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Assessment of Meteorological Drivers of Surface Radio Refractivity for Terrestrial Communication Planning in Jos, Plateau State

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ABSTRACT
This study investigates the assessment of meteorological factors on surface radio refractivity and their implications for terrestrial communication planning in Jos, Plateau State, Nigeria. Using ten years (2011–2020) of satellite-derived data air temperature, atmospheric pressure, relative humidity, and rainfall monthly, seasonal, and annual refractivity values were computed. Results reveal that refractivity is consistently higher during the wet season (≈275 N-units) compared to the dry season (≈200 N-units). Minimum values ranged between 289.84 and 320.30 N-units, while maximum values varied from 351.53 to 374.01 N-units. Elevated refractivity in the wet season reflects increased atmospheric moisture, which enhances signal attenuation. Correlation analysis shows a negative relationship between refractivity and temperature, mixed responses to atmospheric pressure, and positive correlations with humidity and rainfall. These findings are critical for terrestrial radio communication systems such as FM broadcasting networks and microwave relay links, where atmospheric refractivity directly affects signal strength and coverage. For instance, in FM radio transmission, higher refractivity during the wet season can cause reduced signal clarity and unexpected fading, requiring adjustments in transmitter power or antenna height to maintain reliable service. Similarly, microwave backhaul systems used by mobile operators may experience increased attenuation, demanding careful power budgeting and link margin planning. By quantifying refractivity variations across seasons, this study provides valuable insights for optimizing frequency allocation, improving system reliability, and ensuring consistent communication quality in Jos and other regions with similar climatic conditions.

Keywords: Surface Radio Refractivity, Meteorological Drivers, Terrestrial Communication Planning, Atmospheric Parameters, Jos Plateau State and Tropical Climate

INTRODUCTION
Radio communication systems rely on the propagation of electromagnetic waves through the Earth's atmosphere, with the troposphere playing a dominant role in determining signal behavior. Variations in meteorological parameters such as air temperature, atmospheric pressure, relative humidity, and rainfall modify the tropospheric refractive index, thereby influencing signal amplitude, phase, and propagation path. These effects can degrade transmission quality and increase propagation losses, particularly at very high frequency (VHF), ultrahigh frequency (UHF), and super high frequency (SHF) bands (Usman et al., 2023). The troposphere, which extends from the Earth's surface to approximately 7–20 km depending on latitude and season (Akinbolati et al., 2025), is characterized by random spatial and temporal fluctuations in (Ayantunji et al., 2011) refractivity. Such variability gives rise to scattering, absorption, scintillation, and anomalous propagation phenomena, which may result in signal fading and co-channel interference (Usman et al., 2024). Studies have shown that tropospheric refractivity varies significantly across regions and seasons, with higher values observed in humid tropical and rainforest zones compared to drier savannah and Sahel regions (Onuorah et al., 2022). These effects are generally more pronounced in tropical regions due to high humidity levels and frequent intense rainfall. This study seeks to investigate tropospheric refractivity variations across different climatic zones, analyze the impact of meteorological parameters (temperature, pressure, humidity, rainfall) on radio wave propagation, assess seasonal and spatial variability of refractivity and its implications for communication reliability and provide recommendations for optimizing terrestrial radio link design in tropical environments. By addressing these objectives, the study contributes to a deeper understanding of how atmospheric dynamics affect radio communication systems, particularly in tropical regions where refractivity fluctuations are most severe. The findings are expected to guide engineers and network planners in designing more resilient communication systems that minimize signal degradation and improve reliability.

MATERIALS AND METHODS
Study Area
The city of Jos lies on the Jos Plateau in Plateau State, north-central Nigeria, positioned at approximately 9.93° N and 8.89° E. Its mean elevation of about 1,217 m above sea level makes it one of the highest urban centers in the country, a factor that strongly influences its climate (Adewale et al., 2013). Jos serves as the administrative capital and largest urban settlement in the state, with a population estimated at nearly 900,000 residents according to recent demographic reports (National Population Commission, 2022). The elevated terrain moderates the climate, producing conditions that are markedly cooler than those of the surrounding lowlands. The region is classified as tropical savanna (Köppen Aw), but altitude modifies this classification,

resulting in distinctive temperature and rainfall patterns. Mean monthly temperatures generally range between 21–25 °C, while nighttime temperatures during the dry season (November–January) may drop to about 7 °C. The coolest months average 15.5–18.5 °C, whereas the hottest months reach 27.5–30.5 °C. Convective activity and orographic lifting occasionally trigger hailstorms during the rainy season (Adewale et al., 2013). Annual rainfall averages 1,400 mm, though spatial variability is evident across the city: southwestern areas may receive up to 2,000 mm yr^{-1}, while northeastern sectors record less than 1,500 mm yr^{-1}. Rainfall is highly seasonal, concentrated between June and September, with July and August as the peak months. Precipitation is largely driven by moist southwesterly winds from the Atlantic Ocean, further enhanced by orographic effects on the windward slopes of the plateau (Adewale et al., 2013). Relative humidity remains high during the wet season, reinforcing the tropical character of the region.

Source of Data Used for this Study

Ten years (2011-2020) of satellite data of weather parameters, temperature, pressure, humidity, and amount of rainfall at the surface 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 center 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).

Data Sorting and Empirical Tools

The data set was divided into monthly, seasonal, and annual formats for ease of analysis and result discussion.

(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 Nsfc is the refractivity at the atmosphere's surface determined by surface meteorological factors. The surface radio refractivity was calculated using equations (1) through (Usman et al., 2023).

$$N = 77.6\frac{Pd}{T} + 72\frac{e}{T} + 3.75 \text{ X } 10^5 \frac{e}{T^2} \text{ (N-units)} \quad (1)$$

$$e = \frac{H.es}{100} \quad (2)$$

$$es = EF.a.\exp\left[\frac{\left(b-\frac{t}{d}\right).t}{t+c}\right] \quad (3)$$

And:

$$EF = 1+10^{-4}\left[7.2+P.\left(0.0320+5.9\times10^{-6}.t^2\right)\right] \quad (4)$$

Where:

t: temperature $(^{\circ}C)$

P: total atmospheric pressure (hPa)

H is relative humidity (%),

e_s: Saturation vapor pressure (hPa) at the temp t$(^{\circ}C)$

a=6.1121

b=18.678

c=257.14

d=234.5 (ITU-R, 2021).

Where, e_s is the maximum (or saturated) vapour pressure at the given air temperature t $(^{\circ}C)$ 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 (Akinbolati, et al., 2024). To determine the degree of relationship between the variables, Karl Pearson's product correlation coefficient used for continuous data as presented in equation (4) was used. The Pearson correlation coefficient r between two variables X and Y can be expressed as:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{\left(n\sum x^2 - \left(\sum x\right)^2\right)\left(n\sum y^2 - \left(\sum y\right)^2\right)}} \quad (5)$$

RESULTS AND DISCUSSION

Figure 2 shows the monthly variation of surface radio refractivity (N-units) in Jos, Plateau State for the years under study (2011-2020). Table 1 presents the average seasonal variation for dry season and wet season.

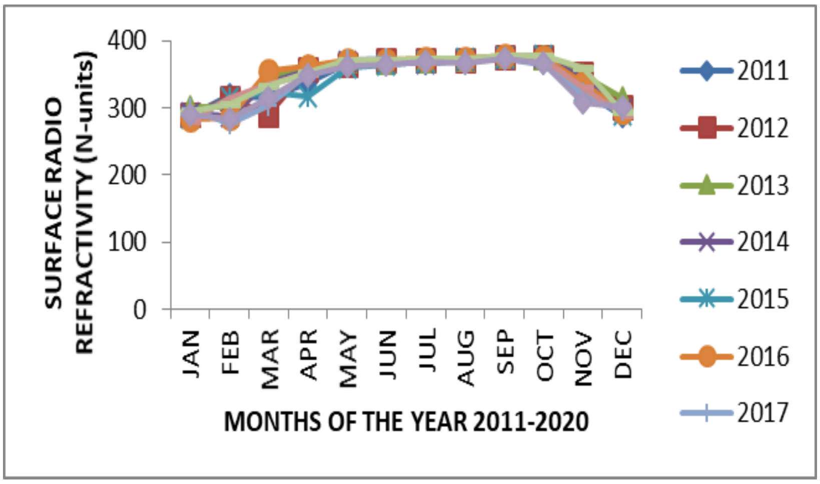

Figure 1: Variation of Surface Radio Refractivity for The ten Years (2011-2020) over Jos, Plateau State

Figure 1: shows the monthly variation of surface radio refractivity (N-units) in Jos, Plateau State over ten years (2011-2020). Surface radio refractivity is an important atmospheric parameter that affects radio wave propagation, communication signals, and radar transmission. The graph shows that surface radio refractivity generally increases gradually from January to October and then decreases toward December. Values start at about 290-310 N-units in January, then rise steadily through the months, and reach a peak of about 410-430 N –units around September to October. The sharp drop in refractivity after October is mainly caused by the transition from the wet season to the dry season in Nigeria. As rainfall ceases and humidity decreases, the atmosphere becomes drier, leading to lower water vapor pressure and reduced refractivity values in November and December. During the wet season (April–October), heavy rainfall increases atmospheric moisture, raising refractivity values. After October, rainfall sharply declines, reducing water vapor content and lowering refractivity to around 360–380 N-units in November and December, high humidity contributes significantly to refractivity. As the dry season begins, relative humidity drops, especially in northern and central Nigeria, leading to reduced refractivity, cooler temperatures in late-year months reduce the amount of water vapor the air can hold. This further lowers refractivity compared to the warmer, wetter months. The seasonal transition from wet to dry climate is the primary driver of refractivity variation across months. Reduced rainfall, lower humidity, cooler temperatures, and the southward movement of the ITD combine to cause the sharp decline observed in November and December.

Average Seasonal Variations of Surface Radio Refractivity

Table 2: The Average Seasonal Variation for Dry Season and Wet Season

Years	Dry (N-units)	Wet (N-units)
2011	304.880	367.864
2012	314.128	369.274
2013	316.141	369.110
2014	304.936	368.474
2015	303.682	366.302
2016	299.590	371.550
2017	298.017	369.989
2018	303.970	368.136
2019	313.223	371.323
2020	295.135	364.931
Mean	305.370	368.695

As seen in Figure2, during the dry season Table 1, Surface Radio Refractivity had a minimum value of 304.880 (N-units) in the first year (2011), increased to 314.128 (N-units) in the following year (2012), and then rapidly increased to its highest value of 316.141 (N-units) in the year (2013) before declining in the following year (2014). After that, it abruptly rises to 313.223 (N-units) in 2019 and then falls to 295.135 (N-units), the first lowest value, in 2020. However, the value of refractivity in the wet season Table 1 was measured in the first year of 2011 at 367.864 (N-units). It then slightly increased to 369.274 (N-units) in the following year, 2012, and it also slightly decreased in the following years, 2013, 2014 and 2015, with values of 369.110 (N-units), 368.474 (N-units) and 366.302 (N-units), respectively. After that, it increased gradually in 2016 to 371.550 (N-units) which is the peak value. It has been noted that 2016 had the highest value of 371.550, while 2020 had the lowest value of 364.931 (N-units). 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 (Usman et al., 2026). Figure3's findings demonstrate that the seasonal radio refractivity for both seasons varies relatively little.

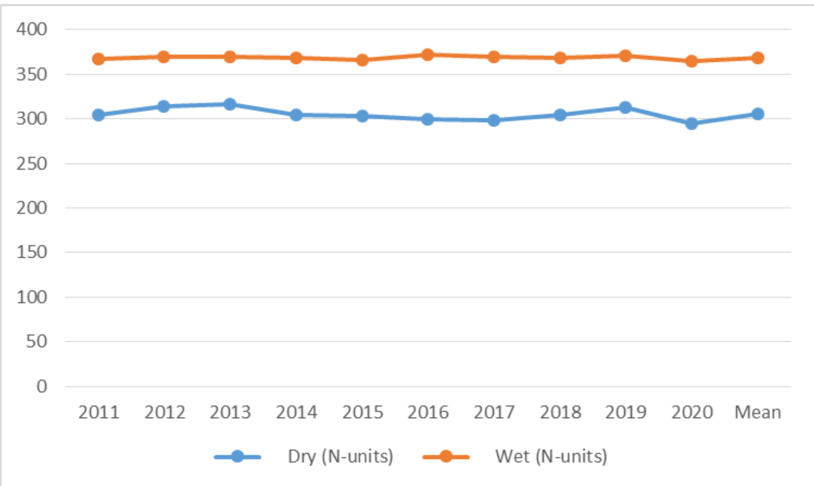

Figure 2: Average Seasonal Variation for Dry and Wet Season for the Years (2011-2020)

Evaluated Degree of Relationship between Radio Refractivity and Atmospheric Variables (Correlation Coefficients) Statistical analysis utilizing a correlation coefficient on 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 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. The remaining years have similar trends.

Table 3: The Correlation Coefficients between Surface Radio Refractivity and Temperature, Atmospheric Pressure, Relative Humidity, and Amount of Rainfall

Years	Temperature (K)	Pressure (hPa)	Relative Humidity (%)	Amount of Rainfall (mm)
2011	-0.335	0.104	0.905	0.358
2012	-0.384	0.382	0.907	0.341
2013	-0.434	0.384	0.929	0.439
2014	-0.235	0.263	0.897	0.534
2015	-0.179	0.254	0.901	0.521
2016	-0.483	-0.109	0.908	0.364
2017	-0.392	0.213	0.895	0.148
2018	-0.987	0.363	0.996	0.463
2019	-1	1	1	1
2020	0	0	0	0

The negative correlation between temperature and surface radio refractivity means as temperature rises, radio refractivity reduces and vice versa. Similarly, a negative atmospheric pressure suggests that surface radio refractivity increases when atmospheric pressure falls.

Temperature (T): Negative correlations with Refractivity (≈ -0.44 to -0.49) suggest that surface radio refractivity decreases as temperature increases. Physically, warmer air has lower density, reducing the refractive index.

Pressure (P): Weak positive or slightly negative correlations (≈ -0.11 to 0.38) reflect that higher atmospheric pressure slightly increases refractivity, but the effect is smaller compared to humidity.

Relative Humidity (RH): Strong positive correlations (≈ 0.90–0.95) indicate that increasing moisture content in the air enhances refractivity, as water vapor contributes significantly to the refractive index.

Rainfall (R): Moderate positive correlations (≈ 0.15–0.53) show that periods of higher precipitation generally coincide with elevated refractivity, reflecting the combined effects of increased humidity and tropospheric moisture.

Overall, the analysis demonstrates that humidity and rainfall are the dominant atmospheric drivers of surface radio refractivity, while temperature inversely affects refractivity, and pressure plays a secondary role. These insights are crucial for radio link design, coverage prediction, and power budgeting in Jos and similar tropical highland environments.

CONCLUSION

This study deals with Statistical Assessment of Meteorological Drivers of Surface Radio Refractivity (12 m) 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 for Terrestrial Communication Planning in Jos, Plateau State, Nigeria. 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 2011 through 2020, average values of surface radio refractivity of 307.741 (N-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 301.509 and 314.088 (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 322.712 and 324.826 (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 the city of Jos, refractivity shows seasonal fluctuations, with high values during the rainy season and low values during the dry season.

i. 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.
ii. It will be crucial in establishing the sites' VHF, UHF, and microwave signal coverage and quality.
iii. 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.

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