 

# Analysis of Radio Refractivity Variations Across Geographical Coordinates of Nigeria

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**Abstract**
Radio refractivity variations across geographical coordinates of Nigeria has been studied using relative humidity, air pressure and air temperature data from 2012 to 2013 obtained from archives of Nigeria Air Space Development Research Agency, Department of meteorological Service, Oshodi, Lagos and Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, automated weather station. Using regression analysis technique on the data obtained, a model was developed which established the relation between average annual surface radio refractivity and latitude across geographical coordinates of Nigeria. The results from the model have shown that average annual radio refractivity decreases with increase in latitude across Nigeria from the Tropical wet climate via Savanna North to the Semi-arid climate. The computed values of the refractivity gradient for the period of years under study showed that both Tropical wet and Savanna North climates were super-refractive in the first 1km above the sea surface while the Semi-arid was sub-refractive except Yola which is exceedingly close to the Savanna North.
**Keywords**: Radio refractivity, Geographical coordinate, Regression technique, Model

## 1. Introduction

Many mobile network communication industries rely on the atmosphere particularly the troposphere for easy and secure transmission of radiofrequency signals whereas the earth's weather system is confined to the troposphere where meteorological variables have great effects on the manner in which radio wave propagation occurs during terrestrial communication links (Seybold, 2005). Some of these meteorological parameters such as rain, wind, fog, wet snow, relative humidity, temperature, pressure and water vapor density of the atmosphere, can combine in many ways to affect radio wave propagation (ITU-R, 2001). The combination allow radio waves to propagate beyond the horizon and at times results into attenuation of the signal that it may not even be received over a satisfactory path (Parson 2000).Tropospheric refraction effects of the atmosphere are in different categories namely refraction on horizontal paths resulting in alteration of the radio horizon due to ray curvature, temperature inversion that is, abrupt changes in the refractive index with height causing reflection, and ducting in which the refractive index is such that electromagnetic waves tend to follow the curvature of the earth. (Seybold, 2005). These effects vary widely with altitude, geographic location, and weather conditions and do permit beyond the horizon communication or interference. Variations of temperature, humidity and pressure influence the way in which radio waves propagate from one point to the other in the troposphere particularly at frequency above 30MHz (Hall, H.P.M, 1979). Sometimes abnormal environmental conditions can end up to ducting phenomenon which usually result to the trapping of the UHF radio waves and contribute to the over-the –horizon-propagation (Isaakidis and xenon, 2004).Ajayi 1989, established that the electric dipole moment of oxygen and water vapor present at the troposphere is the cause of the troposphere exhibiting dielectric constant and hence possessing refractive index. The structure of the refractive index of the atmosphere has very great influence on the tropospheric radio wave propagation (Willoughby, 2003).

Since Nigeria as a whole is made up of different climates and has been categorized into different climatic regions based on variations in meteorological variables, hence quantitative analysis of radio refractivity variations across geographical coordinates of Nigeria is essential in order to be able to design reliable and efficient radio communication links budget across Nigeria.

## 2. Source of Data

Data used for this analysis was obtained from three sources. Daily air pressure, relative humidity and air temperature of some town and cities in southwestern region of Nigeria for the period of two years (2012 to 2013) was collected from the department of Meteorological Service, Oshodi, Lagos, Nigeria. The second source of data was obtained from Nigeria Air Space Development Research Agency (NASDRA) Ayingba Centre. The last source of data was obtained from automated weather station located in the Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria. Due to inaccessibility of data of some locations in the country, the few locations data obtained was used for estimation and modeling of radio refractivity for prediction of other locations across the country.

## 3. Data Analysis Procedures

From (ITU-R, 2001) Refractivity is modeled as

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

Where
P is the total Pressure
T is the absolute temperature
e is the water vapor pressure

$$e = \frac{e_s H}{100} \qquad 2$$

Where
H is the relative humidity (%)
$e_s$ is the saturated vapor pressure (hpa)
Equation 1 can be rewritten as (Bean and Dutton 1966)

$$N = 77.6\frac{P}{T} + 3.75 \times 10^5 \frac{e}{T^2} \qquad 3$$

Where $77.6\frac{P}{T}$ is the $N_{dry}$ and $3.75 \times 10^5 \frac{e}{T^2}$ is the $N_{wet}$
The refractive index can be expressed as (Seybold 2005)

$$n = (1 + N \times 10^{-6}) \qquad 4$$

Where N is the refractivity
The refractive index is approximately unity at sea level and drops off nearly exponentially with height.
The refractivity as a function of height can be modeled as (Seybold 2005)

$$N = N_s e^{-h/H} \qquad 5$$

Where H=7km
It can be seen from equation 4 that

$$\frac{dn}{dh} = \frac{dN}{dh} \times 10^{-6} Nunits/km \qquad 6$$

Hence from equation 5

$$\frac{dN}{dh} = \frac{-N_s}{H} e^{-h/H} \qquad 7$$

where $\frac{dN}{dh}$ is the refractivity gradient. For altitudes below 1km $\frac{dN}{dh}$, is well approximated by its value at 1km.
The refractivity gradient is an important parameter in estimating path clearance and propagation effects (Adediji and Ajewole 2008), such as sub-refraction ($\frac{dN}{dh} > -40$), super-refraction ($\frac{dN}{dh} < -40$) and ducting($\frac{dN}{dh} < -157$).

## 4. Results and Discussion

The annual surface refractivity over some locations in Nigeria were estimated from year 2012 to 2013 and the average annual refractivity of each location for the period of these two years was determined as presented in Table 1. The results were computed from meteorological data, namely; air pressure, temperature and relative humidity obtained from aforementioned data Centre's.

Figure1 represents the graph of annual average radio refractivity variations with latitude of some of the locations obtained from the meteorological Centre's and its deduced model. It was observed that the annual radio refractivity decreases with increase in latitude. The deduced model is of the form

$$Ns = m(L) + C \qquad (1)$$

Where Ns is the surface refractivity, L is the latitude of location, m is the gradient and C is a constant.The model parameters are as shown in Table 2, value of the correlation coefficient obtained from the fitted curve is very close to unity (1), which shows that the correlation between radio refractivity and latitude is very high and hence, the deduced model is accurately suitable for use in prediction of average annual radio refractivity of any other locations in the country once surface refractivity of one location is known. Also smaller values of errors in (m) and (C) shows that the data is accurately fitted and that the model will be efficient for predictions. Prob>F is very small, which also justifies the accuracy of the model obtained.

Table 1. Measured and estimated Radio Refractivity of some Locations in Nigeria from 2012 to 2013

| Location | Climate | Latitude | Longitude | Height above sea level (m) | Annual Radio Refractivity in 2012 | Annual Radio Refractivity in 2013 | Average Annual Refractivity from 2012-2013 |
|---|---|---|---|---|---|---|---|
| Portharcourt | Tropical wet | 4.8156 | 7.0498 | 18.00 | 373.42 | 378.08 | 390.75 |
| Ikeja | Tropical wet | 6.6018 | 3.3515 | 38.0 | 377.53 | 383.33 | 380.43 |
| Unilag | Tropical wet | 6.519 | 3.3972 | 15.0 | 380.40 | 385.46 | 382.93 |
| Abeokuta | Tropical wet | 7.1453 | 3.3590 | 74.0 | 368.46 | 370.48 | 369.47 |
| Ibadan | Tropical wet | 7.3775 | 3.9470 | 134.0 | 373.79 | 374.01 | 373.90 |
| Ogbomoso | Tropical wet | 8.1227 | 4.2436 | 342.0 | 346.84 | 346.32 | 346.58 |
| Osogbo | Tropical wet | 7.7827 | 4.5418 | 229.0 | 358.53 | 369.95 | 364.24 |
| Ondo | Tropical wet | 6.8959 | 4.8936 | 277.0 | 363.70 | 362.76 | 363.23 |
| Akure | Tropical wet | 7.2571 | 5.2058 | 303.0 | 364.26 | 365.34 | 364.80 |
| Ado | Tropical wet | 7.6124 | 5.2371 | 363.0 | 362.13 | 362.77 | 362.45 |
| Ayingba | Savanna North | 7.4934 | 7.1736 | 385.0 | 361.43 | 361.47 | 361.45 |
| Minna | Savanna North | 9.6152 | 6.5478 | 249.0 | 341.46 | 343.98 | 342.72 |
| Makurdi | Savanna North | 7.7322 | 8.5391 | 142.0 | 361.24 | 359.64 | 360.44 |
| Abuja | Savanna North | 9.0765 | 7.3986 | 334.0 | 352.18 | 357.90 | 355.04 |
| Jos | Savanna | 9.8965 | 8.8583 | 1110.0 | 341.52 | 336.72 | 339.12 |
| Yola | Semi-arid | 9.2035 | 12.4954 | 207.0 | 333.19 | 332.65 | 332.92 |
| Sokoto | Semi-arid | 13.0059 | 5.2476 | 247.0 | 300.18 | 296.54 | 298.36 |

Table (2). Values of the best fit parameters m and C in the Model equation of Ns versus Latitude of the measured Average Annual Radio Refractivity of some locations across Nigeria

| m value | Error in m | C value | Error in C | R value | F value | Prob >F |
|---|---|---|---|---|---|---|
| -11.677 | 0.88913 | 451.69 | 7.28759 | 0.95 | 172.48183 | 1.24756E-9 |

 

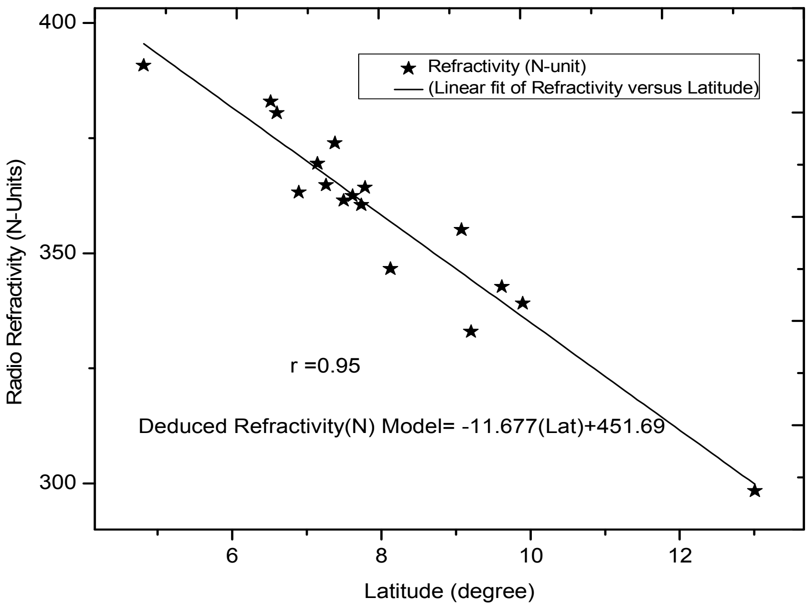


Figure1. Linear fit of the measured Average Annual Radio refractivity variations with Latitude of some locations across Nigeria and its deduced model

Figure 2 shows the Contour Map of measured and deduced Average Annual Radio Refractivity across Nigeria from 2012 to 2013, the model obtained from the fitted curve in figure (1) was used to deduce average annual radio refractivity of some other locations whose data were not available. The Blue (*) points represent measured average annual radio refractivity and the Red (×) points represent the deduced average annual radio refractivity. Interestingly, the contour map in figure 2 shows that the average annual refractivity decreases from the tropical wet climate through the savanna north to the Semi-arid climate. Hence, Radio Refractivity is more significant and higher in the tropical wet climate due to frequent evaporation of water from ocean surface which invariably increase air humidity, air pressure and water vapor contents of the air and hence creates a denser troposphere which increases radio refractivity of the locations in this zone.

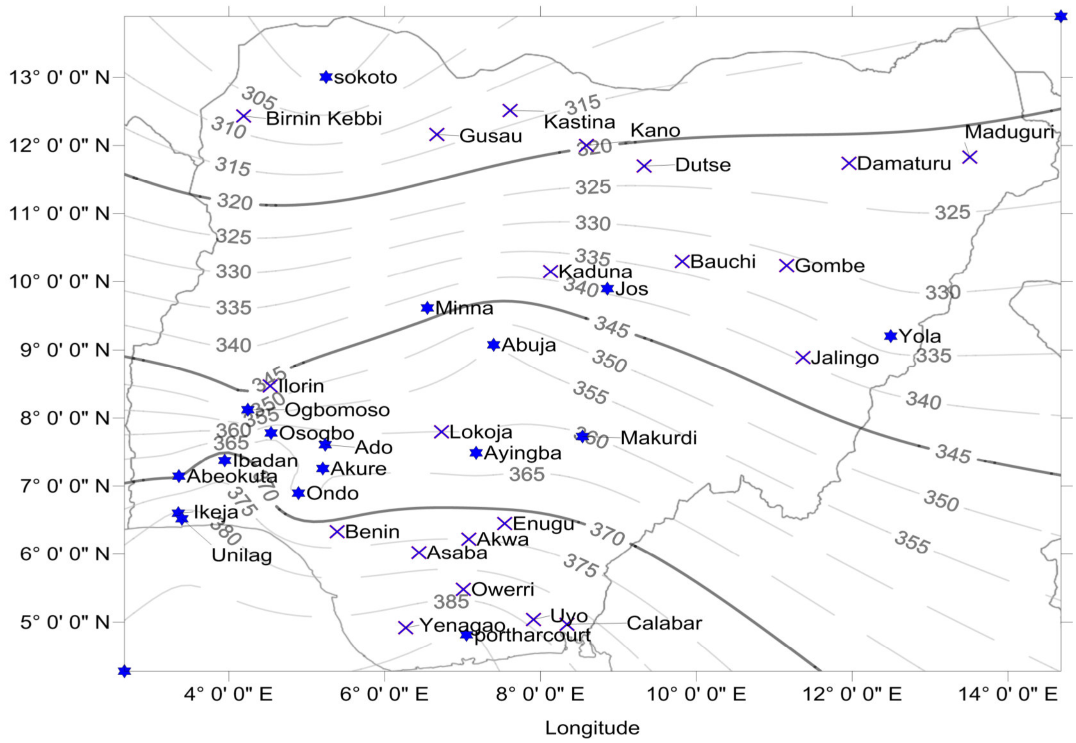


Fig (2): Contour Map of Measured and Deduced Average Annual Radio Refractivity across Nigeria from 2012 to 2013. Blue (*) = Measured Average Annual Radio Refractivity and Red (×) = Deduced Average Annual Radio Refractivity from the model in figure (1)

From the contour Map in figure (2), it was observed that the average annual radio refractivity from 2012 to

 

2013 ranges from (390.75 to 346.58) N-units in the Tropical wet zone, that is, from portharcourt to Ogbomoso and ranges from (361.45 to 331.417) N-units in the Savanna North, from Ayingba to Bauchi, while that of Semi-arid ranges from (332.92 to 298.36) N-units which represents average annual refractivity from Yola to Sokoto. The results show that Semi-arid climatic region is less refractive than Savanna North, while Tropical wet is most refractive. This result can be used to develop average annual radio refractivity link budget acr

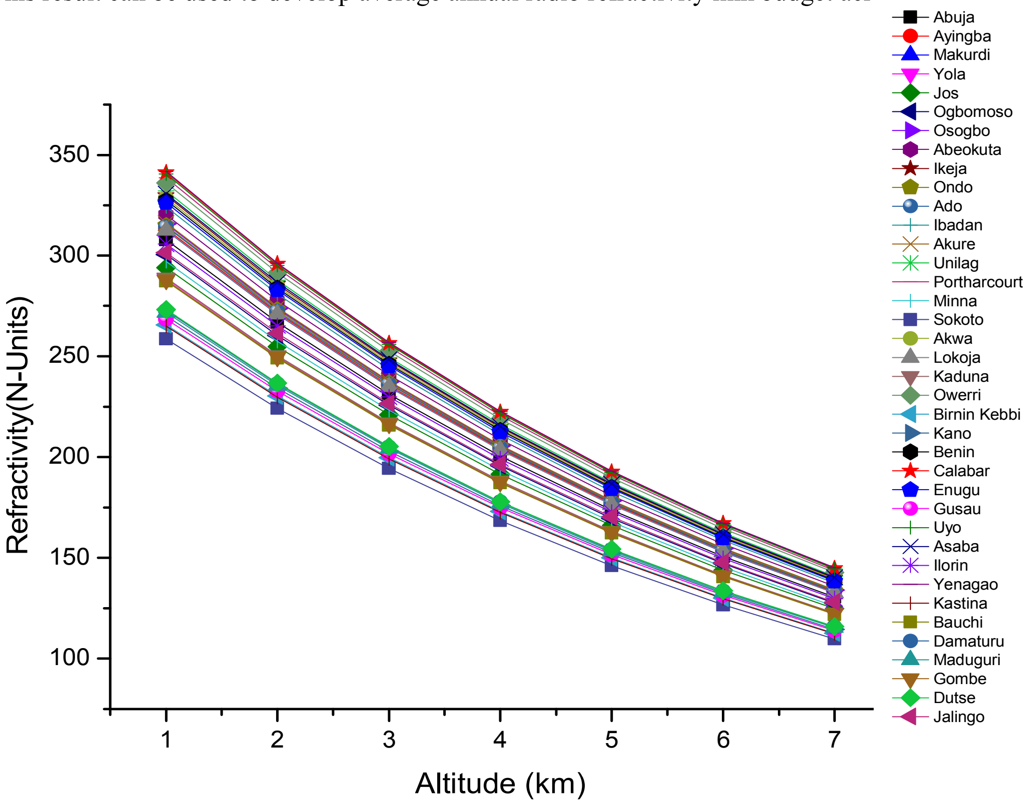


Fig (3) Measured and deduced Average Annual Radio Refractivity variations with altitude across Nigeria from 2012 to 2013

Figure 3 represents the average annual radio refractivity variations with altitude across Nigeria from 2012 to 2013, the result shows radio refractivity decreases with increase in altitude across Nigeria with Sokoto state having the least and portharcourt having the highest variations with altitude. This could also enhance accurate and efficient radio refractivity link across Nigeria since variations in antenna height and terrain nature play a significant role in tropospheric signal transmission and reception. This information will provide a clue on the expected height of transmission antennas for efficient transmission and reception across the earth and radio horizons of the climatic zones under study.

Figure 4 shows the result of average annual radio refractivity gradient variations with altitude across Nigeria from 2012 to 2013. It was observe from figure (4) that in the first 1 km above the sea surface, all the Tropical wet and the savanna North zones were super-refractive. Meanwhile, all the locations in the semi-arid climatic zone were sub-refractive except Yola which is closer to Savanna North zone on the contour Map. There was no traces of ducting within the period observed, as it is not a phenomenon that occur often.

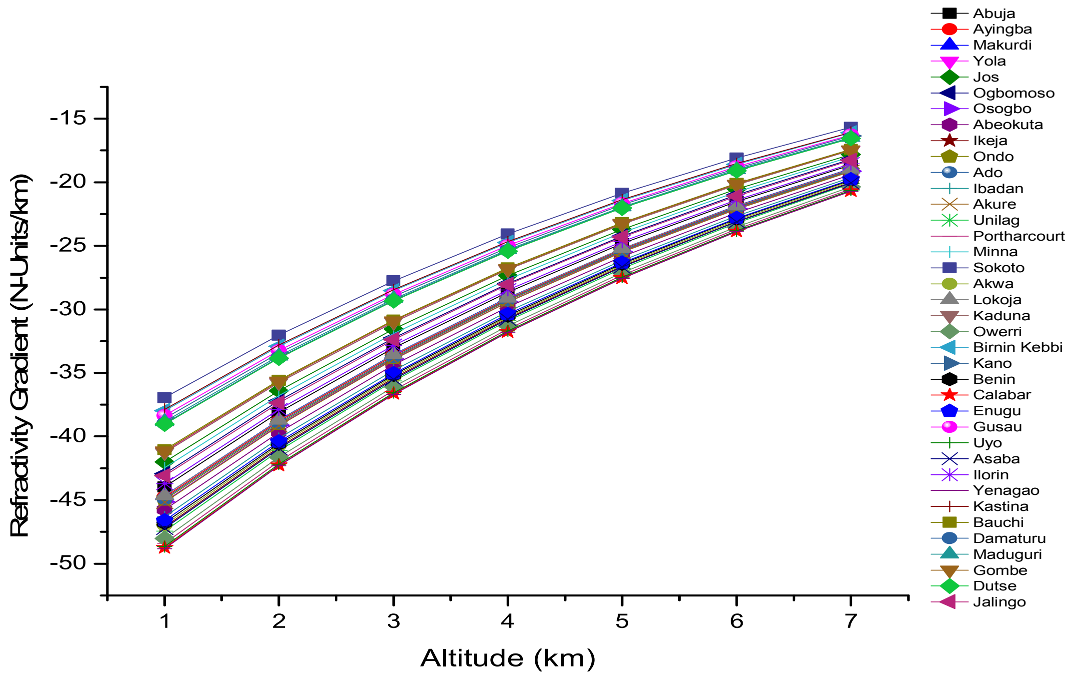


Fig (4) Measured and deduced Average Annual Radio Refractivity Gradient variations with Altitude across Nigeria from 2012 to 2013

## 5. Conclusion

This paper has shown the analysis of radio refractivity variation across geographical coordinates of Nigeria. The overall results obtained showed that radio refractivity decreases as the latitude increases across Nigeria with the tropical wet zone more refractive and the Semi-arid least refractive. The results in this paper will be useful in developing efficient radio refractivity link budget across Nigeria for effective tropospheric communication.

## 6. Acknowledgement

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