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Original Article

Distribution of seasonal variation of point refractivity gradient and geo-climatic factor over Ede-Nigeria

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Abstract

The quantification of anomalies in radio signal transmission has been a serious challenge in using data from radiosondes to determine meteorological parameters in Ede, Nigeria. The point refractivity gradient and geoclimatic factor were analyzed in this study. Air temperature, relative humidity, and pressure for five years (2017 – 2021) are the meteorological parameters used. These parameters were collected from the ERA5 (European Centre for Medium-Range Weather Forecasts, 2017) radiosonde data archives. The results revealed the monthly and seasonal fluctuations in the point refractivity gradient and geoclimatic component within the study period. From the results, Geoclimatic Factor (K) and the yearly average Point Refractivity Gradient (dN_1) for Ede are 3.37E-05 and -143.712 N-units/Km respectively. In July, the highest dN_1 value of -48.332 N-units/Km was recorded, while the lowest value of -225.534 N-units/Km was recorded in November. In addition, the wet season has a higher point refractivity gradient than the dry season, although the wet season has a lower geoclimatic factor. The values obtained in this study are to be considered and adopted for improving the microwave link Quality of service (QoS) and availability in this region.

Keywords: temperature, relative humidity, seasons, geoclimatic factor, point refractivity gradient

1. Introduction

The complexity of the troposphere is increased by atmospheric meteorological characteristics, such as water vapor density, temperature, relative humidity, and pressure, which have a substantial impact on microwave transmission. They interact in a variety of ways in the tropics to influence the propagation of radio waves, as well as the radio refractivity gradient (Zheng & Han-Xian, 2013; Zubair, Haider, Khan, & Nasir, 2011). Behavior of radio signals in the atmosphere is determined by establishing the variations of the refractivity gradient. The vertical profiles of moisture, pressure, and air temperature in the atmosphere are responsible for this fluctuation (Emmanuel, Ojo, & Adedayo, 2020). When it comes to the transmission of radio waves during clear air on terrestrial line-of-sight lines, different behavior of these atmospheric characteristics results in signal losses on the transmission link (Mason, 2010; Shambayati, 2008). The effects of super–refraction and ducting phenomena on radar observations significantly depend on the refractivity gradient in a 1 km region above ground. The field strength at very high frequency (VHF) sites beyond the horizon also cannot be underestimated (Bean & Dutton, 1968; Dairo & Kolawole, 2017; Karagianni, Mitropoulos, Latif, Kavousanos-Kavousanakis, Koukos, & Fafalios, 2014).

The subject of radio refractivity has received more attention, especially in the temperate region. Among such studies are the works of Abdulhadi and Kifah (2010), Řezáčová, Ondřej, and Lucas (2003), and Valma, Tamosiunaite, Tamosiunas, Tamosiuniene, and Zilinskas (2011) to mention but a few. Attention is much needed in the tropics, such as in Ede of Nigeria, due to the intense nature of its climatological environment.

In Nigeria, there are prior studies (Adediji & Ajewole, 2008; Adeyemi & Emmanuel, 2011; Asiyo & Thomas, 2013; Ele & Nkang, 2014; Falodun & Ajewole, 2006; Kolawole, 1983; Ojo, Ajewole, Adediji, & Ojo, 2015; Ononiwu & Constance, 2015) on refractivity gradients and

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point refractivity gradients. However, one of the elements employed in determining multipath fade depth of communication links at any location of interest is the geoclimatic component. The meteorological characteristics collected in the lower and upper atmosphere are primarily used to determine geoclimatic factors.

Multipath fading arises when a signal encounters an obstruction that causes it to take multiple pathways before reaching its destination. As a result of this issue, signal propagation in the troposphere is hampered. Multipath fading can also be caused by the refractive index changes of atmospheric horizontal layers in particular. This is in agreement with Serdege and Ivanovs (2007), who affirmed that due to seasonal variations in refractive index, radio wave systems may become unavailable; and that the structure of the radio refractive index, n, in the lower atmosphere is a significant factor in communication connection estimation.

In addition, the notion of geoclimatic factor assessment is still important to communication engineers, because it stands as the most essential criterion in determining fade depth. The geoclimatic factor is used to calculate the likelihood of a worst-case month outage (Bettouche, Basile, & Kouki, 2014; Göktas, 2015; Ugwu, 2015). The point refractivity gradient (dN_1), which is determined by several meteorological variables like temperature, pressure, and atmospheric vapor pressure, is used to calculate geoclimatic factors. These data are necessary for making adequate plans and designs for communication radio links of satellite networks, radar, or other applications.

The climate in Ede, Nigeria is hot and humid most of the year and is likely to experience anomalous radio wave propagation due to its special climate. In this regard, few studies are available for this region. This study aimed at estimating the seasonal variations in the geoclimatic factor values and point refractivity gradient in Ede, Nigeria.

2. Materials and Methods

Ede (Geo. 7.299^o N, 5.147^o E) in Nigeria's Osun state was chosen as the research area. The meteorological data used in this study were gathered over a five-year period (January 2017 to December 2021) from the archives of European Centre for Medium-Range Weather Forecasts, 2017 (ECMWF). Fifth generation atmospheric re-analysis (ERA-5), which provides hourly meteorological data (relative humidity, pressure, and temperature), was required for characterization of the propagation conditions. ERA-5 uses complex modeling and data assimilation technologies to turn massive volumes of historical data into global estimations. It gives an hourly worldwide value of atmospheric parameters with 137 vertical levels from the surface to 0.01 hPa and a horizontal resolution of 31 km (Hersbach, 2016). Variations of wind regimes and near-surface air temperature are presented by ERA5. The ERA5 data being in NetCDF format is downloaded and processed using the ferret and python packages (Tetzner, Thomas, & Allen, 2019).

In Ede, the wet season usually ranges from late March to end of September, and the dry season most times pick up from October till February. Values of temperature, relative humidity, and pressure were gathered for five years from the daily log of Era5. These data were used to calculate the point refractivity gradients.

The refractive index, n, can be represented by the term ‘radio refractivity, N’ as defined by the International Telecommunication Union (ITU-R) (2012).

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

$$n = 1 + N \times 10^6 \quad (2)$$

In terms of measurable meteorological parameters, the refractivity N, can be expressed as:

$$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) = 77.6 + \frac{p}{T} + 3.73 \times 10^5\frac{e}{T^2} \quad (3)$$

where p denotes atmospheric pressure in hPa, T denotes absolute temperature in degrees Kelvin (K), and e denotes water vapour pressure in hPa.

The dry and wet components of refractivity in the lower atmosphere (troposphere) are distinguished. The dry term makes up a larger portion of the total refractivity in the atmosphere, accounting for roughly 70% of the total value. The dry term varies with the distribution of gas molecules in the atmosphere and is proportional to their density. Surface data of pressure, P (hpa), and temperature, T (Kelvin) can be used to estimate the dry term of refractivity, which is reasonably stable, with an accuracy of about 20%.

$$N_{dry} = 77.6 + \frac{p}{T} \quad (4)$$

The wet term, on the other hand, is responsible for the majority of changes in refractivity in the atmosphere. Due to the electric polarity of water molecules, the term "wet" is used.

$$N_{wet} = 3.73 \times 10^5\frac{e}{T^2} \quad (5)$$

in which e, the water vapour pressure, is calculated using

$$e = \frac{6.112H}{100}\exp\left(\frac{17.502t}{t+240.97}\right) \quad (6)$$

H (%) denotes the relative humidity, and t (^{o}C) denotes the air temperature.

The refractivity gradient in the atmosphere, which is a function of height, is expressed as (ITU, 2003):

$$\frac{dN}{dh} \approx \frac{N_2 - N_1}{h_2 - h_1} \quad (7)$$

where N_1 and N_2 are the refractivities at heights h_1 and h_2, respectively.

N_1 and N_2 are the lower and upper atmospheric refractive indexes, respectively. (Chaudhary & colleagues, 1986).

The point refractivity dN_1 (N – units/Km) according to ITU-R P.530-15 (09/2013) is the point refractivity gradient in the lowest 65 m of the atmosphere, not exceeded for 1% of an average year. The dN_1 value is obtained using (7), where N_1 is calculated considering the h_1 value nearest to 65 m height, so that 60 m < h1 < 70 m

Inverse Distance Weighting (IDW) is a method of spatial interpolation that is employed in data analysis, sometimes to impute missing values.

$$Z_0(x_0) = \sum_i^n \lambda_i \ (x_i) \quad (8)$$

i represents the value approximated with respect to the observed points, x_o, n represents the total number of points that were sampled, Z represents the known value at the sampled point, λ_i and x_i are the weighting parameters.

$$\frac{\frac{1}{(d_i)^p}}{\sum_{i=1}^n \frac{1}{(d_i)^p}} \quad (9)$$

di denotes the distance between x_o and x_i, n is as mentioned earlier, and p is the power factor.

The Geoclimatic factor K was calculated using ITU-R. P.530-14, 2012

$$K = 10^{-4.6-0.0027d\,N_1} \quad (10)$$

3. Results and Discussion

The data in this study encompassed the two climatic seasons that occur in Ede each year, the wet season and the dry season. Every year, the dry season is from October to February, and the rainy season extends from March to September.

The Ede climate is tropical in nature; it is a zone where warm, wet air from the Atlantic meets hot, dry, and often dusty air from the Sahara, known as the 'harmattan.' Equation (6) was used to convert relative humidity to water vapor pressure, e (hpa), while equation (3) was used to calculate the refractivity using the data.

Figure 1 shows the yearly point refractivity gradient variations. The results show that the year 2017 had the highest point refractivity gradient, while the year 2020 recorded the lowest point refractivity. The average point refractivity gradient for the five (5) years is estimated to be -158.39. This is attributed to the climatic changes during that period. Ede experienced very low precipitation in the year 2020.

Table 1 and Figure 2 show the results obtained from the computed values of the point refractivity gradient for the average monthly records. From March to August, high levels of point refractivity were recorded, owing to the presence of high humidity beginning in the month of March, and as a result, there is a lot of water vapor in the atmosphere, which could be attributed to the convective and occasionally thunderstorm forms of rain that were seen during this time. Due to heavy rainfall in the months preceding the event, the atmosphere experiences a lifting of the boundary layer, with significant amounts of water vapor present in the atmosphere (Adeyemi, 2004).

The values of point refractivity were also seen to be low during the dry season. Figure 2 depicts the usual monthly change of point refractivity at the start of the dry season in October, revealing an erratic oscillation. The measured point refractivity gradients are projected to diminish by December as the harmattan haze begins to take impact and becomes intense. These findings are in agreement with the works of (Abdulhadi, & Kifah, 2010; Bettouche et al., 2014; Ilesanmi & Moses, 2021; Odedina & Afullo, 2007; Ojo, Ajewole, Adediji, & Ojo, 2015; Valma et al, 2011).

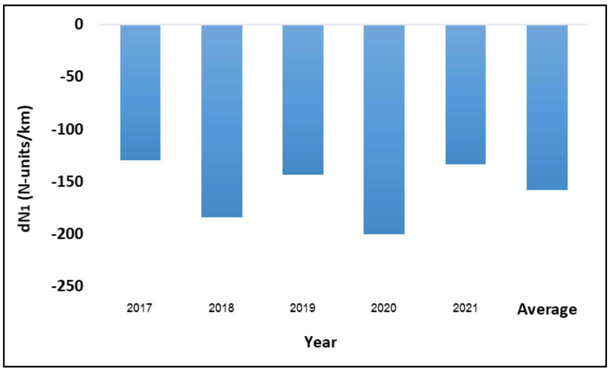

Figure 1. Yearly averages of point refractivity gradient

Table 1. Geoclimatic factor (K) and point refractivity gradient (dN_1) for ede on a monthly basis

Month	Geoclimatic factor (K)	Point refractivity gradient (dN_1 (N-units/Km))
January	3.02E-05	-55.201
February	3.910E-05	-83.471
March	3.74E-05	-198.625
April	4.02E-05	-220-.713
May	3.54E-05	-77.254
June	2.02E-05	-56.311
July	3.07E-05	-48.332
August	3.14E-05	-80.142
September	2.60E-05	-131.631
October	3.71E-05	-180.510
November	4.00E-05	-225.542
December	3.74E-05	-320.144
Annual average	3.37E-05	-143.712

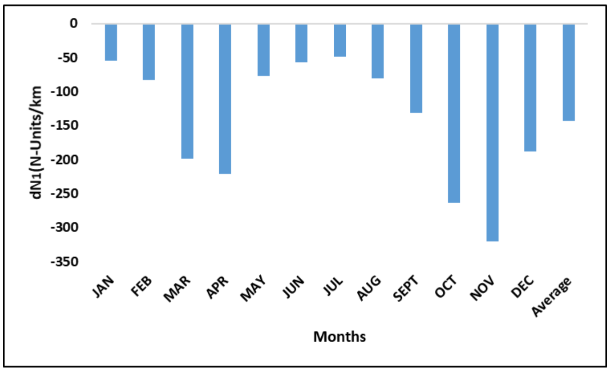

Figure 2. Monthly distribution of point refractivity gradient (dN_1)

The point refractivity gradients at Ede vary greatly; the highest value of -48.33 N-units/Km was recorded in July, while the lowest value of -320.144 N-units/Km was recorded in November. The results also agree to an extent with the global ITU map which theoretically gives the threshold of dN_1 in these coordinates to be -273.2 N/km. However, the variations in the values call for attention in optimizing the performance of digital terrestrial point-to-point links in Ede.

In Table 1, it is seen that the Geoclimatic Factor (K) and annual average Point Refractivity Gradient (dN_1) are 3.37E-05 and -143.712 N-units/Km respectively. Table 2, as reflected in Figures 3 and 4, demonstrates seasonal fluctuations in the duo. -116.17 (N-units / Km) was recorded for the average point refractivity during the wet season while -182.271 (N-units / Km) was estimated for the average dN_1 during the dry season. Obviously, the point refractivity gradient (dN_1) was higher in the wet season compared to the dry season.

The estimated values of the average Geoclimatic factor (K) are shown in Table 3, and in Figure 4: for the wet season 3.1617E-05 was estimated, while 3.68E-05 was estimated for the dry season. The Geoclimatic factor in the dry season was higher than in the wet season. From March to September (rainy months) has lower values, whereas the dry season that runs from October to November has higher values. The results are in agreement with the works of Ilesanmi and Moses (2021), Odedina and Afullo (2007).

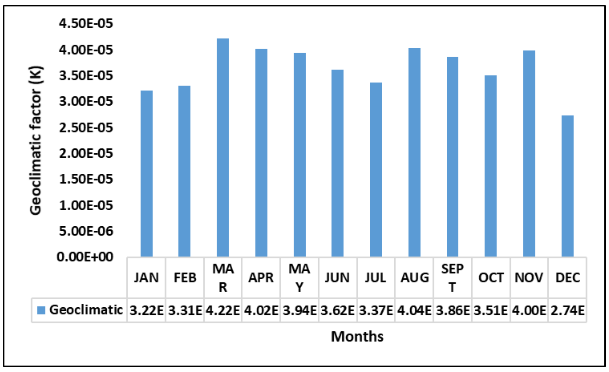

Figure 3. Monthly distribution of geoclimatic factor (K)

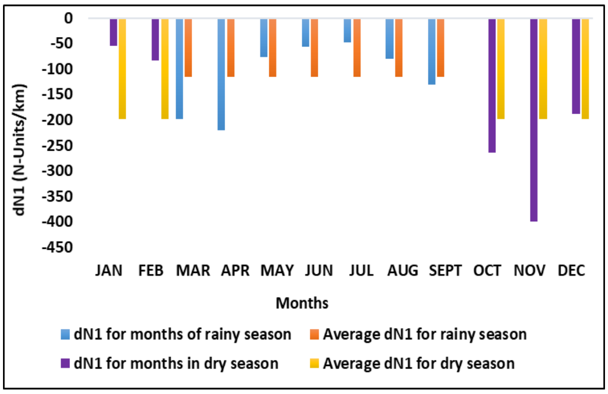

Figure 4. Point refractivity gradient for both dry and rainy months over Ede

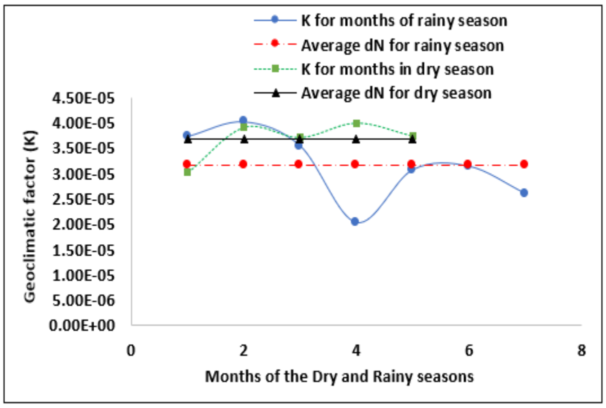

Figure 5. Dry and rainy season monthly variation of geoclimatic factor (K) over Ede

Table 2. Monthly distribution of point refractivity gradient (dN) for the dry and rainy seasons in Ede

Month of dry season	Point refractivity gradient of each month in the dry season	Month of rainy season	Point refractivity gradient of each month in the rainy season
Jan	-55.201	March	-198.625
Feb	-83.471	April	-220.713
Oct	-180.51	May	-77.254
Nov	-225.411	June	-56.311
Dec	-200.54	July	-48.332
		Aug	-80.142
Average point refractivity	-182.271	Sept	-131.631
		Average point refractivity	-116.17

Table 3. Monthly distribution of geoclimatic factor (K) for the dry and rainy seasons in Ede

Month of dry season	Geoclimatic factor of each month in the dry season	Month of rainy season	Geoclimatic factor of each month in the rainy season
Jan	3.02E-05	March	3.74E-05
Feb	3.910E-05	April	4.02E-05
Oct	3.71E-05	May	3.54E-05
Nov	4.00E-05	June	2.02E-05
Dec	3.74E-05	July	3.07E-05
		Aug	3.14E-05
Average K for dry season	3.68E-05	Sept	2.60E-05
		Average K for rainy season	3.16E-05

4. Conclusions

Meteorological parameters, such as humidity, temperature, and air pressure, over Ede, Nigeria, were used to determine the geoclimatic factor and the point refractivity gradient in order to know the behavior of radio waves in the area. This will give the opportunity to make appropriate decisions regarding the type of device, transmitter gain, public guide, and mitigation strategies to be employed in ensuring a smooth transmission of the radio waves in Ede. Monthly and seasonal fluctuations in the geoclimatic factor and point refractivity gradient were observed. The wet season has a higher point refractivity gradient than the dry season, but with a lower geoclimatic factor.

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