

Estimating the Variability of Tropospheric Radio Refractivity and Field Strength over Enugu, South-East Nigeria

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ABSTRACT

The field strength variability (FSV) assessment highlights the significant impact of atmospheric conditions on radio signal propagation. A diurnal variation in radio refractivity is the primary driver of FSV, with local topography and environmental factors also playing important roles. This study investigated the variation of tropospheric radio refractivity and field strength in Enugu, South-East Nigeria. Through a comprehensive measurement of temperature, humidity and pressure obtained from the network of Vantage Pro 2 automatic weather station installed at the study location for a period of six months (January 2024 to June 2024). Using the International Telecommunication Model (ITU-R model), radio refractivity was computed from the collected weather parameters, and subsequently the field strength. The results showed that, radio refractivity displayed diurnal variability with high values in the morning and late evening while low values were observed in the day time. Furthermore, the analysis of the results revealed that, during the months of January, February and March, more pronounced daily variations with lower minimum values between 292N to 332N were observed at about 13:00 hours local time and higher values between 300N to 350N in the morning (0:00 - 6:00) and evening (15:00 - 23:00). Moreover, the analysis of field strength variability showed that the months of January, February, and March (dry season) were marked by higher field strength values. In particular, January recorded the highest field strength value (7.4 dB). On the other hand, the months of April, May, and June (wet season) exhibited lower field strength values, with the lowest value (1.9 dB) observed in May. The results indicate a strong seasonal impact on field strength.

Keyword: Atmospheric parameters, Radio Refractivity and Field Strength Variability.

1.0 INTRODUCTION

The tropospheric radio refractivity is a crucial factor in assessing the quality and reliability of electromagnetic signals within the lower atmosphere. This phenomenon greatly affected communication systems, remote sensing, and radar systems (Ayantunji et al., 2019). Radio refractivity quantifies how much the speed and direction of radio waves change as they travel through the troposphere, thus significantly influencing the propagation of radio waves in several ways, such as the bending of radio waves, extended communication range, multipath propagation, and signal attenuation (Samuel, 2010). As radio waves pass through the troposphere, they encounter layers with varying refractive indices. This bending of the waves is influenced by the refractivity gradient present in the atmosphere. Under certain atmospheric conditions, radio waves can be bent back towards the Earth's surface, allowing for over-the-horizon communication. This effect, referred to as ducting, can greatly increase the range of radio transmissions beyond the line of sight (Suleman et al., 2024). Refractivity variations can cause radio waves to take multiple paths between the transmitter and receiver. This can lead to interference patterns, signal fading, or

enhancement, depending on how the different paths interact (Dan et al., 2019).

Electromagnetic radiation from space encompasses all wavelengths of the spectrum, from gamma rays to radio waves. However, the radiation that reaches us is significantly influenced by the media it traverses. Atoms and molecules in these media can absorb certain wavelengths, scatter (or reflect) others, and allow some to pass through while slightly bending them (refracting). Refraction is the deflection or bending of electromagnetic waves as they move from one type of transparent medium to another (Ayantunji et al., 2019). The index of refraction is the ratio between the speed of electromagnetic energy in a vacuum and its speed in a given medium. The influence of meteorological variables such as pressure, temperature, and relative humidity on the propagation of radio waves at ultra-high frequency (UHF) and microwave frequencies can be assessed by studying the radio refractive index derived from these three parameters (Mat et al., 2020). Since these variables fluctuate significantly both daily and seasonally, particularly in the tropics, understanding refractivity variations quantitatively is essential for designing

reliable and efficient radio communication systems, both terrestrial and satellite.

Enugu, situated in south-east Nigeria, presents a unique weather condition for studying tropospheric radio refractivity due to its diverse climatic conditions. The region experiences significant seasonal variations, with pronounced wet (March through November) and dry (December through February) seasons, which are likely to influence radio refractivity (Sa'adu, et al., 2020). Moreover, Enugu's fast urbanization and expansion of communication infrastructure necessitate a full understanding of how local weather conditions influence radio wave propagation. Effective communication systems are critical to the city's growth, supporting business operations, and personal communications. This study intends to provide insights that will help in planning a reliable and effective communication system in Enugu City and other regions with similar weather conditions. Moreover, the research will not only benefit local telecommunication operators and broadcasters but also provide valuable data for engineers working to enhance Nigeria's overall communication infrastructure. Several researchers have estimated the variability of radio refractivity and its influences on communication systems. For instance (Ajileye et al., 2019; Akpootu, 2021; Iliyasu, 2019; Suleman et al., 2024; Okoro & Agbo, 2021; Dan et al., 2019; Sa'adu et al., 2020) have reported refractivity displayed diurnal variability with higher values in the morning and late evening, and lower values during the daytime, in the dry season and refractivity shows seasonal variation, with higher values during the wet season and lower values in the dry season. The researchers was further determined that refractivity values vary with climatic zones and are also influenced by local meteorological parameters. Furthermore, (Adediji et al., 2013; Tanko et al., 2022; Mirbagheri & Mohammadi, 2019; Akpootu et al., 2019) investigated the FSV and showed that higher values of FSV are recorded during the dry season compared to the rainy season. The spatial variation indicates a marked difference between stations located in drier areas and those situated in coastal regions. Consequently, the studies suggested that the output of the receiving antenna in each region might need to be adjusted for optimal performance. Despite these developments, there remains a gap in lack of localized climatic data for Enugu. At present, International Telecommunication Union (ITU) recommendation is the existing refractivity models used in planning of communication services which often rely on climatic data obtained from temperate region of the world, which may not accurately reflect the specific weather conditions in Enugu. The diverse climatic conditions in Enugu necessitate comprehensive research

to accurately predict radio wave behavior under its specific climatic conditions.

As a result, this study evaluates the variability of tropospheric radio refractivity and examines how these variations impact radio field strength. This assessment is based on average daily measurements of temperature, relative humidity, and atmospheric pressure collected over a six-month period (January 2024 to June 2024) from a network of wireless Vantage Pro 2 automatic weather stations located in Enugu, South-East (4° 48' N, 7° E). The refractivity value is determined from the measured atmospheric parameters using an empirical formula provided by the International Telecommunication Union (ITU – R., 2015). Though, assessing seasonal variation typically requires a more extensive dataset to capture the full range of atmospheric conditions throughout the year. However, six (6) months of data used in the present research provided initial insights into seasonal trends, as it covers periods with significant seasonal changes, such as the transition from dry to wet seasons. This period can serve as a preliminary analysis to identify general trends and patterns in atmospheric parameters and their impact on radio refractivity and field strength. As the data collection is presently ongoing, this approach ensures that all seasonal phases are adequately captured and accounted in the next report, for more robust conclusions and recommendations.

1.1 Theoretical Background

The Earth's atmosphere is characterized by variations in several meteorological parameters, including pressure, temperature, relative humidity, wind direction and speed, precipitation, evaporation, and radiation. These parameters vary according to geographic location, season, time of day, and solar cycle.

1.1.1 Temperature

This is the variation in the conditions of atmosphere that can be described subjectively in terms of relative concepts of warmth or coolness. Temperature can be measured in degrees Celsius (°C) or in Kelvin (K). The temperature in Celsius can be converted to Kelvin using the formula:

$$T = 273.15 + t(\text{K}), \quad (1)$$

Where T, represents the temperature in Kelvin and t, represents the temperature in Celsius.

1.1.2 Pressure

Atmospheric pressure is defined as the force per unit area exerted by the atmosphere on a surface due to its weight. Under standard conditions, atmospheric pressure

decreases as altitude increases (Sa'adu, et al., 2020). The change in pressure with altitude in the atmosphere can be described by the hydrostatic equation.

$$\frac{dp(z)}{dz} = -\rho(z)g, \quad (2)$$

Where $\rho(z)$ is the mass density of air at height z and g is the acceleration due to gravity.

1.1.3 Relative humidity

Humidity refers to the amount of water vapor present in the atmosphere, which can be measured as either vapor density or vapor pressure. Relative humidity, (H), is expressed as a percentage. When the relative humidity of the air reaches 100%, the air is considered saturated. At this point, water vapor condenses into liquid droplets, leading to the formation of phenomena such as rain, fog, and clouds (Sa'adu, et al., 2020).

1.1.4. Saturation vapour pressure

The saturation vapor pressure, e_s , is the vapor pressure that the air would have if it were fully saturated.

$$e_s = a \exp\left\{\frac{bt}{t+c}\right\}, \quad (3)$$

where, t , is temperature in Celsius, $a = 6.1121$, $b = 17.502$ and $c = 240.97$ (ITU – R., 2015).

The water vapour partial pressure, e , can be calculated from the relative humidity, H (%) and from the saturated water vapour pressure, e_s , expressed in hPa using the formula (ITU – R., 2015):

$$e = \frac{He_s}{100}. \quad (4)$$

1.2. Refractive Index and Refractivity of the Troposphere

In the study of radio propagation, the troposphere is treated as a dielectric medium. Although variations in the tropospheric refractive index are minor, they are still essential for radio wave propagation. The refractive index of air is connected to radio refractivity, N , (ITU – R., 2015) as follows;

$$N = (n - 1) \times 10^6, \quad (5)$$

Where n is the refractive index and N is radio refractivity expressed by:

$$N = N_{dry} + N_{wet} = \frac{77.6}{T} \left(P + 4810 \frac{e}{T} \right), \quad (6)$$

With the 'dry term' of radio refractivity given by:

$$N_{dry} = 77.6 \frac{P}{T}, \quad (7)$$

and the 'wet term' given by:

$$N_{wet} = 3.732 \times 10^5 \frac{e}{T^2}, \quad (8)$$

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Where P is atmospheric pressure (hPa), e is water vapor pressure (hPa), and T is absolute temperature (K).

This formula can be applied to all radio frequencies (up to 100 GHz, where the error is less than 0.5%) for typical profiles of temperature, pressure, and water vapor pressure. The water vapor pressure, e , can be determined from relative humidity using equation (4).

1.2.1. Field Strength Variability

Radio refractivity is strongly correlated with radio field strength, particularly in the VHF bands within the 30-300 MHz frequency range. A change of 0.2 dB in field strength can be used for each unit change in N_s (Adediji et al., 2013).

Thus, an assessment of field strength variability (FSV) in a specific region is investigated using the monthly ranges of Surface Refractivity, N_s using the relation;

$$FSV = N_s(\max) - N_s(\min) \times 0.2dB \quad (9)$$

Where;

$$Monthly\ Range = N_s(\max) - N_s(\min) \quad (10)$$

The evaluation of field strength variability highlights the significant impact of weather conditions on radio signal propagation. Diurnal variations in temperature, humidity, and pressure are the primary drivers of FSV, with local topography and environmental factors also playing important roles.

2.0. MATERIALS AND METHODS

Figure 1 showed the study location. Enugu city, the capital of Enugu State, Nigeria, lies ($4^{\circ}48'$ N, 7° E) and elevated to 151m above sea level. Enugu located in a tropical rain forest zone with a tropical wet climate. These equatorial regions experience the most predictable weather on Earth, characterized by consistently warm temperatures and regular rainfall (Iloje & Aniagolu, 2015). In this study, six (6) months meteorological data (January 2024 – June 2024) was collected through the network of wireless Vantage Pro 2 automatic weather stations installed at the measurement sites. The Wireless

Vantage Pro2 features an Integrated Sensor Suite (ISS), a solar panel (along with an optional battery backup), and a console. The ISS gathers external weather data and transmits it to the Vantage Pro2 console. Surface values of temperature, pressure and humidity extracted from the measuring instruments undergoes the following data analysis process:

i. Raw data previewed to remove obvious outliers and determine the data that are visibly extraneous and therefore unneeded, since the data are much.

ii. The data were averaged hourly to produce twenty-four data points representing diurnal variations for each day. These daily twenty-four-hour data sets were then averaged over the month to obtain the monthly diurnal variation. This data was used to assess the diurnal variation in radio refractivity.

iii. The data were utilized to compute surface radio refractivity using the ITU-R Model (ITU, 2012) and to subsequently determine the variability in field strength. Microsoft Excel (2016) was used for the data analysis.



Figure 1: Map of the study Area (Chinago, 2015)

3.0. RESULTS AND DISCUSSIONS

3.1. Dailyvariation of radio refractivity

Figure 2 shows the graph of average daily variations in radio refractivity over Enugu for the six-month period from January 2024 to June 2024. As seen in the plot, the pattern of radio refractivity variations closely followed the same shape, with high refractivity values in the morning and late evening, and lower values in the afternoon. Additionally, the analysis of the results showed that, during January, February, and March, more pronounced daily variations with lower minimum values between 292N to 332N were observed at about 13:00

hours local time and higher values between 300N to 350N in the morning (0:00 - 6:00) and evening (15:00 - 23:00). The larger fluctuations are attributed to clear skies and higher solar radiation, causing significant temperature and humidity changes throughout the day. The results agree with the work of (Ayantunji et al., 2019). During the months of April, May, and June, there was reduced diurnal fluctuation with higher and more stable refractivity values. These months coincided with the rainy season at the study location. The increased cloud cover and rainfall contributed to more stable temperature and humidity levels.

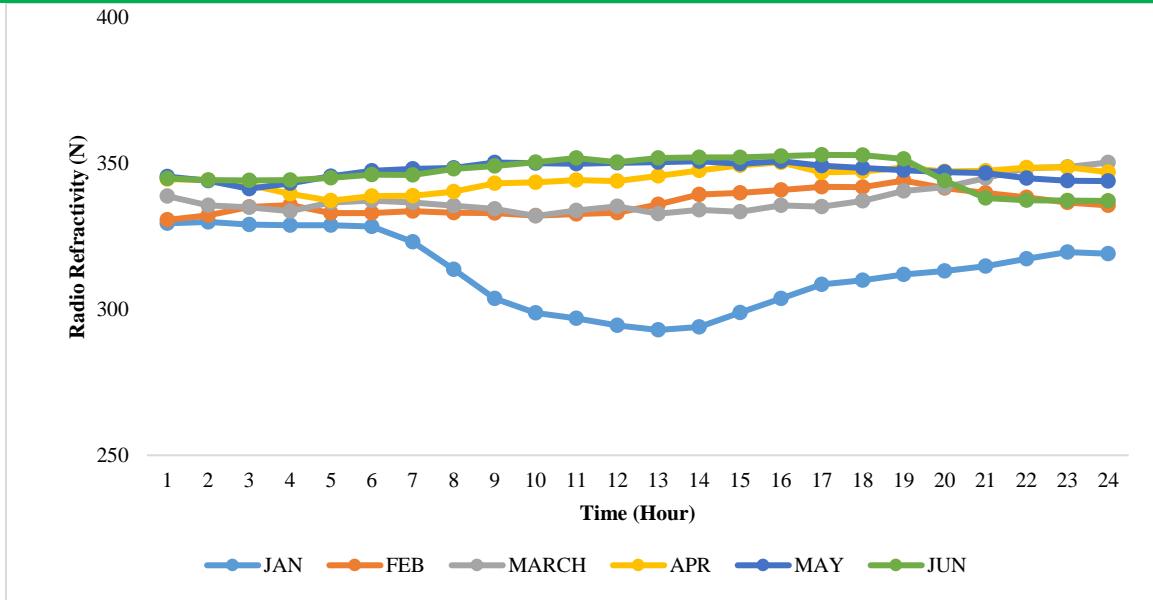


Figure 2: Daily variation of radio refractivity

3.2. Field Strength Variability

Error! Reference source not found. showed the graph of the average monthly variations of field strength, over Enugu for the period of six months (January 2024-June 2024). As observed from the plot, January, February and March (dry season) marked by higher field strength values. In particular, January shows the highest field strength value (7.4 dB) due to the optimal propagation conditions with low humidity and high temperatures. The

transition months of February and March show a decline but still maintain relatively higher values compared to the wet season. During the months of April, May and June (wet season) there was lower field strength values, with the lowest value of (1.9 dB) being observed in May. The increased relative humidity, cloud cover and decreased in temperature during these months lead to higher attenuation, reducing the efficiency of radio wave propagation. The results agree with the work of (Akpootu, 2021; Tanko et al., 2022).

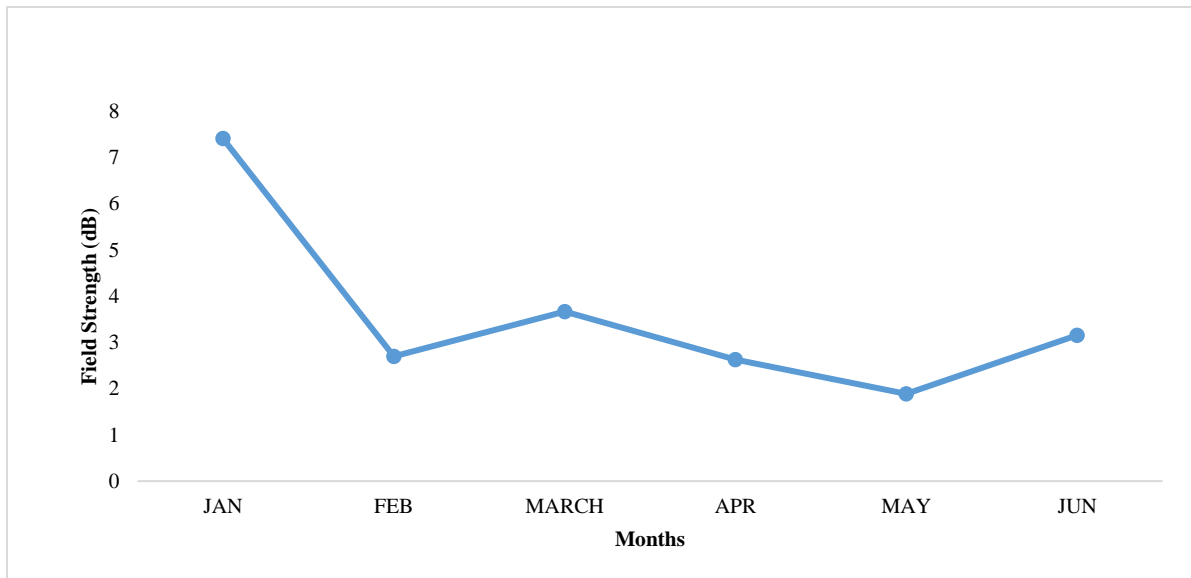


Figure 3: Average monthly variations of field strength

3.3 Implications of the results

The data indicates a clear seasonal impact on radio refractivity, with higher refractivity values were observed during the wet months (April to June) with correspondent low values of field strength compared to the dry months (January to March) with correspondent high values of field strength. Understanding these patterns is important for optimizing communication networks, as variation of radio refractivity can affect signal propagation, by deprecating the signal strength or increased interference. The significant drop in field strength from April to June suggests that communication systems in Enugu may experience reduced performance and reliability during this period. Systems designed may need adjustments or enhancements to maintain performance. Hence, the work could be used for rapid and precise estimation of link budgets while planning and designing radio links budget in Enugu and regions of similar climatic characteristics.

4.0 CONCLUSION

This research determined the diurnal fluctuations in radio refractivity and field strength over Enugu city, Enugu State. Six months (January 2024 to June, 2024) weather parameters data obtained through the network of wireless Vantage Pro 2 automatic weather. The key findings of this study are:

- Radio refractivity exhibited diurnal variability, with higher values in the morning and late evening, and lower values during the daytime.
- Radio refractivity shows strong dependence on relative humidity.
- Strong seasonal impact on field strength, with the higher refractivity values observed in January, February and March. Additionally, the lowest refractivity values were observed in April, May, and June.
- Radio refractivity is a function of local climatology.

Eventually, comparing field strength data with the diurnal variation of radio refractivity indicates that both parameters are influenced by similar atmospheric conditions. The observed trends in field strength correlate well with the patterns of radio refractivity, reinforcing the relationship between atmospheric refractivity and signal propagation. Understanding these Fluctuations is

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essential for optimizing the performance of communication, radar, and navigation systems in the region.

Recommendation

Long time measurement and prediction of radio refractivity in Enugu city should be carried out so as to validate the present research.

Competing interests

None

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Ethical Approval

Not applicable

Consent to Participate

Not applicable

Availability of data and material

All data used will be made available on request.

Code availability

Not applicable

Author Contributions

L, M. contributed to the study conception. I, U. contributed to the study design, and all aspect of the manuscript. The first draft of the manuscript was written by B, M. and I, U.; B, M.; L, M. read and approved the final manuscript.

Consent to Publish

The authors hereby grant consent for the publication of the work.

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