Variability of Microwave Radio Refractivity and Field Strength over Some Selected Locations in Nigeria.

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Abstract

In this study, results of the variation of radio field strength derived from the computation of surface refractivity through measurements of temperature, relative humidity and pressure across seven locations ((Akure (7.15°N, 5.12°E), Lagos (6.30°N, 3.20°E), Abuja (7.10°N, 9.25°E), Jos (9.50°N, 8.50°E), Makurdi (7.30°N,8.53°E), Port-Harcourt(4.20°N,7.00°E), and Nsukka (6.90°N,7.67°E)) in Nigeria are presented. Two years (Jan., 2011–Dec., 2012) archived data as provided by Tropospheric Data Acquisition Network (TRODAN) of the Centre for Atmospheric Research, Anyigba, Kogi State were utilized for the study. Results showed that the values of surface refractivity (N_s) were low during the dry season months and high during the wet season months and also there was high values of N_S at the coastal areas compared with the inland areas. It was also deduced that the average value of N_S for Abuja, Akure, Jos, Lagos, Markurdi, Nsukka and Port-Harcourt is 355, 362, 303, 391, 375, 361 and 399 N-units respectively. Also the average value of Field Strength Variability (FSV) is 30.38, 20.16, 21.39, 24.21, 24.31, 21.49, and 21.48 dB in the respective locations and that the FSV values were high during the dry season months and low during the wet season months. This may be attributed to the prevalence of high temperature during dry season and low temperature during the wet season.

Keywords: Microwave, Radio refractivity, Radio field strength, Troposphere, Telecommunication

1. Introduction

Communication is the process of conveying information through the exchange of thoughts, messages, speech, visuals, signals, writing, or behaviour. It is the meaningful exchange of information between a source and a receiver. Basically, a message is sent from the source through a medium to the receiver. Radio wave propagation is the sending out of electromagnetic energy from a transmitter to a receiver and it is affected by the rate of change of the radio refractivity, N with altitude in the troposphere [1, 2]. The propagation environment is the geographical area over which the wave spreads between a transmitter and a receiver. However, how far a radio signal will travel within the radio horizon is determined by the distribution of the radio refractivity. Mobile communication systems employ the microwave frequency bands because of its broad bandwidth [2, 3]. In radio frequency telecommunications, field strength is the magnitude of the received electromagnetic field which will excite a receiving antenna and thereby induce a voltage at a specific frequency in order to provide an input signal to a radio receiver. In designing a wireless communication system, the spatial and diurnal variation of radio refractive index is important [4]. In wireless network planning and optimization, radio wave propagation prediction modelling is an important tool [5]. Field strength meters are used for such applications as cellular, broadcasting, Wi-Fi and a wide variety of other radio related applications. Several researchers have studied **e**lectromagnetic wave (EMW) medium interaction processes and the propagation implications over Nigeria, especially the study of variation of radio field strength and radio horizon distance over few stations in Nigeria [2, 6]. This is not enough to generalise the variation of radio field strength and radio horizon distance over Nigeria, due to variation of meteorological parameters in each geographical location. Hence, this work studied the variation of radio field strength over seven locations in Nigeria covering the different climatic conditions. Two-year data of atmospheric variables: temperature, pressure and relative humidity obtained for Abuja, Akure, Jos, Lagos, Markurdi, Nsukka and Port-Harcourt locations were employed. The data were used to compute the surface radio refractivity which was then used to study the diurnal and seasonal, variability of radio field strength over Nigeria.

2. **Vegetation zones in Nigeria**.

Nigeria lies between latitudes $4°N$ and $14°N$ and longitude $3°E$ and $15°E$, covering an area of about 924000 km^2. The climate of Nigeria is broadly equatorial and tropical continental. Movement of t he Inter Tropical Discontinuity (ITD) complemented by aspects of ocean – atmosphere coupling make Nigeria's climate truly tropical with generally high temperature ranging from 24℃ to 27℃ and annual mean temperature of 27℃ in the tropical rainforest down south but higher mean value in the sub-Sahel up north. Tropical maritime air mass (South-Westerlies) and tropical continental air mass (North-Easterlies) constitute the main wind system over the country. While the former fills the troposphere with moisture in the wet season, the latter brings a lot of Harmattan dust from the Sahara during the dry season. The characteristics of vegetation zones of the study locations is shown in table 1.

The northern part of Nigeria experiences a long dry season (October to mid- May) followed by a short rainy season (June –September), during which annual mean is about 50 cm. However, the southern part experiences a long rainy season (March-October) with maximum in June/July with a short dry period of about 2-3 weeks in August and a long dry season from mid- October to Early March. Annual mean along the South-Eastern Atlantic coast is about 400 cm. These rainfall regimes endow Nigeria with two broad vegetation belts that comprise the forest to the south and the savannah to the north [6, 7]. Figure 1 shows the map of Nigeria indicating the locations considered for this study.

Tab. 1: Characteristics of the Vegetation Zones of the Study Locations.

LOCATIONS	LATITUDE ($°N$)	LONGITUDE ($°E$)	ELEVATION (m)	CLIMATE
ABUJA	7.10	9.25	840	Guinea Savannah
AKURE	7.25	5.21	396	Tropical Maritime
JOS	9.88	8.86	1217	Sahel Savannah
LAGOS	6.30	3.20	41	Monsoonal
MAKURDI	7.73	8.53	104	Guinea Savannah
NSUKKA	6.90	7.67	552	Tropical Rain Forest/Savannah
PORT-HARCOURT	4.82	7.05	27	Swampy

Source: [6, 8]

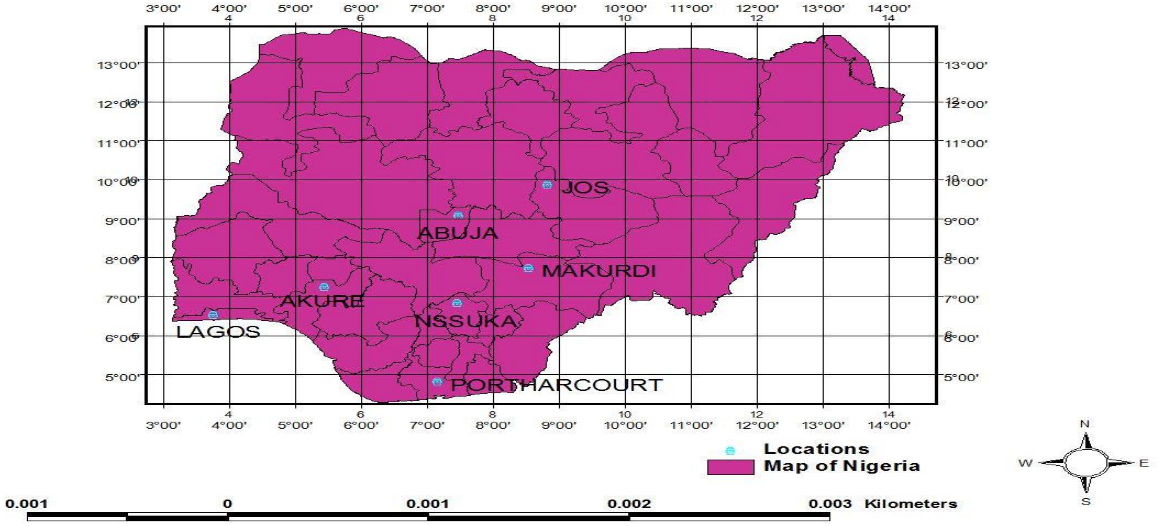

Fig. 1. Digitized map of Nigeria showing the study areas.

3. **Instrumentation**

The instrument used for the measurement of the atmospheric parameters used for this study is the wireless weather station shown in Figure 2, which consists of a solar panel that converts the sun rays into electrical energy, a rain collector that measures the amount of rainfall and a tipping bucket rain gauge that measures the rain rate, sensors that measure temperature, pressure, relative humidity, UV index dose, solar radiation, and an anemometer that measures wind speed and direction. It is calibrated to measure the weather parameters in 5 minutes integration time. The data is stored in the data logger and then copied to a computer for analysis. The components of the Weather Station are shown in Figure 3. The equipment was installed in all the locations considered for this study by the Centre for Atmospheric Research, (CAR) Anyigba, Kogi State. The centre is one of the activity centres of the National Space Research and Development Agency, (NARSDA) in Abuja Nigeria. Tropospheric Data Acquisition Network (TRODAN) is a unit of CAR.

Fig. 2. Tropospheric Data Acquisition Network (TRODAN) set up at a location.

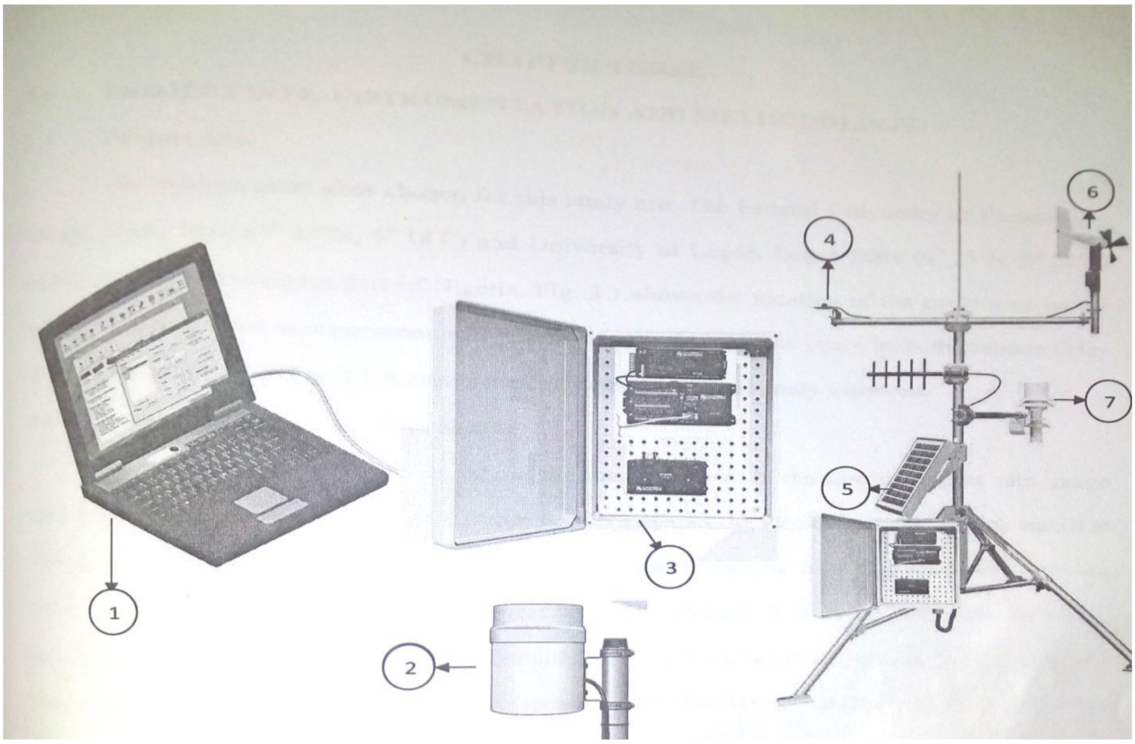

Fig. 3. A typical tropospheric data acquisition system components. Key: (1) Laptop, (2) Tipping bucket rain gauge, (3) CR100 data logger unit, (4) Pyranometer, (5) Solar panel,(6) Wind vane; and (7) Radiation shield.

4. **Theory and Method**

Two-year (2011-2012) meteorological variables (pressure, temperature and relative humidity) were obtained from the archived data of Akure (7.15^{o}N, 5.12^{o}E), Lagos (6.30^{o}N, 3.20^{o}E), Abuja (7.10^{o}N, 9.25^{o}E), Jos (9.50^{o}N, 8.50^{o}E), Makurdi (7.30^{o}N, 8.53^{o}E), Port-Harcourt (4.20^{o}N, 7.00^{o}E), Nsukka (6.90^{o}N, 7.67^{o}E). Each of the locations is equipped with complete wireless weather equipment as provided by Tropospheric Data Acquisition Network (TRODAN). The radio refractivity, N is related to radio refr active index and from the data collected, radio refractivity and field strength are computed [9,10,] as;

$$N = (n-1) \times 10^6 = \frac{77.6}{T}(p + \frac{4810 \times e}{T}) \quad (1)$$

where T (K) is the air temperature, P (hPa) is air pressure and e (hPa) is water vapour pressure. Eq. (1) consists of two terms: the dry term and the wet term.

$$N_{dry} = \frac{77.6\, p}{T} \quad (2)$$

$$N_{wet} = \frac{3.73\times10^5}{T^2}e \quad (3)$$

the dry term contributes about 70% to the total value of refractivity while the wet term is mainly responsible for its variability [10, 11].

Surface refractivity correlates highly with radio field strength, especially at the VHF bands. In the frequency range 30–300 MHz, a factor of 0.2 dB change in field strength may be adopted for every unit change in N_s [13, 14]. Using Ns values obtained in a given calendar month, maximum (N_s(max)), and minimum (N_s(min)) values of N_s are determined, from which the monthly range is obtained as;

$$\text{Monthly range} = N_{S(max)} - N_{s(min)} \quad (4)$$

Thus, an assessment of field strength estimation (FSE) in a given location is explored from monthly ranges of N_s using the relation;

$$FSE = N_{S(max)} - N_{s(min)} \times 0.2\ dB. \quad (5)$$

5. **Results**

5.1 **Diurnal Variation of Surface Refractivity of a typical day over the Stations**

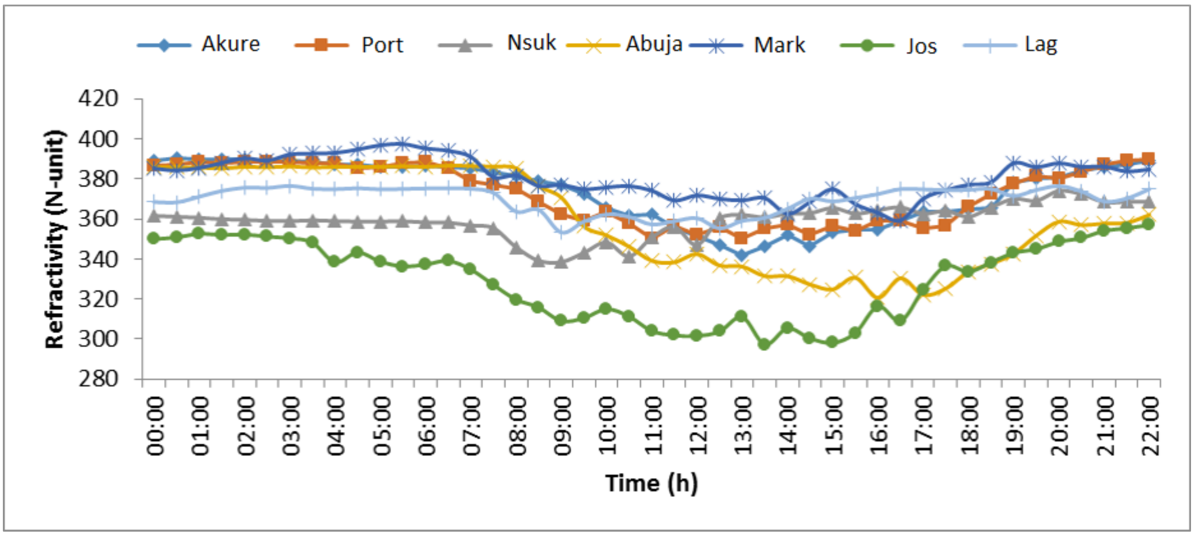

Fig. 4. Diurnal variation of surface refractivity for a typical day (1st June) in wet season over all the stations for the year 2011

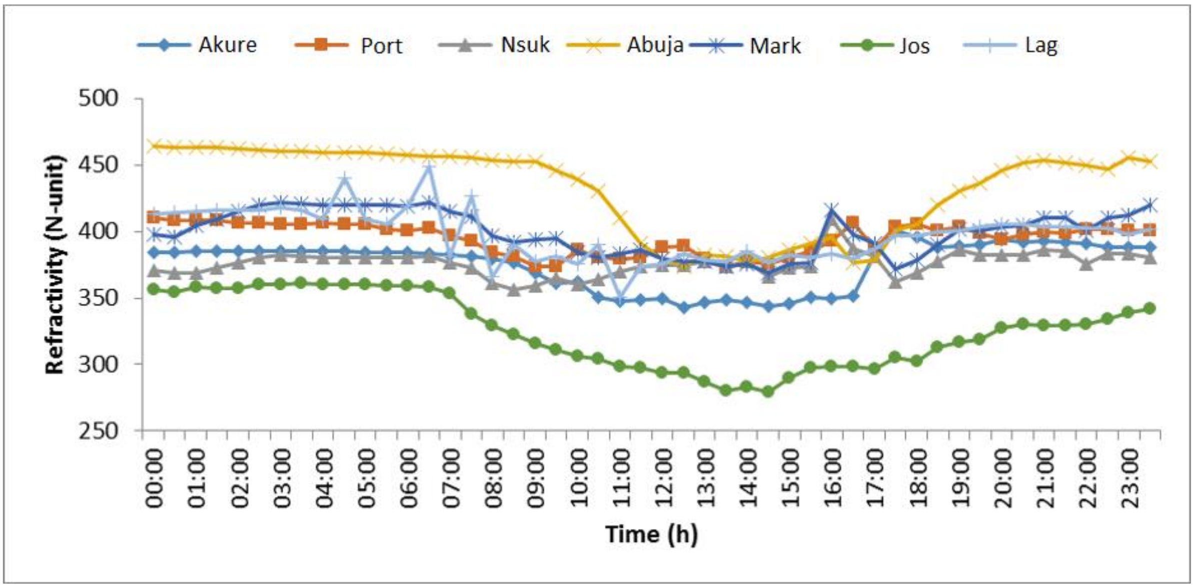

Fig. 5. Diurnal variation of surface refractivity for a typical day (1st June) in wet season over all the stations for the year 2012.

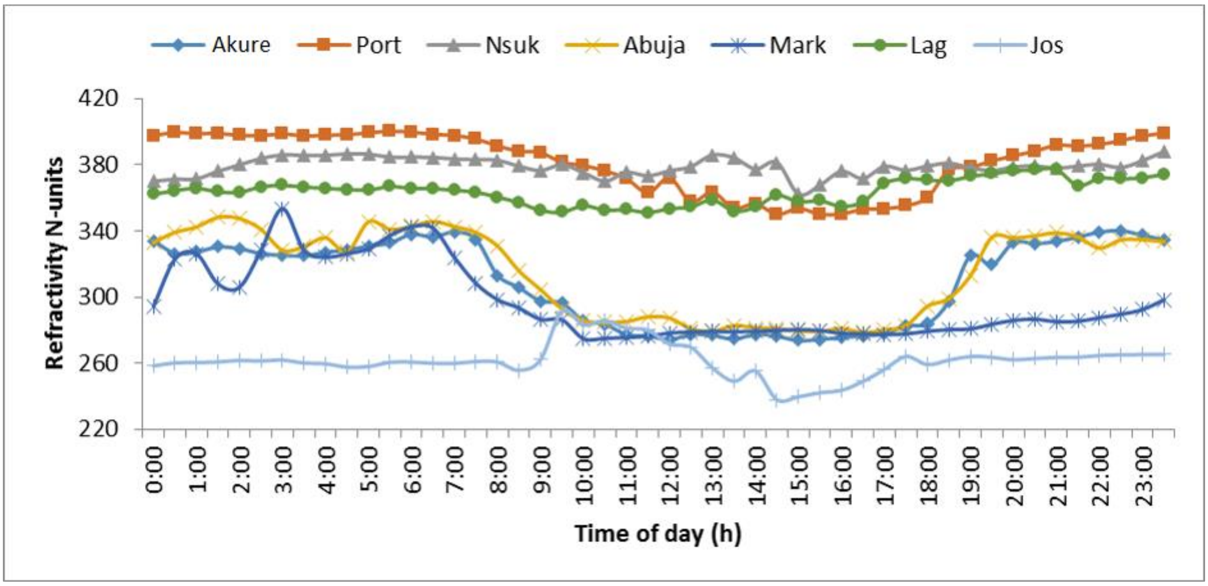

Fig. 6. Diurnal variation of surface refractivity for a typical day (1st January) in dry season over all the stations for the year 2011.

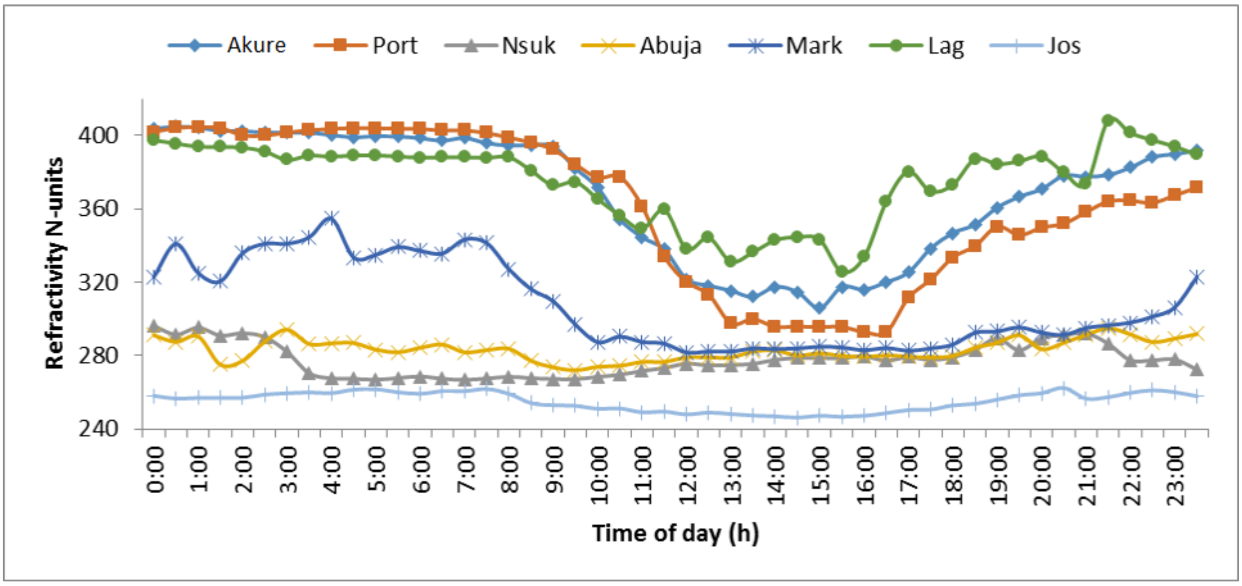

Fig.7. Diurnal variation of surface refractivity for a typical day (1st January) in dry season over all the stations for the year 2012.

5.2 **Seasonal Variation of Surface Refractivity over the Stations**.

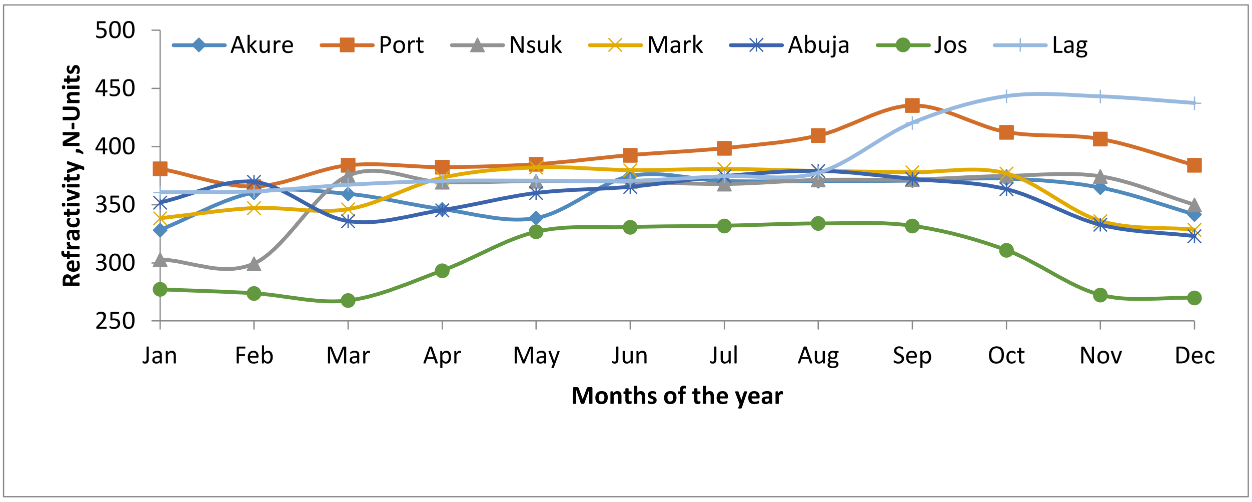

Fig. 8. Seasonal variation of surface refractivity over the stations for year 2011.

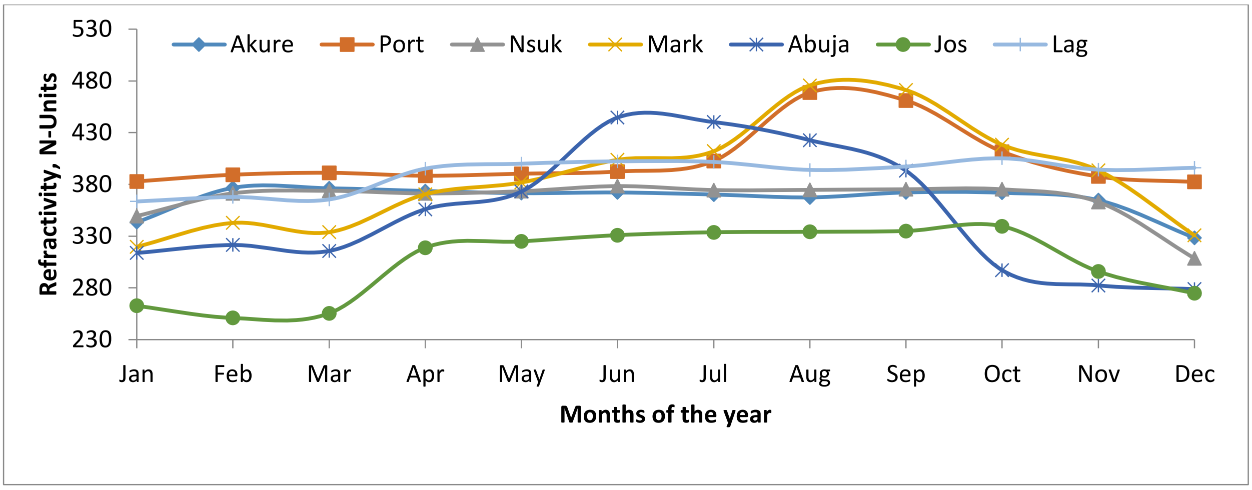

Fig. 9. Seasonal variation of surface refractivity over the stations for year 2012.

5.3 Seasonal Variation of Radio Field Strength over the Stations

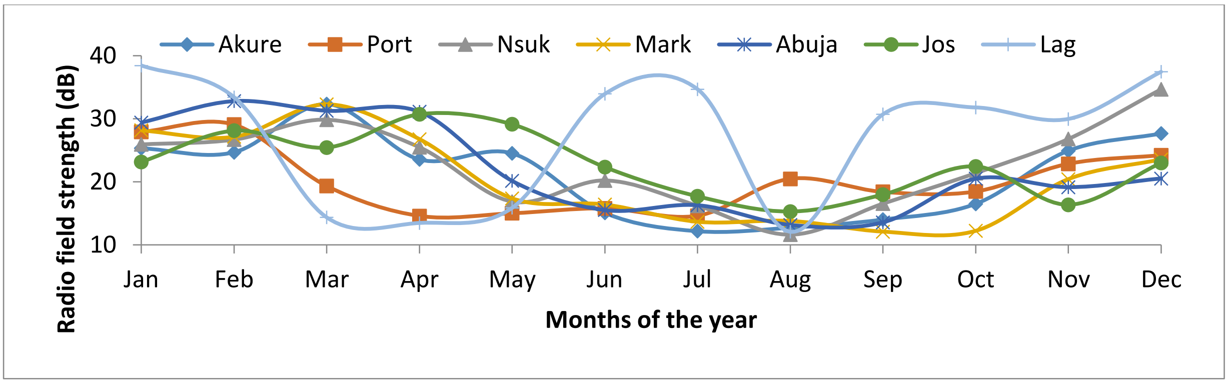

Fig. 10. Seasonal variation of radio field strength over the stations for the 2011.

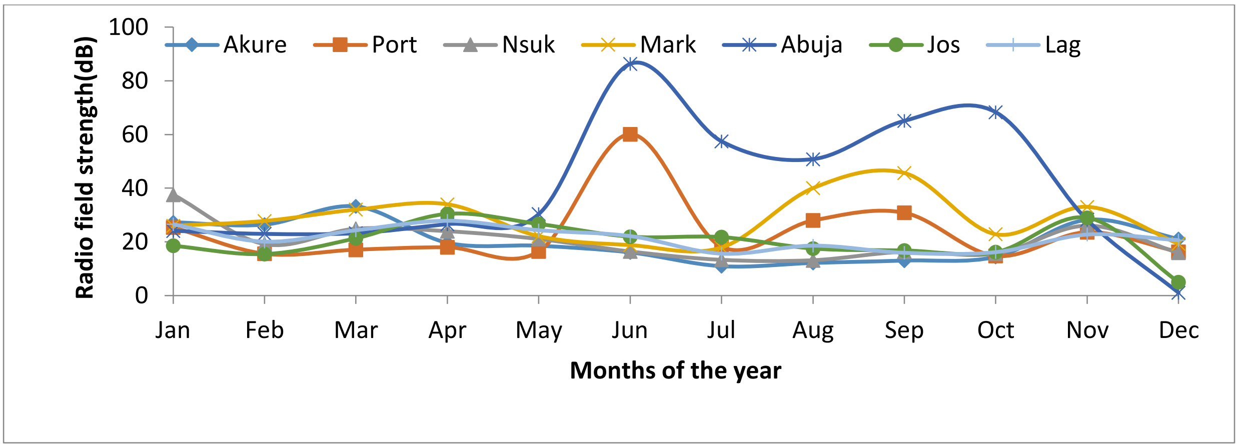

Fig. 11. Seasonal variation of radio field strength over the stations for the 2012.

5.4 Annual variation of surface refractivity.

Stations	N_s (N-units) 2011	N_s (N-units) 2012	Mean N_s (N-units)
Akure	358.157	365.719	361.938
Port-Harcourt	394.747	404.061	399.404
Nsuka	358.090	365.752	361.921
Makurdi	362.177	387.824	375.001
Abuja	353.127	356.263	354.695
Jos	301.722	304.736	303.229
Lagos	390.480	391.244	390.862

Tab. 2. Annual variation of surface refractivity**.**

5.5. Annual variation of field strength variability

Stations	FSV (dB) 2011	FSV (dB) 2012	Mean FSV (dB)
Akure	21.125	20.088	20.606
Port-Harcourt	20.069	23.688	21.879
Nsuka	22.691	20.288	21.489
Makurdi	20.330	28.290	24.310
Abuja	21.959	40.386	31.172
Jos	22.641	20.054	21.347
Lagos	27.187	21.244	24.216

Tab. 3. Annual variation of field strength variability

6. Discussion

6.1 Diurnal Variation of Surface Refractivity for a typical day over all the stations

The diurnal variation of surface refractivity over the stations is depicted in Figures 4-7. It shows the average hourly time mean from 0:00 h. local time to 23:00 h. local time at the surface level for both the dry and the wet season months of years 2011-2012. As shown in Figure 4, the surface refractivity has a high value of 400 N-units to 323 N- units during the early hours of the day (0.00-7:00 h. local time) and in the night hours (19:00-23:00 h. local time) and starts reducing at 7:00 h. local time and reaches a minimum value of about 282 N-units around 12:00 hr. local time in Jos. In Abuja, the surface refractivity shows a high value of about 369 N-units to 374 N- units during the early hours (0:00 -7:00 h. local time) of the day and late in the night (19:00-23:00 h. local time) and starts reducing at 7:00 hr. local time and also increases a little at 12:00 h. local time to about 338 N- units and drops again to a minimum value of 322 N- units at 13:00 h. local time. Furthermore, in Nsuka surface refractivity shows a high value of 356 N- units to 362 N- units during the early hours of the day (0:00-7:00 h local time) and late in the night (19:00-23:00 hr. local time) and starts dropping at 7:30 hr. local time and reaches a minimum of about 331 N-units at around 15:30 h. local time. Moreover, in Markurdi a high value surface Refractivity of about 389 N- units to 373 N-units is shown during the early hour of the day (0:00-6:00 h. local time) and late in the night (19:00-23:00 h. local time) and starts reducing at 6:30 h. local time and reaches a minimum value of 340 N-units at 15:30 h. local time. In Akure, the surface refractivity value is 374 N-units at the early hours of the day (0:00-6:00 hr. local time) and increases to 375 N-units at 7:00 hr. local time and starts dropping at 7:30 hr. of local time and reaches a minimum value of 330 N-units at 15:30 hr. of local time. It also shows that in Port-Harcourt, the surface refractivity value increases from 405 N units in the early hour of the day (0:00 h. local time) to 410 N-units at 7:00 h. local time and starts dropping at 7:30 h. local time and reaches a minimum value of 377 N-units at 12:30 h. local time. In Lagos, the surface refractivity value at the early hours of the day (0:00 h. local time) is 390 N-units and 391 N-units at 6:30 h. local time and starts reducing to a minimum value of 361 N-units at 14:30 h. local time, Also the diurnal variation of surface refractivity shows the same trend in year 2012. Refractivity values are generally high in the early and late hours of the day; the values starts to drop at about 7:30 h. The minimum value is observed around 15:30 h. local time after which the values rise till the end of the day except in Nsukka in year 2011 where there is change in the trend of the curve and this is attributed to the influence of the local meteorology on the area. This variation can be attributed to the response of the earth solar insolation which is the major forcing behind the weather condition observed. The results compare favourably well with the work of [15] where they observed in Nigeria that the diurnal surface refractivity is a function of local meteorology.

It was shown that the diurnal variation of surface refractivity for a typical day in years 2011-2012 varied with high values of surface refractivity in the early hours in the morning and late night and very low between 11:00 LT-16:30 LT for both the dry and wet season. For 1st June (wet season) of the both years, it recorded very high values surface refractivity due to high humidity and low temperature in the troposphere while 1st January dry (dry season) of both years showed the same trend of curve with the wet season but recorded low values of surface refractivity due to high temperature and low humidity in the troposphere.

6.2 **Seasonal Variation of Surface Refractivity over the Stations**

Figures 8 and 9 showed the seasonal variation of refractivity for the study areas over the periods of two years (2011-2012) considered for this study. It is observed from that the result agreed with the works of [14, 15, 16, 17]. There is seasonal variation of surface refractivity at all the stations studied, an increase in the value of refractivity from minimum value of about 250.9 N-units at Jos station to maximum value of about 469 N- units in Port-Harcourt. This result compare favourably well with the works of **[9, 15],** where they obtained 270 N-units as a minimum value of surface refractivity in Sokoto and 390 N-units as the maximum value in Lagos. It can also be seen that in 2011, Lagos has the maximum value of refractivity of 436 N- units in December which is expected to be low. This is due to the influence of the Atlantic Ocean on the station and also high humidity and water vapour. Jos has the minimum value of refractivity 269 N-units in December. In 2012, Port-Harcourt has the maximum value of refractivity of 468 N-units in August. The mean value of surface refractivity for the stations, Akure, Lagos, Abuja, Markurdi, Port-Harcourt, Jos and Nsukka for the two years are 361.86 N-units, 390.87 N-units, 354.74 N-units, 371.41 N-units, 396.91 N-units, 323.76 N-units and 360.35 N-units. The result of Akure station compares favourably well with the works of [18, 19] where they obtained mean value of surface refractivity for five years to be 364.74 N- units and 369 N-units respectively. Similarly, [20] obtained a mean value of surface refractivity of 365 N-units and 367 N-units for years 2007 and 2008 respectively over Akure. It is seen form the results of the mean value of surface refractivity that Jos has a very low value of refractivity. This may be due to the altitude which is $\sim$1217 m above sea level. At this altitude pressure variation seems insignificant. It is also shown from Figures 4 and 5 that the value of refractivity depicted seasonal variation with high value during the rainy season and low value during the dry season. It is also shown that the surface refractivity has high value at the coastal areas compared with the inland areas. This is due to the influence of the Atlantic Ocean on the coastal areas. This result supports the work of [22]. This result is in agreement with the result obtained by [21] which was produced as world atlas for refractivity variation.

6.3 Seasonal Variation of Radio Field Strength over the Stations

The seasonal variation of radio field strength over the stations for the two years (2011-2012) is shown in Figures 10 and 11 respectively. As shown in Figure 10, it is observed that radio field strength for Lagos and Port-Harcourt are out of phase with that of Akure, Abuja, Nsukka, Markurdi and Jos in March. Lagos is also out of phase with Markurdi, Port-Harcourt and Akure in October. It is also seen that the radio field strength is high during the dry season months from November to March and low during the wet season months from March to October, except for Lagos that showed a very high value of 33.93 dB in June and 34.69 dB in July. This may be attributed to the influence of the local meteorology on the area which is due to the response of the earth solar insolation which is the major forcing behind the weather condition observed. In Figure 11, it is seen that the radio field strength shows an irregular oscillations where it is high in January and dropped slightly in December. Abuja has a high value of 86.33 dB in June and Port-Harcourt shows a high value of 60.11 dB in June. The annual mean of radio field strength in Abuja, Akure, Jos, Lagos, Markurdi, Nsukka and port-Harcourt is 30.28, 20.61, 21.39, 24.21, 24.31, 21.49 and 21.48 dB respectively. The difference in radio field strength variation between Northern and Southern Nigeria is affected by other factors such as scattering by dust plumes, which will affect the Northern part mostly in the dry season. From the observed field strength variability in Abuja, Lagos, Jos, Markurdi, Akure, Port-Harcourt and Nsukka, the output of a receiving antenna in all the locations may generally be subjected to variations of not less than 15.53, 12.09, 15.30, 12.11, 12.17, 14.59 and 11.62 dB respectively in 2011, but can be as high as 38.45, 30.72 and 34.67 dB in January, April and December over Lagos, Jos and Nsukka respectively. In Akure and Markurdi, the corresponding values in March are 32.32 and 32.29 dB while in Abuja and Port-Harcourt, are 32.80 and 29.06 dB in February. In Figure 11, the radio field strength variability of an output of a receiving antenna in Akure, Abuja, Lagos, Jos, Markurdi, Port-Harcourt and Nsukka is not less than 10.94, 1.05, 15.60, 5.01, 17.90, 14.78, and 13.15 dB and can be as high as 33.22 dB in March over Akure, 30.43 dB in April over Jos, 45.66 dB in September over Markurdi, 37.61 and 27.85 dB over Lagos and Nsukka in January and 60.11 and 86.33 dB over Port-Harcourt and Abuja. The annual variations of a receiver output in Akure, Abuja, Lagos, Jos, Markurdi, Port-Harcourt and Nsukka in June is 16.47, 86.33, 22.15, 21.94, 18.80, 60.11 and 16.41 dB respectively. Thus, identical systems in Akure, Abuja, Lagos, Jos, Markurdi, Port-Harcourt and Nsukka have outputs differing by as much as 5.53, 85.28, 6.55, 16.93, 0.90, 45.33 and 3.26 dB respectively in June. The knowledge of this radio field strength trends will enhance good assessment of field performance to ensure increased reliability of existing or planned terrestrial radio link over Nigeria.

6.4 Annual Variation of Surface Refractivity N_s and Radio Field Strength over all the Stations for years 2011-2012.

The average values of N_s and radio field strength over the stations for the two years (2011-2012) are shown in table 2 and 3 respectively. It is observed from the table that in year 2011, the average N_s values over the stations, Akure, Abuja, Port-harcourt, Nsuka, Makurdi, Jos and Lagos are 358.157, 353.127, 394.747, 358.090, 362.177, 301.722 and 390.480 N-units respectively and in year 2012, the average N_s values over the stations, Akure, Abuja, Port-harcourt, Nsuka, Makurdi, Jos and Lagos are 365.719, 356.263, 404.061, 365.758, 387.824, 304.736 and 391.244 N_s-units respectively. It is also observed that the average values of N_s were higher in year 2012 than year 2011. This may be attributed to high humidity in the troposphere in year 2012 than year 2011. It is shown that Port-Harcourt and Lagos have the highest average values of N_s of 399.404 N-units and 390.864 N-units respectively while Jos has the lowest average value of N_s of 303.229 N-units. The field strength variability showed that Abuja has the highest average value of 31.172 dB and Akure has the least value of 20.606 dB. The differential field strength variation between the Northern (Abuja) and Southern (Akure) Nigeria is affected by other factors like scattering by dust which will affect the Northern part mostly during dry season.

7. Conclusions

Two-year (Jan. 2011-Dec. 2012) archived data of atmospheric variables: temperature, pressure and relative humidity obtained for Abuja, Akure, Jos, Lagos, Markurdi, Nsukka and Port-Harcourt locations were employed in this study. The data were used to compute the surface radio refractivity which was then used to study the diurnal and seasonal, variability of radio field strength. However, the main findings in the study are as follows: The surface refractivity were high at the early hours of day and very low between the hours of 12:00 LT and 16:00 LT and also high at late night in all the locations for this study. Surface refractivity value over Nigeria increases from about 250.9 N-units in the Northern part to about 469 N-units in the Southern part. Seasonal surface refractivity shows a seasonal variation with high values in the wet season months and low values in the dry season months over Nigeria. The mean surface refractivity value was highest in Port-Harcourt with 404 N-units and lowest in Jos with 302 N- units. The difference in the values of the surface refractivity over Nigeria is attributed to the meteorological influence of the semi- permanent climatological features, such as ITD, Sub-Tropical High Pressure (STHP) and associated monsoonal flow pattern. The FSV values were low during the wet season months and high during the dry season months over Nigeria except in Abuja, Lagos and Port-Harcourt.

7.1 **Acknowledgements**

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