



## STUDIES ON SURFACE RADIO REFRACTIVITY OVER SOME SELECTED CITIES IN NORTH-CENTRAL, NIGERIA

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### ABSTRACT

This research investigated the variations of surface radio refractivity and its propagation effects on radio signal over the cities of Abuja and Ilorin, Nigeria. Six years (2015-2020) satellite data of Temperature, Pressure and Humidity both at the surface (12m) and at 100 m AGL, were used for the study. The data retrieved were used to determine the monthly, seasonal and annual surface radio refractivity values for the locations. Results show that the values of surface radio refractivity ( $N_s$ ) in Abuja was slightly lower than Ilorin with average values of 335.62 and 351.07 N-Units obtained for the six years respectively. Average values of  $N_s$ , obtained during the dry season months in Abuja and Ilorin were 299.40 and 321.03(N-units) respectively while average values of 360.24 and 368.21 (N-units) were obtained during the wet season months in Abuja and Ilorin respectively. Higher values of  $N_s$ , were recorded generally during wet compared to the dry seasons' months in all the years and study locations. The implication of this is higher attenuation of radio signal due to  $N_s$  during wet compared to the dry seasons' months and as well as in Ilorin compared to Abuja. Correlation coefficients of -0.53, 0.98 and 0.53 were determined between ( $N_s$ ) and; temperature, humidity and pressure respectively in Abuja while -0.30, 0.97 and 0.34 were determined between  $N_s$  and; temperature, humidity and pressure respectively in Ilorin. The overall findings of this work will be useful to radio engineers for the proper planning of reliable power budget over the study areas.

**Keywords:** Surface radio refractivity, terrestrial radio link, attenuation and power budget

### INTRODUCTION

During the design of radio link and power budget most wireless and data communication systems depend on the atmosphere as a medium for the signal transmission. As such, the wireless network designers are concerned about the nature of the atmosphere through which the signal propagates from the source which is the transmitter to the destination also known as the receiver (Akinbolati *et al.*, 2020). The refractive index of the troposphere is an important factor at predicting performance of terrestrial radio links. Refractive index variations of the atmosphere affect radio frequencies above 30 MHz, which becomes more significant only at frequencies greater than about 100 MHz especially in the troposphere (Oyedum and Gambo, 1994). Radio refractivity  $N$ , is a measure of deviation of refractive index  $n$ , of air from unity which is scaled up in parts per million to obtain more amenable figures. Surface radio refractivity ( $N_s$ ) is the refractivity values at the surface of the ground. Thus  $N_s$  is a dimensionless quantity defined and measured in N -units (Ayantuji *et al.*, 2011).

Surface radio refractivity  $N_s$ , has a high negative correlation coefficient with radio field strength values (Akinbolati *et al.*,

2018 and 2020; Oyedum and Gambo, 1994). Propagation of radio signal in the troposphere is affected by many processes which include the variations of meteorological parameters such as air temperature, pressure, and humidity. These variations in weather parameters often result in refractivity changes (Okoro and Agbo, 2012). Radio wave propagation is determined by the changes in the radio refractive index of air in the troposphere (Adediji and Ajewole, 2008). These changes can lead to the abrupt changes in propagation direction of a radio wave propagating in the troposphere resulting in attenuation of signal. Based on this premise, studies on radio refractivity have become imperative for radio engineers and scientists for the proper planning of a reliable radio links, power budget and coverage areas. Many works have been done locally and internationally in this regard however, it is important that studies that employ up to date data be used to ensure high reliability of findings due to climate change. Some of the related studies in this regard are as follows: Adediji and Ajewole (2008) studied the vertical refractivity gradient in Akure, Nigeria by measuring atmospheric variables using integrated sensor suits (ISS) at different heights above ground level. Results presented show that propagation conditions have varying degrees of occurrence.

Oyedum *et al.*, (2013) worked on reduced to sea level refractivity in Minna, Central Nigeria. It was based on in-situ measurement of relevant atmospheric parameters between 2008 and 2009. The work underscores the importance of the knowledge of temporal and spatial variation of surface refractivity as an important factor for planning terrestrial radio links over a region. Ayantunji *et al.*, (2011) studied seasonal and diurnal variation of surface radio refractivity in Akure, Nsuka, Minna, Sokoto and Jos (in Nigeria). The result of the work revealed higher values of surface refractivity during wet season in Nigeria compared to dry season months. It added that surface radio refractivity increases from arid region in the north to the southern parts of Nigeria. Okoro and Agbo (2012) studied the effect of variation of meteorological parameters on the tropospheric radio refractivity for Minna, Niger state Nigeria. The work investigated the effect of diurnal variations of meteorological parameters on tropospheric radio refractivity during dry and rainy season in 2008. The data used were obtained from Centre for Basic Space Science (CBSS) Nsuka, Nigeria. The results revealed that hourly average of radio refractivity during rainy season were greater than the results in dry season. Olorode and Adeniji (2013) carried out a study on the variation of tropospheric surface refractivity in four cities in Nigeria (Nsukka, Akure, Minna and Sokoto). Data for the study were obtained from centre for Basic Space Science (CBSS) University of Nigeria Nsukka. The result revealed higher value of refractivity in the coastal region compared to other places. The work concluded that surface radio refractivity has serious impact on radio wave propagation. Adewunmi *et al.*, (2013) investigated the influence of air pressure, relative humidity and atmospheric moisture on UHF radio propagation in the tropical South Western Nigeria. The work was carried out on the 900-960 MHz band. The work revealed the significant influence of three atmospheric parameters on UHF networks links within the region. Emetere *et al.*, (2015) worked on a model for analyzing radio refractivity in some selected locations in north central, Nigeria. A tropical model was derived and tested using National Oceanic and Atmospheric Agency NOAA (USAF) climatology Centre data (1973-2012) for six stations within the North – Central of Nigeria. The work stressed the need to reappraise the existing ITU model due to climate change. The tropical model detected tropospheric perturbations caused by the extensive influx of aerosol influx. Akinwunmi *et al.*, (2015) studied the seasonal variation of surface radio refractivity and water vapour density for 48 stations over Nigeria. The meteorological data used were collected from NOAA covering 39 years (1973-2012). The results show that surface refractivity and water vapour density generally have higher values during the rainy season than the dry season in all the stations studied. It further showed that the values of surface refractivity and water vapour density varies from about 263 N-units and 3 g/cm<sup>3</sup> in the North Eastern parts of Nigeria to about 393 N-units, and 23 g/m<sup>3</sup> in

the coastal area of Southwest Nigeria. The work stressed the need to take effect of the variability of surface radio refractivity and water vapour pressure unto consideration when designing terrestrial radio link across Nigeria. Ajileye *et al.*, (2016) investigated the interaction between terrain features and surface refractivity in North Central Nigeria. Meteorological data obtained from Natural Aeronautic Space Administration (NASA) at 2 m height (AGL) were used. The results of surface radio refractivity were interpolated and compared with North Central terrain features to establish a correlation. The result further showed that surface refractivity reduced with increasing altitude across the North central, Nigeria.

### The uniqueness and motivation for this study

The uniqueness of this work is such that; it uses up-to-date data for its findings compared to other related studies that employed older year's data. Findings from weather related studies have higher reliability when recent data are employed due to climate change. Most of the previous studies in the studied locations did not employ recent data compared to this work that employed recent data (2015-2020).

## MATERIALS AND METHOD

### Study Location

This study was carried out over the cities of Abuja and Ilorin, North Central, Nigeria. Abuja is the capital city of Nigeria with geographic coordinates of Latitude 9.0765° N and Longitude 7.3986° E . In the 2006 census, the city of Abuja had a population of 3,464,123, making it one of the ten most populous cities in Nigeria. It is situated in the Federal Capital Territory (FCT). The FCT experiences three weather conditions annually. This includes a warm, humid rainy season and a blistering dry season (Babagana, 2020). The rainy season begins from April and ends in October, when daytime temperatures reach 28 °C to 30 °C and nighttime lows hover around 22 °C to 23 °C. In the dry season, daytime temperatures can soar as high as 40 °C and nighttime temperatures can dip to 12 °C. The high altitudes and undulating terrain of the FCT act as a moderating influence on the weather of the territory (Babagana, 2020). Ilorin city is a traditional emirate, and capital of Kwara State, Western Nigeria. The geographical coordinates of Ilorin are latitude 8.497° N and longitude 4.542 ° E. Ilorin's population is estimated to be 814,192, according to (World Urbanization Prospects United Nations Population estimates and Agglomeration 2020). Figure 1 presents the map of Nigeria indicating the study areas. Abuja was chosen as a study location being the Federal Capital City of Nigeria and situated in the Sudan Savannah while Ilorin was chosen as one of the biggest cities in the north central situated in the tropical savannah.

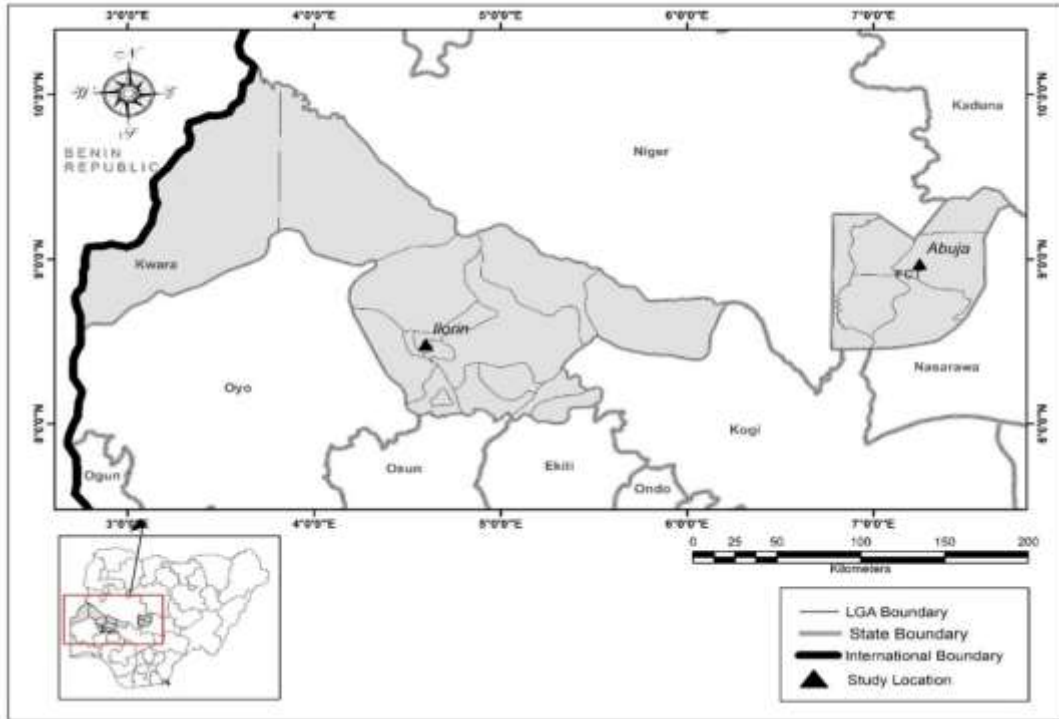


Figure 1: Map of Nigeria indicating the Study Locations

#### Source of Data used for this study

Secondary atmospheric data of temperature, pressure and humidity both at the surface (12m) and 100m Above Ground Level (AGL), were retrieved from the data-base of the European Centre for Medium-Range Weather Forecasts with headquarters in the United Kingdom. The data are high resolution satellite data with high reliability covering 2015-2020. The European Centre for Medium-Range Weather Forecasts (ECMWF) is an independent intergovernmental organization, which was established in 1975. They have a scientific and technical research directed at the development of numerical model and data assimilations systems. They produce global numerical weather predictions and other data. The center has the largest supercomputer facilities and meteorological data archives in the world. They produced global numerical weather forecast for worldwide users. Provision of medium range, monthly and seasonal weather forecast and also provide Copernicus atmosphere monitoring and climate changes (ECMWF, 2021).

#### Data Sorting and Empirical Tools

The set of data for analysis were sorted out in monthly, seasonal and annual format for easy analysis and discussion of results. The general radio refractivity equation is given in (1) (ITU-R, P.453, 2003, P.453-14, 2019; Adediji and Ajewole, 2008; Ayantuji *et al.*, 2011): Surface radio refractivity  $N_s$  is the refractivity at the surface of the atmosphere using surface weather parameters for its computation. Equations (1) - (3) were used to determine the surface radio refractivity.

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

with,

$$e = \frac{H e_s}{100} (\text{hPa}) \quad (2)$$

and

$$e_s = 6.11 \exp \left[ \frac{17.502t}{t + 240.97} \right] \quad (3)$$

where,  $e_s$  is the maximum (or saturated) vapour pressure at the given air temperature,  $t$  ( $^{\circ}\text{C}$ ) and  $H$  (%RH) is the humidity.  $P$  is the air pressure (hPa),  $T$  is temperature (K) and  $e$ , is water vapour pressure (hPa). Generally,  $P$  and  $e$  decrease rapidly with height whereas  $T$ , decreases slowly with height (Adediji and Ajewole, 2008; Ayantuji *et al.*, 2011). For the determination of the degree of relationship between the variables, Karl Pearson's Product Moment Correlation Coefficient used for continuous data as presented in (4) was used:

$$r = \frac{n \sum xy - \sum x \sum y}{\sqrt{[n \sum x^2 - (\sum x)^2][n \sum y^2 - (\sum y)^2]}} = \frac{\text{cov } XY}{\sqrt{\text{var } X \cdot \text{var } Y}} \quad (4)$$

## RESULTS AND DISCUSSION

This section presents the results obtained from the analysis of data for the two study locations of Abuja and Ilorin. Also presented is the discussion of results with major findings well highlighted. Figures 2 and 3 present typical monthly variation of surface radio refractivity for the years 2015 and 2020 respectively in Abuja while Figure 4 presents the annual variations for the six years under study.

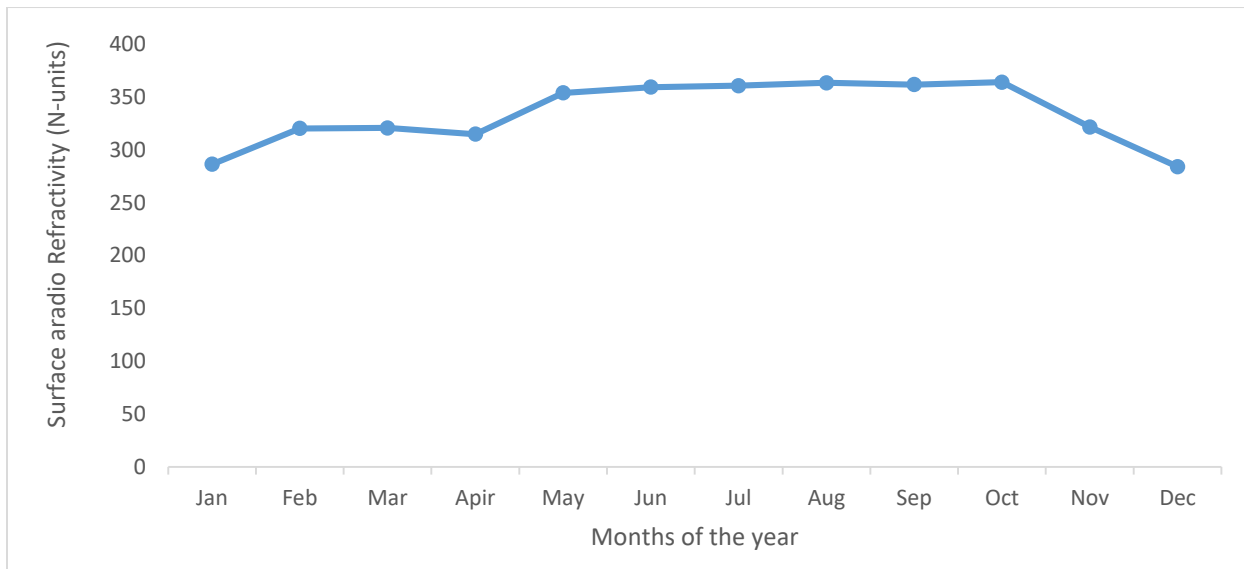


Figure 2: Monthly Variation of Surface Radio Refractivity over Abuja in the year 2015

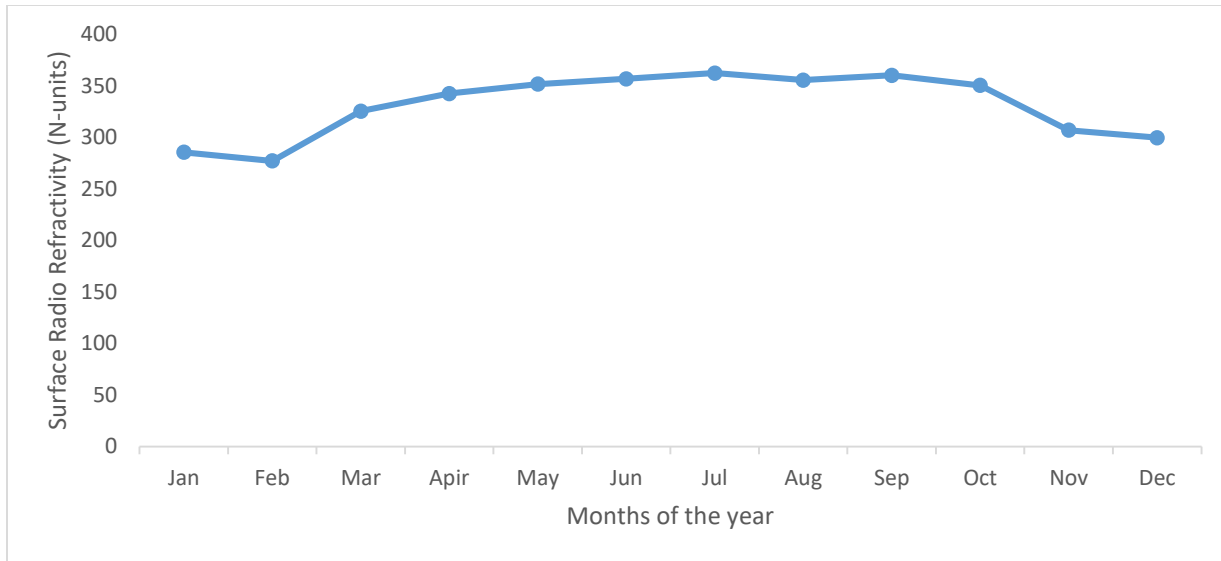


Figure 3: Monthly Variation of Surface Radio Refractivity over Abuja in the year 2020

From Figure 2 in the year 2015, low values were recorded during the dry season months of January to April and from November to December. A minimum value of 283.93 (N-units) was determined in the month of December while the highest of 363.86 (N-units) was determined in the month of October. High values of refractivity were recorded generally during the wet season months covering May to October in all the years under study except in the years 2016 and 2020 where high values were recorded in March and April. In addition, minimum values of 279.63, 275.48, 273.23, 292.58 and 277.25 (N-units) were recorded for the years 2016, 2017, 2018, 2019, and 2020 respectively. On the other hand, highest values of 362.83, 362.16, 362.87, 363.25 and 362.43 were recorded for the years 2016, 2017, 2018, 2019 and 2020 respectively in Abuja. For the seasonal variations; average values of  $N_s$ , obtained during the dry and wet season months in Abuja are 299.40 and 360.24 (N-units) respectively. This seasonal variation could be attributed to the response of the earth to the solar insolation (Ayantuji *et al.*, 2011) which is the major force behind the observed weather condition. This caused the temperature to be higher and humidity to be low during the dry season month and vice versa. Figure 4 presents the comparison plots of surface radio refractivity for the six years under study. The variations over the years follow nearly the same trend with lower values recorded during dry season months compared to the wet season months. In addition, Figure 4 presents typical variation of the dry and wet components of surface radio refractivity over Abuja. For the variation of the dry and wet components; figures 5a and 5b present typical variation in the year 2015 and 2020 respectively. It is observed that the dry term component recorded higher values compared to the wet, however, it remains constant through the year. On the other hand, the wet term component varies and actually determines the trends of the overall Surface Radio Refractivity.

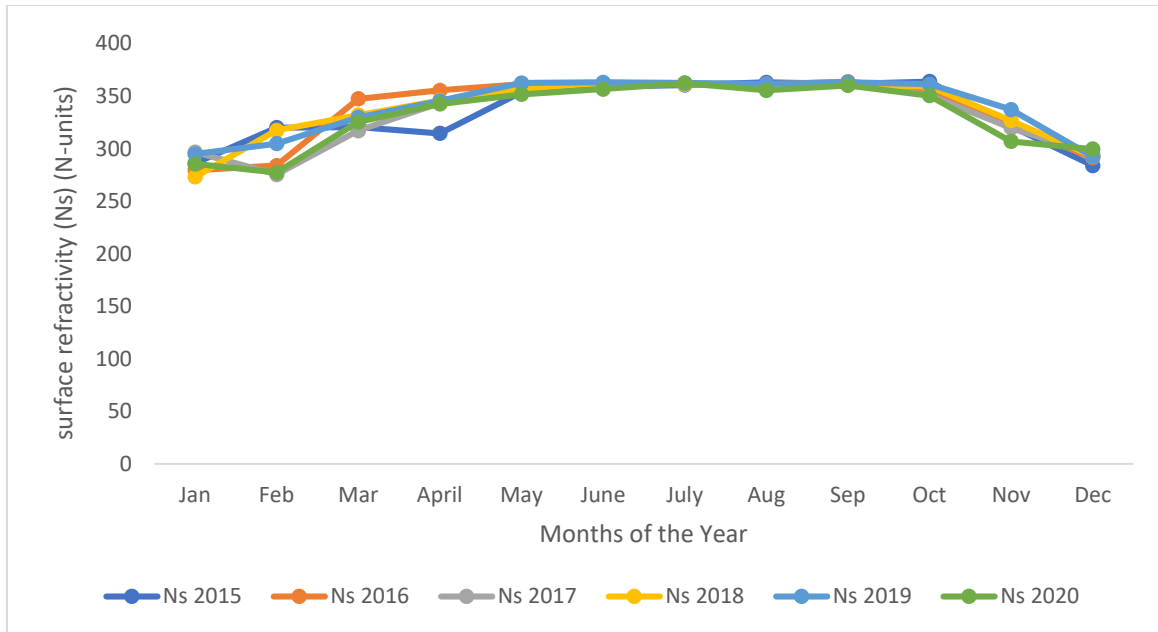


Figure 4: Variation of Surface Radio Refractivity for the Six Years (2015-2020) under study in Abuja

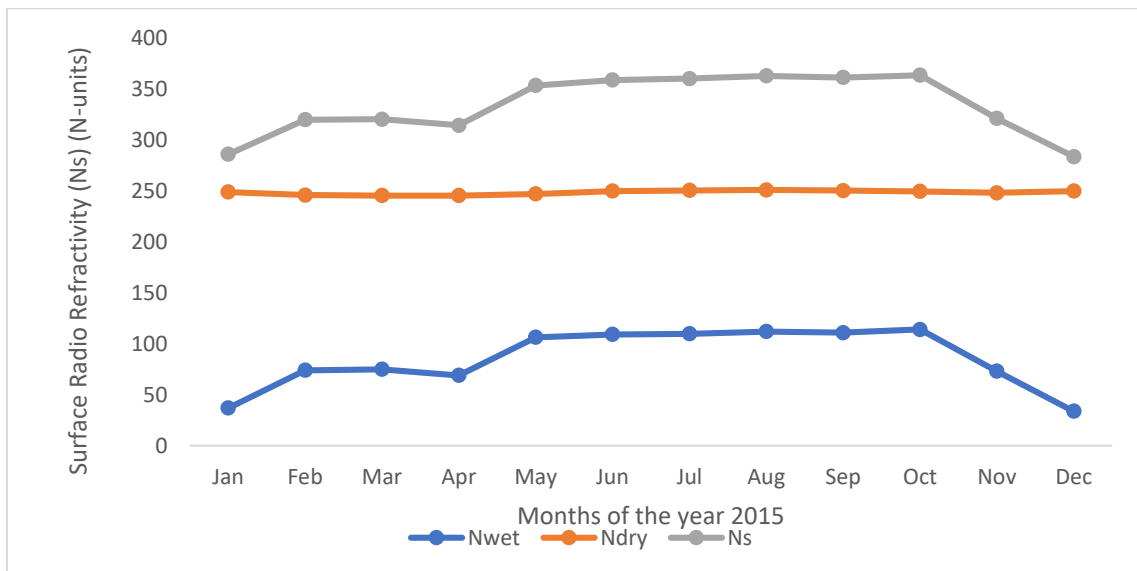


Figure 5a: Monthly variation of dry (Ndry) and wet (Nwet) components of surface radio refractivity in Abuja in the year 2015

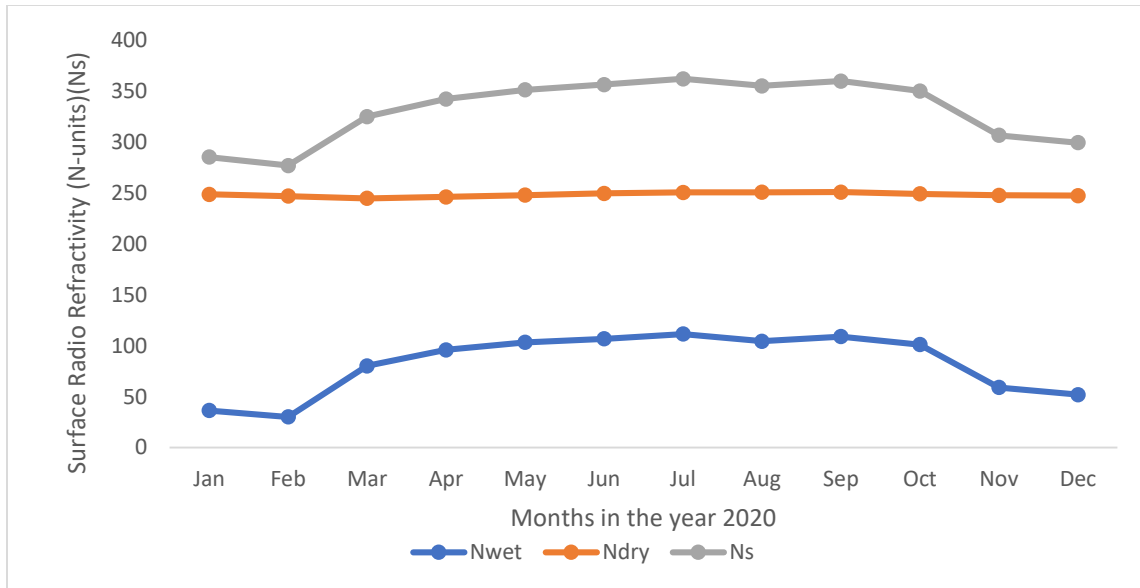


Figure 5b: Monthly variation of Dry (Ndry) and Wet (Nwet) components of surface radio refractivity in Abuja in the year 2015

The findings from this study show that there will be higher attenuation effect of surface radio refractivity on radio signal especially on terrestrial VHF, UHF and microwave frequencies generally and particularly during the wet season months in Abuja compared to the dry season months. This is based on the fact that many literatures (Akinbolati *et al.*, 2020; Oyedum and Gambo, 2004) have established negative correlation coefficients between signal strength over these frequency bands and surface radio refractivity.

Figures 6 and 7 present typical monthly variation of surface radio refractivity for the years 2015 and 2017 respectively in Ilorin while Figure 8 presents the annual variations for the six years under study.

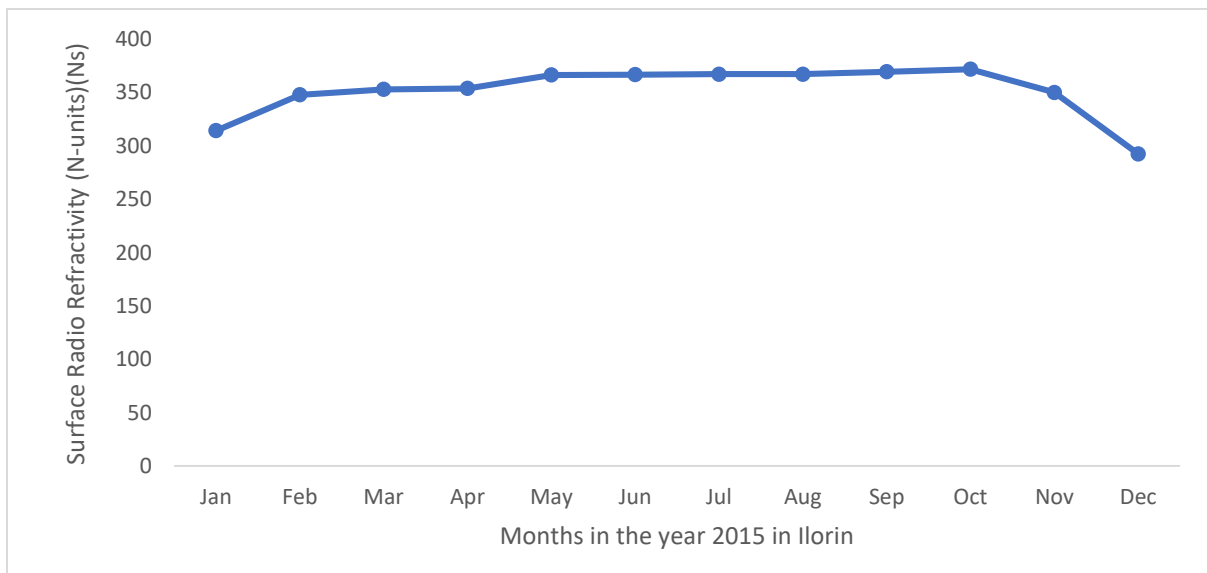


Figure 6: Monthly Variation of Surface Radio Refractivity over Ilorin in the year 2015



Figure 7: Monthly Variation of Surface Radio Refractivity over Ilorin in the year 2017

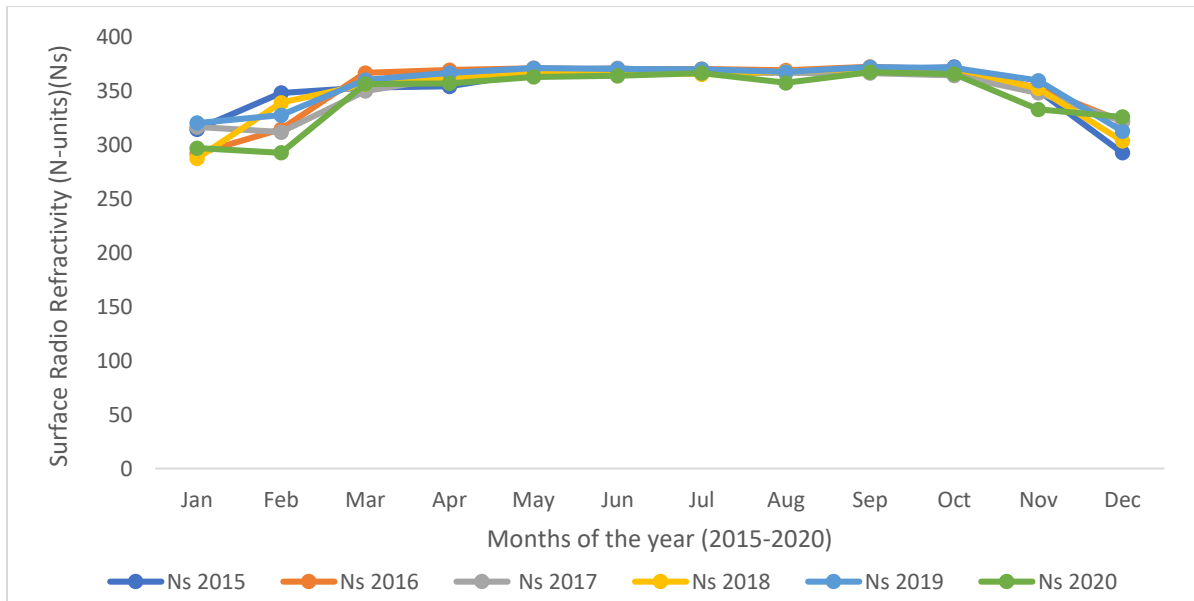


Figure 8: Variation of Surface Radio Refractivity for the Six Years (2015-2020) under study in Ilorin

From figure 6 in the year 2015, low values were recorded during the dry season’s months of January to April and November to December. A minimum value of 292.480 (N-units) was recorded in the month of December while the highest of 371.95 (N-units) was determined in the month of October. High values of refractivity were recorded generally during the wet season months covering May to October. Another point of interest is the sharp drop of surface radio refractivity in the month of February in the year 2017. This could be attributed to the fact that February seems to be the hottest of all the months and that of 2017 was exceptional. In addition, minimum values of 291.59, 311.61, 287.28, 312.52 and 292.47 (N-units) were recorded for the years 2016, 2017, 2018, 2019, and 2020 respectively. On the other hand, highest values of 366.50, 364.04, 370.70, 371.04 and 365.40 (N-units) were recorded for the years 2016, 2017, 2018, 2019 and 2020 respectively in Ilorin. For the seasonal variation; average values of 321.03 and 368.21 (N-units) were determined during the dry and wet season months in Ilorin respectively.

Figure 9 presents the variation of the dry and wet components of surface radio refractivity over Ilorin. Similarly, the dry component remains constant while the wet component determines the trend of variation of the total surface radio refractivity.



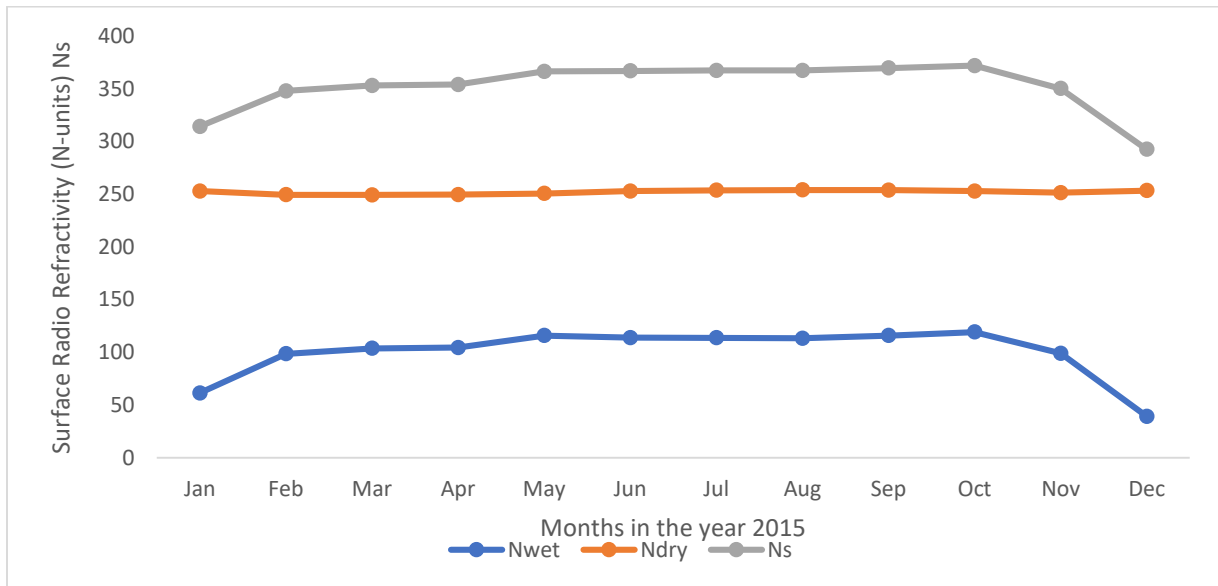


Figure 9a: Monthly variation of Dry (Ndry) and Wet (Nwet) components of surface radio refractivity in Ilorin in the year 2015

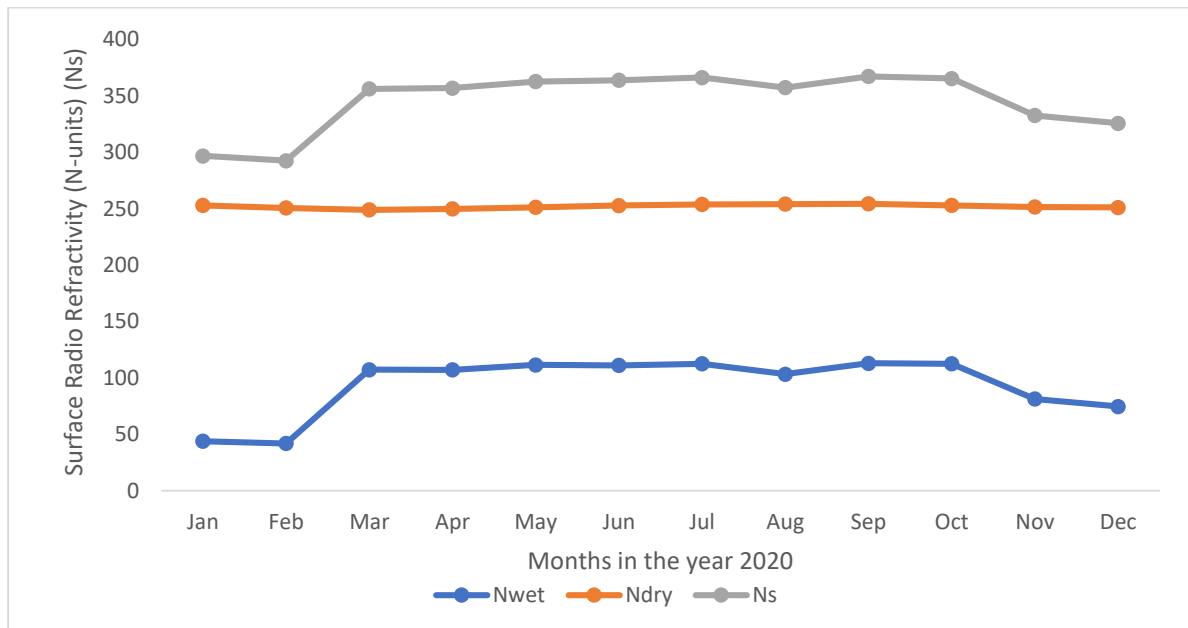


Figure 9b: Monthly variation of Dry (Ndry) and Wet (Nwet) components of surface radio refractivity in Ilorin in the year 2020

Similarly, the findings from this study over Ilorin show that there will be higher attenuation effect of Surface Radio Refractivity on radio signal especially on the VHF, UHF and microwave frequencies during the wet season months in Ilorin compared to the dry season months.

Statistical analysis using correlation coefficient as presented in (4) were carried out to ascertain the degree of relationship between surface radio refractivity (Ns) and atmospheric

variables of temperature, humidity and pressure. Results revealed that correlation coefficients of -0.53, 0.98 and 0.53 were obtained between Ns and temperature, humidity and pressure respectively in Abuja. Similarly, Correlation coefficients of -0.30, 0.97 and 0.34 were obtained between Ns and temperature, humidity and pressure respectively in Ilorin.

## CONCLUSION

The variation in the refractive indices of the atmosphere over Abuja and Ilorin, North Central Nigeria had been studied and presented. Some of the major findings shown monthly, seasonal and annual variations. Higher values were recorded generally during the wet season months of May to October compared to the dry season months and particularly in Ilorin compared to Abuja. From the Correlation coefficients, strong positive correlation coefficients of 0.98 and 0.97 exist between Ns and humidity in Abuja and Ilorin respectively. The implication of this is that the higher the humidity over the study area the higher the surface radio refractivity and the higher the susceptibility of radio signal to losses. Operators of radio communication stations in the study areas should make deliberate efforts at mitigating against losses (especially during wet seasons) such as increase in transmitted output power or increasing the cells in their communication networks. The overall findings of this work will be of great importance to radio scientist and engineers in the planning and design of sustainable wireless network and link's budget that will ensure Quality of Service (QoS) in the study areas and other similar cities over North Central, Nigeria.

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