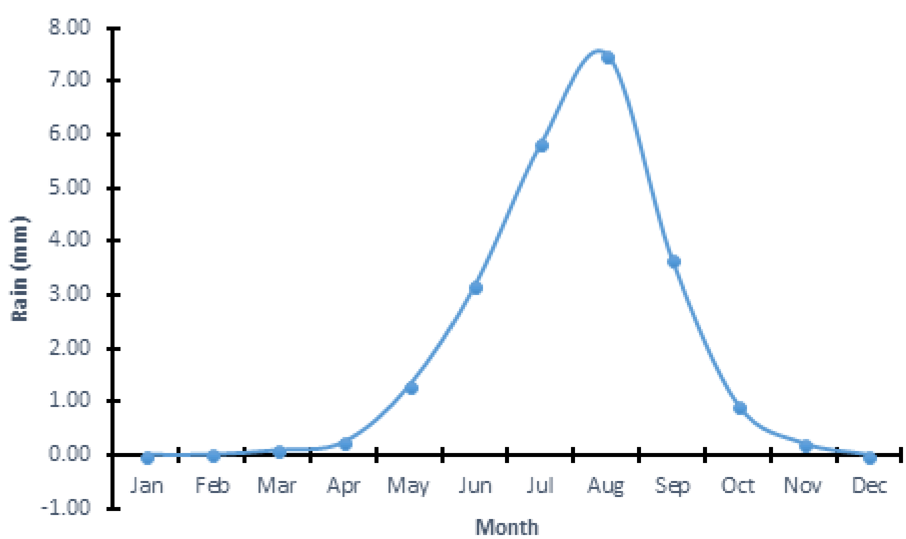

Figure 3(b): Rainfall curve of the Sahel zone of Nigeria.

Fig. 4(a) revealed a seasonal variation of refractivity in Sudan Savannah zone. A minimum of about 274N-units in February and maximum of about 394N-units in May and June was observed. The curve has revealed a sudden increase from February at about 287N-units to May at about 369N-units; after which a steady increase climaxing at 383N-units followed by a sudden decease to December at about 308N-units. The high values of refractivity measured in this zone during the study period were found to be in Yelwa station while the lower values were recorded in Potiskum, Kano and Zaria stations. The average atmospheric refractivity in this zone is about 341.06N-unit which is about 93.2% of the Nigerian refractivity. The difference between the maximum in this zone and the Coastal zone is about 59.47N-unit. Just like the Sahel, the rainfall curve of this zone as shown in Fig. 4(b) revealed a single peak in the month of August.

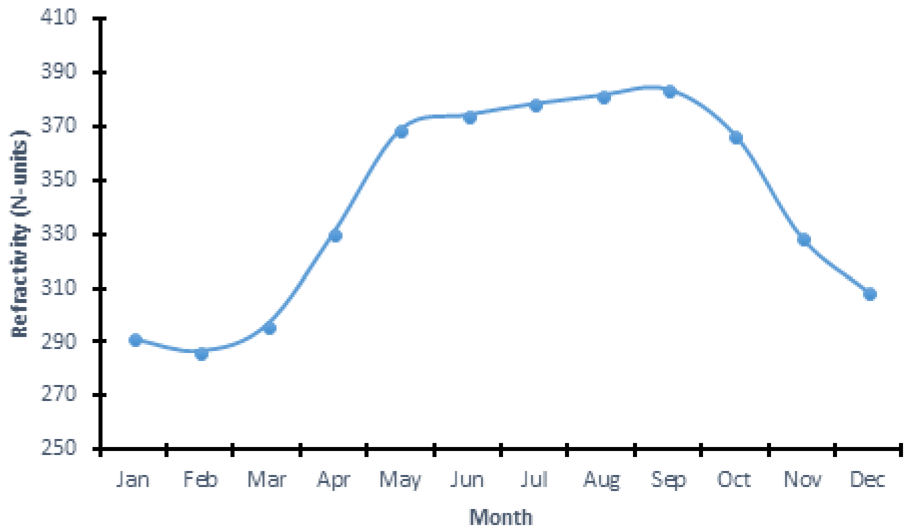

Figure 4(a): Seasonal variation of radio refractivity of over the Sudan Savannah of Nigeria.

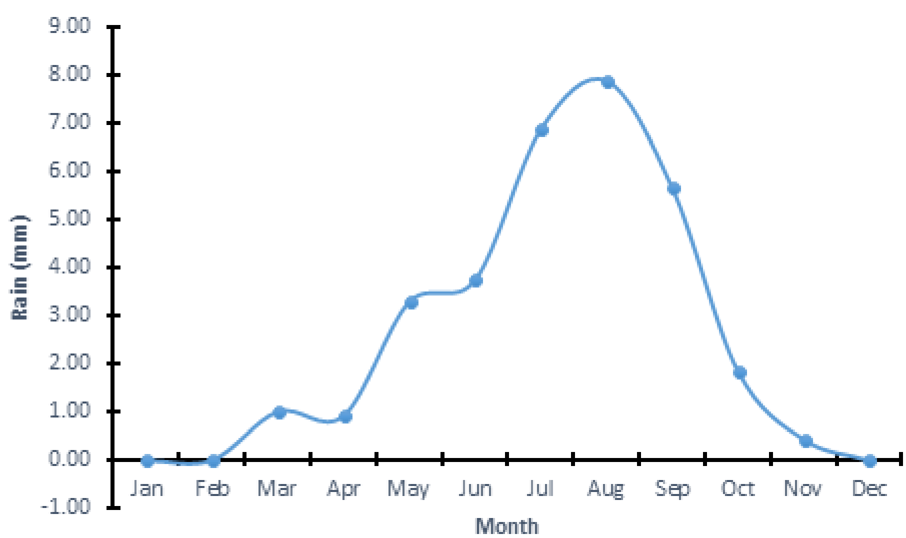

Figure 4(b): Rainfall curve of the Sudan Savannah zone of Nigeria.

Seasonal variation of refractivity over the Guinea Savannah is depicted in Fig. 5(a). A minimum refractivity of about 314N-units and a maximum refractivity of about 386N-units is observed in January and May respectively. A dip is observed in August at about 382N-units after a sudden increase from February at about 315N-units to May at about 387N-units. A minor peak is recorded in September at about 384N-units until a sudden drop to December at about 334N-units. During the study period in this zone, lower values of refractivity were measured in the high grounds of Guinea Savannah (Jos, and Mambila Plateau) while the elevated values spread across the zone. The low value of refractivity over Jos and Mambila Plateau is largely due to high altitude which consequently affects pressure in higher grounds. This affects the values of refractivity since the pressure and the dry component of refractivity correlate positively. The higher values of refractivity evenly distributed across the zone confirm the nature of the rainy season in the zone as depicted in Fig. 5(b). The slight dip observed in August may be attributed to the reflection of the little dry season experience in the coast and the tropical rainforest.

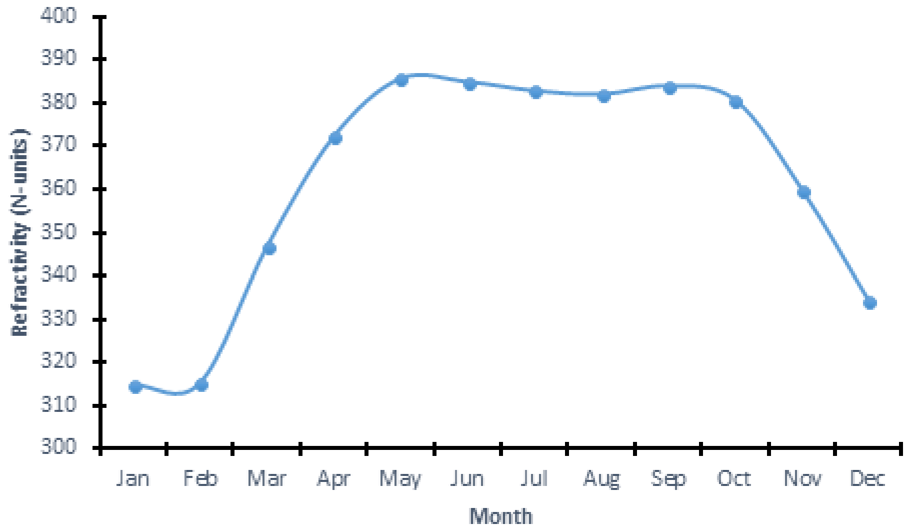

Figure 5(a): Seasonal variation of radio refractivity of over the Guinea Savannah of Nigeria.

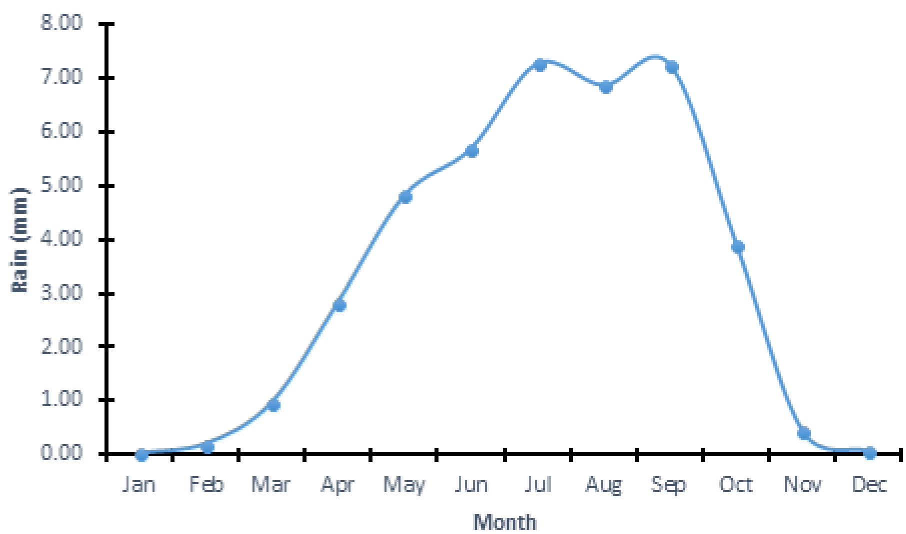

Figure 5(b): Rainfall curve of the Guinea Savannah zone of Nigeria.

The seasonal variation of refractivity over Tropical Rainforest of Nigeria is shown in Fig. 6(a) revealing a sudden increase from January at about 371N-units to a peak of about 403N-units in April from where a steady decrease to August at about 394N-units is observed. A steady increase from a dip in August to October at about 397N-units is recorded until a sharp drop in December at about 381N-units. The mild dip is due to the August break experience in some part of the zone. The higher values of refractivity recorded in the zone during the study period are widely spread across the zone just like the Guinea Savannah. However, the lower values were recorded in the western and eastern flanks high grounds of the zone (Ado-Ekiti and Obudu). Even though these two stations recorded substantial amount of rain during the period but recorded lower refractivity due to their elevated height which affects the station pressure.

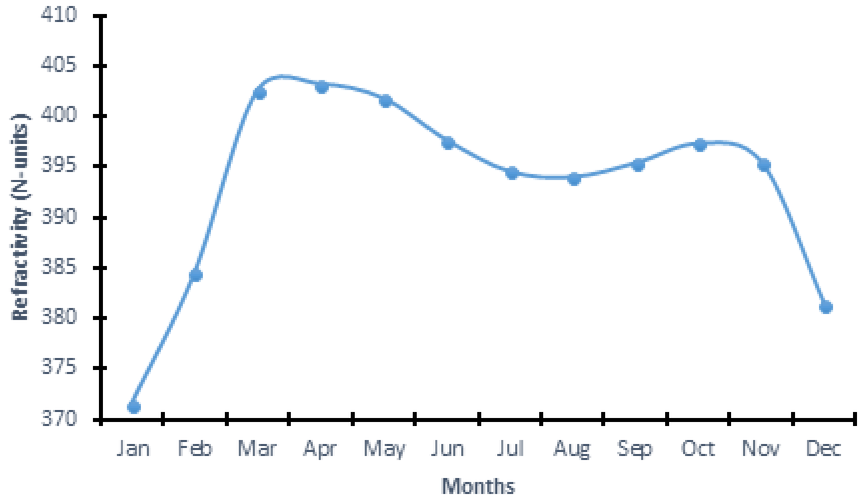

Figure 6 (a): Seasonal variation of radio refractivity of over the Tropical Rainforest of Nigeria.

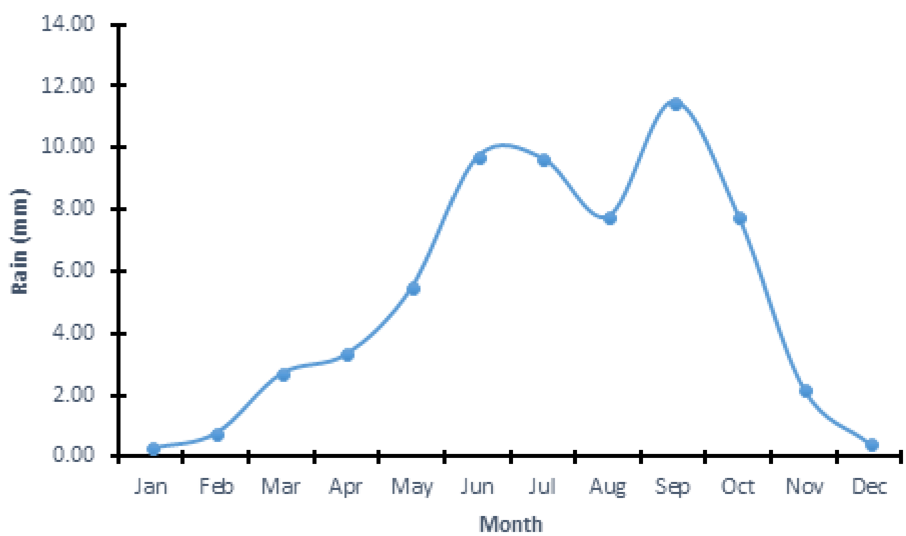

Figure 6(b): Rainfall curve of the Tropical Rainforest of Nigeria.

A minimum value of refractivity of about 391N-units for January and a maximum value of about 407N-unit for March is revealing a seasonal variation in Fig. 7(a). A significant dip is observed in August at about 396N-units rising steadily to another peak in November at about 403N-units until a sudden drop in December at about 396N-units. The dip observed in this curve confirmed the fact that the august break is more of a coastal thing than rainforest or guinea. The mild dip we observed in the both Tropical Rainforest and Guinea Savannah curves is just a little reflection of the activities in the coastal areas. The position of the ITD during the period is approximately 21 degree north. This consequently put the zone under the influence of high pressure cells which dampens weather activities. Throughout the study period, the lower values of refractivity was measured in Eket station despite being more coastal than any other station in the zone. This situation could be attributed to continuous influence of Atlantic Ocean as suggested by Ayantunji *et al*. [3].

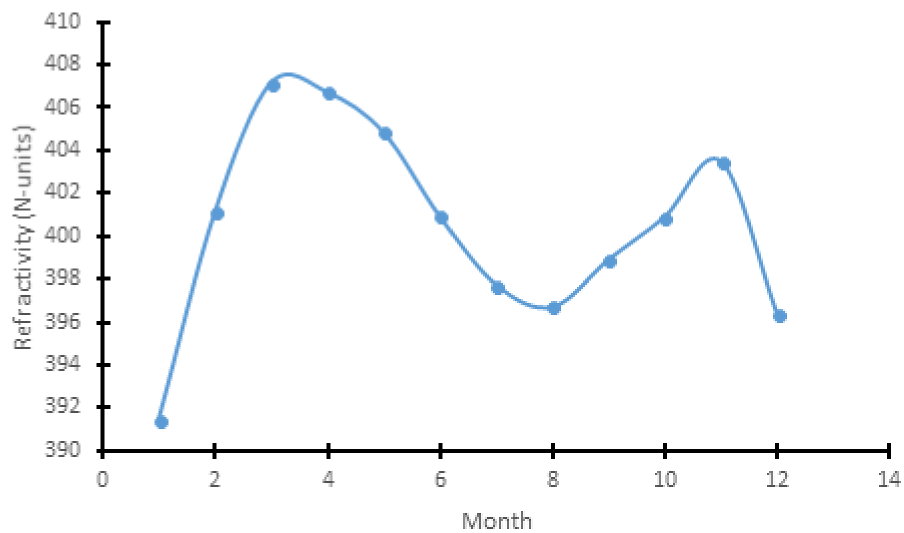

Figure 7(a): Seasonal variation of radio refractivity of over the Coastal zone of Nigeria.

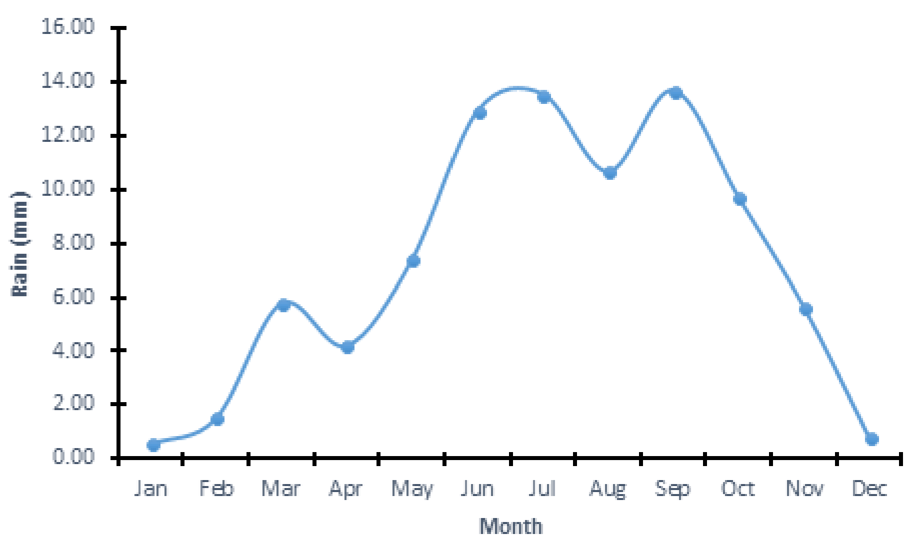

Figure 7 (b): Rainfall curve of the Coastal zone of Nigeria.

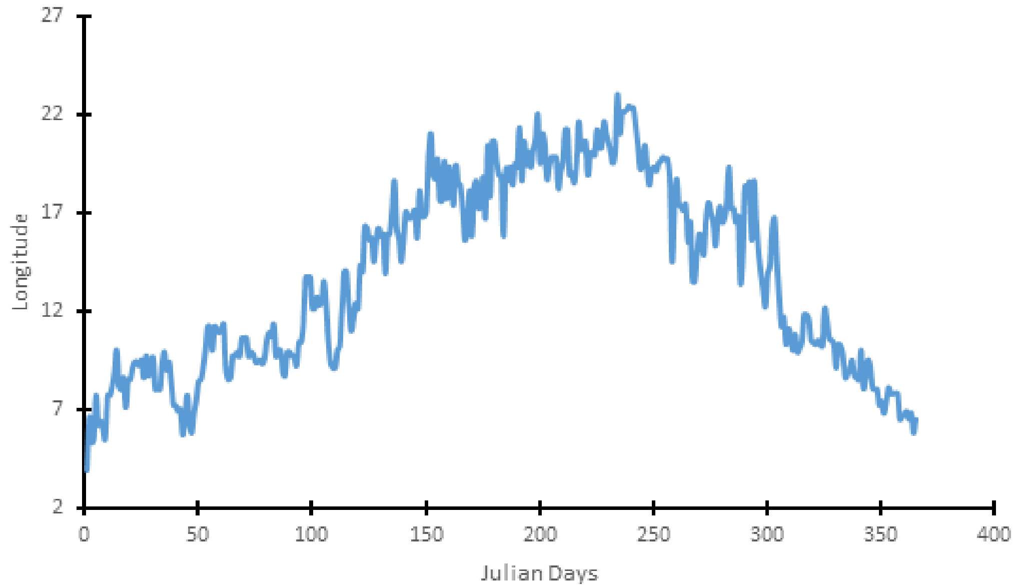

Figure 8: Average ITD position during the study period.

5. Conclusion

The spatial and seasonal variation of tropospheric radio refractivity of Nigeria has been studied from a satellite meteorological parameters (temperature, relative humidity and pressure) sourced from NASA. Just like Refs. [3, 10-13, 15, 16], this work established a seasonal variation. These researches looked into more than 5 stations each covering most part of Nigeria randomly. The study also revealed an increase in radio refractivity from about 270N-units at Abadam to about 415N-units at Warri. This is in agreement with Refs. [3, 10, 11, 13]. The variation of radio refractivity is synchronous with rainfall in most of the stations especially those in the Guinea Savannah, Tropical Rainforest and Coastal areas where the effects of august break manifest vividly on the curves. Intense refractivity was measured mostly in the tropical rainforest and coastal areas. This could be attributed to the intensity of rain and the length of the wet season in those locations. The Sahel, Sudan savannah which experience less rain with short period of wet season recorded reduced refractivity. The massive injection of the dust plum from the Sahara desert into the atmosphere in the month of February give rise to reduce humidity which consequently affects the refractivity of both Sahel and Sudan zones in the month. When dust is raised, both the dew point temperature and relative humidity drop because the dust dampen the available moisture, given rise to a dry air. The dip observed is largely attributed to the fall in relative humidity in the month. However, agreeing with Ref. [14], it is worthy of note that this study found out that large percentage of the values of refractivity can be determined by temperature in the wet season compared to dry season which is largely driven by relative humidity. Just like rainfall, the oscillation of Inter Tropical Discontinuity (ITD) is also found to be linked to the radio refractivity variation. The northward movement of the ITD brings with it elevated refractivity while the southward movement leads to reduced refractivity. This is because the ITD is an element of two high pressure cells which influences its motion.

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