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ORIGINAL RESEARCH ARTICLE

The Investigation of Surface Radio Refractivity Over Lokoja, Kogi State Nigeria

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ABSTRACT

This research investigated the variation of Surface Radio Refractivity and its propagation effects on radio signals over Lokoja, Kogi State, Nigeria. The study used six years (2015-2020) of satellite data on temperature, pressure, relative humidity and rainfall at the surface (12 km) above ground level. The data retrieved were used to determine the monthly, seasonal, and annual Surface Radio Refractivity value for Lokoja Kogi State. Results show that high Surface Radio Refractivity values were recorded generally during the wet season months compared to the dry season months in all Six years (2015-2020). The average values of Surface Radio Refractivity 307.7407 (N-units) and 323.4674 (N-units) were obtained during the dry and wet season, respectively. The minimum surface radio refractivity values of 280.7245, 284.6583, 308.0021, 285.2304, 304.2521 and 285.9139 (N-units) were recorded for the years 2015, 2016, 2017, 2018, 2019, and 2020 respectively. On the other hand, the highest values of 330.8153, 331.8133, 330.3580, 330.9278, 332.4704, and 331.1316 (N-units) were recorded for the years 2015, 2016, 2017, 2018, 2019 and 2020, respectively. Higher values of Surface Radio Refractivity were recorded generally during the wet season compared to the dry season months in all years (2015-2020) in Lokoja, Kogi State. This implies higher radio signal attenuation due to Ns during the wet season compared to the dry season. The correlation coefficients between Surface Radio Refractivity Ns and temperature are -0.41, -0.51, -0.49, -0.48, -0.46, -0.50, pressure 0.07, -0.15, -0.28, -0.08, -0.11, -0.26, relative humidity 0.89, 0.84, 0.75, 0.84, 0.77, 0.83, and the amount of rainfall 0.76, 0.64, 0.73, 0.58, 0.51, 0.65 respectively in the year 2015, 2016, 2017, 2018, 2019, 2020. The overall findings of the work will be useful to radio engineers for properly planning a reliable power budget for terrestrial radio communication over Lokoja, Kogi State.

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KEYWORDS
Surface Radio Refractivity, radio signal attenuation, temperature, pressure and rainfall.

INTRODUCTION

In communicating, ideas, voices, writing, signs, and other signals are among the various ways information can be shared. According to Akinbolati *et al.* (2020), radio communications essentially include sending a signal from the source to the recipient via a medium without connecting wires. Any communications system's design and operation must consider how the Earth's atmosphere affects radio waves travelling across space. These circumstances can result in uncontrollable variations in signal amplitude, phase, polarization, and angle of arrival on the earth-space link when they exist alone or in combination. This lowers the quality of analog transmissions and raises the error rate of digital transmissions (Rotheram, 1989). The transmission medium is always a primary source of signal quality degradation in radio communication. Thus, it becomes important to ensure the signal can handle tropospheric-induced degradations caused by changes in temperature, relative humidity, atmospheric pressure, rainfall, and atmospheric gases when this medium contains the troposphere (Rotheram, 1989). The majority of wireless and data communication system designers are concerned with the nature of the atmosphere through which the signal propagates from the source, or transmitter, to the destination, or receiver, during the design of radio links and power budgets (Akinbolati *et al.,* 2020).

Radio signal scattering, absorption, amplitude and phase scintillations, and other complex mechanisms are caused by random spatial fluctuations in the troposphere's refractive index. Co-channel interference and signal transmission losses can result from these mechanisms. Because of the high frequency of intense tropical rains, the influence of interference caused by variations in troposphere refractivity is significantly greater in tropical climates than in temperate climates (Rotheram, 1989).

The characteristics of the atmosphere have an impact on all radio waves that travel through space. The various components of the atmosphere can absorb, scatter,

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reflect, and refractive. The part of the atmosphere most closely related to human life is the troposphere; it extends from the Earth's surface to an altitude of about 10 km at the Earth's poles and 17 km at the equator (Akpootu and Iliyasu, 2017). The degree of atmospheric effects depends mainly upon the signal's frequency and power and on the state of the troposphere through which the radio wave propagates. The characterization of tropospheric variability is significant to radio communications, aerospace, environmental monitoring, disaster forecasting, etc. (Akpootu and IIiyasu, 2017). Changes in temperature, pressure and humidity as well as clouds and rainfall, influence how radio waves propagate from one point to another in the troposphere. Although this effect only became important at frequencies greater than 100 MHz, especially in the lower atmosphere, this region still significantly influences radio waves at frequencies above 30 MHz (Hall, 1979).

Based on the analysis of the radio refractive index, which is generated from these three factors, the impact of meteorological variables pressure, temperature, and relative humidity on radio wave propagation at the ultrahigh-frequency (UHF) and microwave frequencies are examined (Bean and Dutton, 1966). Currently, International Telecommunication Union Recommendation ITU-R P.370-7* (VHF and UHF propagation curves for the frequency range from 30 MHz to 1000 MHz Broadcasting services), ITU-R (1994-1995), serves as the basis for designing broadcasting services for frequencies beyond 30 MHz. Most of the propagation curves and formulas in the recommendation are based on measurements that were made mostly in North America, Europe, and Japan, temperate regions of the planet. Due to the lack of reliable data from these areas, these curves were utilized to develop radio services in sub-Saharan Africa even though the climate differs from those of the above locations (Hughes, 1998). Therefore, rather than basing such designs on extrapolated or interpolated data derived from mostly temperate countries of the world, any contribution based on actual, long-term measurements and scientific interpretation of the results should be of interest, especially to engineers interested in designing terrestrial or satellite-based microwave radio links in the tropics.

When evaluating the quality of ultrahigh-frequency (UHF), very high frequency (VHF), and super high frequency (SHF) communications, the radio refractive index is a crucial factor. Both surface (ground level) and elevated refractivity data are frequently needed for radio channel characterization; in particular, surface refractivity is highly helpful for predicting some propagation effects. The most helpful indicator of the likelihood of refractivity-related effects occurring, which is necessary for prediction approaches, is local coverage and refractivity statistics, such as refractivity gradient (Bean and Dutton, 1966). Consequently, the planning and construction of terrestrial radio links for communication networks, radar, and propagation applications require a precise understanding of the radio refractive index of the lower atmosphere (Caglar *et al.,* 2006; Naveen *et al.*, 2011). Therefore, fluctuations in refractive index over time and space should be considered in any model. The radio refractive index is roughly equivalent to 1.0003 near the Earth's surface in standard atmosphere conditions. The radio refractivity N, which is defined as the measure of the deviation of the refractive index n of air from unity and scaled up in parts per million to obtain more palatable figures, is often used to measure the refractive index of air in the troposphere because its value is very close to unity. As a result, N is a dimensionless quantity that can be expressed as N units (Hughes, 1998).

Refractive changes frequently result from these differences in meteorological conditions (Okoro and Agbo, 2012). Changes in the troposphere's air's radio refractive index govern the propagation of radio waves (Adediji and Ajewole, 2008). These alterations may cause a radio wave propagating in the troposphere to abruptly change its direction of propagation, attenuating the signal. This idea has led to the need for radio engineers and scientists to research radio refractivity to properly plan dependable radio links, power budgets, and coverage areas.

MATERIALS AND METHODS

Study Area and Location

The city of Lokoja in Kogi state, North-Central Nigeria, was the subject of this investigation. The coordinates of Lokoja are 07°48'07"N and 06°44'39"E. It is bordered by the Niger to the north and east, upstream from the capital to the boundary of Kwara State; it is also flanked by the Kogi State capital and the point where the Niger and Benue rivers converge. With a land area of 3,180 km^2 and a population of 195,261 at the 2006 census, Lokoja is also a Local Government Area of Kogi State (World Urbanization Prospects United National Population Estimates and Agglomeration 2020). It is located at about 7.8023° N of the equator and 6.7333° E of the Meridian. According to the crow's tail, it is roughly 165 kilometres southwest of Abuja and 390 km northeast of Lagos. Felele, Adankolo, Otokiti, and Ganaja are just a few of the city's numerous suburbs. Residential areas vary in density. The town is located in Nigeria's tropical wet and dry savanna climate zone, where daytime highs average around 34.50C and lows of 22.80C. The town has year-round heat. Due to the higher elevation in the north during the dry season, there is a reduction in relative humidity in the research area from south to north. This variance vanishes during the rainy season, and the region is covered in a thick layer of clouds due to the high relative humidity (Alabi, 2009). Figure 1 shows a map of Nigeria with the study area highlighted.

Source of data used for this study

Six years (2015-2020) of satellite data of weather parameters, temperature, pressure, humidity, and amount of rainfall at the surface (12km and 100m) above ground level were obtained from the European Center for

Medium-Range Weather Forecast (ECMRF, 2022) in January 2022. The European Center for Medium-Range Weather Forecasts (ECMWF)-ERA5 is an independent intergovernmental organization established in 1975. They have scientific and technical research to develop numerical models and data assimilation systems (ECMWF. 2022). They generate data and provide numerical weather predictions on a global scale. The world's largest supercomputer facilities and meteorological data archives are found at this site. For users worldwide, they generated a global numerical weather forecast. medium-range, monthly, and seasonal weather forecasts in addition to climate change and Copernicus atmosphere monitoring. Their forecasts are intended to illustrate the most likely course of the weather, and the centre generates an ensemble of forecasts that displays the climatic re-analysis, re-forecast, forecast, analysis, and multi-model database in real-time and in the past (ECMWF, 2021). Their data are trustworthy, and numerous publications have used them in their published works (Mmahi *et al.*, 2021; Ojo *et al.*, 2023; ITU-R P453, 2017). One interesting feature of this study is recent satellite atmospheric data (2015–2020) over Lokoja, utilizing an ITU-recommended approach to generate secondary data.

Figure 1: Map of Nigeria showing the study area

Data Sorting and Empirical Tools

The data set was divided into monthly, seasonal, and annual formats for ease of analysis and result discussion. (1) (ITU-R, P.453, 2003, P.453-14, 2017); (Adediji and Ajewole, 2008; Ayantuji *et al.*, 2011) provides the universal radio refractivity equation: Surface radio refractivity, or Ns, is the refractivity at the atmosphere's surface determined by surface meteorological factors. The surface radio refractivity was calculated using equations (1) through (3) (Mmahi, 2021).

$$N = 77.6\frac{P}{T} + 3.73\, X10^5 \frac{e}{T^2}. \qquad (1)$$

$$e = \frac{He_s}{100}. \qquad (2)$$

$$e_s = aexp\left\{\frac{bt}{t+c}\right\}, \qquad (3)$$

Where t is the temperature in Celsius, a= 6.1121, b=17.502 and c=240.97 (ITU-R, 2019).

Where, e_s is the maximum (or saturated) vapour pressure at the given air temperature, t (^{o}C) and H (%RH) is the humidity. P is the air pressure (hPa), T is the 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).

To determine the degree of relationship between the variables, Karl Pearson's product correlation coefficient used for continuous data as presented in (4)

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

RESULTS AND DISCUSSION

Variation of Surface Radio Refractivity and Its Effects on Radio Communication over Lokoja, Kogi State.

Figures 2, 3, 4, 5. 6 and 7 show the calculated monthly variation of surface radio refractivity in Lokoja, Kogi State, for the six years under investigation (2015-2020).

Low readings were seen between January and December of the dry season 2015, as shown in Figure 2 below. December had the lowest value, measured at 280.7245 (N-units), while May had the greatest value, measured at 330.8153 (N-units). Before reaching the peak value of 330.8149 (N-units) in May, it displayed a sharp increase in February, continued to plateau from February to April, then gradually decreased from May to August, increased from August to October, decreased in November, and finally reached the minimum value of 280.7245 (N-units).

A minimum value of 284.65893 (N-units) was determined in the dry season month of January, and a maximum value of 331.8133 (N-units) was determined in the wet month of April. The Surface Radio Refractivity in the beginning of the year recorded was very low, but later in March, it experienced a rapid increase before reaching a peak value of 331.8133 (N-units) in the wet season month of May. Figure 3 below shows low values observed during the dry season months of January, February, and December in 2016.

Figure 4 below shows how the refractivity in 2017 began with a low value in January and February and then gradually increased from March to May, reaching its peak value of 330.3580. After that, it fluctuated from May to September, then increased gradually in October before slowing down until the end of the year. The dry season month of February yielded a low value of 308.0015 (N-units), while the rainy season month of May yielded a maximum value of 330.3580 (N-units).

Figure 5 below shows how the Surface Radio Refractivity in 2018 started at a minimum value of 285.2303 (N-units) in 2018 and then rapidly increased between March and May. From June onward, there was a gradual drop in surface radioactivity, maintained from July through November, before declining in December. January and December during the dry season had the lowest values. The dry season month of January had the lowest value, 285.2303 (N-units), and the wet season month of April had the greatest value, 330.9278 (N-units).

According to Figure 6 below, 2019 began with a low value of 309.822 (N-units) in January. It then gradually increased in February through May, reaching its peak value of 332.4072. June saw a slight decline, but it then maintained a plateau between July and October, after which it gradually increased in November before reaching the lowest value of the year in December. January, February, and December—the dry season months—saw low readings. The dry season month of December had the lowest value of 304.2521 (N-units), while the rainy season month of May recorded the greatest value of 332.4704 (N-units).

According to Figure 7 below, in 2020, Surface Radio Refractivity began at its lowest point in January and remained on a plateau until February. Then, in March, a sharp increase continued on a plateau until June, when it reached its highest value of 334.0723 (N-units). After that, it gradually decreased in July and August before gradually increasing in September and October and declining in November and December. January was a dry month with a minimum value of 285.9139 (N-units) and a maximum value of 334.0723 (N-units).

In addition, minimum values of 280.**7245, 284.6583, 308.0015, 285.2304, 304.2521 and 285.9139(N-units)** were recorded for the years 2015, 2016, 2017, 2018, 2019, and 2020 respectively. On the other hand, the highest values of 330.8153, 331.8133, 330.3580, 330.9278, 324.4007, and 334.0723 (N-units) were recorded for the years 2015, 2016, 2017, 2018, 2019 and 2020, respectively.

This volatility may be explained by the Earth's reaction to solar insolation, which is the primary cause of the observed weather conditions (Ayantuji et al., 2011). As a result, during the dry season month, the temperature was higher the humidity was lower, and vice versa. The surface radio refractivity comparison charts for the six years of the investigation are shown in Figure 8. In Lokoja, Kogi State, the fluctuation follows almost the same trend, with lower values observed during the dry season than in the wet season. Furthermore, typical variations in the dry and wet components of surface radio refractivity over Lokoja, Kogi State, are shown in Figures 9, 10, 11, 12, 13, and 14. It is observed that the dry term recorded higher values compared to the wet. However, it remains constant throughout the year and determines the overall surface Radio refractivity trends.

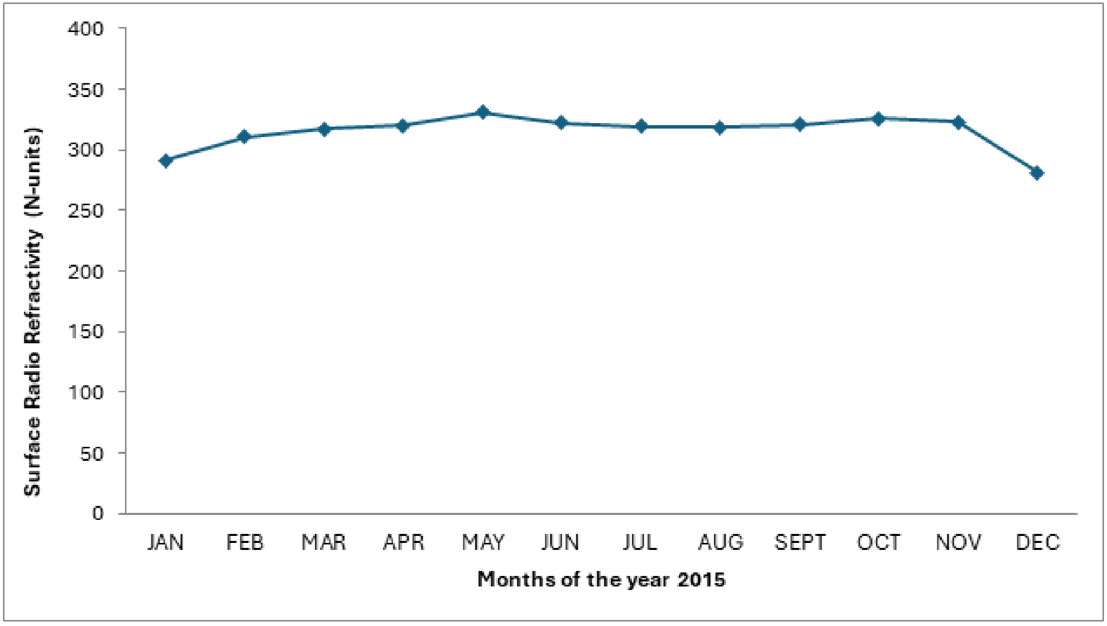

Figure 2: Monthly Variation of Surface Radio Refractivity over Lokoja in the Year 2015

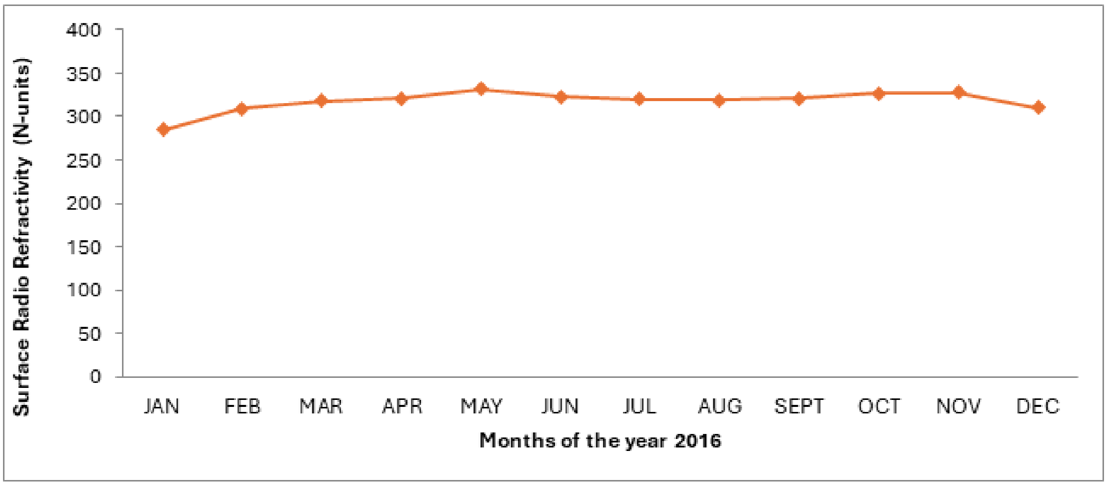

Figure 3: Monthly Variation of Surface Radio Refractivity over Lokoja in the Year 2016

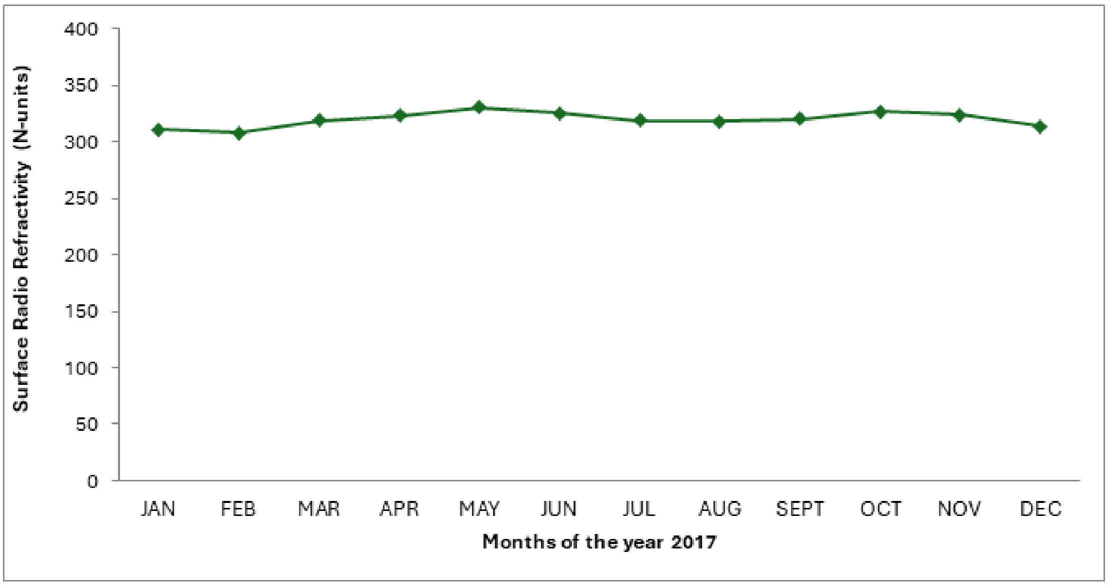

Figure 4: Monthly Variation of Surface Radio Refractivity over Lokoja in the Year 2017

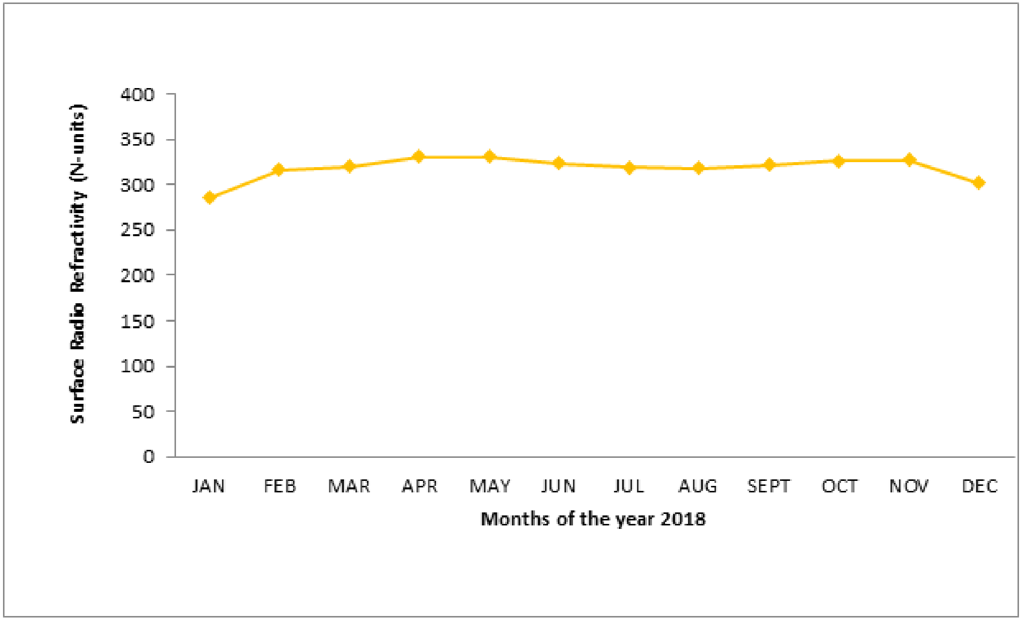

Figure 5: Monthly Variation of Surface Radio Refractivity over Lokoja in the Year 2018

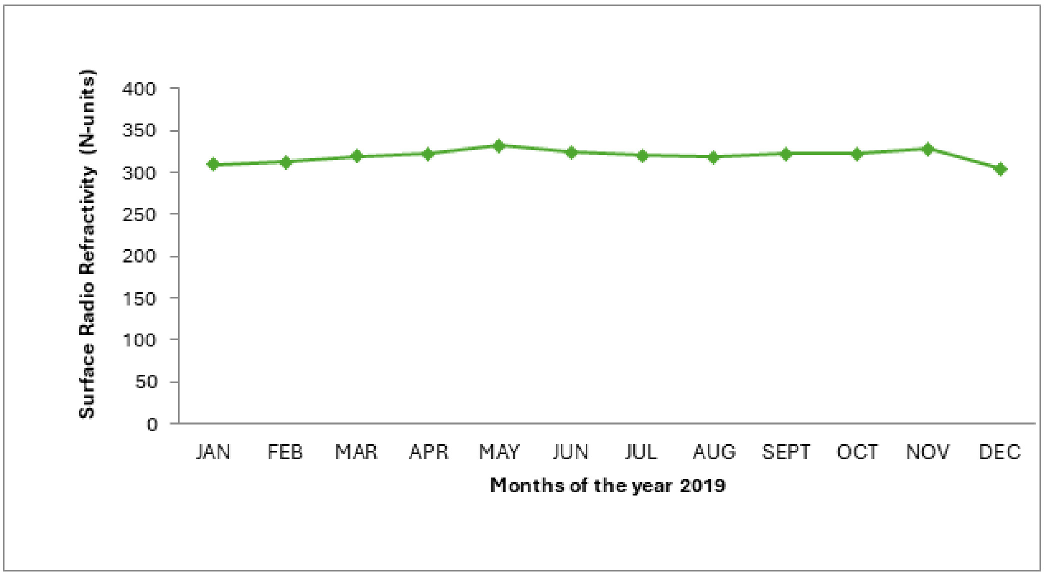

Figure 6: Monthly Variation of Surface Radio Refractivity over Lokoja in the Year 2019

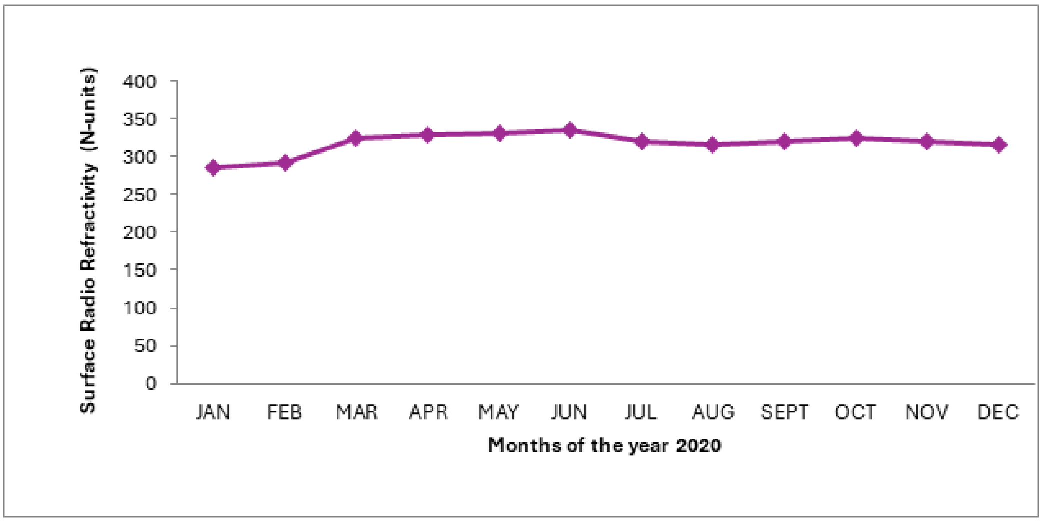

Figure 7: Monthly Variation of Surface Radio Refractivity over Lokoja in 2020.

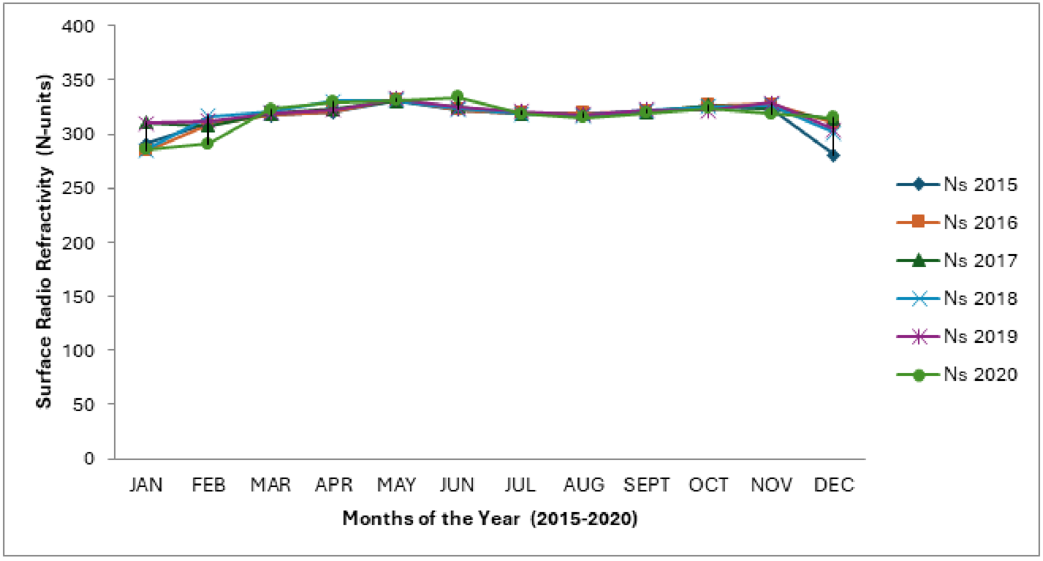

Figure 8: Variation Of Surface Radio Refractivity for The Six Years (2015-2020) over Lokoja, Kogi state.

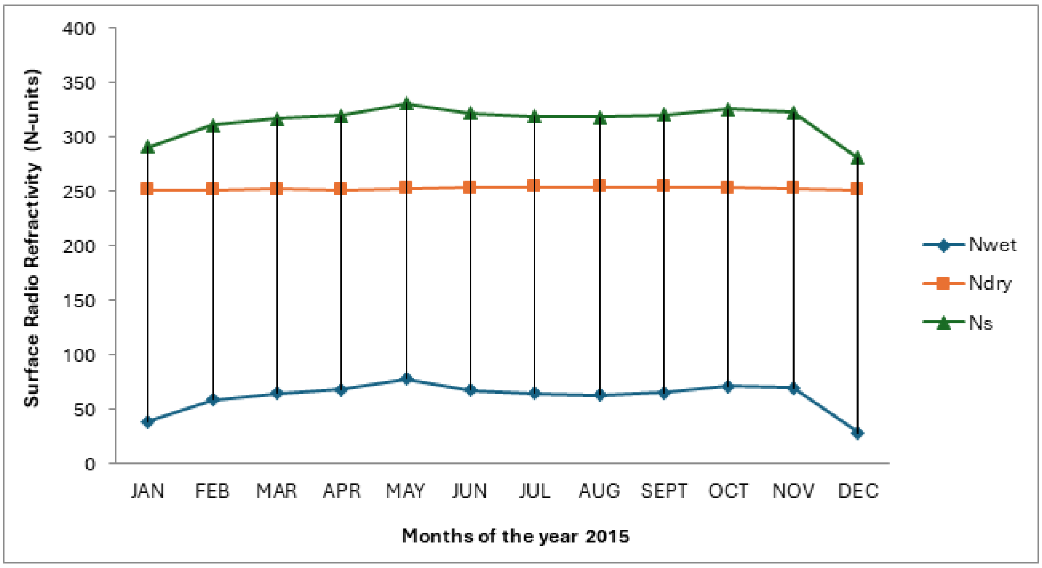

Figure 9: Monthly variation of dry (Ndry) and wet (Nwet) components of surface radio refractivity in Lokoja in the year 2015

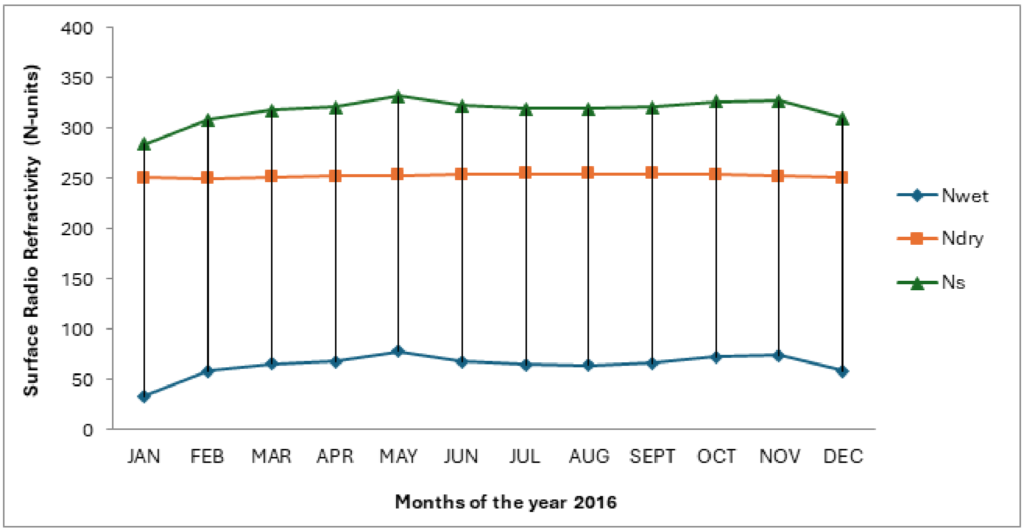

Figure 10: Monthly variation of dry (Ndry) and wet (Nwet) components of surface radio refractivity in Lokoja in the year 2016

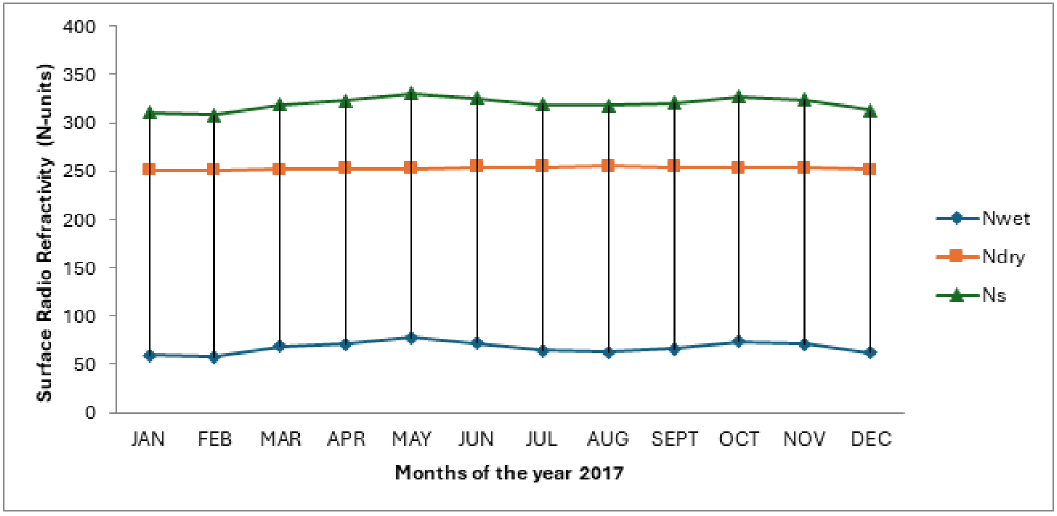

Figure 11: Monthly variation of dry (Ndry) and wet (Nwet) components of surface radio refractivity in Lokoja in the year 2017

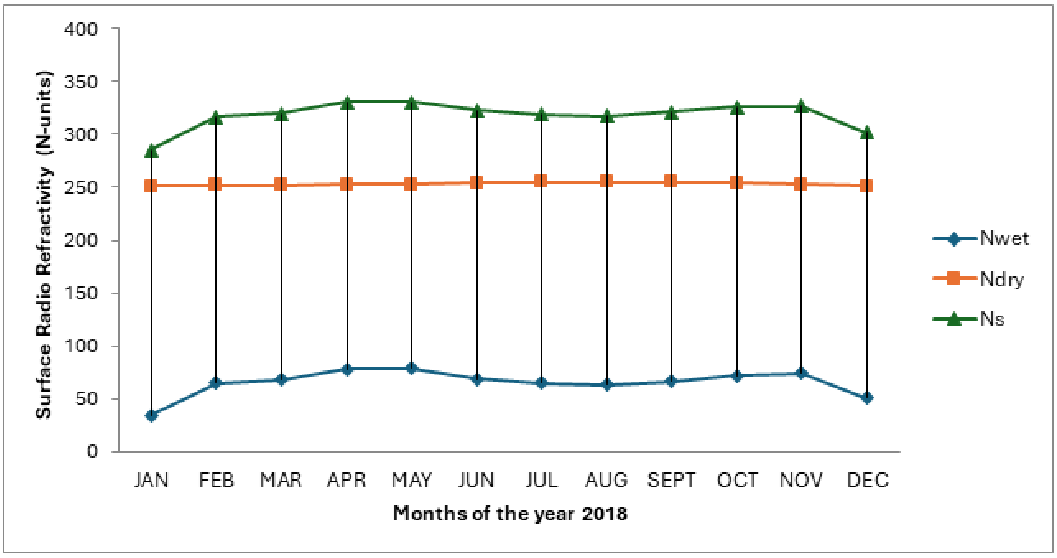

Figure 12: Monthly variation of dry (Ndry) and wet (Nwet) components of surface radio refractivity in Lokoja in the year 2018

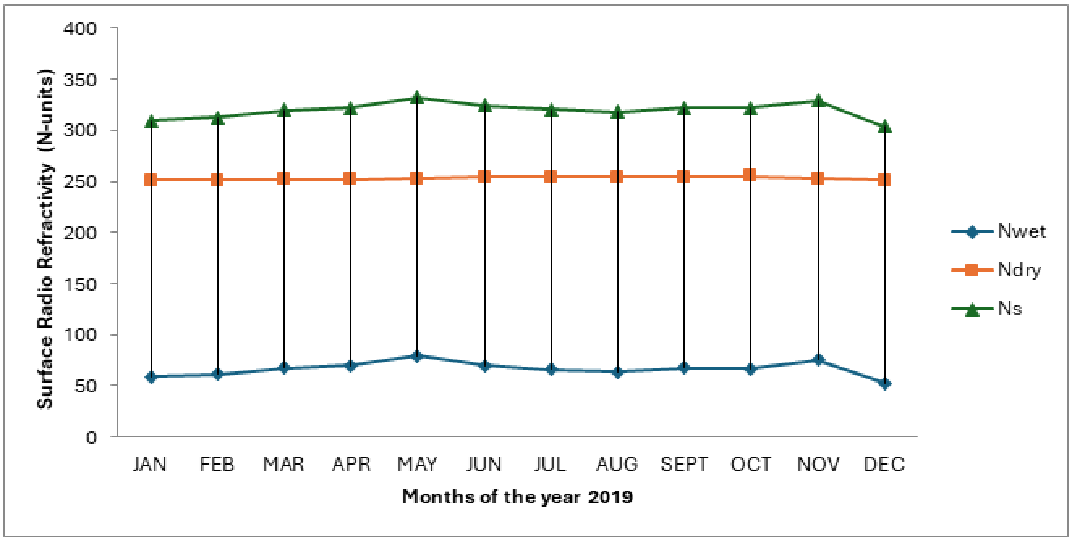

Figure 13: Monthly variation of dry (Ndry) and wet (Nwet) components of surface radio refractivity in Lokoja in the year 2019

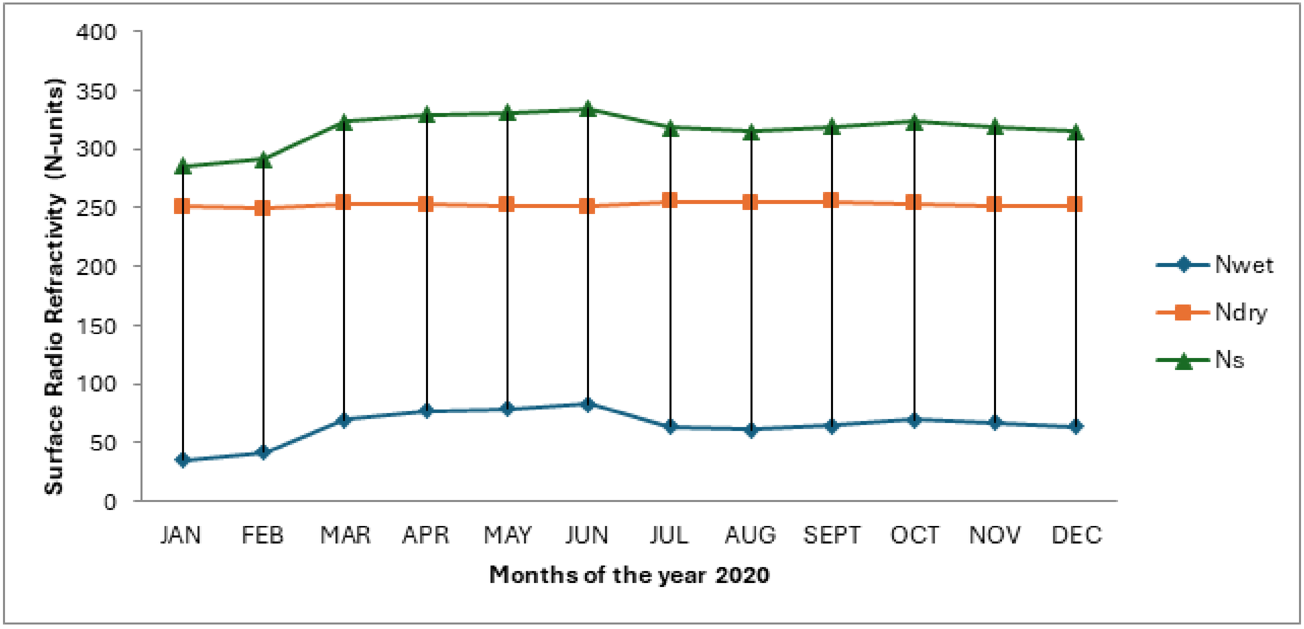

Figure 14: Monthly variation of dry (Ndry) and wet (Nwet) components of surface radio refractivity in Lokoja in the year 2020.

Average Seasonal Variations of Surface Radio Refractivity

Table 1: showing the average seasonal variation for dry season and wet season

Years	Dry Season (N-unit)	Wet Season (N-unit)
	Jan, Feb, Nov, Dec	**May, Jun, Jul, Aug**
2015	301.5091	322.7354
2016	307.7763	323.3498
2017	314.0883	323.2223
2018	307.5244	322.7123
2019	312.8042	323.9589
2020	302.7418	324.8258
Mean	**307.741**	**323.467**

Mean of the dry season =

$$\frac{301.5091+307.7763+314.0883+307.5244+312.8042+302.7418}{6}$$

$$=\frac{1846.444}{6}$$

Mean of the dry season = 307.7407

Mean of the wet season =

$$\frac{322.7354+323.3498+323.2223+322.7123+323.9589+324.8258}{6}$$

$$=\frac{1940.805}{6}$$

Mean of the wet season= 323.4674

As seen in Figure 15 below, During the dry season Table 1, Surface Radio Refractivity had a minimum value of 301.5091 (U-units) in the first year (2015), increased to 307.7763 (U-units) in the following year, and then rapidly increased to its highest value of 314.0883 (N-units) in the year (2017) before declining in the following year (2018). After that, it abruptly rises to 312.80421 (U-units) in 2019 and then falls to 302.7418 (U-units), the second lowest value, in 2020.

However, the value of refractivity in the Wet season Table 1 was measured in the first year of 2015 at 322.7356 (U-units). It then slightly increased to 323.1001 (U-units) in the following year, 2016, and it also slightly decreased in the following years, 2017 and 2018, with values of 323.3498 (U-units) and 322.7123 (U-units), respectively. After that, it increased gradually in 2019 to 323.9589; in 2020, it reached its peak value of 324.8258 (U-units). It has been noted that 2020 had the highest value of 324.8258, while 2018 had the lowest value of 322.7123.

Because the lower atmosphere is denser during the wet season due to increased moisture content, radio refractivity is often slightly higher here than during the dry season. When waves pass through a dense material, they move more slowly than through a less dense one (Edet, 2017). Figure 15's findings demonstrate that the seasonal radio refractivity for both seasons varies relatively little.

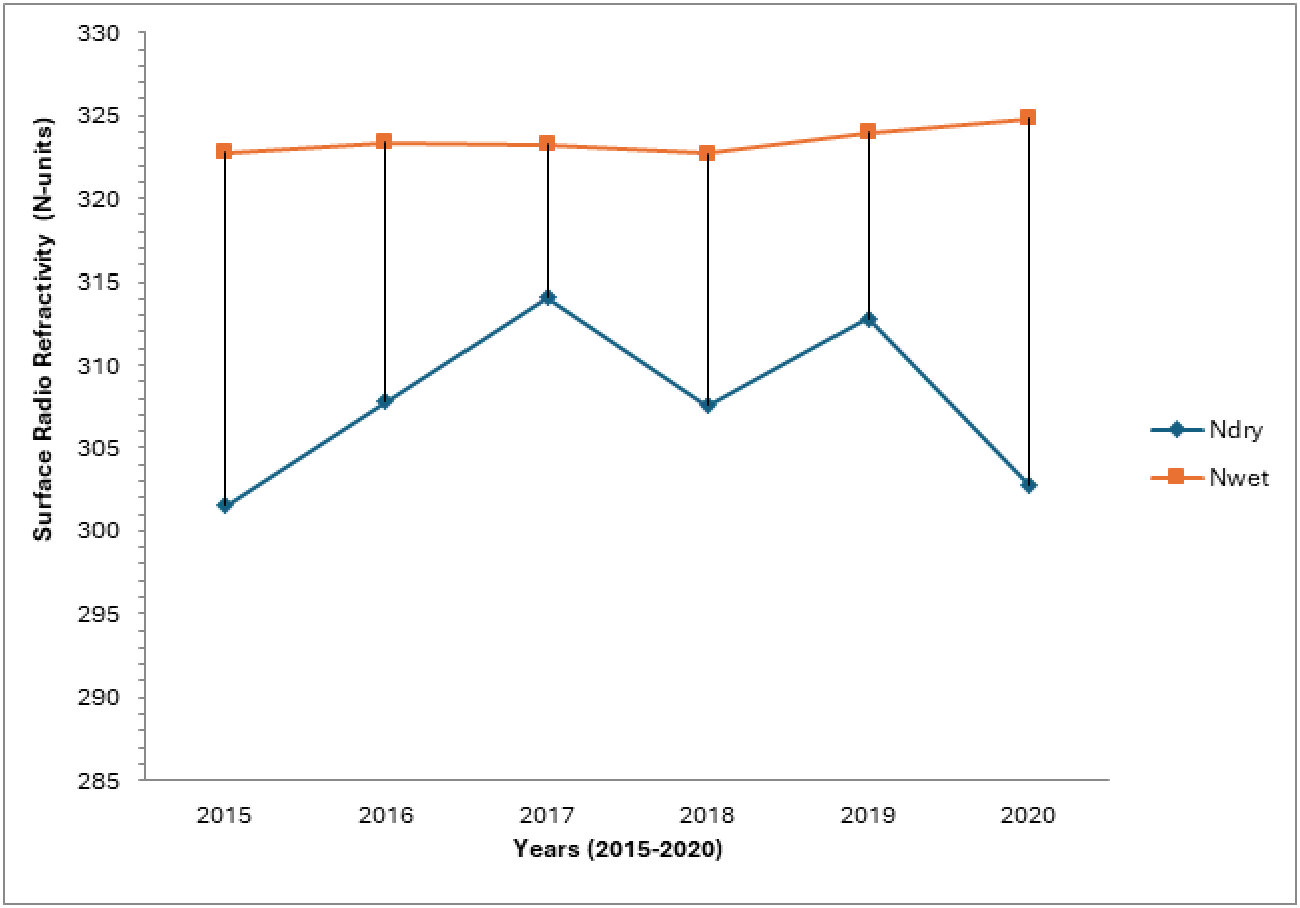

Figure 15: Average seasonal variation for Dry and Wet season for the years (2015-2020)

Evaluated Degree of Relationship between Radio Refractivity and Atmospheric Variables (Correlation Coefficients)

Statistical analysis utilizing a correlation coefficient Table 2 was conducted to determine the degree of relationship between radio refractivity Ns and atmospheric variables of temperature, humidity, pressure, and rainfall. According to the results in 2015, the correlation coefficients between Ns and temperature, pressure, humidity, and rainfall amounts were -0.41, 0.07, 0.89, and 0.76, respectively. The negative sign suggests that surface radio refractivity (Ns) decreases with increasing temperature and vice versa. The pressure, relative humidity, and precipitation increase when connected with the surface radio refractivity (Ns).

The degree of correlation between radio refractivity Ns and atmospheric variables, temperature, humidity, pressure, and rainfall amount, for 2016 was determined. The results showed that Ns and temperature, pressure, humidity, and rainfall had correlation coefficients of -0.51, -0.15, 0.84, and 0.64, respectively. Additionally, in 2017, the following year, the Ns were found to be -0.49, -0.28, 0.75, and 0.73 in relation to temperature, pressure, humidity, and rainfall amount, respectively. In contrast, the relationship between Ns and temperature, pressure, humidity, and rainfall amount was found to be -0.48, -0.08, 0.84, and 0.58 in 2018 and -0.46, -0.11, 0.77, and 0.51 in 2019, respectively.

Table 2: The correlation coefficients between surface radio refractivity and temperature, atmospheric pressure, relative humidity, and amount of rainfall

Years	**Surface Radio Refractivity (Ns)** **R**			
	Temperature(K)	**Pressure (pha)**	**R. humidity (%)**	**Amount of Rainfall (mm)**
2015	-0.41	0.07	0.89	0.76
2016	-0.51	-0.15	0.84	0.64
2017	-0.49	-0.28	0.74	0.73
2018	-0.48	-0.08	0.83	0.58
2019	-0.45	-0.11	0.77	0.51
2020	-0.50	-0.26	0.83	0.65

The relationship between Ns and temperature, pressure, humidity, and rainfall amount was found to be -0.50, -0.26, 0.83, and 0.64 for 2020, respectively. This suggests a negative temperature means surface radio refractivity drops when temperature rises and vice versa. Similarly, a negative atmospheric pressure suggests that surface radio refractivity increases when atmospheric pressure falls.

CONCLUSION

This study examines the variations in surface radio refractivity above ground level on a monthly, seasonal, and annual basis, as well as the correlations between surface radio refractivity and atmospheric variables such as temperature, pressure, relative humidity, and rainfall over Lokoja, Kogi State. Using the ITU-R standard, the propagation effects of the secondary radio climatic parameters were calculated. The main conclusions are outlined below:

- Compared to the dry season months, higher values of radio refractivity were generally recorded during the wet season months covering all years. Furthermore, during the years 2015 through 2020, average values of surface radio refractivity of 307.7407 (U-Units) were obtained during the dry season. In addition to the average values of surface radio refractivity, which were recorded during the wet season months for the years 2015 to 2020, the minimum and maximum values of 301.5091 and 314.0883 (N-Units) during the dry season months were recorded in the years 2015 and 2017, respectively. 2018 and 2020, respectively, had the lowest and greatest values of 322.7123 and 324.8258 (N-Units) during the wet season.
- Compared to the dry season months, higher values of radio refractivity were generally recorded during the wet season months covering all years. Furthermore, during the years 2015 through 2020, average values of surface radio refractivity of 307.7407 (U-Units) were obtained during the dry season. In addition to the average values of surface radio refractivity, which were recorded during the wet season months for the years 2015 to 2020, the minimum and maximum values of 301.5091 and 314.0883 (N-Units) during the dry season months were recorded in the years 2015 and 2017, respectively. 2018 and 2020, respectively, had the lowest and greatest values of 322.7123 and 324.8258 (N-Units) during the wet season.
- The monthly fluctuations in refractivity during the dry season are primarily caused by changes in the wet (Humidity) component of refractivity, whereas both the wet (Humidity) and dry (Pressure) components of refractivity contribute to the monthly variations during the rainy season.
- Over Kogi state's Lokoja, refractivity shows seasonal fluctuations, with high values during the rainy season and low values during the dry season.
- As can be shown from data gathered from the study site, the local meteorology affects the troposphere's refractivity.

CONTRIBUTION TO KNOWLEDGE

i. Planning for frequency reuse in the sites can benefit from understanding meteorological characteristics acquired from this study.
ii. Radio engineers will have access to sufficient data from this study's surface radio refractivity measurements to aid in designing communication systems at the sites.
iii. It will be crucial in establishing the sites' VHF, UHF, and microwave signal coverage and quality.
iv. To compensate for potential losses from high refractivity, owners of communication systems using the VHF and UHF bands are encouraged to boost their output power during the rainy season.

The necessity for this kind of study is even more pressing now that communication channels have expanded. Thus, efforts should be made to connect with research participants to obtain funding to purchase more advanced equipment.

REFERENCES

Adediji, A. T. and M. O. Ajewole, Vertical profile of radio refractivity gradient in Akure South-west Nigeria, Progress In Electromagnetic Research C, Vol. 4, 157-168, 2008. **[Crossref]**

Adediji, A.T., Ajewole M.O., Fallout S.E and Oladosu, O.R, "Radio Refractivity Measurement at 150m Altitude on TV Tower in Akure, South-West Nigeria" journal of engineering and applied science 2(8), Medwell journals, (2007) 1308-1313.

Adedokun, J.A.I (1998), West Africa precipitation and dominant atmospheric mechanism Arch. Meteorology. Geo physics, Biok limatol.ser.A, 27, 289-310. **[Crossref]**

Agbo, G. A., and O. N. Okoro, A.O. Amechi (2013): Atmospheric Refractivity Over Abuja, Nigeria, International Research Journal of Pure and Applied Physics, Vol.1, No. 1, pp.37-45. Published by European Centre for Research Training and Development UK (www.ea-journals.org)

Ajewole, M. O., Ayedum, O. D., Adediji, A.T., Eichie, J.O., (2013) Spatial variability of VHF/UHF electric field strength, in Niger State, Nigeria, International Journal of Digital Information and Wireless Communications (IJDIWC) 3(3): 26-34 The Society of Digital Information and Wireless Communications, 2013 (ISSN: 2225-658X).

Akinbolati, A., and M. O, Ajewole, (2020). Investigation of path loss and modeling for digital terrestrial television over Nigeria, Elsevier Heliyon Journal; **[Crossref]**

Akpootu D.O and Iiyasu M. I (2017): "Estimation of Troposheric Radio Refractivity and Its Variation with Meteorological Parameters over Ikeja, Nigeria", Journal of Geography Environment and Earth Science International 10(1): 1-12, 2017; Article no. JGEESI.32534 ISSN: 2454-7352 PP 1-12 **[Crossref]**

Alabi, M.O (2009) "Revitalizing Urban Public Open Spaces, Through Vegetative Enclaves in Lokoja, Nigeria", Journal of Geography and Regional Planning Vol. 2(3), pp. 051-054, March, 2009 Available online at http://www.academicjournals.org/JGRP ISSN 2070-1845 © 2009 Academic Journals

Ayantunji BG, Okeke PN, Urama JO. Diurnal and seasonal variation of surface refractivity over Nigeria. Progress in Electromagnetics Research. 2011;30:201-222. **[Crossref]**

Ayatunji, B. G. and Okeke, P. N., (2011): "Diurnal and seasonal variation of surface refractivity over Nigeria", Progress in electromagnetic Research B, vol. 30, pp 201-222nd Earth Science International 10(1): 1-12, 2017; Article no. JGEESI.32534 ISSN:2454-7352 **[Crossref]**

Babin, S.M Young, G.S. and Cartun, J.A., (1997). A new model of the oceanic evaporation duct, journal of applied meteorology, vol. 36, pp193-204. **[Crossref]**

Bean,D.R., Dutton, E.J., (1966). Radio Meteorology, Dover Edition, New York, USA, 1-20 **[Crossref]**

Bothias L (1987) Radio Wave Propagation, ,McGraw-Hill inc. New York St. Louissan francisca montreal Toronto.

Caglar, Y., Peter, G., William, S.H., (2006). Estimation of radio refractivity from radar clutter using Bayesian monte carlo analysis, IEE transaction on antennas and propagation 54 (4), 1318-1327. **[Crossref]**

Edet C. O., Eno. E. E., and Ettah E. B. (2017). Monthly Variation of Radio Refractivity in Calabar, Nigeria, International Journal of Scientific Research Engineering & Technology (IJSRET), ISSN 2278 - 0882 Volume 6, Issue 4, April 2017. https://www.researchgate.net/publication/319043536

Ekpe, O. E., Agbo, G. A., Ayantunji, B.G., Yusuf N, G., and Onugwu A. C. (2010) Variation of Tropospheric Surface Refractivity at Nsukka in South Eastern Nigeria, Nigerian Journal Of Space Research 7: 42 - 48

European Centre for Medium-Range Weather Forecasts (ECMWF) 15-year re-analysis (ERA-15) model data (May 2020): The ERA5 global reanalysis. Dataset Collection **[Crossref]**,

Faruk, N., Ayeni, A. and Adediran, Y. (2013) Empirical path loss models for accurate prediction of television signal for secondary users progress in Electromagnetic research 13 Vol. 49, 155-176 2013. **[Crossref]**

Freeman, R.L. (2007). Radio system design for telecommunications, 3rd ed., Wiley- Interscience, New York; 2007. **[Crossref]**

Gogtay, N. J. and Thatte, U. M. (2017), Principles of correlation Analysis, Journal of The Association of Physicians of India, 65 (March), pp. 78-81 PMID: 28462548

Hall MPM. Effect of the troposphere on radio communication, IEEE electromagnetic wave series, Peter Peregrinus Ltd, United Kingdom. 1989; 105-116. 1980IEWS....8.....H

https://www.nationalgeographic.org/encyclopedia/atmosphere/ 2022 https://www.researchgate.net/figure/Atmospheric-layers_fig1_271387301 https://www.researchgate.net/figure/Nigeria-showing-the-study-Area-Lokoja_fig1_343484696

Hughes, K.A (1998). Radio propagation data from Tropical Regions: A Brief Review of a seminar on Radio Propagation in Tropical Regions, Anun published lecture note presented at center for Theoretical physics, Trieste (Italy).

Igwe K.C. and Adimula, I.. A., (2009). Variation of surface radio refractivity and radio refractive index gradient in sub-sahel, Nigeria journal of space research, vol. 6, pp 135-144. @2009 NASRDA Centre for Basic Space Science https://www.researchgate.net/publication/291256111_

International Telecommunication Union recommendation, ITU-R. The radio refractive index: Its formula and refractivity data. 2003;453–459. https://www.itu.int/dms_pubrec/itu-r/rec/p/R-REC-P.453-11-201507-S!!PDF-E.pdf

International Telecommunication Union, 1970–1986–1990–1992–1994–1995–1997–1999–2001–2003. The radio refractive index: its formula and refractivity data. Recommendation ITUR, pp. 453–459. http://www.itu.int/ITU-R/go/patents/en

International Telecommunications Union, Radio Study Group (ITU-R), Recommendation on Radio refractivity, ITU-Rec. P. 453(2003-2019)

Kenedy, G., Bernard D.,(1992) electronic communication system, McGraw-Hill/macrmillan, Singapore, pp80-85. soaneemrana.com

Korak shaha, P. N., (2003). The physics of earth and its atmosphere, John and sons Inc., New York, USA.

Manning, T. (1999). "Microwave Radio Transmission Guide" British library cataloguing in the publication data. pp 89-115

Mmahi, N. O., Akinbolati, A., Nkechiamaka, F. N., Akpaneno, A. F., Joseph, E. and Ekundayo, K. R (2021): Studies on surface radio refractivity over some selected cities in North-Central, Nigeria FUDMA Journal of Sciences (FJS) ISSN online: 2616-1370 ISSN print: 2645 - 2944 Vol. 5 No. 4, December, 2021, pp 90 - 99 **[Crossref]**

Naveen, K.C., D.K.,Roopam G., (2011). The impact of k-factor on wireless link in Indian semi-desert international journal of advanced networking and Application 07(4), 776-779. https://www.researchgate.net/publication/22904429

Nnenna, O.N, and Akinbolati A. (2021) Studies the Surface Radio Refractivity over some selected Cites in North Central Nigeria Fudma journal of Science (fjs) Vol.5 No.4, pp 90-99. **[Crossref]**

Ojo, J.S., Ojo, O.L., and Olaitan, J.A (2023): Characterization and spatial distributions of atmospheric visibility, relative humidity and temperature for possible effect on optical communication links in Nigeria. Journal of Optics, - Springer. **[Crossref]**

Okoro O. N and Agbo G.A. (2012). The effect of variation of meteorological parameters on the tropospheric radio refractivity for Minna; Global Journal of Science Frontier Research Physics & Space Science Volume 12(2) pp 1-10.: Double Blind Peer Reviewed International Research Journal Publisher: Global Journals Inc. (USA) Online ISSN: 2249-4626 & Print ISSN: 0975-5896

Otolia, C. and Marian, A., (2004): Propagation effects in GPS Accuracy. The precision improvement of positioning in real condition of propagation". Electronics Sozopol, Bulgaria https://ecad.tu-sofia.bg/et/2005/pdf/Paper090-O_Croitoru.pdf.

Oyedum and Gambo. (1994). Surface radio refractivity in Northern Nigeria, Nigerian Journal of Physics, Vol. 6, 36-40.

Oyedum O.D., Igwe K.C., Echie J.O and Moses A.S., (2010) Reduced-to-sea-level refractivity in Minna, central Nigeria. Natural and Applied Science Journal 11(2). ISSN 1119-9296 Available online at www.naasjournal-ng.org

Rotheram,(1989). Clear Air Aspect of the tropospheric and their effects on propagation mechanism from VHF to millimeter wave. Radio wave propagation, Peter peresrinus Ltd., 150-153.

Smith, E. K., Weintraub, S. 1953. The constants in the Equation for Atmospheric Refractive index at Radio Frequencies. Proceeding of the institute of Radio Engineers (I.R.E), 41: 1035-1037. **[Crossref]**

Thayer, G.D. 1974 An Improved Equation for the Radio Refractive Index of Air. Radio science, 9(10): 803-807. **[Crossref]**

Willoughby, A. A., T. O. Aro, and I. E. Owolabi, Seasonal variations of radio refractivity gradients in Nigeria, Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 64, 417-425, 2002. **[Crossref]**

Willoughby, A. A., T. O. Aro, and I. E. Owolabi, Seasonal variations of radio refractivity gradients in Nigeria, Journal of Atmospheric and Solar-Terrestrial Physics, Vol. 64, 417-425,2002. **[Crossref]**