

Study of Seasonal Surface Refractivity over North-Central Nigeria

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Abstract

Tropospheric radio wave signals experience loss due to multipath effect, scattering and other forms of attenuation through the atmospheric medium, primarily due to variations in weather conditions with time. The knowledge of surface refractivity profile is important for optimal planning of Very High Frequency/Ultra High Frequency (VHF/UHF) terrestrial radio links in a region. The study of surface refractivity (N_s) over the North-Central Nigeria was carried out using meteorological data from seven locations in North-Central zone of Nigeria. The seasonal variations of N_s were also derived using the monthly summaries of surface data obtained from Nigerian Meteorological Agency (NIMET) over seven stations of Abuja, Lafia, Lokoja, Makurdi, Jos, Minna and Ilorin between 2005 and 2010. The results indicated that the monthly averages of radio refractivity during the rainy season months (April to October) are greater than the N_s values during the dry season months (November to March) for all the locations throughout the years of the study. The computed of mean monthly N_s over all the seven stations in the first 1 km above the ground level is 348 N-units, which gives mean refractivity gradient (dN/dh) of -49 N/k, these shows that the region is characterised by low scale super-refraction. The mean k-factor over the entire region in the first 1 km above the ground level is 1.4; the mean Field Strength Variability (FSV) in first 1 km of height in the region was calculated to be 14 dB. The mean Radio Horizon distance within 1 km height for a transmitter height of 100 m over the stations is 42 km. The results provide useful information needed by radio engineers to set up new terrestrial radio propagation links or to improve on the existing ones especially at VHF, UHF in the North-Central region of Nigeria, as recommended by International Telecommunication Union Recommendations (ITU-R P.453, 2013), which observed the need for local reference data on refractivity and refractivity gradients all over the world.

Keywords: Temperature; Barometric Pressure; Relative humidity and Tropospheric surface refractivity

I. INTRODUCTION

Radio communications use electromagnetic waves propagation through the earth's atmosphere to send information over long distances without the use of wires [1]. Tropospheric radio signal transmissions at frequencies above 30 MHz are prone to the effect of fluctuations of weather and climate, because of water vapour molecules with their permanent electric dipoles account for the atmosphere having a complex dielectric constant and a complex refractive index [2]. The molecules are largely subjected to varying temporally and spatially, and consequently refract as well as absorb the radio waves; and this leads to variability and attenuation of signals [3]. Radio propagation parameters are dependent on radio refractivity, which in itself is a function of the weather [4]. The effect of meteorological variables of pressure, temperature and relative humidity on radio wave propagation at UHF and microwave frequencies has been analysed from the study of radio refractive index derived from these three parameters [5]. When designing radio communication systems operating in these frequency bands, radio engineers normally use long-term data of atmospheric refractive index and its derivatives, based on statistical analysis in order to be able to predict the systems performance at such frequency bands [6]. An important derivative of the refractive index used in studying the effects of the troposphere on radio propagation is vertical refractivity gradient [7]. The variations in the vertical profile of the refractive index and its gradients are responsible for the change in the trajectory of radio rays in the troposphere [8]. The study of radio refractivity has aroused considerable interest primarily because of its influence on radio wave communication in the lower atmosphere. In particular, the manner in which the refractive index changes with height has much consequence for radio wave propagation at frequencies greater than 30 MHz, although these effects become significant at frequencies greater than about 100 MHz in the lower atmosphere [9]. Hence, the refractive index, 'n' of the troposphere is of major concern in the propagation of radio waves at these frequencies. The value of refractive index n at the earth's surface is slightly greater than unity and gradually decreases towards unity with increase in altitude [10]. At the earth's surface, radio refractive index is usually between 1.00025 and 1.00035 [11]. This study presents an easy method for calculating radio refractivity and enhances understanding of the concept of signal variations between the dry and rainy seasons in the North-central region of Nigeria.

II. METHODOLOGY

A. Source of Data

The monthly summary of surface Temperature, Pressure and Humidity for the seven stations (Abuja, Lafia, Lokoja, Makurdi, Jos, Minna and Ilorin), were obtained from Nigeria Meteorological Agency (NIMET). NIMET has observatory stations (synoptic stations) across the country (at least one in

each of the 36 states and the Federal Capital Territory, Abuja). These stations are called Data Points and recognised by the World Meteorological Organisation (WMO). The observatory stations or data points that are WMO certified in the North Central Region are: Abuja, Minna (Niger State), Ilorin (Kwara State), Lokoja (Kogi State), Lafia (Nasarawa State), Jos (Plateau State) and Makurdi (Benue State). These weather stations are manned by professional weather observers (WMO Certified). The observatories or data Points have all the weather measuring instruments ranging from rain gauge for measuring rain, thermometers for measuring temperature, barometers for measuring atmospheric pressure and hygrometers for measuring relative humidity. NIMET weather data were observed and recorded within some selected times intervals i.e. half hourly, hourly and daily throughout the year. The data from the stations was collected by NIMET throughout the country. The data used in this study were collected from the stations listed above, for a period of six (6) years from 2005 to 2010. Fig. 1 presents the map of the study area.

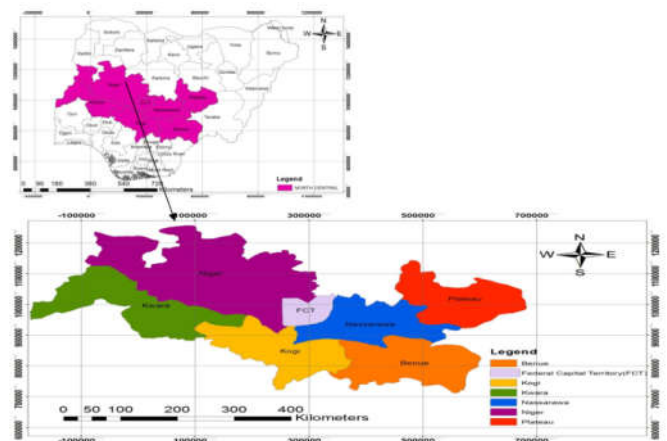


Fig. 1 The Cities of North-Central region of Nigeria

B. Computation of Radio Refractivity (N)

Radio refractivity (N) is evaluated using the relation defined by [12]:

$$N = (n - 1) \times 10^6 \quad (1)$$

Where 'n' is the refractive index of air

For instance, when $n = 1.000350$, then we have $N = 350$. N is strictly the refractivity, but sometimes wrongly referred to as refractive index. For frequencies up to about 30 GHz, the radio refractivity of clear air is given by the formula proposed by [13], which is given in equation (2).

$$N = \frac{77.6}{T} (P + \frac{4810e}{T}) \quad (2)$$

Where P is the atmospheric pressure in millibars (mb), e is the water vapour pressure in mb and T is the absolute temperature in Kelvin. Equation (2) may be split into two and rewritten as:

$$N = \frac{77.6}{T} P + \frac{3.73 \times 10^5 e}{T^2} \quad (3)$$

The first and second parts of equation (3) are represent the dry (N_{dry}) and wet (N_{wet}) components of refractivity, respectively. The dry term contributes about 70 % to the total value of N and the wet term is responsible for a major part of the variation in N at a given location of the atmosphere. At very low temperatures, N_{wet} reduces to a very small value even for saturated air and this makes refractivity, N almost independent of relative humidity. An increase in temperature will force N_{dry} to decrease but at the same time causes a rapid increase in the saturated value $N_{wet.max}$. At high temperatures, value of $N_{wet.max}$ may become larger than N_{dry} , so that N will vary with relative humidity. When both temperature and relative humidity are high, N becomes very sensitive to small changes in temperature and relative humidity. Consequently, the variability of water vapour content in the atmosphere (and hence the refractivity) in tropical areas is far greater than that of cold climate [12]. The atmospheric radio refractivity is an important factor in the propagation of radio waves at very high frequency (VHF) and higher frequency band, as the path and general characteristics of the signals are very much tied to the refractive conditions of the troposphere [14].

The refractivity, N (which is actually the refractive index in excess of unity in part per million) is as given in (1) to (3).

The vapour pressure, e is estimated by [12].

$$e = \frac{(R.H \times e_s)}{100} \quad (4)$$

Where R.H is relative humidity (%) and e_s is the saturated vapour pressure (mb).

e_s is calculated as proposed by [12] :

$$e_s = 6.11 \exp[(19.7t)/(t+273)] \quad (5)$$

Where t is the air temperature in °C.

C. Computation of reduced-to-sea-level refractivity (N_o) in North-Central part of Nigeria and its environs

The null refractivity (N_o) can be computed using the relation in (6) as proposed by [13]:

$$N_o = N_s \exp\left(\frac{h_s}{h_o}\right) \quad (6)$$

Where N_o is the average value of atmospheric refractivity extrapolated to sea level, N_s is the surface refractivity calculated using (3) above, h_o is the scale height in (km) and h_s is the height of the earth's surface above the sea level (km) potential."

D. Computation of Gradient (dN/dh) and k-factor

The Gradient (dN/dh) and k-factor can be computed via (7), as reported by [15]:

$$N = N_s e^{(-h/H)} \quad (7)$$

Where h is the height above the surface, and is taken to be 1 km for surface refractivity calculations. H is the scale height; H is 7 km, as obtained for tropical conditions [16]. However, N_s is the calculated surface refractivity from (3), but,

(dN/dh) is expressed as:

$$\frac{dn}{dh} = \left(\frac{dN}{dh}\right) 10^{-6} \quad (8)$$

Therefore, the equation for obtaining the gradient (dN/dh) parameter is further expressed as:

$$\left(\frac{dN}{dh}\right) = \left(\frac{-N_s}{H}\right) e^{(-h/H)} \quad (9)$$

Meanwhile, the k-factor was given by [16]:

$$k = \frac{1}{(1+a\left(\frac{dN}{dh}\right)10^{-6})} \quad (10)$$

Where k is the k-factor, a , is the earth radius, and the term (dN/dh) is the gradient given in (9).

E. Field Strength Variation (FSV)

Using (11) as established by [17], the Field Strength Variation is defined as

$$FSV = (N_{Smax} - N_{Smin}) \times 0.2 \text{ dB} \quad (11)$$

Where N_{Smax} and N_{Smin} are the maximum and minimum values of surface refractivity respectively.

F. Radio Horizon Distance (d_{RH}) Calculation

The radio horizon distance (d_{RH}) can be obtained via (12), as reported by [17]:

$$d_{RH} = \sqrt{2kaha} \quad (12)$$

Where k is the effective earth's radius factor, a is the equivalent earth's radius and h is the transmitter height.

G. N_s Contouring

The confirmation of the calculated N_s variation was achieved using surfer 11 software applications and contouring of the mean yearly N_o for the seven stations in the period 2005-2010 with the station elevations.

III. RESULTS

The results obtained from the data were analysed from year 2005 to 2010 are presented in Fig. 2-16 respectively. Fig. 2-8 shows the graph of variations of Monthly Surface Refractivity over the cities of: Makurdi, Abuja, Ilorin, Minna, Jos, Lokoja and Lafia respectively. Also Fig. 9 shows the graph of mean monthly Surface Refractivity (N_s) over the stations in the North-Central Nigeria. Fig. 10 shows the graph of Mean variation over the stations between Rainy and Dry season months. Fig. 11 shows the graph of yearly Refractivity variation for the years. Fig. 12 shows the graph of mean reduced-to-sea-level refractivity (N_o) for the entire North Central Zone. Fig. 13 shows the 2-D Contouring of mean yearly N_o with elevation for the seven stations. Fig. 14 shows the graph of mean monthly k-factor variations for the seven stations during this period. Fig. 15 shows the graph mean Field Strength Variability (FSV) for the seven stations. Furthermore, Fig. 16 shows the graph of mean yearly field strength variability over the stations. Fig. 17 shows the graph of variation of the Radio Horizon Distance across the seven stations. Fig. 2 shows the N_s variation for the years 2005 to

2010 in Makurdi at the elevation of 0.104 km above mean sea level.

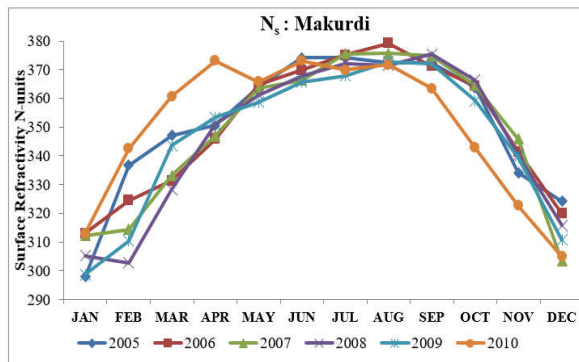


Fig. 2 Variation of Monthly Surface Refractivity over Makurdi (2005-2010)

Fig. 2 shows that generally N_s increased steadily from January to May. This is followed by a gradual increase to the month of October, before a steep decrease to the month of December. The least value of 298 N-units is observed in January, while the highest value of 375 N-units occurred in the month of August, which is a typical rainy season month in the Middle Belt region of Nigeria. Thus, N_s is generally higher during the rainy season months of (April to October). This could be due to high air humidity observed in Makurdi during the period. Hence, in this period, Makurdi could have been under the influence of moisture-laden tropical maritime air, resulting from South to North migration of the inter-tropical discontinuity (ITD) with the Sun. In the month of December, N_s dropped because this is the period when the dry and dust-laden northeasterly winds become dominant and the dry harmattan sets in, hence the low N_s values observed in January and February. On the other hand, between the months of April and October, the whole city would have been subjected to widespread rainfall, which leads to increase in moisture in the atmosphere, that results to increase in humidity, hence N_s is increased. The month of January is the driest month, followed by February; while the months of March and April are transition months between dry and wet seasons, hence the observed N_s seasonal profile. This result is in agreement with the result obtained by [18] and [19]. Fig. 3 shows the variation of mean monthly surface refractivity for Abuja which is at an elevation of 0.339 km above mean sea level, during the period of study.

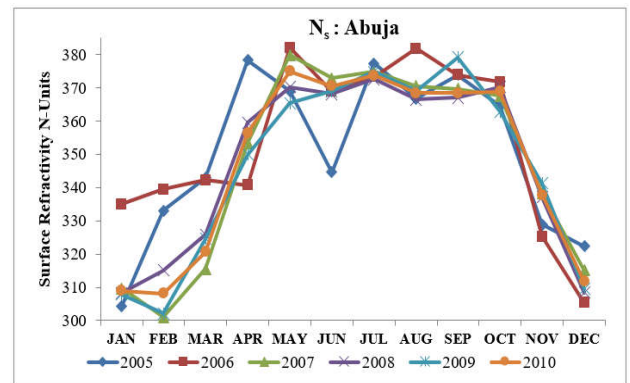


Fig. 3 Variation of Monthly Surface Refractivity over Abuja (2005-2010)

The variations of surface refractivity over Abuja for a period of six years have been analysed and presented as follows. From Fig. 3, the months of January and February have low refractivity values ranging from 304 N-units to about 328 N-units. The months of November and December are also characterised by the similar N_s patterns. The factor responsible for this variability is the wet term factor given by (2). Generally, in the dry season, refractivity values range between 305 and 338 N-units. The data for these months reflect the strong influence of the dry continental air mass prevalent during the dry season due to the North-South migration of ITD; hence, pronounced variation is observed in these months. Low humidity and high temperature values combine to make the moisture content low, and as a result refractivity values are reduced.

Comparing the rainy season months from May to October in the same Fig. 3 with those for the dry season months, relatively uniform refractivity values are observed during the rainy season. The refractivity values are observed to be higher than the values obtained in the dry season. These high values are attributed to the saturation of the atmosphere with large amount of water vapour as evidenced by extensive cloud cover during this period. Refractivity values are found to vary between 362 and 379 N-units; only the month of June 2005 gives a sharp fall in N_s value at 344 N-units. Fig. 4 shows the computed values of mean monthly surface refractivity and the variation for the years 2005-2010 in Ilorin, which is at an elevation of 0.29 km above the mean sea level.

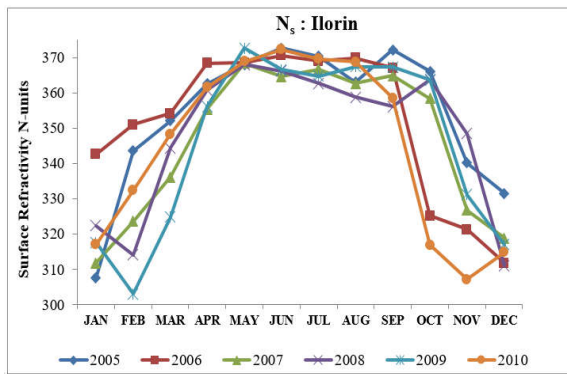


Fig. 4 Variation of Monthly Surface Refractivity over Ilorin (2005-2010)

The same pattern of seasonal variations are observed with the dry season months having the least refractivity values, that is, November, December, January and February. The refractivity values are range between 304 and 348 N-units for dry season months in the stations, while the wet season months, that is, May, June, July, August, September and October, have refractivity values ranging between 356 N-units and 372 N-units. The result shows that the stations are under the same climatic conditions as influenced by the N-S migration of the ITD. Fig. 5 shows the mean monthly N_s variation for the years 2005 - 2010 in Minna, which is at an elevation of 0.299 km above the mean sea level.

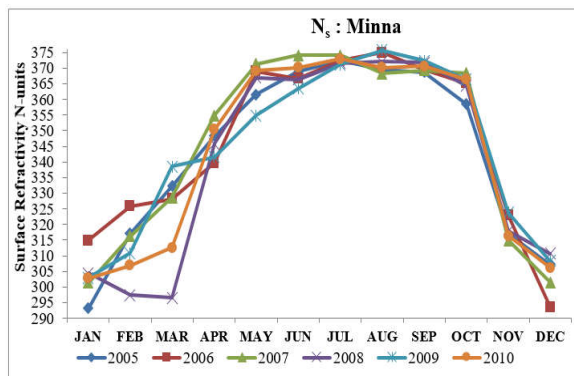


Fig. 5 Variation of Monthly Surface Refractivity over Minna (2005-2010)

Similar seasonal variations of N_s are observed with least N_s values in the dry season months that is, November, December, January and February. The refractivity values range between 293 and 320 N-units during dry season months in the stations, while the wet season months, (May, June, July, August, September and October) have refractivity values ranging between 355 and 376 N-units.

Fig. 6 shows the mean monthly N_s variation for the years 2005 - 2010 in Jos, which is at an elevation of 1.208 km above sea.

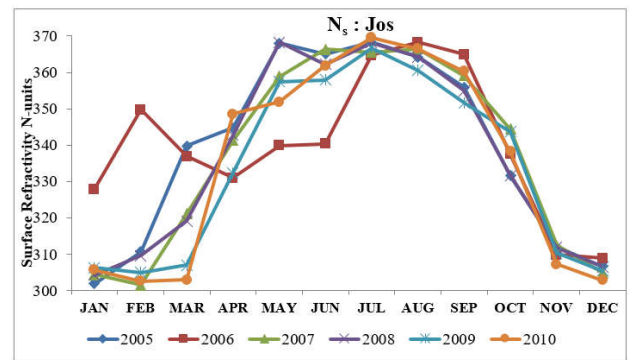


Fig. 6 Variation of Mean Monthly Surface Refractivity over Jos (2005-2010)

Again, similar trend of seasonal variations is observed, with least N_s values in the dry season months (November, December, January and February). The refractivity values range between 302 and 327 N-units. A sharp increase was observed for the month of February 2006 with N_s value of 350 N-units which also one of dry season months. The wet season months that of May, June, July, August, September and October, have refractivity values ranging between 345 and 370 N-units.

Fig. 7 shows the mean monthly N_s variations for the years 2005 - 2010 in Lokoja, which is at an elevation of 0.055 km above the mean sea level.

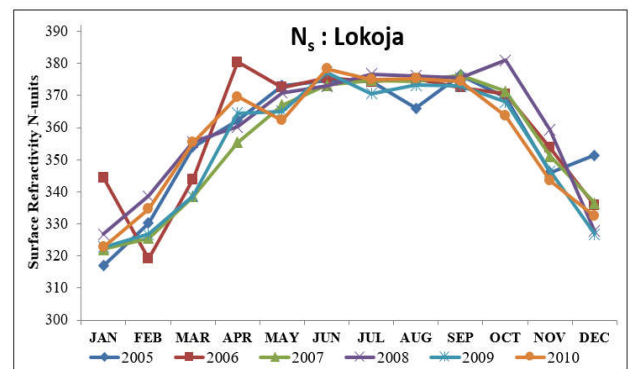


Fig. 7 Variation of Monthly Surface Refractivity over Lokoja (2005-2010)

Again a similar trend of seasonal variation is observed, with least N_s values in the dry season months of November, December, January and February. The refractivity values are in the range between 326 and 350 N-units. The wet season months i.e. May, June, July, August, September and October, have refractivity values ranging between 356 and 382 N-units.

Fig. 8 shows the mean monthly N_s variations for the years 2005 - 2010 in Lafia, which is at an elevation of 0.29 km above mean sea level.

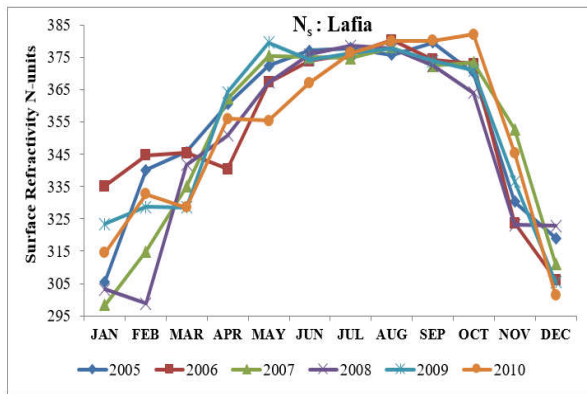


Fig. 8 Variation of Mean Monthly Surface Refractivity over Lafia (2005-2010)

Again a similar trend of seasonal variation is observed, with the dry season months having the least refractivity values that is in November, December, January and February. The refractivity values range between 298 and 345 N-units in all dry season months for the stations. The wet season months that of May, June, July, August, September and October have refractivity values ranging between 360 and 380 N-units. From the results, it is clear that all the stations are under the same climatic conditions influenced by N-S migration of the ITD.

Fig. 9 show the monthly N_s averages for all the seven stations.

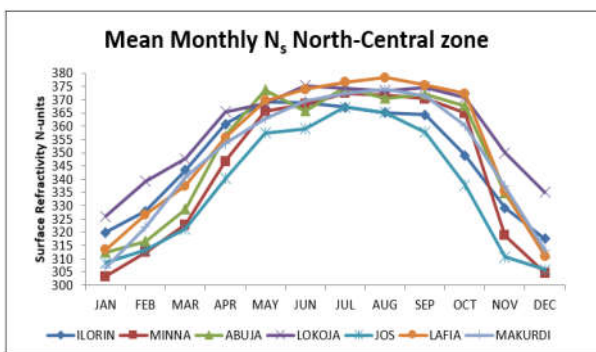


Fig. 9 Mean Monthly Surface Refractivity (N_s) over the North-central Stations for (2005-2010)

Fig. 9 the results show that N_s values are generally higher during the rainy season months of April to October. This could be due to high air humidity observed in the zone during the period. Hence, in this period, the zone could have been under the influence of the moisture-laden tropical maritime air, resulting from the South to North migration of the inter-tropical discontinuity (ITD) with the sun. In the months of November to December, N_s values dropped, because this is the period when the dry and dust-laden north-easterly winds

become dominant and the dry harmattan sets in, which accounts for the low N_s values observed in January and February. On the other hand, between the months of April and October, the whole zone would have been subjected to widespread rainfall, which leads to increased moisture in the atmosphere, that results in increased humidity, hence N_s values increased. The month of January is the driest month, followed by February; while the months of March and April are transition months between dry and wet seasons, hence the observed N_s seasonal profile. It can be said from the result in Fig. 9 that all the seven stations are under the same climatic conditions. The VHF/UHF signal propagation can be said to be better in the wet months in the zone because of high N_s values in those periods and less in the dry months due to decrease in N_s values in those months for all period of the study.

Fig. 10 show the average monthly N_s variations between the rainy and dry season months over the seven stations in the zone in 2005-2010.

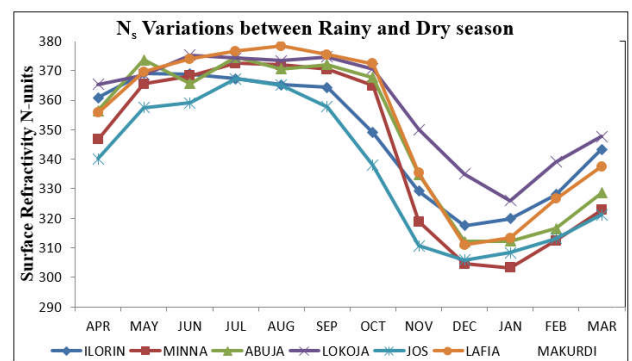


Fig. 10 Mean Monthly variation over the stations between the Rainy and Dry Season months

Fig. 10 shows similarities between all wet season months and dry season months across all the seven stations, it is observed that all the stations have similar pattern, which could be due to the facts that all the seven stations have the same climatic conditions. The result agrees with all the standard works on refractivity because all the rainy season months have the highest N_s values and the dry season months have the least N_s values [20]. The increase in the N_s values in wet season and the decrease in the values of N_s in the dry months are due to the N-S migration of the ITD in the zone. Fig. 10 has shown that VHF/UHF signal propagation would be enhanced in wet season months in the zone, since the higher N_s the better the VHF/UHF propagation efficiency, and the wet months have the highest N_s values while least N_s occur in dry season months in all the seven States. Thus, the wet season months have better VHF/UHF signal propagation potential than the dry season months.

Fig. 11 shows the mean yearly N_s variation for the Seven Stations between 2005 - 2010.

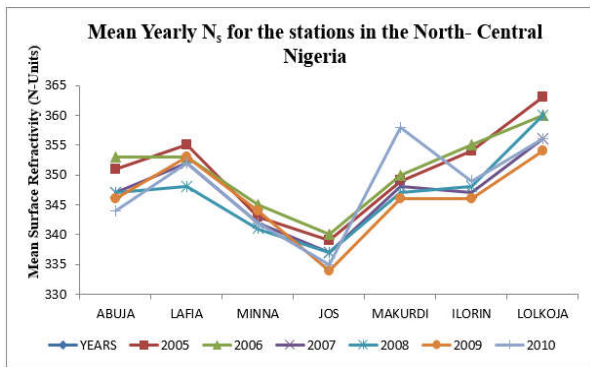


Fig. 11 Mean Yearly Surface Refractivity over the Stations from 2005-2010

Fig. 11 shows the Mean N_s variations within the years of study, which are due to the stations' elevations and variability of the atmospheric parameters. From this result, the least value of refractivity was recorded in each of the years in Jos (with highest elevation), while the highest N_s values were recorded in Lokoja (with lowest elevation).

Fig. 12 shows the variation of mean monthly reduced-to-sea-level refractivity N_0 for the seven stations between 2005-2010.

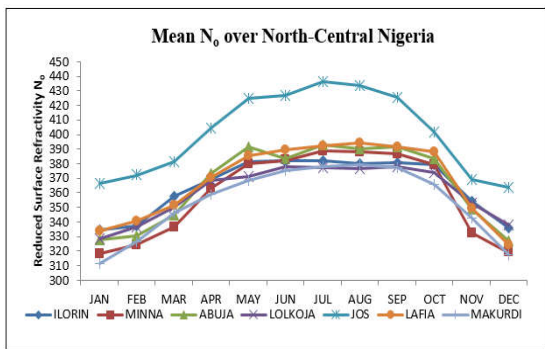


Fig. 12 Mean Monthly Reduced to-sea-level Refractivity N_0 for the seven stations between 2005-2010

From the results obtained the curves are similar to those of surface refractivity except that reduced-to-sea level refractivity has higher values than the Surface Refractivity. The effect of station elevation is also seen between Lokoja and Jos values. Fig. 12 above it is observed that N_0 values are higher at the rainy months than dry months.

Fig. 13 shows the 2-D contour of mean yearly reduced-to-sea-level refractivity for the seven stations between 2005-2010. The N_0 values varies with height above mean sea level as can be from Fig. 12 and 13; Jos has highest of 1.208 km

which give N_0 of 402 N-units which is highest in the zone, while Lokoja has the lowest elevation of 0.055 km respectively, which gives the least N_0 value of 359 N-units, followed by Makurdi with elevation of 0.104 km.

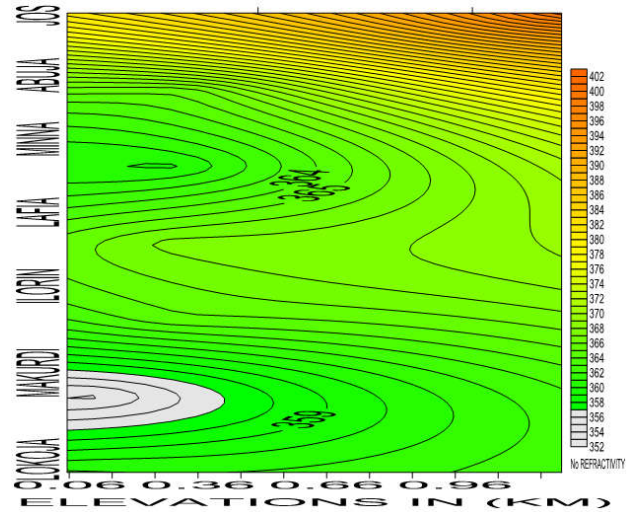


Fig. 13 2-D contour of mean yearly N_0 with elevations for the seven stations 2005-2010

The 2-D contouring shows clearly the effect of height from one station to another in the zone Jos has the highest elevation of 1.208 km above the sea-level and has the highest value of 402 N-units as represented with brown colour on the legend. Lokoja with the least elevation of 0.055 km above the sea level, it has the least N_0 of 352 N-units as represented by white colour on the legend.

Fig. 14: shows the mean monthly k-factor variation for the seven stations for the period 2005 - 2010.

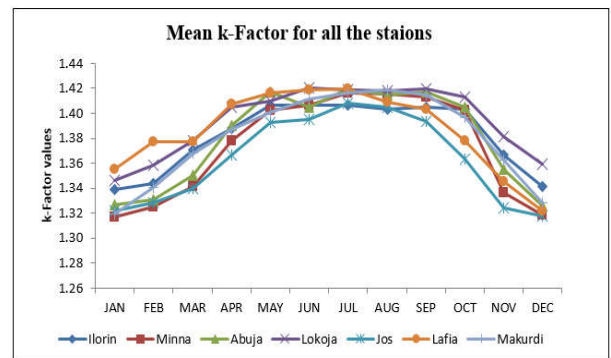


Fig. 14 Mean k-factor for North-Central Zone

Fig. 14 shows that the average k-factor values for the dry and wet months are 1.32 and 1.42 respectively; this result is very important in determining the coverage distance of a VHF/UHF transmitter, as given in (4), which shows a strong relationship between coverage distance and k-factor. The results show the relationship between the N_s and k-factor

values and it can be said that the higher N_s values the higher the k-factor values and that's why dry months with least N_s have low k-factor values, while the rainy season months with higher N_s values have the greater k-factor values. The values are similar across all the seven stations in the zone, which is an indication that the stations are under similar climatic conditions.

Fig. 15 shows the Mean Field Strength Variability for the seven stations for 2005 – 2010.

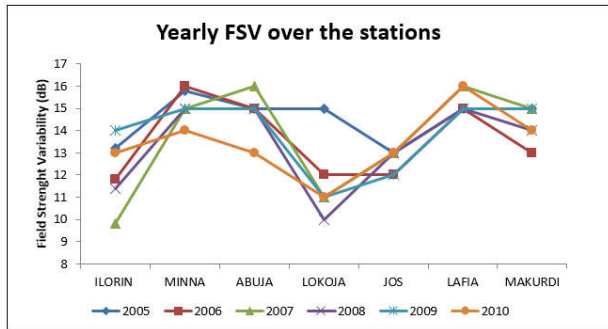


Fig. 15 Yearly Field Strength Variability

Fig. 15 shows that Lokoja, Jos and Ilorin have mean least values FSV of 10, 12 and 11dB while Minna, Lafia, Makurdi and Abuja have the mean highest values of 15, 15, 15 and 16 dB respectively.

Fig. 16 shows the Mean yearly Field Strength Variability for the seven stations in the zone for 2005–2010.

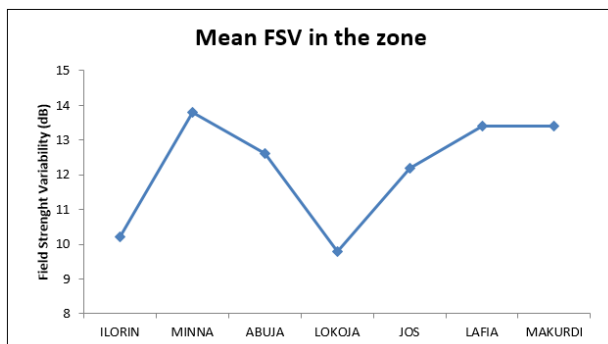


Fig. 16 Mean Yearly Field Strength Variability

Fig. 16: shows that Minna has highest value FSV of 14 dB, while Lokoja has the lowest value FSV of 10 dB over the period of study. The observed diurnal and seasonal N variation causes corresponding field strength variations in the zone, especially at VHF band. The implication of this to VHF/UHF propagation is that the higher N_s in a station the lower the FSV and the better the radio propagation at VHF/UHF bands.

Fig. 17 shows the values of radio horizon distance or the coverage distance of a transmitter of 100 m height in each of the seven stations for 2005 – 2010.

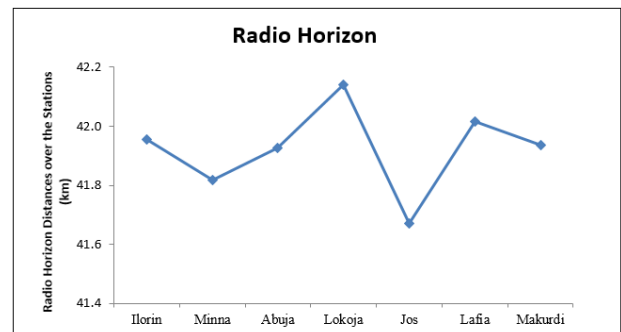


Fig. 17 The Radio Horizon across the seven stations

From the results obtained, all the stations have radio horizon values of between 41.0 and 42.1 km for a 100 m transmitter height, with Ilorin, Lokoja and Lafia having the highest values of 42.0, 42.1 and 42.0 km respectively, while Jos has the least value 41.7 km. This is in agreement with [18]. The implication of this result to a radio engineer is that even when Jos has highest elevation over mean sea level, it has the least coverage value 4.17 km, which implies that the engineers have to increase the transmitter antenna's height in the area before achieving the same radio horizon as other states in the zone. From the result, it can be concluded that Lokoja has highest coverage of 4.21 km, which implies that better radio propagation at VHF/UHF bands are expected in the station. These results are in agreement with [21] and [22].

IV. CONCLUSION

Generally, from the results obtained, the Surface Refractivity values in the North-Central region are between 290 to 390 N-units. N_s values obtained indicates seasonal variation with higher values in the rainy season and lower values in the dry season. The computed mean monthly N_s over all the seven stations in the first 1 km above the ground level is 348N-units, which gives refractivity gradient (dN/dh) of $-49N/km$, these shows that region is averagely characterised by low level Super-refraction. Jos has the highest of N_o (401 N – units), while Lokoja has the least value of N_o (361 N – units). These results conclude that refractivity varies according to height above the mean sea-level from one station to another. The computed mean monthly N_o over all the stations is 368 N – units in the first 1 km of height. The computed mean k-factor over the entire region in the first 1 km is about 1.4. The observed seasonal variations of N cause corresponding field strength variations in the zone, especially at VHF band. From the FSV values obtained, Lokoja and Ilorin have the least values FSV of (10 and 11 dB) while Minna and Abuja have the highest values of (15 and 16 dB) respectively. The mean FSV over the region is 14 dB. The

mean Radio Horizon for a transmitter height of 100 m over the stations is 42 km. The result implies that the higher the refractivity values, the better would be the radio wave propagation. Thus, radio signals are better received in the wet season months than in dry season months. The results provide useful information needed by radio engineers to set up new terrestrial radio propagation links or to improve on the existing ones in the North-Central region of Nigeria. The results obtained from this study will be particularly useful in any planning of communication links in the North-Central region of Nigeria especially at VHF, UHF and microwave frequencies since several studies have shown that there is a very high correlation between signal strength and surface refractivity. The higher refractivity values observed in the rainy season will lead to less energy loss by the signals at the VHF range and above, thereby improving the signal strength received by the receiver. The signal level will be more stable in the wet season than in the dry season owing to higher vapour content in the atmosphere as shown by low field strength variability observed in the period.

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