UMYU Scientifica, Vol. 4 NO. 2, June 2025, Pp 100 – 108
https://doi.org/10.56919/usci.2542.012
ISSN: 2955 – 1145 (print); 2955 – 1153 (online)
*A periodical of the Faculty of Natural and Applied Sciences, UMYU, Katsina*

**ORIGINAL RESEARCH ARTICLE**

# Temporal Analysis of Radio Refractivity Variation over Kaduna: Implications for Radio Wave Communication Systems

Aminu Yaradua Sabiru[1,2]*, Akinbolati Akinsanmi[1] and Florence N. Ikechiamaka[1]
[1]Department of Physics, Federal University Dutsin-Ma, P.M.B. 5001 Dutsin-ma, Katsina State, Nigeria
[2]Department of Physics, , Umaru Musa Yar'adua University, PMB 2218, Batagarawa, Katsina State, Nigeria

## ABSTRACT
Surface radio refractivity is a crucial parameter in studying radio wave communication as it quantifies the bending of electromagnetic waves by atmospheric factors. This study examines the temporal variations of this parameter in tropical savannah region of Kaduna, Nigeria, for a long time. Accurate measurements of temperature, atmospheric pressure, and relative humidity extracted from high-resolution meteorological data from the ECMWF ERA5 reanalysis dataset were used to perform this research. The radio refractivity is computed using ITU-recommended models integrating these variables to express radio refractivity in N-units, which is a global standard for values comparison. The analysis revealed that yearly mean refractivity remained notably stable, fluctuating between 340.0565 and 353.4296 N-units, a modest range of 13.3731 N-units across four decades. This stability points out how easily atmospheric conditions can be predicted in long-term communication planning in Kaduna. On the other hand monthly radio refractivity show high variability ranging from 279.0400 N-units in March 1990 to 391.5037 N-units in October 1997—a difference of 112.4637 N-units. This variability originated from the wet and dry seasons of the location of the study. Higher radio refractivity values during the rainy season indicate a sharp increase in water vapour pressure and humidity, while lower refractivity values mark the dry season. These results indicate the necessity of utilising local climate conditions when studying electromagnetic wave propagation and fill a critical gap in long-term refractivity research, especially in tropical savannah areas.

**ARTICLE HISTORY**
Received February 16, 2025
Accepted April 30, 2025
Published May 19, 2025

**KEYWORDS**
Radio Refractivity, Tropical Savannah Climate, Atmospheric Parameters, Radio Wave Propagation, Long-Term Variability, Tropospheric Propagation



## INTRODUCTION

Radio refractivity is a crucial variable in the study of atmospheric science and communication engineering, which quantifies the bending of radio waves when propagating through the atmosphere. It is defined as the measure of how the refractive index, which depends on temperature, pressure, and humidity, affects radio wave paths (Akinbolati et al.,2016). Surface refractivity specifically refers to the value of radio refractivity at the earth's surface level, which is crucial for terrestrial communication systems such as broadcasting radar and mobile communications. This variable significantly influences signal strength, coverage areas, and potential interference, basically making it a key player in designing and optimisation of communication networks (Amajama, 2023). The radio refractivity depends on some meteorological variables such as absolute temperature T in Kelvin, atmospheric pressure P in hPa, and water vapor pressure e in hPa (Yusuf et al., 2019). The refractive index, n, can be typically expressed as

$$n = 1 + N \times 10^{-6}$$

Where N is the radio refractivity in N-units, calculated using the International Telecommunication Union (ITU) recommended formula:

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

Here, T is Kelvin's absolute temperature, P is hPa's atmospheric pressure, and e is water vapor pressure in hPa (ITU-R P.453-14, 2019). This indicates how the radio refractivity depends on atmospheric parameters and transforms the refractive index into an inhomogeneous variable across the troposphere.

Many researchers conduct comprehensive studies that help in understanding this relationship. Adeyemi and Adedayo (2004) established relationships between surface water vapor density and tropospheric radio refractivity across three stations in Nigeria. Their findings indicated a strong correlation between them, underscoring the role of water vapour in driving refractivity variations.

**Correspondence:** Aminu Yaradua Sabiru. Department of Physics, , Umaru Musa Yar'adua University, PMB 2218, Batagarawa, Katsina State, Nigeria. ✉ aminu.sabiru@umyu.edu.ng.

**How to cite**: Sabiru, A. Y., Akinsanmi, A., & Ikechiamaka, F. N. (2025). Temporal Analysis of Radio Refractivity Variation over Kaduna: Implications for Radio Wave Communication Systems. *UMYU Scientifica*, 4(2), 100 – 108. https://doi.org/10.56919/usci.2542.012

(Adeyemi and Adedayo, 2004). Similarly, Aro and Willoughby (1992) conducted research on radio refractivity and evaporation ducting in the lower atmosphere which is relevant for having a complete idea of propagation anomalies. Their study highlighted the seasonal pattern, with higher radio refractivity during the rainy season. Consistent with other tropical studies (Aro and Willoughby, 1992). Falodun and Ajewole (2006) conducted their research where they measured the reflective index at Akure. The research provides comprehensive insights into temporal variability. They found out that values were generally high during the wet season, and refractivity values were generally high during the rainy season, with mean values around 365–369 N-units, reflecting the influence of humidity.(Falodun and Ajewole, 2006).

Amajama (2023) explored the impact of radio refractivity on mobile communication signal strength, noting seasonal variations and their effects on signal quality. The study highlighted higher refractivity during the wet season, affecting signal propagation in tropical monsoon climates (Amajama,2023). These studies provide valuable insights into the behavior of radio refractivity in tropical climates (Wang et al., 2018).

These researches either cover broader regions or are limited to a shorter period, typically decade or less, and lack specific location analysis details. Despite all the existing studies, there is still a huge gap in long-term, comprehensive radio wave refractivity studies in savannah regions of West Africa like Kaduna, Nigeria. The research gap identified by this study is the limited number of specific location studies of radio refractivity in the savannah regions of West Africa on a long-term basis, which is characterized by two types of seasons, i.e., wet season (April-October) and dry season (November-March). These present an opportunity to research how temporal changes impact electromagnetic wave propagation over a long period. Guinea savannah region experiences climatic conditions that pose higher rainfall and humidity during the rainy season, which significantly impact radio refractivity. Despite its importance in building infrastructure in communication such as mobile networks, broadcasting stations etc. (Sa'adu et al., 2020), there is insufficient research focusing on the variation of radio refractivity on a long-term basis across Kaduna. The lack of this kind of research is highly significant due to how the reliability of communication systems in these regions becomes very significant due to how atmospheric conditions greatly affect surface wave propagation (Akinbolati et al., 2018).

The research gap is particularly notable given the need for reliable data to optimize the performance of the communication system. To address the gap, this study aims to investigate radio refractivity in Kaduna over forty-one years from 1980-2020. The objectives are threefold: first, to calculate the radio refractivity using ITU recommended formula; second, to conduct an analysis on the variations in radio refractivity on a temporal basis; and third, to discuss the practical implications of the variations of radio refractivity for communication systems in the region. By providing a comprehensive analysis, this research will become essential to a better understanding of the effects of atmospheric conditions on radio propagation in tropical savannah, thereby aiding in the design and optimisation of communication networks in an environment that is similar. (Wang et. al., 2018).

## MATERIALS AND METHODS

### 2.1 Study Area

The study was conducted in Kaduna, Nigeria, located at 10.5167° N, 7.4333° E, as shown in Figure 1. It has an elevation of 760 meters. It is situated in the Guinea Savannah region, characterized by a distinct wet season (April–October) and dry season (November–March). The region experiences significant seasonal variations in temperature and humidity, which are expected to positively impact radio refractivity. The choice of Kaduna as a study location was informed by its unique environmental conditions and its role in regional communication networks (Adikpe et al., 2021).

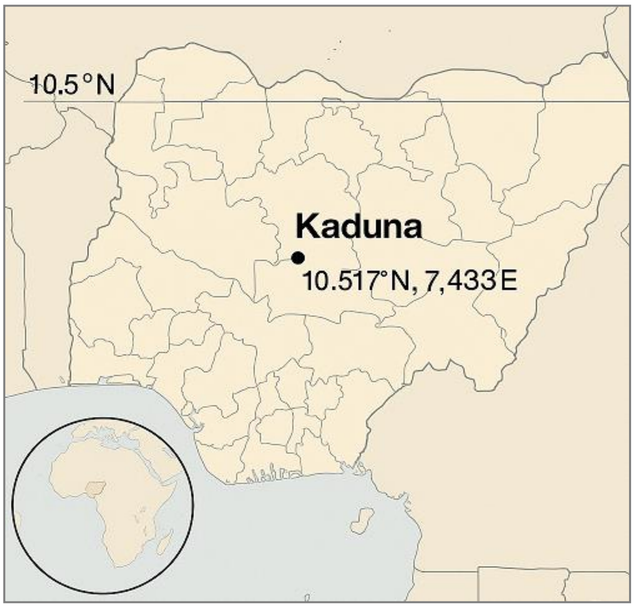


**Figure 1: A Map indicating the study location**

### 2.2 Data Acquisition and Mathematical Background

Meteorological data spanning from 1980 to 2020 were retrieved from European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 reanalysis dataset (Hersbach et al., 2020). The ERA5 dataset provides estimates of atmospheric variables, including temperature, atmospheric pressure, and relative humidity.

The ERA5 dataset reliability for a long-term climate study has been well-established in various scientific contexts. Hersbach et al. (2020) demonstrated the accuracy of the ERA5 dataset by comparing it with in-situ observations. The comparison demonstrates high correlation coefficients for temperature, pressure, and humidity, particularly in tropical regions (Hersbach et al., 2020). This reliability is crucial for ensuring the radio refractivity analysis, given the research solely depends on these meteorological parameters. Additionally, the ERA5 dataset's global coverage and high temporal resolution make it suitable for analysing temporal variations, as validated in many studies like Wang et al. (2002), which evaluated its accuracy for diagnosing evaporation ducts.

Radio refractivity (N) was calculated using the formula recommended by the International Telecommunication Union (ITU):

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

Where:

- N is the radio refractivity in N-units,
- T is the absolute temperature in Kelvin (K),
- P is the atmospheric pressure in hPa,
- e is the water vapour pressure in hPa.

The water vapour pressure (e) was derived from relative humidity (H, in percent) and saturated vapour pressure (es):

$$e = H \times \frac{e_s}{dh}$$

The saturated vapour pressure ($e_s$) was computed using

$$e_s = \mathrm{EF} \times 6.1121 \times \exp\left(\frac{\left(18.678-\frac{t}{234.5}\right)\times t}{(t+257.14)}\right)$$

and

$$\mathrm{EF} = 1 + 10^{-4}\,[7.2 + P \times (0.0320 + 5.9\times10^{-6}\times t^2)]$$

Where:

- t is the temperature in Celsius (°C),
- EF is the enhancement factor for water:

All calculations were carried out using monthly mean values of temperature, pressure and relative humidity. The computation method is similar to that of Sabiru et al. (2024), assuming that the meteorological values represent near-surface conditions. This assumption is consistent with many studies, such as Adeyemi and Adedayo (2004), which used same meteorological data for radio refractivity calculations in Nigeria. (Adeyemi and Adedayo 2004). The mean, maximum and minimum of yearly, seasonal and monthly variations were computed to analyze temporal variations. This multi-scale analysis of the radio refractivity provides a comprehensive understanding of the temporal variability of radio refractivity in Kaduna which is very important in understanding its implication in the propagation of radio waves for the communication systems. The methodology

## RESULTS AND DISCUSSION

Figures 2a, 2b, 2c, 2d, 2e, 2f, 2g, and 2h show the mean monthly radio refractivity of Kaduna for different five-year periods (1980-1984, 1985-1989, 1990-1994,1995-1999, 2000-2004, 2005-2009, 2010-2014 and 2015-2020) respectively. The figure illustrates the seasonal pattern with higher values acquired in rainy season months. Monthly radio refractivity exhibited significant variation. The highest recorded value of radio refractivity is 391.5037 N-units in October 1997, and the lowest value was 279.0400 N-units in March 1990. The difference between these extremes was 112.4637 N-units, underscoring the substantial impact of seasonal meteorological changes on radio refractivity. This range indicates that the months of the wet season, such as October, experience high humidity, increasing water vapour pressure, and therefore refractivity will be high. While the months of dry season such as March, show decreased values due to lower values of humidity. The mean monthly value of radio refractivity in Figure 2a-h illustrates the consistency of the higher radio refractivity during the months of wet season across the time of study with slight variations with time

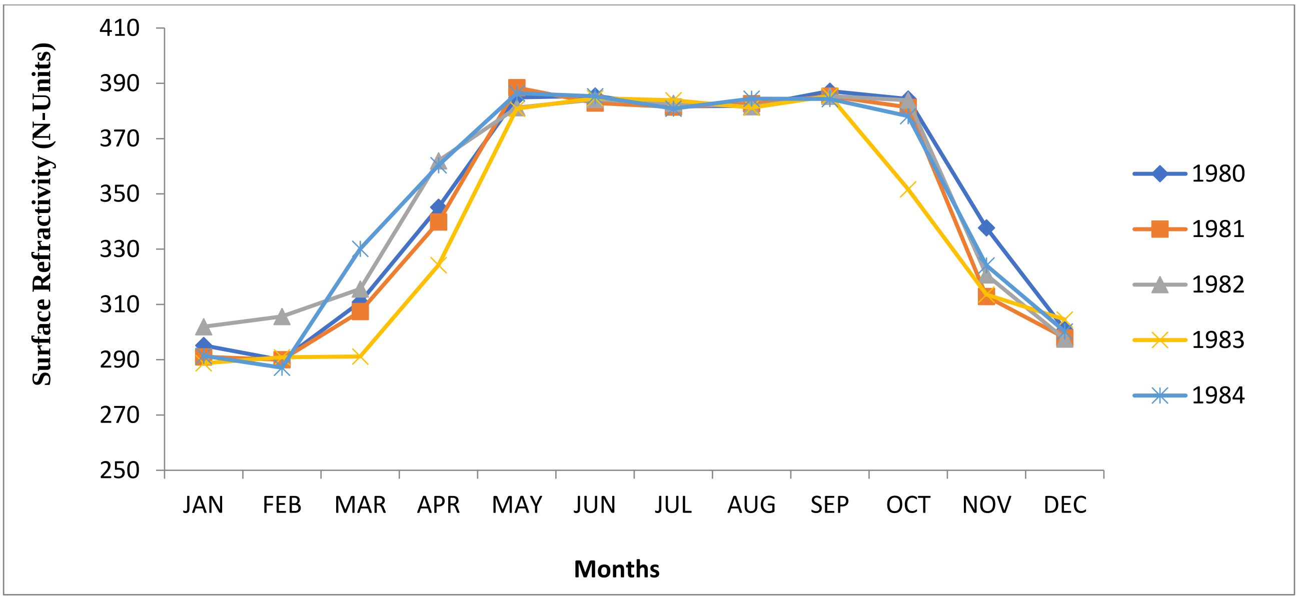


**Figure 2a: Mean Monthly Radio Refractivity of Kaduna from 1980-1984 years**

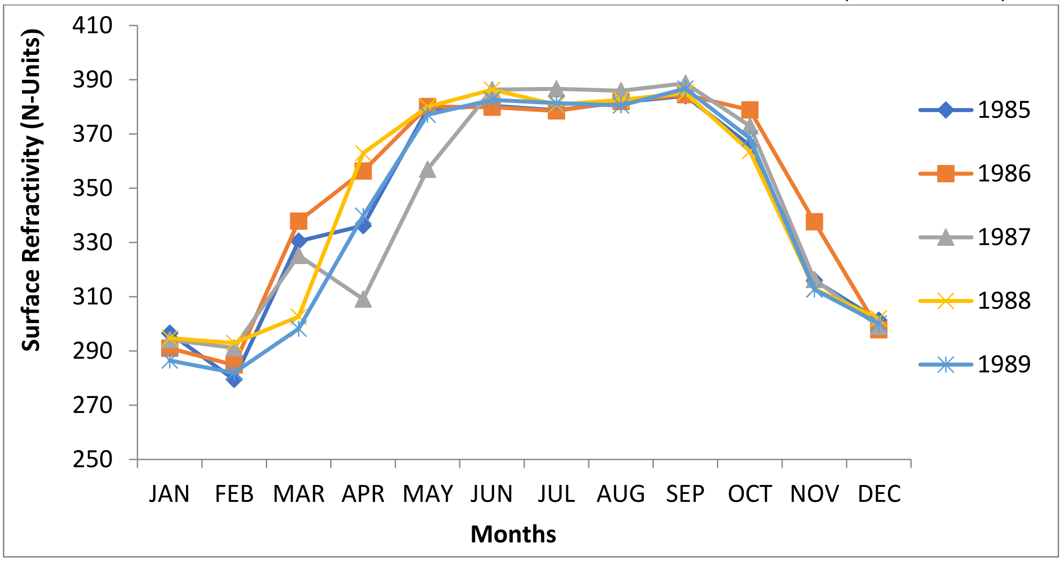


**Figure 2b: Mean Monthly Radio Refractivity of Kaduna from 1985-1989 years**

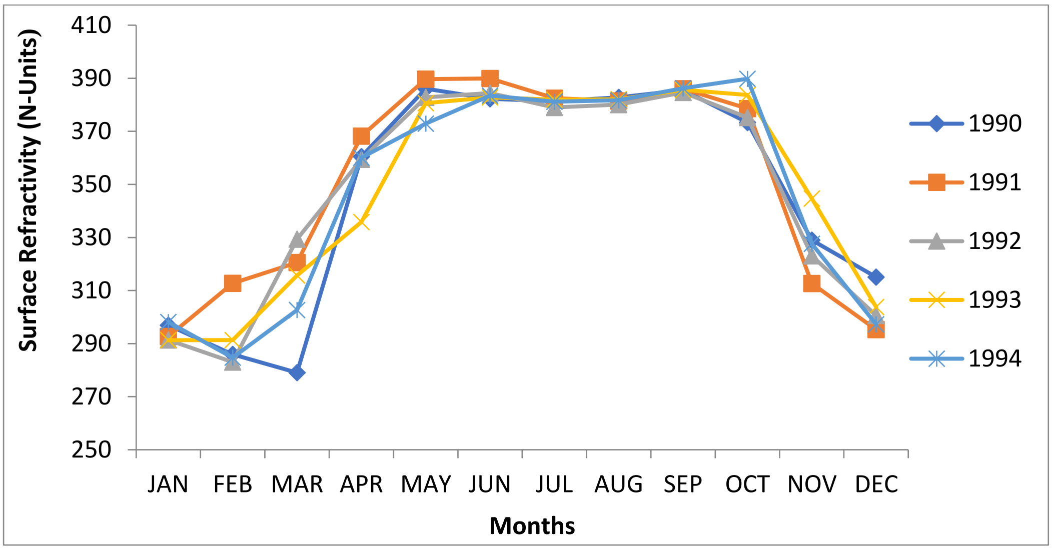


**Figure 2c: Mean Monthly Radio Refractivity of Kaduna from 1990-1994 years**

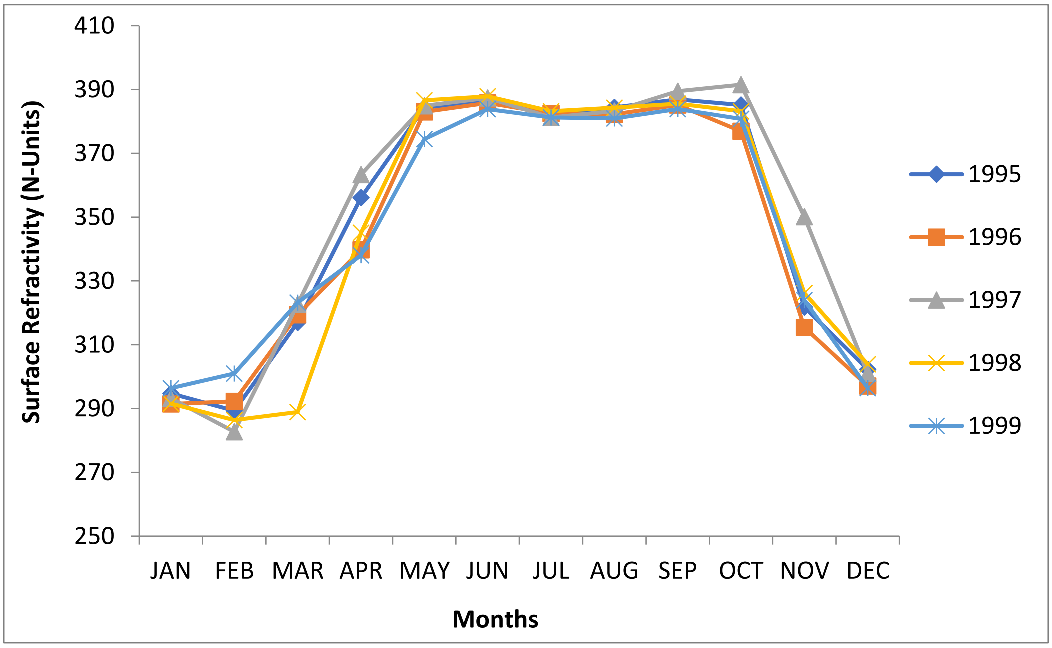


**Figure 2d: Mean Monthly Radio Refractivity of Kaduna from 1995-1999 years**

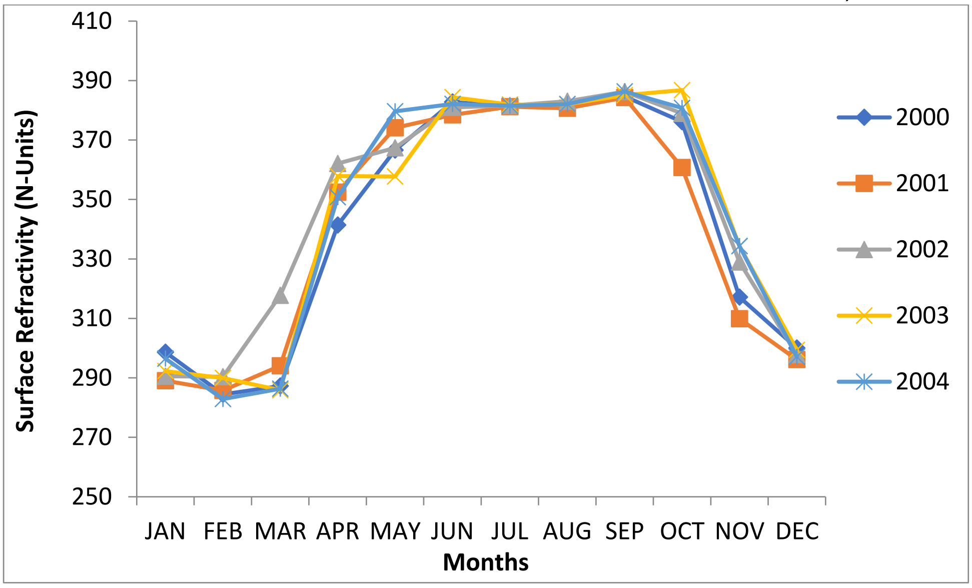


**Figure 2e: Mean Monthly Radio Refractivity of Kaduna from 2000-2004 years**

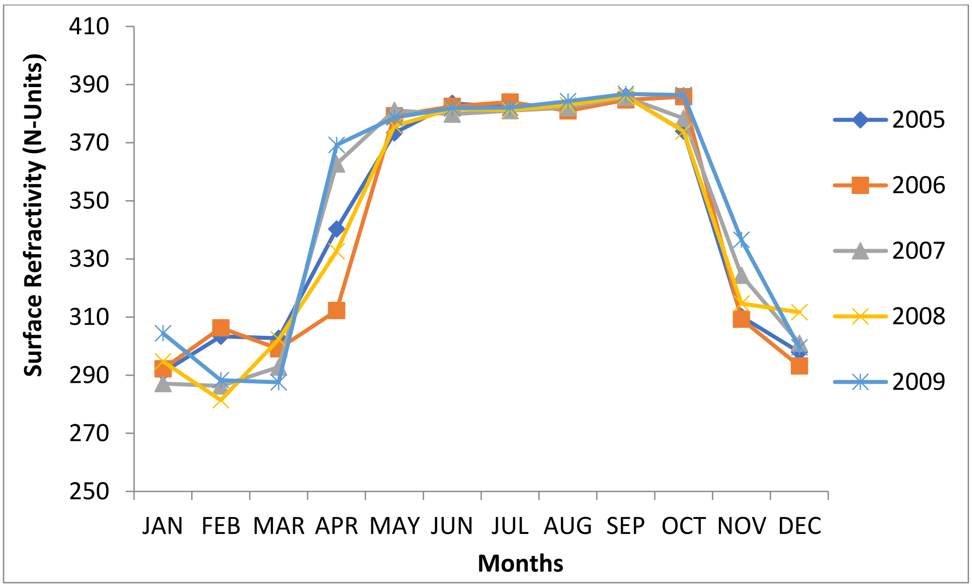


**Figure 2f: Mean Monthly Radio Refractivity of Kaduna from 2005-2009 years**

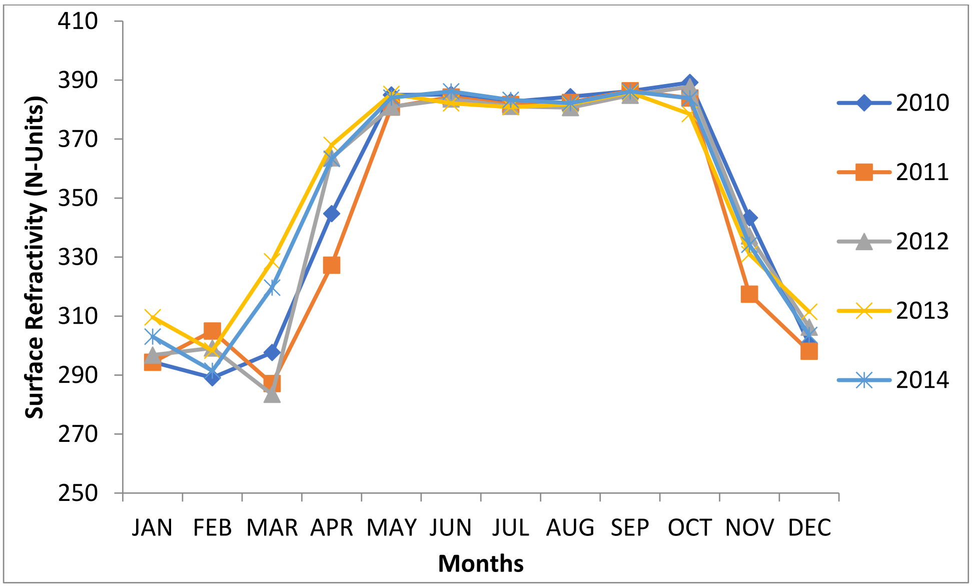


**Figure 2g: Mean Monthly Radio Refractivity of Kaduna from 2010-2014 years**

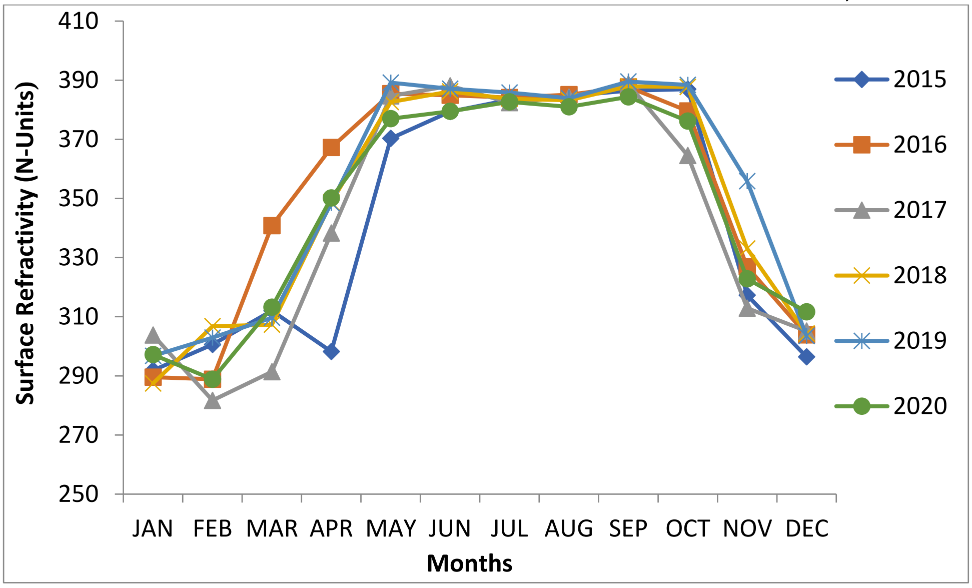


**Figure 2h: Mean Monthly Radio Refractivity of Kaduna from 2015-2020 years**

Figure 3 below depicts Kaduna's mean yearly radio refractivity from 1980 to 2020, providing a long-term trend with minor fluctuations, peaking in 2013. The mean yearly radio refractivity analysis in Kaduna revealed the range from 340.0565 N-units to 353.4296 N-units over the forty-one year's study period, with the highest value recorded in 2013 and the least in 1983. The difference between the maximum and minimum yearly mean was 13.3731 N-units, indicating a stable profile of radio refractivity over a long period. This stability suggests that the climate conditions in Kaduna, which is characterised by the Guinea Savannah region, have not significantly altered the average atmospheric conditions affecting the propagation of radio waves over the period of study. Figure 3 highlights a minor fluctuation of mean yearly radio refractivity, with the highest and lowest points in 2013 and 1983 being the notable points

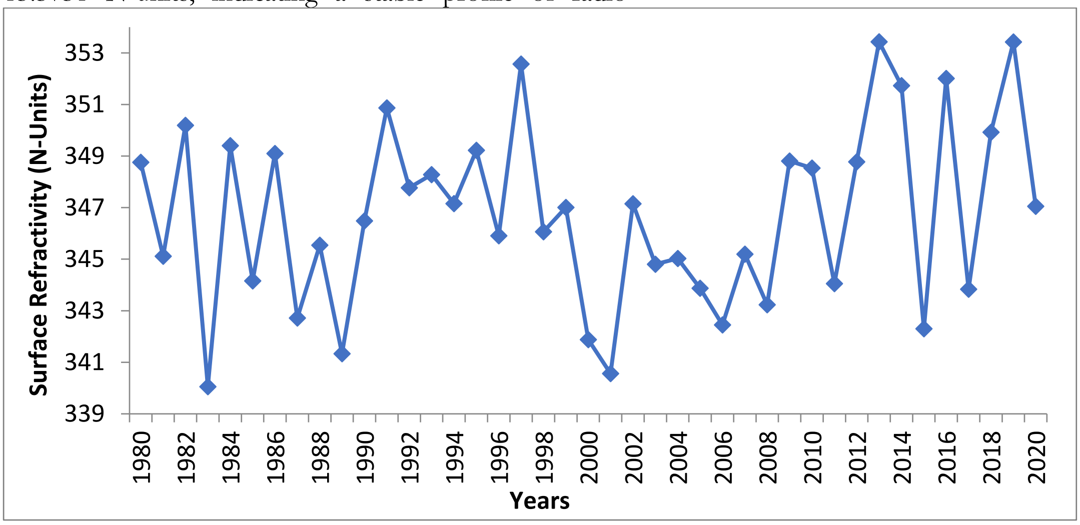


**Figure 3: Mean Yearly Radio Refractivity of Kaduna from 1980-2020 years**

Figure 4a and b shows the mean radio refractivity of Kaduna during wet and dry seasons. Seasonal analysis of radio refractivity revealed that it was higher during the wet season (April-October) and lower during the dry season (November-March). This pattern that was illustrated is consistent with the variation of increased temperature and humidity during the wet season, which increase the water vapour pressure, a key component in the formula for radio refractivity provided by ITU. It was observed that the mean radio refractivity during the wet season is higher, as illustrated in Figure 4a & b. Observing the monthly extremes with 391.5037 N-units in October (Wet season) and 279.0400 N-units in March (Dry season), it can be inferred that the mean radio refractivity during the wet season is significantly higher.

Comparing the findings of this research with the studies from other regions provides valuable insight as shown in Table 1. For the sake of the comparison prior studies from different regions across Nigeria were selected to ensure a diverse geographical representation

Table 1 provides the comparison of figures from the study area with the other locations, including mean radio refractivity and the range of mean monthly values where available, together with the type of climate for context.

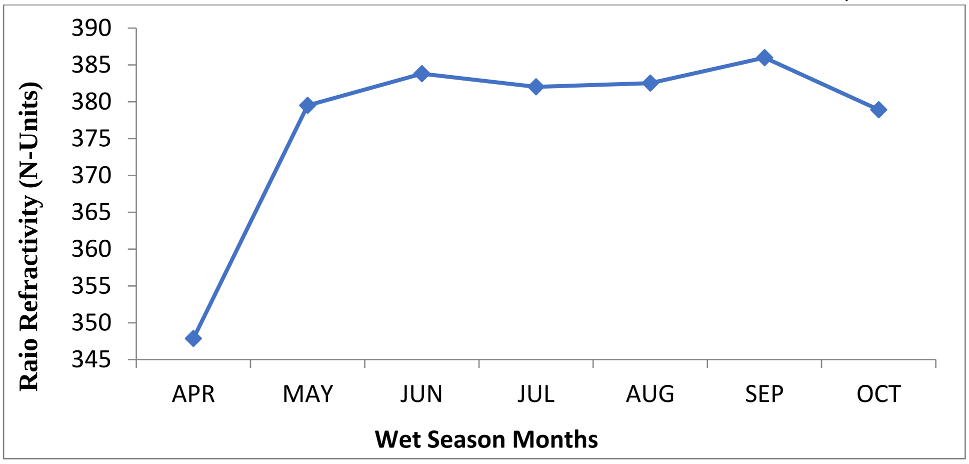


**Figure 4a: Mean Radio Refractivity of Kaduna during Wet Season**

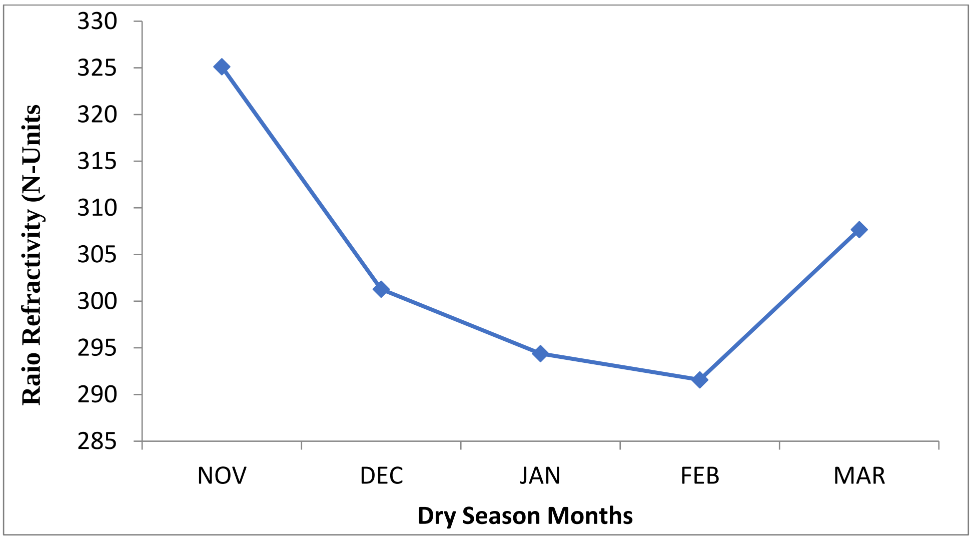


**Figure 4b: Mean Radio Refractivity of Kaduna during dry Season**

**Table 1: comparing radio refractivity figures, with climate types adjusted for accuracy:**

| Study Location | Mean RF (N-units) | Range of MMV (N-units) | CT | Reference |
|---|---|---|---|---|
| Kaduna, Nigeria | 346.7[a] | 279.04 to 391.50[1] | GS | This study |
| Akure, Nigeria | ~364[b] | 352.0 to 369.0 | TR | Falodun& Ajewole, 2006 |
| Maiduguri, Nigeria | ~335[c] | Not specified | SS | Adeyemi & Adedayo, 2004 |
| Kano, Nigeria | ~340[c] | Not specified | SS | Adeyemi & Adedayo, 2004 |
| Enugu, Nigeria | ~350[c] | Not specified | TR | Adeyemi & Adedayo, 2004 |

RF = Radio Refractivity; MMV = Mean Monthly Values; CT = Climate Type; GS = Guinea Savannah; TR = Tropical Rainforest; SS = Sahel Savanna

[a]Calculated from yearly means provided in this study

[b]Falodun and Ajewole (2006) reported mean monthly values during rainy and harmattan seasons

[c]Adeyemi and Adedayo (2004) reported mean annual values for Nigerian stations

The results of this study are found to be consistent with those from the same tropical savannah climates and show the importance of local climate characteristics consideration in the studies of radio wave propagation studies. The comparison with temperate regions indicates that higher seasonal variation in the study area is likely due to its highly distinct seasons (wet and dry seasons), which are influenced by changes in humidity rather than temperature. The findings provide a huge contribution to understanding the propagation of electromagnetic waves in tropical savannah regions and its implications for the optimization of communication networks.

The comparison reveals that the radio refractivity of the study area aligns with the refractivity from tropical savannah and rainforest climates. The higher values during the wet seasons are consistent with studies like Falodun and Ajewole (2006) in Akure, Nigeria, where the value of the mean rainy season was around 364 N-units. The comparison of values with Sahel savannah locations like Maiduguri (~335 N-units) and Kano (~340 N-units) indicates lower mean values. This may be likely due to drier conditions, highlighting the impact of regional climate. This aligns with Adeyemi and Adedayo (2004), who noted lower refractivity in drier northern Nigerian stations. The wider range in Kaduna compared to these locations underscores the need for location-specific studies in savannah climates, particularly for communication system design.

The practical implications that are derived from understanding the variation of radio refractivity for the optimisation of communication systems are described below:

(i) Network Planning:

The operators of the communication network can adjust the antenna configurations and power of the transmitter based on the radio refractivity pattern, which can optimize the signal's coverage and minimize interference. For instance, when refractivity is high (up to 391.5037 N-units) during the wet season, there might be an increased likelihood of signal bending, which could be exploited for extended coverage or managed to avoid multipath interference, as suggested by Amajama (2023).

(ii) Frequency Selection:

Atmospheric conditions affect different frequency bands differently. Knowing the variations in radio refractivity can greatly help select appropriate frequencies for specific applications. This can minimize signal degradation, particularly for VHF and UHF bands that are used in mobile communications (Akinbolati and Ajewole, 2020).

(iii) Weather-Dependent Operations:

Real-time monitoring of radio refractivity can inform dynamic adjustments in the communication system, enhancing performance during adverse weather conditions like during the wet season when there is a high possibility of ducting.

These applications are particularly relevant given Kaduna's role in regional communication infrastructure, as noted in studies on GSM network performance.

## CONCLUSION

The present study examined the variations of radio refractivity in Kaduna, Nigeria, over forty-one years. This investigation has elucidated key insights into the temporal dynamics of radio refractivity and its implications for radio wave propagation within a tropical savannah climate. The analysis revealed several critical findings. Firstly, a notable stability of the yearly mean radio refractivity is observed, fluctuating between 340.0565 and 353.4296 N-units, with a difference of only 13.3731 N-units across the four decades. This consistency of yearly mean values indicates that the Guinea-savannah climate of the study area maintains relatively stable atmospheric conditions over the study periods. This is essential for long term strategic communication infrastructure planning. In contrast, monthly radio refractivity variability was observed to be very high. Ranging from 279.0400 N-units in March 1990 to 391.5037 N-units in October 1997, resulting in a difference of 112.4637 N-units. This fluctuation indicates the effects of the seasonal transition of meteorological variables, specifically between the wet and dry seasons. On the refractivity levels, the pattern is consistent with the observations in other tropical regions where humidity drives seasonal changes

Further seasonal analysis reveals that radio refractivity is significantly elevated during the wet season when compared to the dry season. This aligns with the expectation of the influence of the increased water vapour pressure on the refractive index. Additionally, a comparison of the radio refractivity of this research to that of other studies from other regions reveals that values of Kaduna`s radio refractivity align closely with those of tropical savannah and rainforest climates and exceed those observed in drier drier Sahel Savannah locales such as Maiduguri and Kano. These findings underscore the pivotal role of local climatic characteristics in shaping radio refractivity profiles and indicate the necessity for conducting location-specific studies in regions that pose pronounced seasonal variations.

These findings are essential not only to the scientific implications but also to the practical implications. In term of communication engineering, the observed stability in the mean yearly refractivity provides a reliable insight for designing robust communication networks capable of sustained performance over decades. However, the substantial monthly and seasonal variations necessitate adaptive strategies.

## REFERENCE


Adeyemi, B., & Adedayo, K. D. (2004). Surface water vapour density and tropospheric radio refractivity linkage over three stations in Nigeria. *Atmospheric Research, 69*(1–2), 99–113. [Crossref]

Adikpe, A. O., Iyobhebhe, M., Amlabu, C. A., & Bashayi, J. G. (2021). Congestion analysis of a GSM network in Kaduna State Nigeria. *International Journal of Advanced Natural Sciences and Engineering Researches, 5*(1), 1–6.

Akinbolati, A., & Ajewole, M. O. (2020). Investigation of path loss and modeling for digital terrestrial television over Nigeria. *Heliyon, 6*(7), e04101. [Crossref]

Akinbolati, A., Ajewole, M. O., & Adediji, A. T. (2018). Path loss prediction modeling for digital terrestrial television (DTTV) in the tropical rain forest zone of Nigeria. *FUDMA Journal of Sciences, 2*(3), 2–8.

Akinbolati, A., Akinsanmi, O., & Ekundayo, K. R. (2016). Signal strength variation and propagation profiles of UHF radio wave channel in Ondo State, Nigeria. *International Journal of Wireless and Microwave Technologies, 8*(4), 12–28. [Crossref]

Amajama, J. (2023). Radio refractivity impact on signal strength of mobile communication. *Journal of Electrical and Computer Engineering*. [Crossref]

Aro, T. O., & Willoughby, A. A. (1992). Radio refractivity and evaporation ducting in the lower atmosphere in Nigeria. *Journal of Atmospheric and Terrestrial Physics, 54*(6), 687–692.

Falodun, S. E., & Ajewole, M. O. (2006). Radio refractive index in the lowest 100-m layer of the troposphere in Akure, South Western Nigeria. *Atmospheric Research, 81*(1), 65–73. [Crossref]

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., ... & Thépaut, J.-N. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society, 146*(730), 1999–2049. [Crossref]

International Telecommunication Union. (2019). *The radio refractive index: Its formula and refractivity data* (ITU-R P.453-14). itu.int

Li, X., Chen, Y., & Wang, B. (2023). Structure and variations of global planetary boundary layer top from 2008–2022 multiple GNSS RO observations. *Atmospheric Research, 285*, 106–118.

Sa'adu, L., Abubakar, A., & Usman, A. D. (2020). A review on the effects of radio refractivity and atmospheric parameters on signal quality at Ultra High Frequency (UHF). *International Journal of Science for Global Sustainability, 6*(2), 123–134. [Crossref]

Sabiru, A. Y., Akinbolati, A., Ikechiamaka, F. N., & Abe, B. T. (2024). Characterization of some secondary radio-climatic factors for reliable radio wave propagation and link's design over North Western Nigeria. *Advances in Space Research, 74*(2), 890–898. [Crossref]

Wang, Y., Zhang, J., & Li, X. (2022). Analysis of the accuracy of using ERA5 reanalysis data for diagnosis of evaporation ducts in the East China Sea. *Frontiers in Marine Science, 9*, 1108600. [Crossref]

Wang, Y., Zhang, J., & Li, X. (2018). Evaluation of global horizontal irradiance estimates from ERA5 and COSMO-REA6 reanalyses using ground and satellite-based data. *Solar Energy, 170*, 123–135.

Yusuf, N., Ekpe, O. E., Said, R. S., Ayantunji, B. G., & Umahi, A. E. (2019). Seasonal and diurnal trends of radio refractivity in a tropical environment using ground-based automatic weather stations. *Meteorology and Atmospheric Physics, 132*, 327–340. [Crossref]