# Seasonal Modelling of Radio Refractivity in Jos, Nigeria

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**ABSTRACT**

The refractivity of the lower atmosphere is responsible for several anomalies in microwave propagation such as ducting, scintillation, refraction, fading, including range and elevation errors in radar and data acquisition. It is needful to develop models which could be used to predict refractivity. In this paper, refractivity has been estimated from meteorological data archived on Weather Underground (WU) website. The website contains data collected from Yakubu Gowon Airport station (9°38'20"N, 8°58'15"E, 1289 m a. s. l). Daily data of humidity, temperature, and pressure (HTP), acquired over a 12-month period (January to December 2023), were analyzed to model monthly and seasonal atmospheric refractivity over Jos. The refractivity values in the rainy season were higher and more clustered, ranging from a minimum value of 340 N-units to a maximum value of 360 N-units. In the dry season, the refractivity values were lower and more scattered, varying between a minimum value of 270 N-units and a maximum of 320 N-units. Several graphical regression models were used to test the relationship between refractivity and the three meteorological parameters (HTP). The best fit graphical models were found to be linear (y = mx + c). The findings show that while refractivity was strongly correlated to humidity, refractivity had little or no correlation with pressure and temperature. The regression correlation coefficients between refractivity and humidity (N-H) were found to be stronger in the dry season ($R^2 = 0.96$), than in the rainy season (where $R^2 = 0.73$). Finally, the average month-by-month straight line parameters (slope, intercept) of N-H characteristics were (1.14, 255 N-units, $R^2 = 0.96$) and (0.755, 281 N-units; $R^2 = 0.466$) for the dry and rainy months respectively. These parameters could serve as inputs for designing refractivity-prediction instruments, improved radio communication links, and safe deployment of aviation tools and navigation aids. However, data covering many more years will be further investigated to validate these findings.

**Keywords**: Troposphere, radio propagation effects, prediction of seasonal refractivity, regression parameters.

## 1. INTRODUCTION

### *1.1 Troposphere, constituents and variations*

The atmosphere serves as the communication medium for earth space links, but the troposphere creates the greatest nuisances to the propagation of radio-waves. Based on its temperature, The atmosphere is divided into five layers, namely: - troposphere, stratosphere, mesosphere, thermosphere (with the ionosphere) and the exosphere. Beyond the exosphere are the two bands of the magnetosphere (NIWA, 2024). The troposphere is the lowest part of the atmosphere (0 -10 km; or 12 to 17 km at the equator). It contains 75% of all the gases (oxygen, carbon-dioxide, nitrogen) in the atmosphere, more than 90% of the water vapour, and most of our weather - clouds, rain, snow, the major threats to communication links. (Ajewole, 2011). Within the troposphere, the temperature decreases with height above the Earth's surface with a gradient of about -6.5°C per kilometre.

Refractivity is the physical property of the atmosphere that is determined by the air index of refraction. It is a measure of the bending away of the radio-wave signal as it travels through the Earth's atmosphere. As air rises from the land it is heated by the sun, and when wind blows over the land, it generates turbulence which redistributes heat, moisture and other constituents of the atmosphere within the troposphere along its vertical heights. According to Zilinskas et al., (2011) and Mohammed et al. (2021), this variation in the vertical gradient of atmospheric temperature and humidity distributions is responsible for the anomalous refractivity, where refractive index deviates from the normal (or standard) atmospheric conditions. Normal air refractive


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index is 1.000, but, due to changes in the constituents of the troposphere, refractivity becomes greater than 1 (Mohammed et al., 2021).

### *1.2 Effects Anomalous Refractivity on Radio-wave Propagation*

As the refractive index of the atmosphere varies on a broad scale, the propagating radio waves are increasingly bent towards the Earth. During standard atmospheric conditions, the air density and refractive index gradually decrease with height; causing the bending radio-waves to follow the curvature of the Earth, at a rate of about 0.05 N-units per kilometre (Aremu et al., 2018). Also, the signal range is predictable using simple geometric calculations. This standard condition is the basis for modelling many radio communication and navigation systems, such as line of sight (LOS) propagation, free space propagation and simple atmospheric refraction. However, unusual atmospheric conditions like temperature inversions, atmospheric ducts, high humidity and wind shear lead to abnormal refraction namely:-super-refraction and sub-refraction.

For a refractivity gradient greater than normal (> 0.05 N-units/km), the downward bending of the radio wave is stronger than normal; and is called super-refraction. Edet et al., (2017) explained that super refraction could give rise to a detour of a ground-target radar detector, causing it to travel longer distances than during normal conditions. This could result in multipath effects interference, dispersion, delay, signal fading and loss. Super refraction is prevalent in marine radio communication and navigation systems, especially in ice-lands and mountainous regions. Although super-refraction can be deployed to improve system performance, it requires careful study to avoid its numerous pitfalls.

When the refractivity of the atmosphere is less than normal (< 0.05 N-units/km) the radio waves bend upwards and is called sub-refraction. According to Grabner and Kvicera (2008), subrefraction is caused by abnormal weather conditions, temperature inversions, dry air, low atmospheric pressure. In these cases, subrefraction could prevent the detection of targets by radar, ducting, scintillation and fading (Adewumi et al., 2018). More radio propagation effects include loss of signal for mobile communication, inaccuracy in radio-, star- or planet- tracking devices such as telescopes, GPS, satellites, missiles, radar system and so on.

Within the last two decades (2005 to date), many researchers in Nigeria and around the globe have contributed immensely to this field stressing the implications of radio refractivity gradient. A few such researchers include Falodun and Ajewole (2005);); Oyedum et al. (2016;); Adediji et al., (2017); Johnson, (2018); Williams, (2019).; Balogun et al. (2021) and Sabiru et al. (2024). These researchers had established the use of HTP for computing the value of N. Also, many of them such as Adeyemi and Emmanuel (2011); Adediji et al., (2017) and Adewumi, et al., (2018) have observed useful relationships in their separate studies; and have demonstrated that annual radio refractivity decreases with increase latitude across Nigeria, that is, from the coastal region in Southern Nigeria to the arid region in the north.

Mohammed et al. (2021) also observed that during rainy season, the values of refractivity are high and uniform, while low values of refractivity are observed during dry season. They explained that the higher values observed in the rainy months resulted from the atmosphere that is laden with moist content of water vapour, which increases the humidity in the atmosphere and subsequently the surface radio refractivity. Researchers have further established that, among the three meteorological parameters affecting refractivity, atmospheric humidity has the greatest effects, followed by atmospheric temperature and pressure (Oyedum et al. (2016;); Adediji et al. (2017); Johnson, (2018); Balogun et al. (2021)) . Since humidity has the greatest effects on refractivity, this paper seeks to explore the possibility of developing an empirical model for determining the surface refractivity, N from the value of humidity.

### *1.3 Prediction of Atmospheric Refractivity*

ITU-R P.453-14, (2019) has prescribed mathematical procedures generally adopted by researchers for estimating refractivity. Refractivity, N is the excess of the refractive index of air, above unity; and is estimated as a function of HTP with the expressions in equations (1) to (4). (ITU-R P.453-14, 2019):

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

Where, *n* is the refractive index of the atmosphere, and N is given as expressed in equations (2a) and (2b):

$$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) = \frac{77.6P}{T} + \left(3.732 \times 10^5 \frac{e}{T^2}\right) \quad (2a)$$

Where, $e = \frac{e_{sH}}{100}$; and $e_s = 6.11exp^{\left(\frac{17.26(T-273.16)}{(T-35.87)}\right)}$ (2b)

Where: P is the atmospheric pressure (hPa), $e_s$ is the water-vapour pressure (hPa), T is the absolute temperature (K). Refractivity of the lower atmosphere (troposphere) is divided into two parts – the dry and the wet composition. The dry term is responsible for about 70% of the total refractivity in the atmosphere, and it is proportional to the density of the gas molecules in the atmosphere and changes with their distribution.( Ayantunji et al., 2011), The dry term of refractivity is stable, and can be modeled with an accuracy of about 20%, using surface measurements of pressure, P and temperature, T as:

$$N_{dry} = 77.6\frac{P}{T} \quad (3)$$

Conversely, the wet term contributes the major variation of refractivity in the atmosphere due to the polar nature of the water molecules and is given by:

$$N_{wet} = 3.732 \times 10^5 \frac{e}{T^2} \quad (4)$$

### *1.4 Prediction of Seasonal Refractivity*

In their work, Okoro and Agbo (2012), attributed the variation of radio refractivity in Minna to seasonal variations in weather in the troposphere, most especially at the lower part (below sea level). The weather variation was observed to be more pronounced in the rainy season than the dry season in Minna owing to the increase in the tropospheric temperature and humidity, therefore resulting in higher radio refractivity within that period.

In another study, Jari and Ismo (2015) in Benin, Nigeria, showed that UHF had inverse relationship with humidity, temperature, and pressure (HTP) bearing negative correlation values of -0.96, -0.94, -0.92 respectively. Also, Joseph, (2016), in Calabar, Nigeria, while characterizing the propagation of radio signals through the atmosphere as a function of weather parameters, showed that radio signal strength was inversely proportional to the atmospheric humidity with a correlation factor of -0.94. This corroborates Jari and Ismo's (2015) results.

Characterizing tropospheric refractivity is critical to planning radio links for communications, aerospace, environmental monitoring, disaster forecasting, to name a few. Aremu et al., (2018) stressed the need for more refraction models and measurements to accurately predict radio wave propagation during other abnormal cases. Secondary radio-climatic data, especially the surface refractivity as well as the diurnal and seasonal variability could be used in planning terrestrial radio links. This paper sets out to measure refractivity of the atmosphere and model its variability with respect to weather HTP.

## 2. MATERIALS AND METHOD

Daily values of meteorological data of humidity, temperature, and pressure (H. T, P) were retrieved from Weather Underground (WeatherUndeerground.com, 2023) over a period of twelve months (January to December 2023). Meteorological data archived on Weather Underground (WU) consist of data uploaded from DAVIS rain equipment installed at Yakubu Gowon Airport (9°38'20"N, 8°58'15"E, 1289 m. a. s. l), Jos, Nigeria. The average daily values of HTP were inputted into the ITUR refractivity equations (2a) and (2b)

(ITU-R P.453-14, 2019). The various equations were entered step by step into MS-Excel as a formular, following the sample presented in Table 1. Graphs of refractivity were plotted and analyzed on Microsoft Excel for various days and months, of the year 2023 (January-December) to obtain graphical regression models for each month and season of the year.

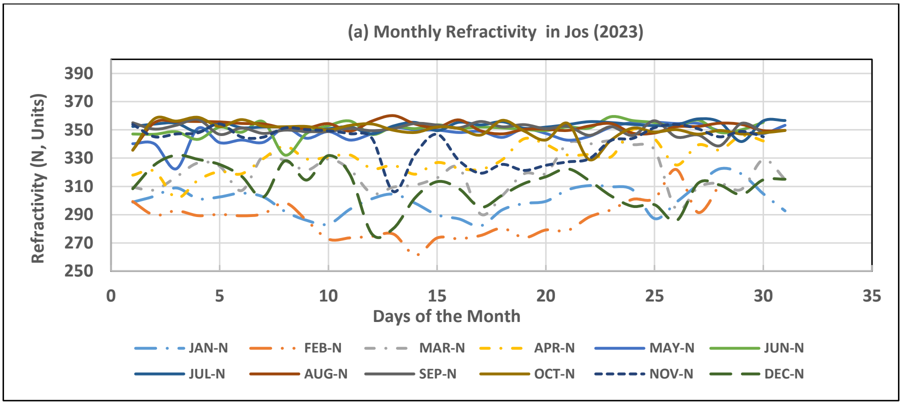
**Table 1: Sample of MS-Excel computations of refractivity N, using ITUR (P.453-14, 2019)**

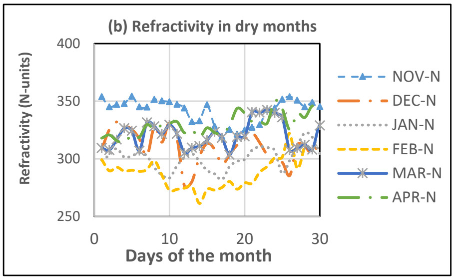
| January | t (℃) | T(K) | H(%) | es | e | P(hPa) | N |
|---|---|---|---|---|---|---|---|
| **1** | 22.70 | 295.70 | 40.8 | 24.87 | 10.15 | 972.7 | 298.87 |
| **2** | 26.50 | 299.50 | 42.7 | 28.64 | 12.23 | 972.2 | 303.07 |
| **3** | 26.10 | 299.10 | 47.7 | 28.25 | 13.47 | 972.8 | 308.89 |
| **4** | 27.90 | 300.90 | 40.6 | 30.00 | 12.18 | 972.5 | 301.30 |
| **5** | 26.60 | 299.60 | 42.1 | 28.74 | 12.10 | 972.7 | 302.54 |
| **6** | 25.80 | 298.80 | 44.5 | 27.95 | 12.44 | 973.9 | 305.22 |
| **7** | 27.20 | 300.20 | 41.8 | 29.32 | 12.26 | 973 | 302.57 |
| **8** | 25.50 | 298.50 | 33.7 | 27.66 | 9.32 | 973 | 292.29 |
| **9** | 23.30 | 296.30 | 28.3 | 25.47 | 7.21 | 973.6 | 285.93 |
| **10** | 21.00 | 294.00 | 25.8 | 23.14 | 5.97 | 974.3 | 283.26 |
| **11** | 24.80 | 297.80 | 35 | 26.96 | 9.44 | 974.3 | 293.90 |
| **12** | 27.10 | 300.10 | 40.8 | 29.22 | 11.92 | 972.6 | 301.20 |

## 3. RESULTS

### 3.1 Monthly Variation of Refractivity in Jos

Daily variation of refractivity for each month of the year is shown in Figures 1(a-c). The broken lines in figure 1(a) are refractivity curves for the dry months (November through April); they are fairly scattered over a wide range from 270 to 320 N-units. (as exploded in Figure 1(b)). The unbroken lines represent daily refractivity curves for the rainy months (that is, the rainy season – May through October); exploded in Figure 1(c); which





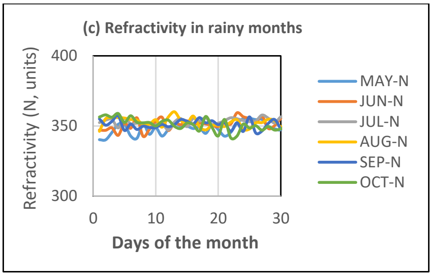




**Fig.1 (a) Monthly Refractivity in Jos (b) Refractivity in dry Months (c) Refractivity in rainy months.**

are higher and more clustered together between 340 and 360 N-units. The higher values suggest that during the rainy months, a higher level (or threshold) of rain-induced humidity (and refractivity) is sustained in the troposphere mostly due to increased water content introduced into the atmosphere by hydrometeors (rain clouds and rain droplets). This threshold could be responsible for the general degradation in propagation of radio signals, signal drops, cracking networks and network disappointments observed when attempting to make phone calls in the rainy season. Conversely, in the dry season, the daily humidity (and refractivity) is lower and fluctuates over a very wide range as the sun rises and sets each day.

### 3.2 Seasonal Trend of Surface Refractivity

Figure 2 presents the seasonal trend of the average surface refractivity for the year 2023; where, the average surface refractivity rises steadily from a minimum value of 290 units in February during the dry season, to a maximum value of 353 units in July, during the rainy season. The threshold of about 350 was maintained throughout the rainy season up to October. From October the average surface refractivity begins to drop until it reaches a minimum value in February. The lower and higher values of average surface refractivity observed in the dry and rainy seasons respectively, agree with that of Mohammed et al. (2021).

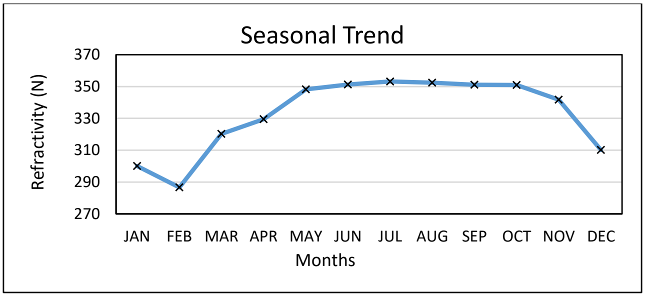



**Fig.2 Seasonal Trend of Refractivity**

However, the peak average value of surface refractivity observed in the month of July 2023, agrees with the previous study of Durodola et al., (2017) where July was observed to be the worst month in Jos. As earlier observed, the higher values of refractivity observed during the rainy season is attributed to the overload of moist water vapour which increases the humidity, and the surface radio refractivity in the atmosphere. On the contrast, the low values of surface radio refractivity observed were due to the low atmospheric humidity caused by the reduction in moist water vapour in the atmosphere.

### 3.2 Annual Variation of Surface Refractivity

Figures 3 (a-c) display how refractivity varies with humidity, temperature and pressure, respectively. From the regression values of $R^2$ = 0.06 and 0.007 in Figures 2(a) and 2(b), which are summarized in Table 2, it is obvious

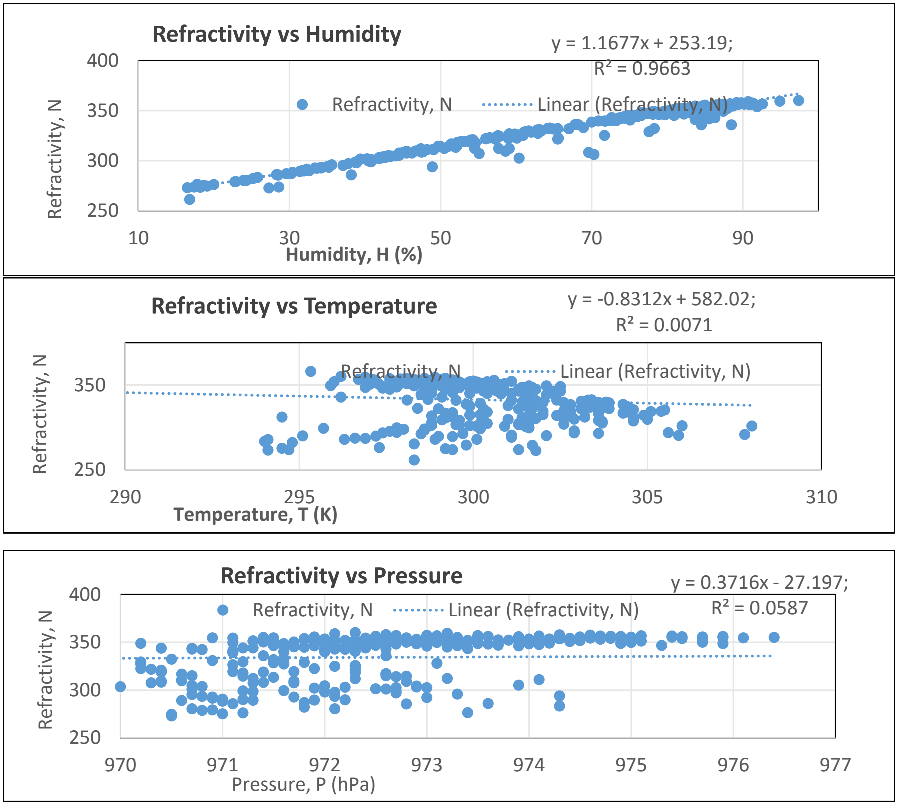



**Fig.3 Modelling Refractivity against... (a) Humidity (b) Temperature (c) Pressure**

that the annual surface refractivity has little or no correlation with pressure and temperature, which disagrees with Jari and Ismo's (2015) results. Conversely, there is a very strong correlation between

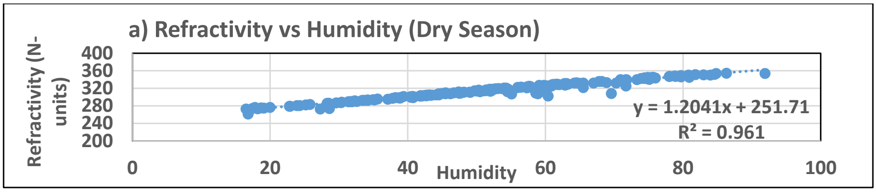
**Table 2: Summary of results of annual regression**

| | N vs Humidity (N-H) | N vs Temperature (N-T) | N vs Pressure (N-P) |
|---|---|---|---|
| Regression equations | N = 1.1677H + 253.19; $R^2$ = 0.9663 | N = -0.8312T+ 582.02; $R^2$ = 0.0071 | N = 0.3716P - 27.197; $R^2$ = 0.0587 |

refractivity and humidity (where $R^2 = 0.97$); and this agrees with the findings of Joseph (2016) but disagrees with the findings of Jari and Ismo (2015). An application of this finding is that humidity may be used to predict refractivity.

### 3.4 Regression Modelling of Seasonal Refractivity

Graphical regression models of seasonal variation of refractivity with humidity presented in figures 3(a) and 3(b) show that the dry season regression model of refractivity was strongly correlated with humidity, while



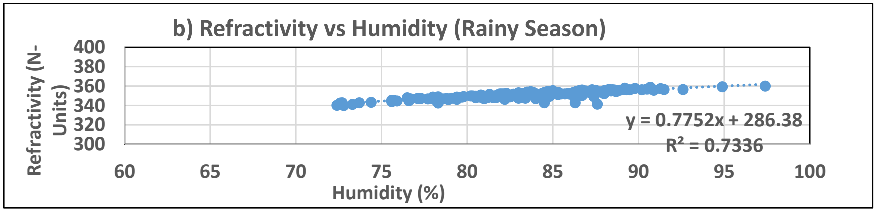




**Fig.3 Regression Modelling of Seasonal Refractivity (a) Dry Season (b) Rainy Season**

the rainy season model was less strongly correlated as expressed in equations (5) and (6) respectively: For this

$$N = 1.204\,H + 252; \quad R^2 = 0.96 \quad - \quad \text{Dry season model} \qquad (5)$$

$$N = 0.775\,H + 286; \quad R^2 = 0.73 \quad - \quad \text{Rainy season model} \qquad (6)$$

reason, a month-by-month investigation of the variation of refractivity was carried out for the dry and rainy seasons and summarized on Table 1. It was observed that the slope and intercept of dry months were averagely 1.14 and 255 respectively while the average slope and intercept in the rainy months were 0.822 and 281 respectively.

**Table 3: Monthly variation of refractivity with humidity**

| Month | Regression Equation (Dry) | |
|---|---|---|
| **Nov** | N = 1.146H + 256 | $R^2 = 0.762$ |
| **Dec** | N = 1.026H + 259 | $R^2 = 0.8181$ |
| **Jan** | N= 1.166H + 253 | $R^2 = 0.9194$ |
| **Feb** | N = 1.284H + 248 | $R^2 = 0.9181$ |
| **Mar** | N = 1.180H + 253 | $R^2 = 0.8346$ |
| **Apr** | N = 1.053H + 263 | $R^2 = 0.9302$ |
| **Average** | N = 1.14**H** + 255 | $R^2 = 0.8673$ |

| Month | Regression Equation (Rainy) | |
|---|---|---|
| May | N = 1.113H + 260 | $R^2 = 0.7488$ |
| **Jun** | N = 0.862H + 279 | $R^2 = 0.6816$ |
| **Jul** | N= 0.860H + 279 | $R^2 = 0.4286$ |
| **Aug** | N = 0.804H + 283 | $R^2 = 0.41$ |
| **Sep** | N = 0.791H + 284 | $R^2 = 0.5681$ |
| **Oct** | N = 0.791H + 283 | $R^2 = 0.2392$ |
| **Average** | N = 0.822**H** + 281 | $R^2 = 0.466$ |

A closer study of the slopes and intercepts for rainy months and dry months in Table 1, the month of May could be classified as a borderline month between the dry and the rainy seasons. This is because all the parameters of the month of May - slope, intercept and regression coefficient – were close to that of the dry month's parameters. This closeness suggests that May could be classified as a dry month in Jos, albeit it needs to be subject to collecting and analyzing data over many more years. In Table 1, May was excluded while calculating the average values for rainy months. It was also observed from the intercepts that the threshold of refractivity in the rainy season (281 N-units) is higher compared to threshold of refractivity (255 N-units) in the dry season.

These models and parameters could be used to design instruments that would simplify the process of measuring and predicting refractivity. Such instruments would facilitate faster, easier planning of radio communication links and several applications deployed on satellite links, such as GPS, satellite television, aviation and navigation aids. These results can be leveraged to improve system performance, but more studies are required to avoid over-generalization.

## 5. CONCLUSION

In this study, refractivity was estimated and modelled from meteorological data of humidity, temperature, and pressure (HTP) archived on Weather Underground (WU) website, using a 12-month period (January to December 2023). Higher values of refractivity were observed in the rainy season, which could mainly be adduced to elevated moisture content and humidity in the troposphere during rainy season. While refractivity values in the dry season were lower and more scattered between a minimum value of 270 N-units and a maximum of 320 N-units, refractivity in the rainy season clustered around higher values of 340 to 360 units. The graphical regression models with the various HTP parameters revealed that temperature and pressure were weakly correlated to refractivity (where $R^2 = 0.007$, and 0.06 respectively), while humidity was strongly correlated to refractivity (where $R^2 = 0.97$). The seasonal model of refractivity against humidity revealed a stronger regression coefficient of 0.96 in the dry season, than in the rainy season with a value of 0.73. For the refractivity-humidity (N-H) characteristic curves, the average slopes and intercepts for dry and wet months were (1.14; 255, $R^2 = 0.96$ ) and (0.822; 281, $R^2 = 0.47$) respectively. The parameters for the month of May as a rainy month suggest that May could be classified as a dry month, but this should be subjected to analysis of many more years of data. The models derived could serve as useful input for design and construction of an instrument for predicting and/or estimating refractivity in the region. These results can be leveraged to improve system performance, however data covering many more years would be studied further to validate the results.

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