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Review

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

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A R T I C L E I N F O

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A B S T R A C T

The surface refractivity, the refractivity gradient and effective earth radius factor (*k*-factor) are useful ingredients for predicting the local radio wave propagation conditions in the troposphere. In this study the surface refractivity, refractivity gradient and *k*-factor were estimated and analyzed from the measurements of air temperature, relative humidity and atmospheric pressure in Auchi area of Edo State, Nigeria which is located within Latitude 7.07°N and Longitude 6.27°E using a set of three self designed cost effective portable weather monitoring systems for a period of two years (2016 and 2017) in order to derive the radio propagation conditions. The weather monitoring devices were positioned at three different height levels of 50, 100 and 150 m at the administrative block of Edo University Iyamho, Auchi area of Edo State, Nigeria of about 200 m height for the measurements of the atmospheric weather variables respectively. The results show that the surface refractivity and the *k*-factor values were generally higher during rainy seasons compared to that of the dry seasons; while the refractivity gradient values were higher in the dry seasons compared to the rainy seasons and that surface refractivity was inversely proportional to the height; while the refractivity gradient and the *k*-factor have no defined pattern of proportionality variance with the height for the period under consideration. The average values of the surface refractivity, refractivity gradient and the *k*-factor for the period under consideration are 355.83 N-units, −55.85 N-units/km and 1.50 respectively. Consequently, it is deductively concluded that the local radio propagation condition for the Auchi area of Edo State, Nigeria is predominantly super-refractive.

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1. Introduction

Weather variables are useful ingredients in the predictions of refractivity distributions and the anomalous radio wave propagation conditions of the atmosphere due to their obvious influence on radio wave communication links in the atmosphere (Agbo et al., 2013). Accessing these weather variables will certainly help

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in providing a better the local radio propagation conditions that will assist cellular network service providers, navigation and radar system designers in improving their quality of services. Refractivity distributions studies are important in cellular network, navigation and surveillance systems in order to cope with the problems that occur as a result of anomalous radio wave propagation and unpredicted path loss that affects the performance of these systems. These unpredicted radio wave propagations can cause severe effects to the extent of complete breakdown of communication between the transmitters and the receivers or even make radar to completely miss its intended target. Hence, it is necessary for the management of radio communication systems to take into account the deviation of the propagating radio wave due to the changes in the distribution of refractivity (Alam et al., 2016).

Since the radio wave communication links are affected by weather variables, so in order to have a better communication link for radio wave, the transmission medium need to be considered so as to have a better signal from the radio communication network (Adediji et al., 2011). The attitude and phase scintillations, absorption, scattering of radio wave network signals and other numerous complex mechanisms that occur in the lower atmosphere (troposphere) are caused by the random changes in the surface and vertical refractivity which can result in transmission signals lost and co channel interference. The effect of interference as a result of refractivity difference in the lower atmosphere is much in the humid climate than in the moderate climate regions due to the occurrence of lofty intensity humid rainfall (Rotheram, 1989; Adediji et al., 2011). Some commonly used format of referring the International Telecommunications Union recommendation, (ITU-R) is presently being used in planning of broadcasting services for frequencies greater than 30 MHz, the mostly used radio propagation wave curves and formulae from this recommendation are obtained from measurements carried out in most moderate climate regions of the world like Europe, Asia and North America. Although, the sub-Sahara African climate is different from these moderate climate regions own, these curves and formulae can still be used for the planning of radio wave propagation services in the sub-continent due to the paucity of accurate data from these regions, (ITU-R, 1997; Adediji et al., 2011; Martin and Vaclav, 2011). The radio refractive index is a crucial ingredient in determining the quality of the various radio signals; Ultra High Frequency (UHF), Very High Frequency (VHF) and Super High Frequency (SHF) signals. To determine the characteristics of a radio channel, surface and elevated refractivity data are mostly needed. The surface refractivity is more important for the prediction of some propagation effects than the elevated refractivity. Local coverage, refractivity gradient and other statistics of refractivity provide the most crucial explanation of the likely occurrence of refractivity related influence needed for local radio wave prediction methods (Bean and Dutton, 1968; Adediji et al., 2011; Alam, et al., 2016; Martin and Vaclav, 2011).

In this study the measurement results of air temperature, relative humidity and atmospheric pressure were made at three different height levels with an interval of 50–150 m at the Administrative block of Edo University Iyamho, around Auchi area of Edo State, Nigeria of about 200 m height using a set of three self designed cost effective portable weather monitoring devices. The measured weather variables (air temperature, atmospheric pressure and relative humidity) were used to derive and analyze the surface refractivity, refractivity gradient and the *k*-factor which are crucial in describing local radio signal propagation as recommended by the International Telecommunications Union. Although, there have been similar studies done elsewhere such as: Adediji et al., (2011) and some other researchers. The uniqueness of this study is obvious not only for the fact that we are using a self designed inexpensive portable weather monitoring devices for the measurements of the weather variables but also it is one of the most recent studies to the best of our knowledge from existing literatures on the deviation of the local radio wave propagation conditions of the atmosphere specifically in Auchi area of Edo State, Nigeria.

2. Theoretical background

The stratification of the atmosphere and its permittivity makes the electromagnetic waves that goes through it to bend, otherwise it would have travel in a straight if it was homogeneous, Watson (1996); (Alam, et al., 2016). This makes the atmosphere's refractive index, $\boldsymbol{n}$ and the relative permittivity, ε_r to have this relationship;

$$n^2 = \varepsilon_r \tag{1}$$

$$\text{Recall that} \varepsilon_r = \varepsilon/\varepsilon_o \tag{2}$$

where ε is the permittivity of vacuum and ε_o is the permittivity of free space. The radio refractivity, N; is which is commonly applied in terms of $\boldsymbol{n}$ is assumed as;

$$N = (n-1) \times 10^6 \tag{3}$$

This is as a result of small change in $\boldsymbol{n}$, which is occasioned by the various atmospheric weather variables, like atmospheric temperature, atmospheric pressure and water vapour pressure which can result to large changes in the electromagnetic wave propagation (ITU-R, 2004; Barclay, 2003). Thus, the radio refractivity, N can be expressed as Eq. (4) in terms of these atmospheric weather variables and can be used for radio frequencies up to the range of 100 GHz and its error is less than 0.5% (Babin et al., 1997; ITU-R, 2004).

$$N = 77.6\frac{\boldsymbol{p}}{\boldsymbol{T}} + 373 \times 10^5 \frac{\boldsymbol{e}}{\boldsymbol{T}^2} \tag{4}$$

where p is the atmospheric pressure (hPa), e is the water vapour pressure (hPa) and T is the absolute temperature (K).

The water vapour pressure ($\boldsymbol{e}$) can be estimated from the relative humidity and the saturated water vapour using Eq. (5);

$$e = rh \times \frac{6.1121\boldsymbol{v}(17.502\boldsymbol{t}/\boldsymbol{t} + 240.97)}{100} \tag{5}$$

where rh is the relative humidity (%), t is the temperature in degree Celsius (°C) and v is the saturation vapour pressure (hPa).

If the height, h of a ray above the earth's surface, the radius, r, of the ray curvature and the vertical gradient of refractive index, ($d\boldsymbol{N}/dh$) the horizontal angle of the path, θ to a given point can be written as;

$$\frac{1}{\boldsymbol{r}} = \frac{1}{\boldsymbol{N}}\left(\frac{\boldsymbol{dN}}{\boldsymbol{dh}}\right)\cos\theta \tag{6}$$

According to Brussaard and Watson, (1995), r may be connected to the relative earth radius (R) in terms of the refractive index gradient;

$$\frac{\boldsymbol{r}}{\boldsymbol{R}} = \mathrm{k} \tag{7}$$

where $\boldsymbol{k}$ is the effective earth radius factor which can now be expressed as;

$$\boldsymbol{K} \approx \frac{1}{1 + \boldsymbol{R}\left(\frac{dN}{dh}\right)} \tag{8}$$

Afullo et al., (1999) in their work show that the effective earth radius factor, $\boldsymbol{k}$ can be used for categorizing the refractive conditions as normal refraction or standard atmosphere, sub-refraction, super-refraction and ducting as the case may be.

Recall that $\boldsymbol{R} \approx 6370$ km, hence, Eq. (8) may now be expressed in terms of refractivity, $\boldsymbol{N}$ as;

$$\mathbf{k} \approx \frac{1}{1 + \left(\frac{dN}{dh}\right)/157} \tag{9}$$

Around the earth's surface the value of $d\boldsymbol{N}/dh$ is approximately -39 N-units/km, which will give a k-factor of 1.33; this is referred to as normal refraction or standard atmosphere. Here, radio signals are transmitted along a straight line path on the earth's surface and go into space unhindered. If $1.33 > \boldsymbol{k} > 0$, we will have sub-refraction; which indicates that the radio waves propagate abnormally away from the earth's surface. But when $\infty > \boldsymbol{k} > 1.33$ we will have super-refraction and this signifies that the radio wave signals spread irregularly towards the earth's surface, hence extending the radio horizon and increasing path clearance thereby giving irregularly huge ranges above the line of view as a result of several reflections. Therefore, if $-\infty < \boldsymbol{k} < 0$, there will ducting and this will make the radio waves to bend downwards with a curvature bigger than the earth's own. The radio signals can become trapped between a layer in the lower atmosphere and the surface duct which is the earth's or sea's surface or between two layers in the lower atmosphere which is the elevated duct. In this wave guide-like propagation, very lofty radio signal strengths can be obtained at a very long range which is far above the line of view (Adediji et al., 2011).

3. Materials and methods

The measurements of the atmospheric weather variables used for this study were done at the administrative building block of Edo University Iyamho, Auchi area of Edo State, Nigeria, with an approximate height of about 200 m which is located within Latitude 7.07°N and Longitude 6.27°E of the Greenwich Meridian (Ojeifo Magnus and Akhimien Francis, 2013), using three set a self designed inexpensive, effective and portable weather monitoring devices which measure air temperature, atmospheric pressure, relative humidity and light intensity. The weather monitoring devices are designed in such a way that they can be used remotely and the readings are displayed on the user friendly LCD display in numerical digital values for atmospheric temperature (°C), atmospheric pressure (mbar), relative humidity (%) and light intensity (lux) which can also be sent to computer via the programmed micro SD card or/and through the serial port (the Arduino SD card module). The user has the option of choosing how often the weather variables will be logged, measured, recorded, stored and displayed. The acquired weather variables are analyzed and the LCD displays the values respectively. In addition, the weather variables for each day are saved on the micro SD card in Excel format on a separate file with each file created with a file name that corresponds to the date and time when the weather variables were acquired. The users also have the option to stop the weather variables acquisition process at anytime by interrupting the routine. Details of the design and implementation of the weather monitoring device including its validity is contained in Ukhurebor et al., (2017).

The fixed measuring method by placing each of the weather monitoring devices on the various respective height levels of 50, 100 and 150 m was employed for the measurements of the atmospheric weather variables of air temperature, atmospheric pressure, relative humidity and light intensity at the administrative building block of Edo University Iyamho, Auchi area of Edo State, Nigeria for continuous measurement of these weather variables. The measured weather variables are then copied from the weather monitoring devices to the computer from the micro SD card. The measurements of the atmospheric variables were made for a period of two years (January to December, 2016 and January to December, 2017). The weather variables were collected at all the afore-said height levels and the records cover twenty-four hours each day from 00 h to 2300 h local time at intervals of one hour. Although, the weather monitoring system measures about four atmospheric weather variables as stated earlier, only the daily records of air temperature; which is defined as the measure of temperature at different levels of earth's atmosphere which is expressed in degree Celsius (°C), atmospheric pressure; which is defined as the force exerted on unit surface area on the earth by the weight of earth's atmospheric air above its surface which is often expressed in (mbar) and relative humidity (%); which is defined as the ratio of the amount of water vapor in the air at any given temperature to the maximum amount of water vapor that the air can hold (Ukhurebor et al., 2017; Devaraju et al., 2015), were used for this part of the research.

4. Results and discussion

Table 1 shows the summarized range values of the surface refractivity for both 2016 and 2017 of the respective height levels. The average values were found to be 357.34 N-units and 354.31 N-units for 2016 and 2017 respectively, with an overall average of 355.83 N-units for the two years period under consideration. These results agree very well with the results of Adediji et al., (2011) and Falodun and Ajewole (2006) were they acquired the average surface refractivity values of 366 N-units and 369 N-units for Akure, Ondo State, Nigeria, respectively. Both results have again affirmed the results of Bean and Dutton (1968) where they acquired an annual average value of surface refractivity for subtropical savannah as 350–400 N-units with an annual range of 30–60 N-units.

In Figs. 1 and 2 the surface refractivity variations for the two years period under consideration (2016 and 2017) on monthly basis which were obtained from the monthly records are shown. It was observed that the values are higher during the months of April, May, June, July, August, September and October which happens to be the period of much rainfall and are occasioned by very lofty air humidity values; while, the values were lower in the months of November, December, January, February and March which happens to be the dry period were rainfall are limited and are occasioned by very low air humidity. It was also found the values were reducing with increasing altitude and are accomplished by similar pattern of variations for both Figures.

In Figs. 3 and 4 the refractivity gradient values for the periods under consideration (2016 and 2017) on monthly basis which were obtained from the calculation of the average monthly statistical distribution of the surface refractivity at the various respective altitude levels are shown. A critical look at the Figures revealed that the months with lesser rainfall have higher refractivity gradient values compared to the ones with much rainfall and this makes the Figures to exhibit vacillating display. As we can see that the values were higher in the months of November, December, January, February and March which happens to be the dry period were rainfall are limited and drops gradually during the months April, May, June, July, August, September and October which happens

Table 1
The Summarized Range Values of the Surface Refractivity for 2016 and 2017.

Altitude (m)	Surface Refractivity (N-Units)	
	2016	2017
50	305.00–372.00	320.00–370.00
100	307.00–372.00	316.00–370.00
150	302.00–367.00	310.00–362.00

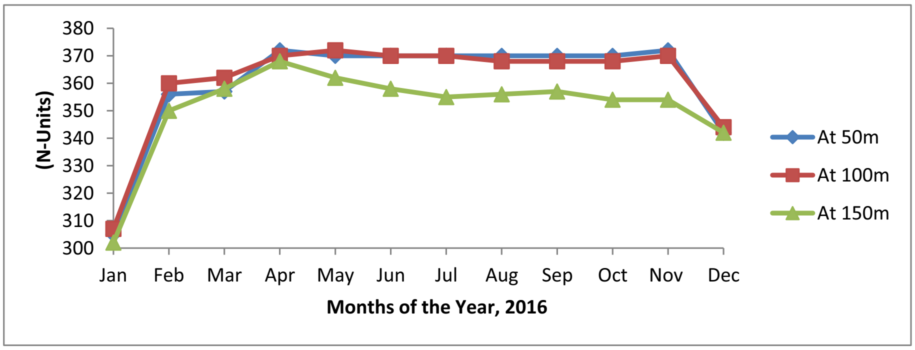

Fig. 1. Monthly Variations of Surface Refractivity for 2016.

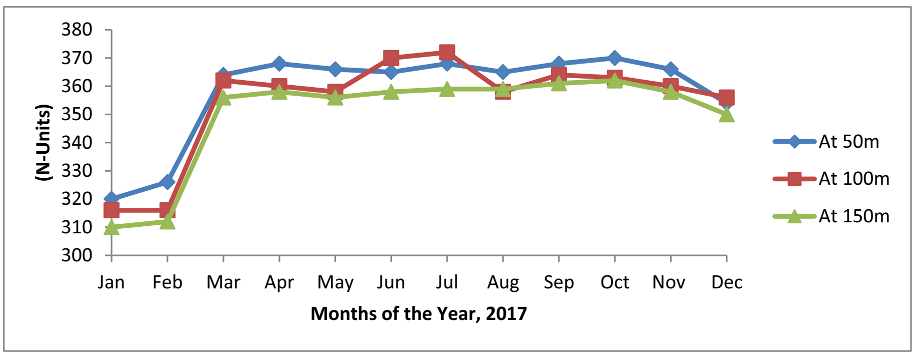

Fig. 2. Monthly Variations of Surface Refractivity for 2017.

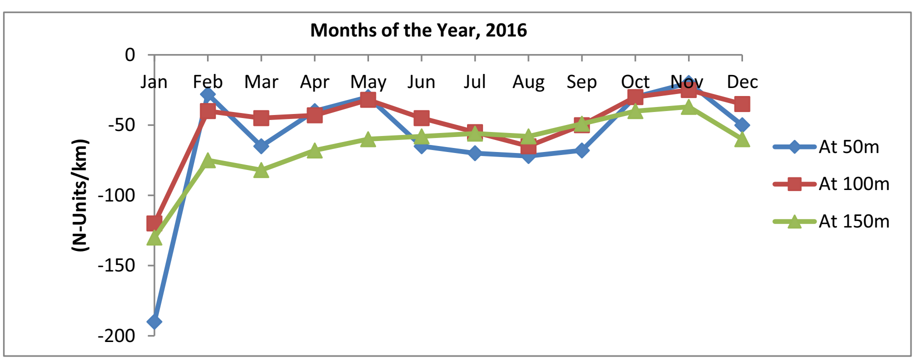

Fig. 3. Monthly Variation of Refractivity Gradient for 2016.

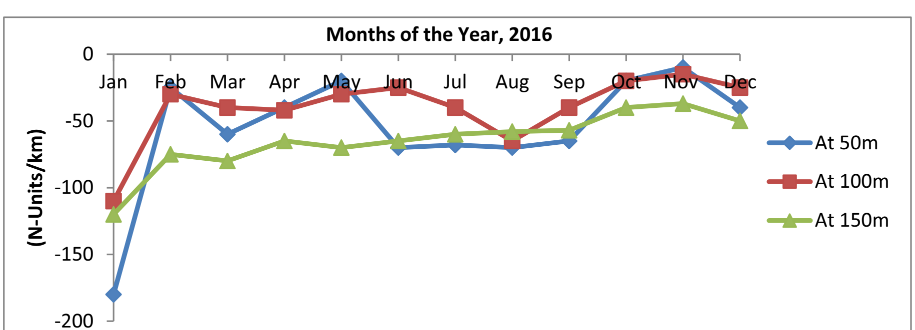

Fig. 4. Monthly Variation of Refractivity Gradient for 2017.

to be the period of much rainfall. The obtained average values of the refractivity gradient are −57.95 N units/km and −53.75 N-units/km for 2016 and 2017 respectively with an overall average of −55.85 units/km for the two years period under consideration. These results again agree very well with the results of Adediji et al., (2011) and Falodun (2004).

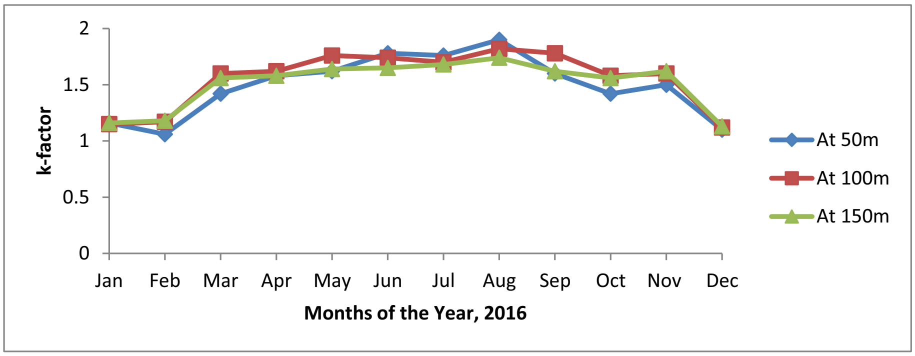

Fig. 5. Monthly Variation of *k*-factor for 2016.

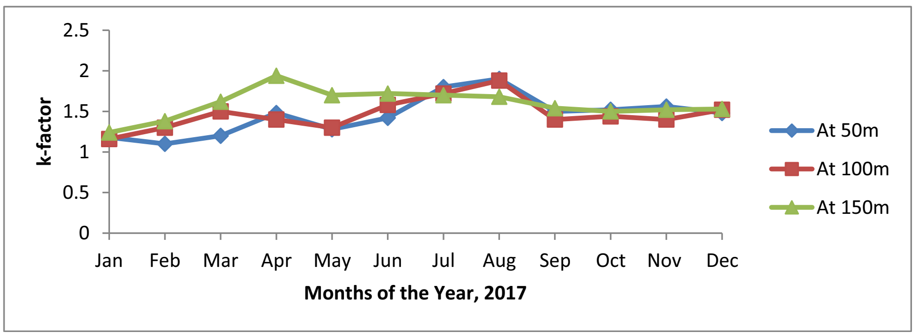

Fig. 6. Monthly Variation of *k*-factor for 2017.

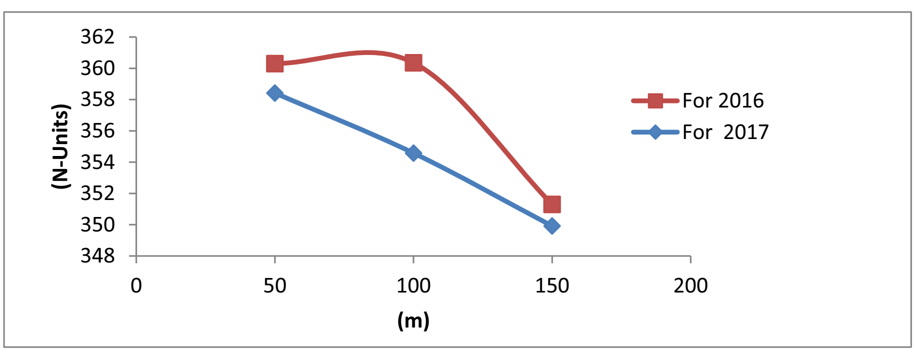

Fig. 7. Variation of Surface Refractivity with Height Levels for 2016 and 2017.

In Figs. 5 and 6 the *k*-factor for the two years period under consideration (2016 and 2017) on monthly basis which were obtained from the monthly records are shown. Critically looking at the Figures revealed that the months with much rainfall (April, May, June, July, August, September and October) have higher values compared to the ones with lesser rainfall (November, December, January, February and March), the values range from 1.20 to 1.94 during the months with much rainfall for both years; while, the values for the months of less rainfall range from 1.06 to 1.62 also for both years. The obtained average values of the *k*-factor are 1.53 and 1.47 for 2016 and 2017 respectively with an overall average of 1.50 for the two years period under consideration. These results again agree very well with the results of Adediji et al., (2011) and Kolawole (1981).

In Figs. 7–9 the variations of the surface refractivity values with the respective height levels, variation of the refractivity gradient values with the respective height levels and the variation of the *k*-factor values with the respective height levels for the period under consideration (2016 and 2017) are shown respectively.

Critically looking at Fig. 7, it was observed that the surface refractivity decreases with increasing height; this implies that the surface refractivity is inversely proportional to the height; while in Figs. 8 and 9, it was observed that they were having a kind of undulating pattern; implying that the variation patterns were not that defined; this could be attributed to the fact that the radio waves are likely to be trapped by the atmosphere at lessen height and that there could be an occurrence between two layers in the lower atmosphere at this building height.

Due to these results obtained, it is deductively concluded that the local radio wave propagation condition for Auchi, Edo State, Nigeria is predominantly super-refractive. This signifies that the radio wave signals spread irregularly towards the earth's surface, hence extending the radio horizon and increasing path clearance, thereby giving irregularly huge ranges above the line of view as a result of several reflections.

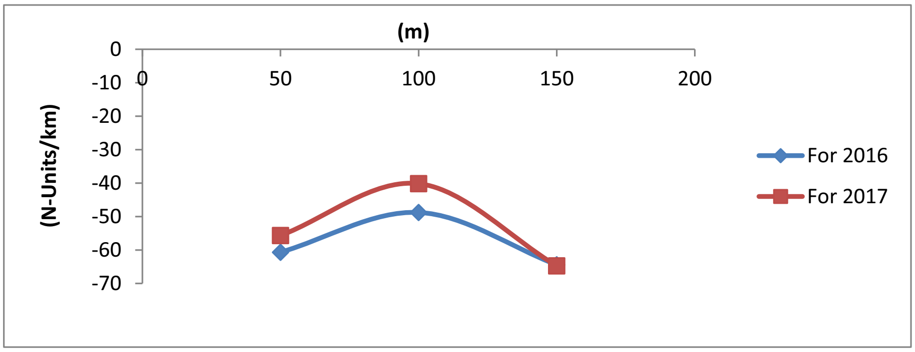

Fig. 8. Variation of Refractivity Gradient with Height for 2016 and 2017.

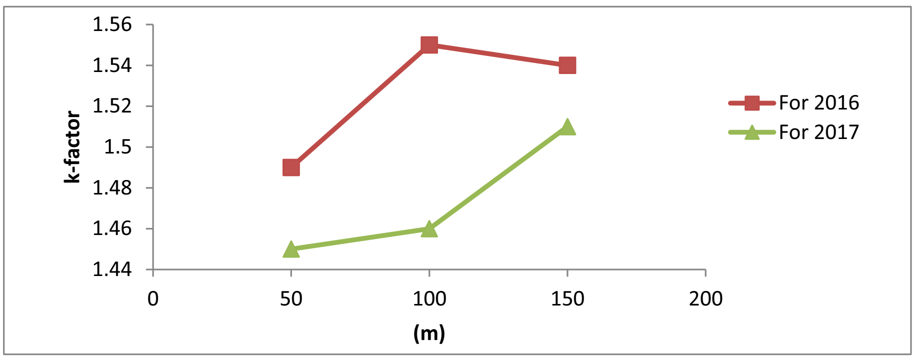

Fig. 9. Variation of *k*-factor with Height for 2016 and 2017.

5. Conclusion

The measurements of air temperature, atmospheric pressure and relative humidity were made at various height levels of 50, 100 and 150 m at the administrative b block of Edo University Iyamho, Auchi area of Edo State, Nigeria of about 200 m height for a period of two years (2016 and 2017) using a set of three self designed inexpensive portable weather monitoring systems respectively so as to ascertain and analyze the surface refractivity, the refractivity gradient and *k*-factor in order to derive the local radio wave propagation conditions in the (lower) atmosphere for Auchi area of Edo State, Nigeria as a part of an going doctorate degree (PhD) research work.

The summarized results obtained from this study for the two years (2016 and 2017) period under consideration are;

- The surface refractivity and the *k*-factor values were generally higher during the rainy seasons compared to the dry seasons; while, the refractivity gradient values were generally higher in the dry seasons compared to the rainy seasons.
- The average values of the surface refractivity, refractivity gradient and *k*-factor are 355.83 N-units, −55.85 N-units/km and 1.50 respectively.
- The surface refractivity was inversely proportional to the height; while the refractivity gradient and the *k*-factor have no defined pattern of proportionality variance with the height.
- Deductively, the local radio wave propagation condition for Auchi area of Edo State, Nigeria and environs is predominantly super-refractive.

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References

Adediji, A.T., Ajewole, M.O., Falodun, S.E., 2011. Distribution of radio refractivity gradient and effective earth radius factor (*k*-factor) over Akure, South Western Nigeria. J. Atmosp. Solar-Terrestrial Phys. 73 (2011), 2300–2304.
Afullo T.J., Motsoela T., Molotsi D.F., 1999: Refractivity Gradient and k-factor in Botswana, Radio Africa, pp 107–110.
Agbo, G.A., Okoro, O.N., Amechi, A.O., 2013. Atmospheric Refractivity over Abuja, Nigeria. Int. Res. J. Pure Appl. Phys. 1 (1), 37–45.
Alam, I., Mufti, N., Shah, S.A.A., Yaqoob, M., 2016. The effect of refractivity on propagation at UHF and VHF frequencies. Int. J. Antennas Propagation 2016, 1–8.
Babin, S.M., Young, G.S., Carton, J.A., 1997. A new model of the oceanic evaporation duct. J. Appl. Meteorol. 36, 193–204.
Bean, B.R., Dutton, E.J., 1968. Radio Meteorology. Dover Publication Co., New York, pp. 259–273.
Brussaard G; Watson P.A (1995): Atmospheric Modeling and Millimetre Wave Propagation, Chapman and Hall.
Devaraju, J.T., Suhas, K.R., Mohana, H.K., Vijaykumar, A., Patil, 2015. wireless portable microcontroller based weather monitoring station. Measurement 76 (2015), 189–200.
Falodun, S.E., 2004. Experimental Studies of Super-refraction of Microwave Signal, Unpublished Ph.D. Thesis. Department of Physics, Federal University of Technology, Akure, Nigeria.
Falodun, S.E., Ajewole, M.O., 2006. Radio refractive index in the lowest 100 m layer of the troposphere in Akure, South Western Nigeria. J. Atmos. Solar-Terrestrial Phys. 68, 236–243.
ITU-R (1997): The Radio Refractive Index: Its Formula and Refractivity Data, ITU Radio Communication Assembly, ITU-R P-Series, No. 453-9.
ITU-R (2004): The Refractive Index: Its Formula And Refractivity Data, No. 453-9.
Kolawole, L.B., 1981. Vertical profiles of radio refractivity over Nigeria. J. West Afr. Sci. Assoc. 26, 41–60.
Martin, Grabner and Vaclav, Kvicera, 2011: Atmospheric Refraction and Propagation in Lower Troposphere, Electromagnetic Waves, Prof. Vitaliy Zhurbenko (Ed.), ISBN: 978-953-307-304-0, In Tech (www.intechopen.com).

Ojeifo Magnus, O., Akhimien Francis, O., 2013. Pattern of fencing and impacts in Urban Auchi, Edo State, Nigeria. Int. J. Phys. Human Geography 1 (1), 26–34.
Ukhurebor, K.E., Abiodun, I.C., Azi, S.O., Otete, I., Obogai, L.E., 2017. A cost effective weather monitoring device. Arch. Curr. Res. Int. 7 (4), 1–9.
Watson, R.J., 1996. Data Comparisons for Spatially Separated Meteorological Radars, Unpublished Ph.D. Thesis. Department of Electronics Systems Engineering, University of Essex, UK.