Jewel Journal of Scientific Research (JJSR) 6(1&2): 55–60, 2021
©Federal University of Kashere-Nigeria (Print ISSN: 2384 – 6267, Online ISSN 2756-651X)
jjsr.fukashere.edu.ng

Propagation Trends of Radio Signals in Yola Metropolis, North-East Nigeria

Yusuf, N. A[1]; Udo, A. A*[1]; Abe, A. O[1]; Nosike, C. V.[1]; Dick, M. D.[2] and Ekanem, K. R.[2]

[1]Department of Physics, Federal University of Kashere, Gombe State, Nigeria.
[2]Department of Physics, Akwa Ibom State Polytechnic, Ikot Ekpene.
*Corresponding Author: nnamukoani@gmail.com +234 803 255 7391

Abstract

The propagation pattern of radio signals from the radio transmitter to the radio receivers as they pass through the transmission media is of great significance in the management and planning process of radio communication systems. With variable climatic factors, which are the main determinants of tropospheric propagation of radio waves, it becomes necessary to study these variables for a considerable period of time to see if a trend could exist. To ascertain this trend, a ten-year (2009-2018) primary weather data from the Nigerian Meteorological Agency (NIMET) was used to calculate: refractivity (N), refractivity gradient (G), and k-factor for radio signals in the Yola metropolis. The results showed a sharp increase in the refractivity values during the onset of the rainy season in May with a mean value of 1452.975 N-units/km. The refractivity gradient calculated at 190.5 m above the ground level showed an inverse relationship with the obtained refractivity values. The Computed k-values showed that, the radio signals within the study area propagated with a sub-refraction mean value of 0.946, less than the global standard value of 1.333 by the International Telecommunication Union (ITU).

Key words: Refractivity, k-factor, refractivity gradient, radio waves, sub refraction

Received: 16th May, 2021 *Accepted:* 25th July, 2021 *Published Online:* 15th Aug, 2021

Introduction

The recent effort by the international community to update the radio-climatological data base for tropospheric propagation predictions has led to a rise in the number of meteorological stations involved in new potential variables prediction, analysis and the introduction of improved mapping and other presentation procedures. This became necessary in view of the fact that a radio signal propagating through the troposphere does not arrive at its destination with the same amount of energy with which it was propagated from the source due to tropospheric attenuations. The influence of atmospheric conditions on the propagation of electromagnetic waves has been studied from the beginnings of radio wave technology (Kerr, 1987). The propagation of radio waves in terrestrial systems is mainly affected by the refractive index (the ratio of the propagation speed in a vacuum to the speed of propagation in another medium) of the troposphere. This refractive index is related to the common atmospheric quantities of pressure, temperature, and water vapor. It is these quantities that cause radio waves to bend as they travel through the lower atmosphere. The variations in these variables cause the refractive index of the air in the troposphere to differ in both time and space (Ayantunji, *et al*., 2011; Okoro, and Agbo, 2012; Ukhurebor and Azi, S.O. 2018). This path bending of electromagnetic waves due to inhomogeneous spatial distribution of the refractive index of air causes effects such as multipath fading and interference, attenuation due to diffraction on the terrain obstacles or so-called radio holes (Lavergnat and Sylvain, 2000; Adediji and Ajewole, 2008; Adedayo, 2016). These effects can have severe implications on radio wave propagation including ghosting on old analog television sets, interference in mobile networks that employ frequency reuse schemes, and further than expected signal propagation.

The path of a radio ray becomes curved when the radio wave propagates through the Earth's atmosphere due to the variations in the atmospheric refractive index along its path. The value of the atmosphere's refractive index is very close to the unit and changes of the atmospheric refractive index value are very small in time and space (Freeman, 2007). To make those changes more noticeable, the term refractivity is used. The atmospheric refractivity of a radio wave is dependent on physical parameters of air such as pressure, temperature and water content. It varies in space, and time due to the physical processes in the atmosphere that are often difficult to describe in a deterministic way and have to be, to some extent, considered as random with its probabilistic characteristics (Martin and Vaclav, 2011; Adedayo, 2016). A decrease in pressure with altitude is mainly responsible for a standard vertical gradient of the atmospheric refractivity which can lead to sub-refractivity, super-refractivity, or ducting.

Refractivity of the atmosphere affects not only the curvature of the radio ray path but also gives some insight into the fading phenomenon. This anomalous propagation can be a problem for radars because the variations of refractivity can induce loss of radar coverage (Norland, 2006). In practice, the propagation conditions are more complicated such that even small changes of temperature, humidity, and partial water vapor pressure lead to noticeable changes in the atmospheric propagation conditions (Priestley and Hill, 1985; Kablak, 2007).

It is therefore important to understand the variational trends of these secondary variables over a considerable period of time to enable appropriate planning and predict the likely effects to be encountered within a given time of a year.

Materials and Methods

The primary data: temperature, pressure, and humidity or water vapor pressure covering a period of ten years (2009-2018) were obtained from the Nigerian Metrological Agency (NIMET), Yola. The data included mean monthly temperature (°C), mean monthly atmospheric pressure (hPa) and mean monthly relative humidity (%). From these data, the average for each month was computed, which represented the mean variations for the ten years. The secondary climatic variables: refractivity (N), refractivity gradient (G) and effective earth's radius (k-factor) were calculated using the relevant equations.

The surface refractivity was deduced using the relation presented in (Smith and Weintraub, 1953).

$$N = (n-1) \times 10^6 = \frac{77.6}{T}\left[P + \frac{4810e}{T}\right] \quad 1$$

Where N is the refractivity, n is the refractive index, T is the absolute temperature, P is the atmospheric pressure (hPa) and e is the water vapor pressure (hPa). The equation is valid at surface level and for radio frequencies between 1 GHz and 100GHz (Jackson *et al*., 2016).

Alternatively; the equation can be rewritten as;

$$N = \frac{77.6P}{T} + \frac{3.73 \times 10^5 e}{T^2} \quad 2$$

Where the parameters retain their usual meanings.

The water vapor pressure was calculated using equation (3).

$$e_s = \frac{100e}{H} \quad 3$$

Where H is relative humidity, e_s is the saturated vapor pressure.

Ayatunji *et al.,* (2011) had shown that e_s relate to temperature by the following equation:

$$e_s = 6.1121\, exp\left[\frac{17.502T}{T+240.97}\right] \qquad 4$$

Where T is the temperature in degree Celsius (°C) and e_s is the saturated vapor pressure (hPa). Hence, the equation used in calculating the water vapor was obtained by substituting equation (3) into (4) to give

$$e = 0.061121Hexp\left[\frac{17.502T}{T+240.97}\right] \qquad 5$$

Where H = relative humidity (%), and T = temperature (in °C).

The gradient of refractivity was determined, using the relation presented in (Smith and Weintraub, 1953).

$$G = \frac{\Delta N}{\Delta h} \qquad 6$$

Where G is the gradient of refractivity, h is the height (altitude) taken at 190.5 meters above the meteorological station and N is refractivity.

However, k-factor was determined using the relation presented in (Akanni, *et al.,* 2018).

$$K = \left[1 + \frac{\left(\frac{dN}{dH}\right)}{157}\right]^{-1} \qquad 7$$

This simplified to:

$$K = \frac{1}{1+0.006371G} \qquad 8$$

Where k is the effective earth radius (k factor) and G is the gradient of refractivity respectively.

Results

The computed secondary climatic variables such as surface refractivity (Ns), refractivity gradient (G), and K-factor were plotted against the months of the year to distinguish between computed, and trend curves with respect to changing times of the year. As shown in Figures 1-3.

Discussions

The results obtained showed that, the average radio refractivity, N, over the period of consideration rose steadily from January with a sharp increase during the onset of the rainy season, with a peak in the month of May. Refractivity values ranged from (787.7 to 2066.5) N unit/km in January and May with an average value of 1452.975 N unit/km. This is attributed to the sudden rise in atmospheric moisture content in the region during this period. Though May is not the peak of the rainy season in the study area, the average temperature of May was observed to be slightly higher than that of other rainy months. Also, during the onset of rainy seasons, the area witnesses sand storms which fill the atmosphere with dust particles and sand leading to reduced visibility (Temi, and Tamuno, 2003). A combination of these factors during the onset of rains leads to an increase in the value of the refractivity compared to other months of the year. An increased refractivity value during the rainy season in Nigeria was also reported by Adedayo, (2016); Amajama, *et al*., (2016) and Akanni, *et al*., (2018). Milda *et al*., (2011) had reported that radio signal attenuation due to rain, fog, and clouds can lead to the perturbations of the wireless, mobile, satellite, and other communications. The scattering of radio waves by dust and sand particles in the atmosphere was also reported by Chima, *et al*., (2018) which also agrees with what is observed in the study area. The slightly parabolic variation of refractivity with the months of the year observed in Figure 1 can be approximated with a trend curve equivalent to $y = -30.52x^2 + 414.8x + 409.8$ with X representing the month of the year.

The vertical gradient of refractivity in the lower layer of the atmosphere is an important parameter in estimating path clearance and propagation effects such as sub-refraction, super-refraction and tropospheric ducting (Afullo, *et al*., 1999; Akanni, *et al*., 2018). In the study, the refractivity gradient was calculated at a height of 190.5 m. The observed trend follows that of the refractivity with a trend given by $y = -0.160x^2 + 2.178x + 2.147$.

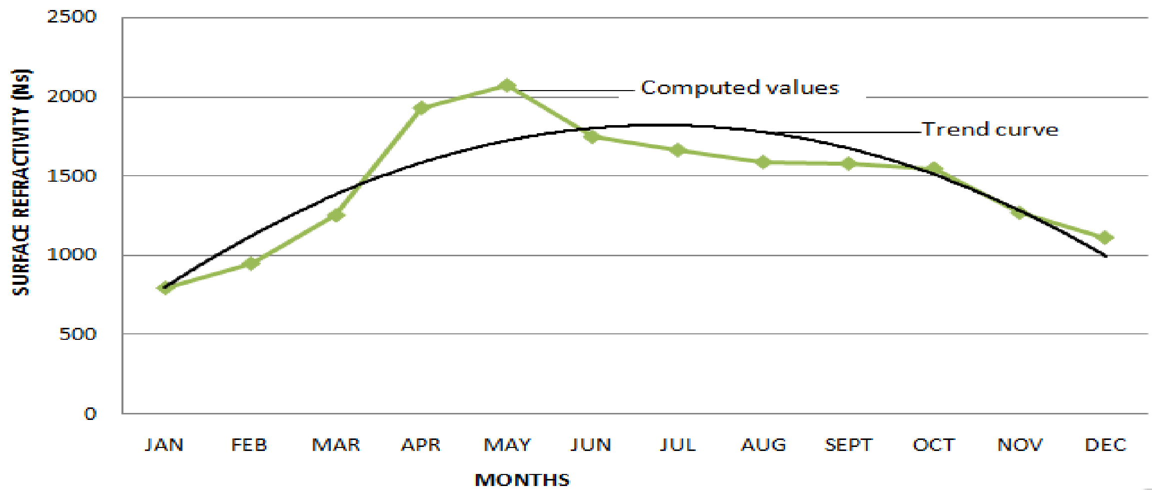

Figure 1: Variation of surface refractivity with months from 2009-2018.

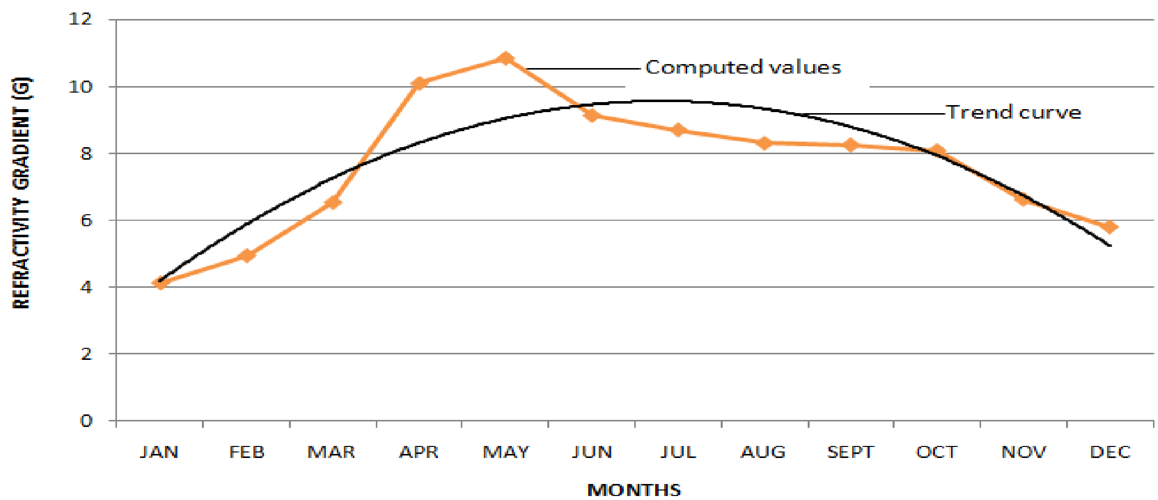

Figure 2: Variation of refractivity gradient at 190.5 m with months from 2009-2018.

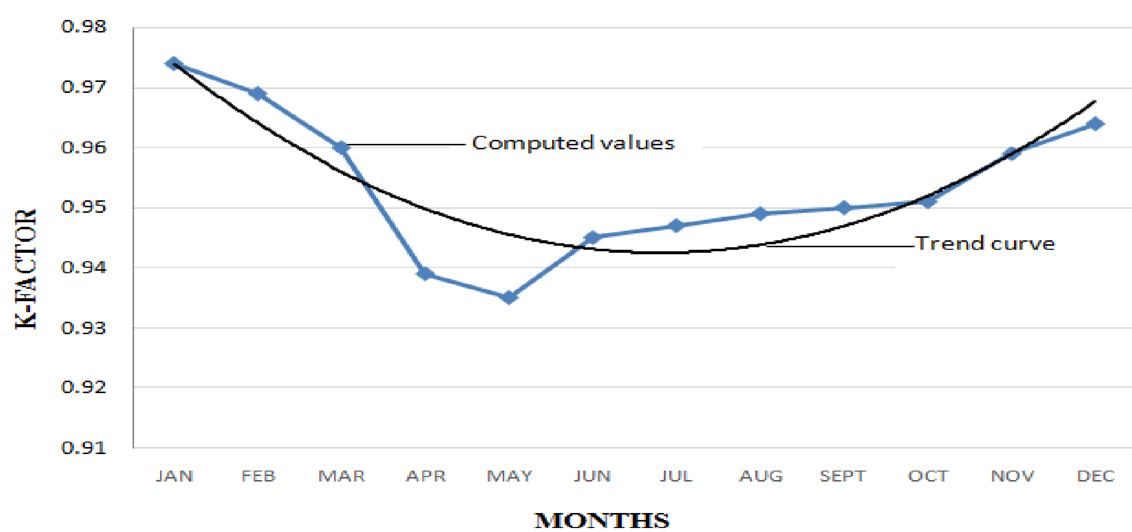

Figure 3. Variation of effective earth radius (k-factor) with months from 2009-2018.

For the k-factor, it was observed that the effective earth's radius (k-factor) values decreases in the rainy season with the values ranging between 0.935 and 0.974 with a mean of 0.946. This value is less than the global standard value of (1.333) (ITU-R, 2012). Here, we have that $1.33 > k > 0$, which results in a sub-refraction condition. The implication of this is that the radio waves propagate abnormally away from the earth's surface. They bend upwards away from the earth and this tends to shorten the radio horizon (Harvey, 2010). The radio beam traveling in the link within the study area will be refracted upward. On the other hand, the portion of the wavefront that is received at the end will travel close to the ground than usual resulting in signal attenuation. The variational trend of the k-factor over the decade can be represented with a trend equation given by $y = 0.000x^2 - 0.012x + 0.985$. These findings are important in radio link planning for the study area.

Conclusion

An analysis of the propagation trends of radio signals in Yola Metropolis, North-East Nigeria has been carried out. The study showed that a trend exist between the secondary weather parameters, and the month of the year. The obtained empirical relationship for predicting the radio refractivity at different times of the year within the study area can be used for planning wireless links in the area. The average k-factor value of 0.946 showed that radio signals propagate with sub-refraction. This k-factor value can be used successfully for planning long term wireless communication within Yola Metropolis.

References

Adedayo, K. D. (2016). Statistical analysis of the effects of relative humidity and temperature on radio refractivity over Nigeria using satellite data. *African Journal of Environmental Science and Technology*, 10(7): 221-229. DOI: 10.5897/AJEST2016.2095

Adediji, A.T. and Ajewole, M.O. (2008). Vertical profile of radio refractivity gradient in Akure, Southwest Nigeria. *Progress in Electromagnetic Research*, 14:157-168.

Afullo, T. J, Motsoela, T and Molotsi, D.F (1999). Refractivity gradient and k-factor in Botswana. *Radio Africa*, 3: 107-110.

Akanni, A.O., Lateef, O.A., Ademola, A. and Adebayo, A.W. (2018). Effects of radio refractivity gradient and k-factor on radio signal over Ibadan, Southwestern, Nigeria. *Global Scientific Journal*, 6(5): 248-253.

Amajama, J., Mopta, S. E. and Fina, F. (2016).Variation of tropospheric radio wave refractivities across northern Nigeria – the Savannah. *International Journal of Engineering Research and General Science*, 4(3): 474-480.

Ayantunji, B.G; Okeke, P.N; Urama, J.O (2011). Diurnal and seasonal variation of surface refractivity over Nigeria. *Progress in Electromagnetic Research*, 30: 201-222.

Chima, A.I., Onyia, A.I and Udegbe, S.U. (2018). The effects of atmospheric temperature and wind speed on UHF radio signal: A case study of ESUT community and its environs in Enugu State. *IOSR Journal of Applied Physics*, 10(2): 83-90. DOI: 10.9790/4861-1002018390.

Freeman, R.L. (2007). Radio system design for telecommunications, 3rd ed., Wiley–Interscience, New York.

Harvey, R.W. (2010). Refractive and relativistic effects on ITER low field side reflectometer design. *Review of Scientific Instruments*, 81(10): 24-30.

ITU-R (2012). The radio refractivity index: its formula and refractivity data, International Telecommunication Union, Geneva. p. 453.

Kablak, N. I. (2007). Refractive index and atmospheric correction to the distance to the Earth's artificial satellites. *Kinematics and Physics of Celestial Bodies*, 23(2): 84-88.

Jackson, E. I., Udofia, K. M. and Isaac, A. E. (2016). Determination of atmospheric effective earth radius factor (*k*-factor) under clear air in Lagos, Nigeria. *Mathematical and Software Engineering*, 2(1):30-34.

Kerr, D. E. (1987). *Propagation of short radio waves*. Peter Peregrinus Ltd./IEE, ISBN 086341-099-5, London, UK.

Lavergnat, J. and Sylvain, M. (2000). *Radio Wave Propagation: Principles and Techniques.* John Wiley & Sons, ISBN 0-471-49027-X, Chichester, UK.

Martin G, and Vaclav, K. (2011). Atmospheric refraction and propagation in lower troposphere, Electromagnetic Waves, Vitaliy Zhurbenko (Ed.). Intechweb.org 7:139-156.

Milda, T., Mindaugas, Ž., Milda, T. and Stasys, T. (2011).Atmospheric Attenuation due to Humidity. Electromagnetic Waves, Vitaliy Zhurbenko (Ed.). Intechweb.org 7: 157-172

Norland, N. (2006). Temporal variation of the refractive index in coastal waters. Proceedings of IRS 2006, International Radar Symposium, pp. 221-224, Krakow, Poland, 24 – 26 May 2006, ISBN 83-7207-621-9

Okoro, O.N and Agbo, G.A (2012). The effect of variation of meteorological parameters on the tropospheric radio refractivity for Minna, *Global Journals Inc.* 12(2): 1-10.

Priestley, J. T. and Hill, R. J. (1985). Measuring high–frequency refractive index in the surface layer. *Journal of Atmospheric and Oceanic Technology*, 2(2): 233–251.

Smith, E. and Weintraub, S. (1953). The constants in the equation for atmospheric refractive index at radio frequencies. Proceedings of the IRE, vol. 41, no. 8, pp. 1035-1037.

Temi, E.O and Tamuno, T.T. (2003). Annual sandstorm fluctuations and trends in Nigeria. *Journal of Meteorology*, 28(277): 93-102.

Ukhurebor, K.E and Azi, S.O (2018). Review of methodology to obtain parameters for radio wave propagation at low altitudes from meteorological data: New results for Auchi area in Edo State, Nigeria, *Journal of King Saud University – Science* 31(4): 1445-1451