Tanzania Journal of Science 48(1): 134-139, 2022
ISSN 0856-1761, e-ISSN 2507-7961

Investigation of the Vertical Profile Radio Refractivity Gradient and Effective Earth Radius Factor (k-factor) in Transmission Link Over Oyo, Oyo State, South Western Nigeria

Akeem L Sheu[1*], Kamaldeen O Suleman[2] and Qasim A Adeniji[3]
[1]*Department of Physics, Emmanuel Alayande College of Education, P.M.B. 1010, Oyo, Oyo State, Nigeria*
[2]*Department of Physics, Nigeria Maritime University, Okerenkoko, Delta State*
[3]*Department of Physics, Federal University of Kashere, Gombe State, Nigeria*
[*]*Corresponding author, e-mail: sheuakeemlawal73@gmail.com*
[*]*Co-authors' e-mail: kosuleman@lautech.edu.ng; qadeniji@yahoo.com*
Received 13 Sep 2021, Revised 21 Mar 2022, Accepted 24 Mar 2022, Published Mar 2022
DOI: https://dx.doi.org/10.4314/tjs.v48i1.12

Abstract

Surface radio refractive gradient and k-factor are very imperative in observing propagation conditions, designing and planning of microwave communication links in the lower part of the atmospheric boundary layer. The measurement of weather variables (air temperature, atmospheric pressure, relative humidity and wind speed) were conducted in this study at the School of Science, Emmanuel Alayande College of Education, Oyo (7.83°N, 3.95°E), Oyo State, Nigeria. The research was carried out for a period of one year (January to December, 2020) using self-designed cost effective portable weather monitoring systems. The systems were sited from the ground to a height of 200 m on a 220 m Nigeria Television Authority (NTA) UHF channel 37 tower at Oke-Apitipiti in Oyo Town of Oyo State. The calculated daily and monthly averages data are employed to investigate the vertical surface radio refractivity and its refractivity gradient. The highest value of -1.093E+26 N-units/km was recorded in January, while the month of July experienced the least of about -9.305E+19 N-units/km. The months of January–July verified sub-refractive conditions with propagation conditions having varying degree of occurrence. On the other hand, super-refraction and ducting were recorded mostly between August–December from the study. The results also find applicability in radio engineering for refining VHF/UHF terrestrial links based on clear-air considerations which will support operational planning of terrestrial radio networks in Oyo, South Western Nigeria.

Keywords: Microwave; k-factor; refractivity gradient; sub-refractive; super-refraction.

Introduction

The quality of Ultra High Frequency (UHF), Very High Frequency (VHF), and Super High Frequency (SHF) signals is basically determined by the radio refractive index parameter. The surface refractivity is very expedient for prognostication of some propagation effects and depicting a radio channel (Agbo et al. 2013). The probable manifestation of refractivity-related effects prerequisite for prediction methods is typically indicated and provided by local coverage and statistics of refractivity such as refractivity gradient and earth radius factor (k-factor) (Aboualmal et al. 2015).

The refractivity is liable for range and elevation errors in radar acquisition, fading of electromagnetic waves and other wave propagation such as ducting, scintillation and refraction. The assessment of radio refractive index and k-factor variations is accountable for the path bending of propagating radio wave towards or away from the earth (Ukhurebor et al. 2018). This necessitates the management of radio communication systems to take the changes in the distribution of refractivity into consideration (Aremu et al. 2018). Refractive characteristics studies are very crucial and relevant in the planning and designing of terrestrial communication systems, telecommunication network, navigation and surveillance systems (Akinwumi et al. 2017).

The refractivity is useful in order to lessen with the difficulties that may occur as a result of inconsistent radio wave propagation and unexpected path loss that affects the performance of these systems (Ayantunji et al. 2018). These unforeseen radio wave propagations can cause forceful effects to the magnitude of wide-ranging cessation of communication between the transmitters and the receivers or else make radar to completely miss its projected target (Alam et al. 2016).

In this study, the measurements of primary atmospheric weather variables were made at Emmanuel Alayande College of Education (EACOED), Oyo for a period of one year using a self-designed weather monitoring systems. The results obtained would be useful in the reliable and efficient planning, designing and management of terrestrial radio communication systems.

Materials and Methods

Radio refractivity (N)

The radio refractive index is the ratio of the radio energy propagation's velocity in a vacuum to the velocity in a specific medium. It is expressed in terms of a dimensionless parameter called refractivity N which is the measure of deviation of refractive index from unity in parts per million (Chukwunike and and Chinelo 2016). The radio refractivity, N and the refractive index, n of air are related as:

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

The refractivity, N and atmospheric weather variables such as the air temperature, atmospheric pressure, vapor pressured are connected by;

$$N = \frac{77.60}{T}\left(P + 4810\,\frac{\ell}{T}\right) \text{ and}$$

$$N = 77.60\,\frac{P}{T} + \left(3.73\times 10^{5}\,\frac{\ell}{T^{2}}\right) \quad (2)$$

Where P is the atmospheric pressure (hpa), T is the absolute temperature and ℓ is the atmospheric water vapour. The water vapour pressure, ℓ is obtained from the relative humidity, H, and temperature, T, by:

$$\ell = H\left(\frac{6.1121\exp\left(\frac{17.502T}{T+240.97}\right)}{100}\right) \quad (3)$$

The radio refractivity decreases exponentially in the troposphere with height, H given as:

$$N = N_{S}\exp\frac{h}{H} \quad (4)$$

Refractivity gradient (G)

The refractivity gradient is developed by differentiating equation (4) with respect to h as presented in equation (5):

$$\frac{dN}{dh} = -\frac{N_{S}}{H}\exp\left(-\frac{h}{H}\right) \quad (5)$$

The point refractivity gradient, dN/dh was achieved using;

$$G = \frac{dN}{dh} = \frac{N_2 - N_1}{h_2 - h_1} \quad (6)$$

where N_1 is the refractivity at the ground level, N_2 is the refractivity at the reference heights, h_1 is the ground level, while h_2 is the height at which the measurement took place. 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 such sub-refraction, super-refraction and tropospheric ducting. The vertical radio refractivity gradient G (N-units/km) at the surface level is expressed as in equation (7) with Ns are the values of surface radio refractivity (Ukhurebor and Azi 2019).

$$G = \frac{dN}{dh} = -7.32\exp(0.005577\,N_{s})(N - Units/km) \quad (7)$$

Effective Earth radius factor (k-factor)

K-factor can be used to depict refractive conditions as normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting, it is given as in equation (8) (Isikwue et al. 2013).

$$K = \frac{1}{\left(1 + \left(\frac{\frac{dN}{dh}}{157}\right)\right)} \tag{8}$$

Methods

The research engaged a self-designed inexpensive portable weather monitoring system for the continuous measurements of the primary atmospheric weather variables for a period of one year (January to December, 2020). Daily and monthly mean values were calculated by averaging the 30 minutes documented data. The refractivity values for both the dry and wet seasons were obtained using radio refractivity equations and the seasonal variation for each of the twelve months.

Results and Discussion

The result of the study has been analyzed to substantiate the investigation of the vertical profile radio refractivity gradient and effective earth radius factor (k-factor) in transmission link over Oyo, Oyo State, South Western Nigeria as shown in Table 1 and Figures 1 to 4.

Table 1: Radio refractivity, Earth's radius Factor (K-factor) and Refractivity gradient distribution over Oyo Metropolis for 2020

Time (hr)	Temperature (ºC)	Humidity (%)	Pressure (hpa)	Refractivity (N)	Refractivity Gradient (N-Units/km)	K-factor
01:00	23.0	34	976.7	8105.726	-3.141E+20	976.8
02:00	22.9	33	975.8	7887.048	-9.277E+19	975.9
03:00	22.7	32	975.4	7689.083	-3.076E+19	975.6
04:00	22.5	32	975.1	7731.531	-3.897E+19	975.2
05:00	21.2	37	975.6	9301.999	-2.48E+23	975.7
06:00	20.7	37	976.2	9462.432	-6.069E+23	976.4
07:00	19.8	39	976.6	10312.11	-6.935E+25	976.7
08:00	19.1	40	977.0	10882.57	-1.67E+27	977.2
09:00	20.3	37	977.4	9601.188	-1.316E+24	977.6
10:00	22.4	31	977.3	7514.01	-1.159E+19	977.5
11:00	23.2	30	977.0	7115.242	-1.253E+18	977.1
12:00	24.2	27	976.3	6249.888	-1.005E+16	976.5
13:00	27.1	23	975.2	5041.618	-1.19E+13	975.3
14:00	28.1	22	974.1	4754.464	-2.399E+12	974.3
15:00	28.9	21	973.2	4493.935	-5.612E+11	973.4
16:00	29.3	21	972.9	4474.14	-5.025E+11	973.0

The results in Figure 1 show that surface refractivity upsurges as temperature declines tremendously. The temperature values throughout the experiment are equitably constant and vary from 23 °C at minimal to 29.3 °C maximally. It is observed that the refractivity is 8105.726 N-units at the lowest temperature rate and 4474.14 N-units at the highest value of temperature. Figure 2 justifies the variations and drop in surface refractivity between 12.00 and 2.00 am of the midnight. There are fairly constant refractivity values between 2:00 and 9:00 pm which consequently heighten by 10 pm to maximum value of 7514.01 N units.

The low values of temperature, relative humidity and atmospheric water vapour are primarily due to descent in values of refractivity from 12 midnight to a minimum value in the day. The high saturated moisture content around the city of Oyo is as a result of better values of refractivity which are less than that in classic rainy season of July/August in those hours of the day and night. During the rainy season, the refractivity values are more or less constant all over the night and day than a typical dry season month of January/February. This clarifies that in Oyo Metropolis, radio refractivity has greater effects during rainy season than dry season due to the rise in atmospheric moisture content.

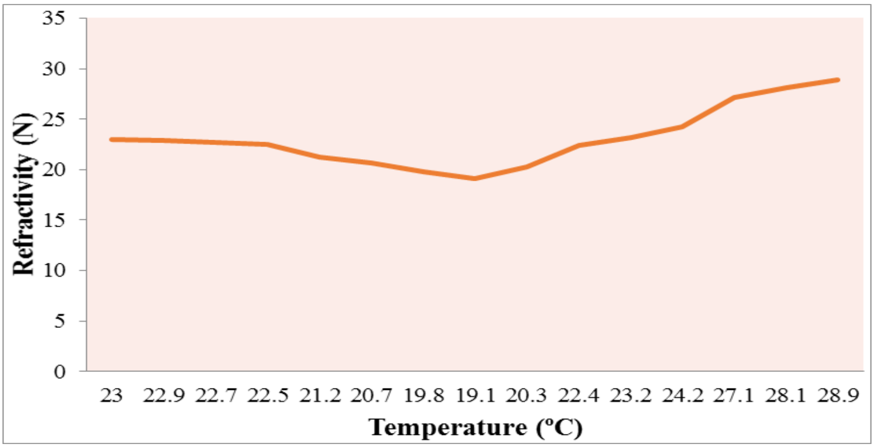

Figure 1: Hourly variations of refractivity against temperature over Oyo Metropolis for 2020.

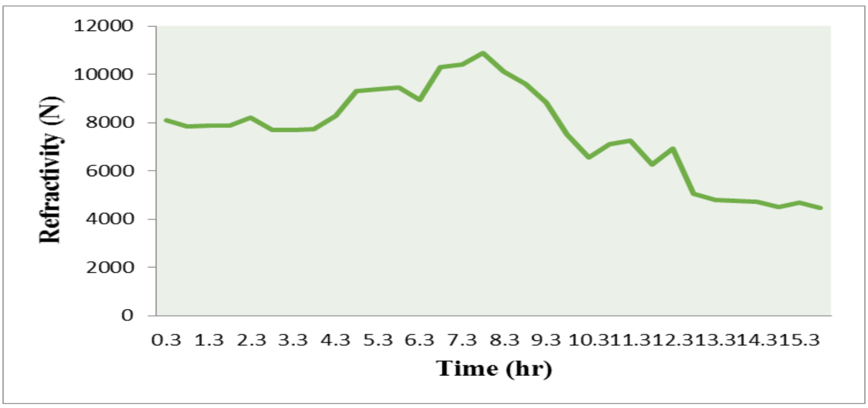

Figure 2: Hourly variations of refractivity over Oyo Metropolis for 2020.

Figure 3 shows the hourly variation of the effective Earth's radius (K-factor). It is observed that there is increase in effective Earth's radius values in the rainy season with the values ranging between 973.0 and 976.8. The results indicate that the propagation in this study area is mostly super-refractive.

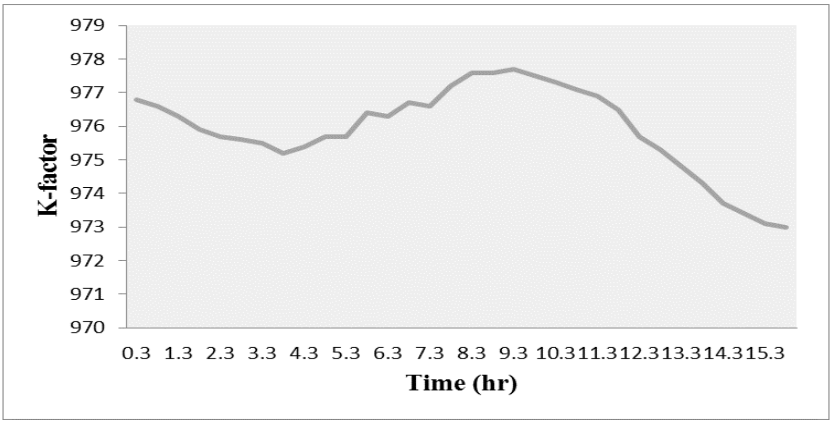

Figure 3: Hourly variations of K-factor over Oyo Metropolis for 2020.

Figure 4 shows refractivity gradient ranges from the minimum value of -3.141E+20 N-units/km to a maximum value of -5.612E+11 N-units/km. The study elucidates that there is increasing ripple from 12 midnight to the peak value of -5.612E+11 N-units/km by 11 am in the day time. This is as a result of all-pervading impact of dry north easterly winds that offer upswing to resilient harmattan in those epochs of night and day. Greater perpetual signal strength in Oyo Metropolis results to reasonably unwavering lesser refractivity gradient value between the hours of 2:00–9:00 pm. The consequence is that the further negative the refractivity gradient value befits the more super refractive the troposphere and the resilient or enhanced the signal strength.

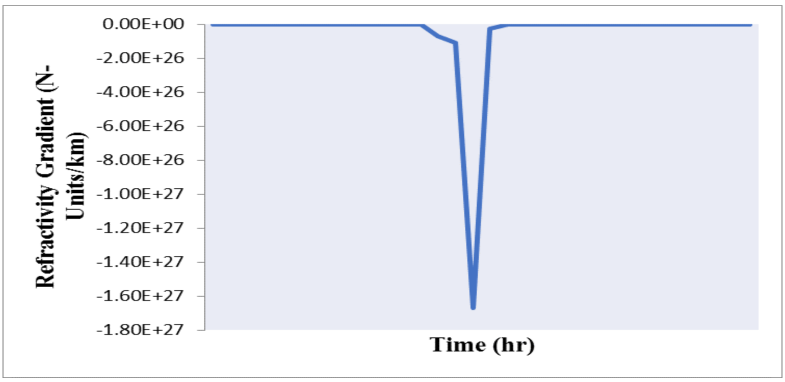

Figure 4: Hourly variations of refractivity gradient over Oyo Metropolis for 2020.

Conclusion

The surface radio refractivity gradient during rainy season as discovered in the research had lower values in the year 2020 over Oyo Metropolis besides greater values in dry period. The transmission circumstances based on the study could be typically super refractive and attainment of higher signal strength is probable for radio promulgation through the troposphere.

References

Aboualmal A, Abd-Alhameed RA, Jones SM and Al-Ahmad H 2015 New methodology for predicting vertical atmospheric profile and propagation parameters in subtropical arabian gulf region. *IEEE Trans. Antennas Propag.* 63(9): 4057-4068.

Agbo GA, Okoro ON and Amechi AO 2013 Atmospheric refractivity over Abuja, Nigeria. *Int. Res. J. Pure Appl. Phys.* 1(1): 37-45.

Akinwumi SA, Omotosho TV, Willoughby AA and Emetere ME 2017 Sectional investigation of seasonal variations of surface refractivity and water vapour density over Nigeria. *Int. J. Appl. Eng. Res.* 12(14): 4587-4598.

Alam I, Mufti N, Shah SAA and Yaqoob M 2016 The effect of refractivity on propagation at UHF and VHF frequencies. *Int. J. Antennas Propag.* 2016: 1-8.

Aremu OA, Oyinkanola LOA, Akande A and Azeez WA 2018 Effects of radio refractivity gradient and k-factor on radio signal over Ibadan, South western Nigeria. *Global Sci. J.* 6(5): 249-253.

Ayantunji BG, Musa B, Mai-Unguwa H, Sunmonu LA, Adewumi AS, Sa'ad L and Kado A 2018 Atmospheric humidity and its implication on UHF signal over Gusau, North West, Nigeria. *Int. J. Sci. Eng. Res.* 9(3): 599-611.

Isikwue BC, Kwen YA and Chamegh TM 2013 Variations in the tropospheric surface refractivity over Makurdi, Nigeria. *Res. J. Earth Planet. Sci.* 3(2): 50-59.

Chukwunike OC and Chinelo IU 2016 The investigation of vertical surface radio refractivity gradient in Akwa, south eastern Nigeria. *Int. J. Acad. Res. Reflect.* 4(6): 28-36.

Ukhurebor KE, Azi SO, Abiodun IC and Ojiemudia SE 2018 Influence of weather variables on atmospheric refractivity over Auchi Town, Edo State, Nigeria. *J. Appl. Sci. Environ. Manage.* 22 (4): 471-475.

Ukhurebor KE and Azi SO 2019 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. *J. King Saud Univ. Sci.* 31(4): 1445-1451.