THE INVESTIGATION OF THE VERTICAL SURFACE RADIO REFRACTIVITY GRADIENT IN AWKA, SOUTH EASTERN NIGERIA

Okeke C. Chukwunike[1*] & Ikeh U. Chinelo[1]
[1]Nnamdi Azikiwe University, Awka, Anambra State, **NIGERIA**

ABSTRACT

In the designing and planning of terrestrial radio links in the lower atmosphere for communications, surface radio refractivity gradients are very important for observing propagation conditions. In this work, we made use of mean data collected from meteorological variables (temperature, pressure and relative humidity) for two-year period of 2013 and 2014.Davis Weather Station equipped with Integrated Sensor Suits (ISS) was mounted close to the ground level to be used in collecting the data for meteorological measurements. The diurnal, daily and monthly averages of the data were calculated and used to investigate the vertical surface radio refractivity gradient. The results obtained for both wet and dry seasons during the period showed that the whole months were mostly super-refractive. The month of January has the highest value of -55 N-units/km but the least of about -63 N-units/km occurred in the month of July. The results obtained from this work find relevance in radio engineering for improving VHF/ UHF terrestrial links based on clear-air considerations. There is need to increase the spatial spread of surface and upper air weather stations, and to extend the period of measurements to obtain more reliable surface and upper air refractivity profiles which will support effective planning of terrestrial radio networks in Nigeria.

Keynotes: Terrestrial radio links; meteorological variable; vertical surface radio refractivity gradient.

INTRODUCTION

Radio frequency or radio wave is a type of electromagnetic radiation of the highest wavelength in the electromagnetic spectrum with the frequencies ranging from 300GHz to as low as 3kHz. It has amplitude modulated (AM) radio usually in kilohertz, kHz, ranges and the frequency modulated (FM) radio in the Megahertz, MHz, ranges. The propagation of electromagnetic waves in the atmosphere (mainly the troposphere) is greatly affected by the composition of the atmosphere. This is due to the fluctuations of atmospheric parameters like temperature, pressure and relative humidity primarily at the troposphere which is normally referred to as "the lower" part of the earth and the site of all weather phenomena. These fluctuations of the atmospheric parameters cause the refractive index of the air in this layer to vary from one point to the other. The atmosphere is non homogeneous and the radio waves passing through it are not straight but bent. The velocity of radio wave in a medium depends on the refractive index n, which is a function of refractivity N [1]. This refractive index causes the bending of propagation direction and that is why same radio wave signals which follow different paths have different time of arrivals to the target point [2]. This may result in the interference of radio wave signals during propagation through the troposphere. One of the important characteristics of the atmosphere is the vertical gradient of refractivity G. The profiles of G values are useful for the estimation of propagation conditions such as sub-refraction, super-refraction and ducting. It is also responsible for bending of propagation direction of the electromagnetic wave signals. If it is negative, the signals bend downwards but if it is positive, the signals bend upwards and away from the line of sight range [3].

However, the knowledge of radio refractivity gradient within the atmosphere which is the function of surface radio refractivity is very significant for radio engineers to accurately predict electromagnetic radio wave signals; to characterize a radio channel, surface and elevated refractivity data are often required. It is useful for good planning of terrestrial radio link over a region [4] as well as in determining the quality of UHF, VHF and SHF signals for proper design of their communication stations.

Hence, this study presents the investigation of vertical surface refractivity gradient in Awka South Eastern Nigeria using meteorological data of average diurnal and seasonal variations in 2013 and 2014.

The Theory of Surface Refractivity Gradient

The radio refractive index is defined as the ratio of the velocity of propagation of radio energy in a vacuum to the velocity in a specific medium. The value of refractive index *n* decreases from the near Earth troposphere surface of about 1.0003 to the top of the atmosphere (free space) of the value of unity (*n* = 1.0). Refractive index can be expressed more conveniently in terms of a dimensionless parameter called refractivity *N* which is defined as the measure of deviation of refractive index from unity in parts per million [5]:

$$N = (n - 1)10^6 \text{ (N- units)} \qquad 1$$

Where N can be expressed in terms of wet term and dry term by

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + 4.810\frac{e}{T^2}\right)(N - units) \qquad 2$$

With the 'dry term' of radio refractivity given by:

$$N_{dry} = 77.6\frac{P}{T}$$

And the 'wet term' given by

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

where : P is atmospheric pressure (hPa)
e is water vapour pressure (hPa) and
T is absolute temperature (K)

In general, changes in temperature (T), atmospheric pressure (P) and water vapour (e) cause change in radio refractivity N. The relative importance of these parameters (T, P, e), particularly water vapour content, could also be observed from the differentials of eq. (2):

$$\delta N = 77.6\frac{\delta P}{T} - \left(77.6\frac{P}{T^2} + 7.46 \times 10^5 \frac{P}{T^3}\right)\delta T + 3.73 \times 10^5 \frac{\delta e}{T^2}(N - units) \qquad 3$$

For typical atmospheric conditions, pressure P = 1000hPa, relative humidity RH= 60%, temperature K= 290K and vapour pressure e= 13.7hPa. The above equation reduces to:

$$\delta N = 0.268\delta P - 1.132\delta T + 4.435\delta e \qquad 4$$

It can be seen from eqn (4) that for a given change in radio refractivity the contribution of *e* is large relative to ***T*** and ***P*** in the gradient of radio refractivity. This is primarily due to the fact that water vapour molecules become polarized on interaction with the radio signal. This effect causes the dielectric constant of water vapour to rise resulting in relatively larger contribution in $\boldsymbol{\delta N}$ than ***T*** and ***P***. in standard atmosphere conditions, the ***P, T***, and ***e*** also decrease with height resulting in decreasing ***N*** with a gradient of 40 N/km.

The relationship between water vapour *e*(hPa) and relative humidity R.H(H%) is given by [6]:

$$e = \frac{He_s}{100}\,(hPa) \qquad 5$$

Where e_s is saturation vapour pressure determined by Clausius- Clapeyron equation given by:

$$e_s = 6.1121\exp\left(\frac{17.502t}{t+240.97}\right)(hPa) \qquad 6$$

The vertical radio refractivity gradient G(N-units/km) at the surface level is expressed as [7]:

$$G = \frac{dN}{dh} = -7.32\exp(0.005577N_s)\,(N - units/km) \qquad 7$$

Where, N_s are the values of surface radio refractivity.

The vertical refractivity gradient in the lower layer of the atmosphere is an important parameter in estimating path clearance and propagation effects. The refractivity gradient values may give rise to propagation conditions which are sub-refraction, super-refraction and ducting [8]. In sub-refraction, dN/dh >-40 N-units/km and refractivity gradient G is tending more positive. Radio wave signals bend less than normal and move away from the Earth's surface and the line-of-sight range; thus the range of propagation decreases accordingly. In extreme cases, the radio signals may be refracted out into space. During super-refractive conditions, dN/dh < -40 N-units/km and G is tending more negative. The radius of curvature of the radio wave path is smaller than the Earth's radius and the rays moving upwards from the transmitting antenna undergo total internal reflection in the troposphere and return to the Earth at some distance from the transmitter thereby increasing the range of propagation. During ducting phenomenon, the radio signals bend downwards with a curvature greater than that of the Earth. When this condition is present (dN/dh < -157 N-units/km), two things happen, the radio signals will remain close to the Earth's surface beyond the normal horizon. Secondly, the refractivity gradient must be maintained over a height of many wavelengths. Under this situation, a wave guide-like propagation called ducting is created, and very high signal strengths can be produced at very long range far beyond line-of-sight. Hence the signal strength may exceed its free space value [1].In the case of critical positive refraction, the radio wave signals will travel in a straight line because propagation conditions are uniform and it occurs in a vacuum (free space).

AREA OF STUDY AND DATA

Nnamdi Azikiwe University, Awka is situated in the capital territory of Anambra State with the coordinates of 6°12′25″N and 7°04′04″E. Awka is a tropical rain forest zone of Nigeria having two seasons: wet and dry seasons. The seasons are predominantly ruled by winds from Atlantic oceans and Sahara desert for wet and dry seasons respectively. The wet season falls from April to October and is characterized with heavy rainfall while dry season is characterized with dust-laden atmosphere and falls between November and March. The temperature in Awka has a minimum value of 27°C and maximum value of 30°C between June and December but rises from 32°C to 34°C between January and April.

The Davis instrument equipped with Integrated Sensor Suite (ISS) and other accessories was mounted close to the ground surface for the continuous measurement of atmospheric pressure, air temperature and relative humidity. The data were transmitted by wireless radio connection to the data logger which were then copied to the computer for analysis. The data cover two-year period of 2013 and 2014 with the measurement which covers 24 hours per day beginning with 12am and logs at 30 minutes intervals. The measured values of temperature, pressure and relative humidity at the surface were analysed for the observed readings at all local times. The average diurnal variations were computed to give a data point for daily variation, and average daily variations were computed to give a data point for monthly variations over the two-year period.

RESULTS AND DISCUSSION

The averages of diurnal variations of meteorological parameters were obtained from the data collected for both dry and wet seasons in 2013 and 2014 in Awka. The results obtained were used to compute radio refractivity and refractivity gradients at the surface level.

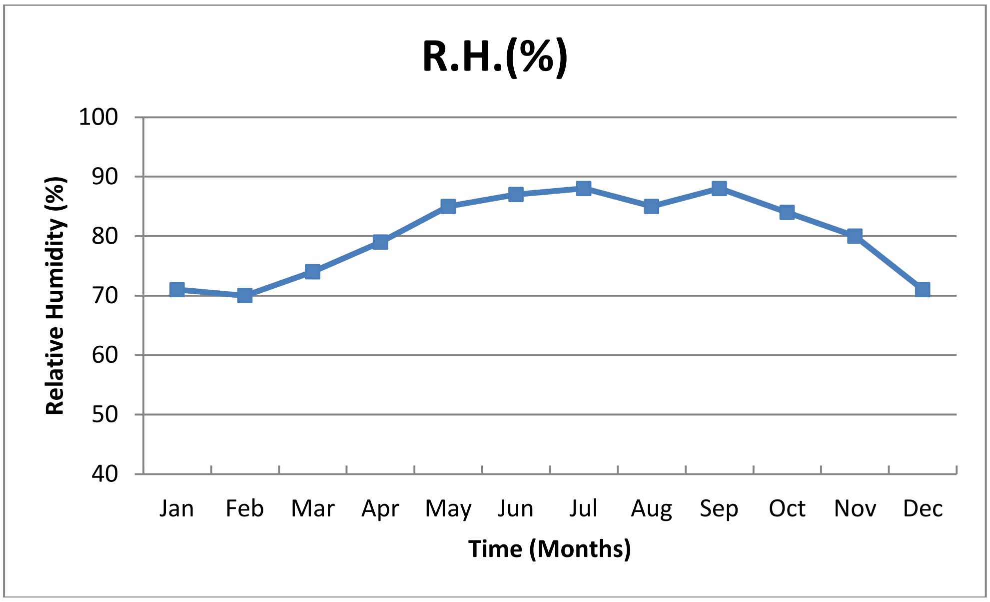

Fig. 1: Mean Monthly Variation of Relative Humidity in Awka

Fig. 1 shows monthly variation of relative humidity. It is observed that relative humidity is higher in the rainy season months than the dry season months. The highest relative humidity values of 80%-88%are observed between April and October which produces the highest rainfall as a result of high moisture content in the atmosphere. The least relative humidity values are observed in the months of January, February and December which are characterized by lowest rainfall and high insolation in the atmosphere.

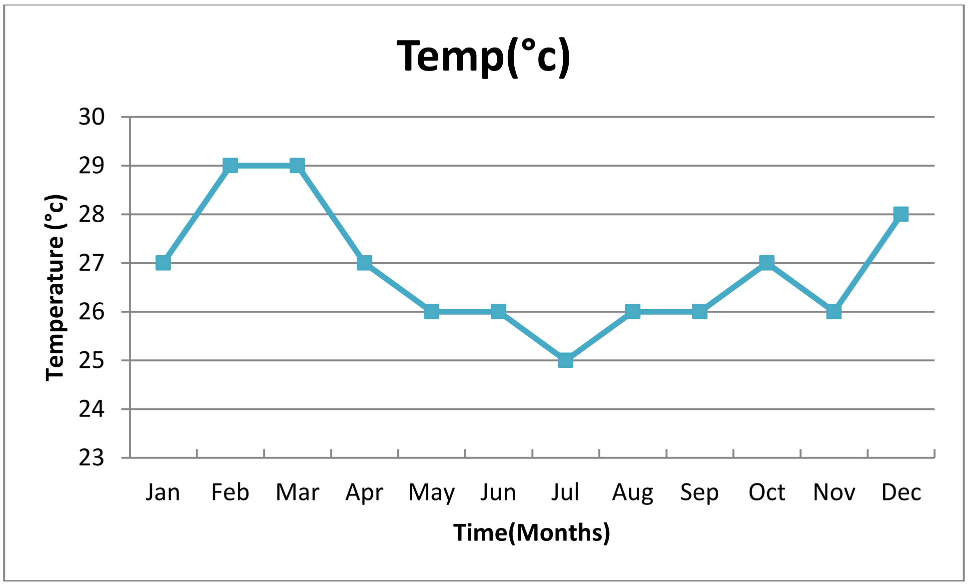

Fig. 2: Mean Monthly Variation of Temperature in Awka

It is observed in Fig. 2 that February and March have highest temperature values. The month of July has the lowest temperature value of 25 ^{o}C due to high moisture content and cloud cover in the month. There is a steady temperature rise from November to February due to decreasing moisture content, reduced cloud cover and greater insolation in the atmosphere. Temperature falls from April to July due to heavy cloud cover and reduced insolation during rainy season period.

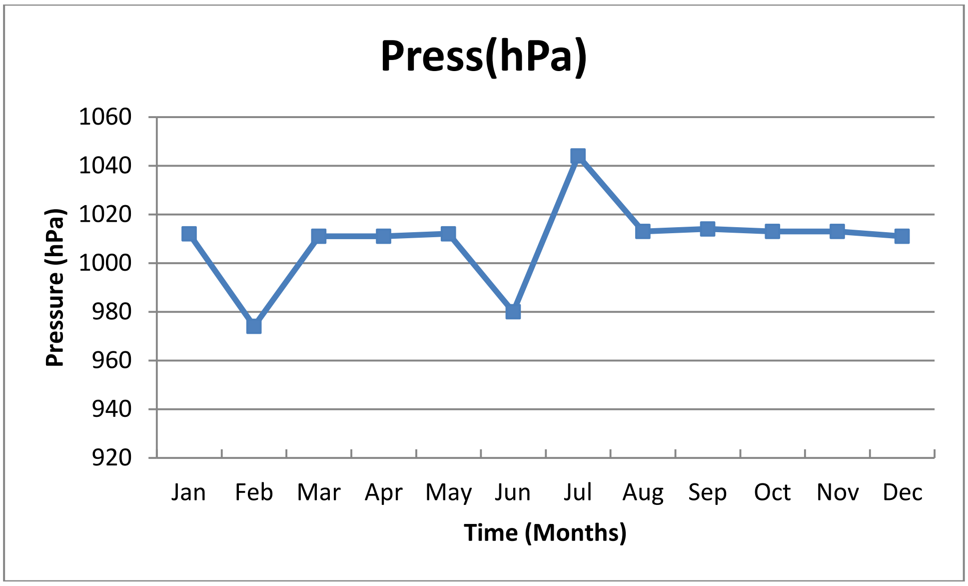

Fig. 3: Mean monthly Variation of Pressure in Awka

It is observed in Fig. 3 that the month of July has the maximum pressure value of about 1044hPa; this shows that pressure is higher during the rainy season than the dry season.

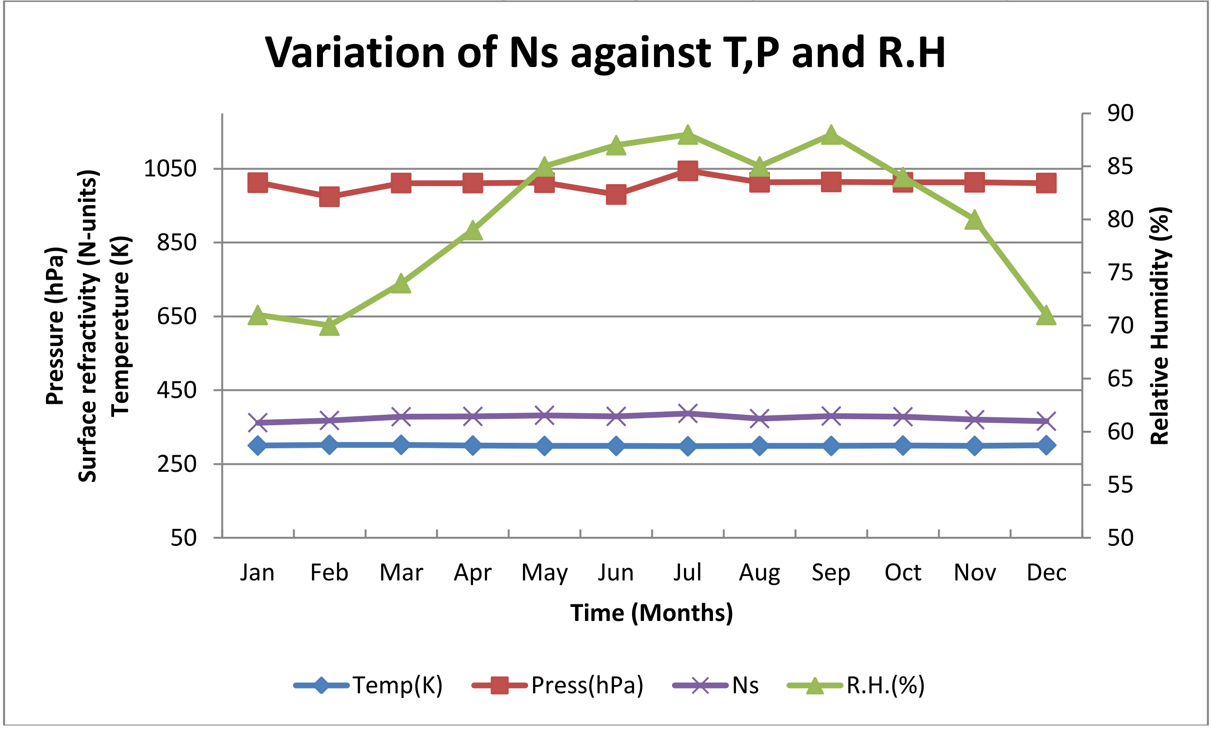

Fig. 4: Variation of T, P and R.H with N_s

From fig. 4, temperature is fairly constant and it varies from the minimum value of 298K to the maximum value of 302K.We observed that at the lowest value of temperature N_s is 387

N-units and at the highest value of temperature N_s is 368 N-units. This shows that surface refractivity increases with temperature decrease. The profile of relative humidity against N_s shows that relative humidity increases as the values of surface refractivity become higher. At 387 N-units, the relative humidity is 88% while at 362 N-units, R.H. is 71%. Again, the profile of pressure with N_s shows that pressure is highest at 387 N-units and lowest at 368 N-units showing that at higher pressure and presence of cloud cover we experience greater surface refractivity in the city of Awka. From the general observations of T, P, R.H and N_s in Awka, P and R.H increase with N_s while T decreases as the N_s increases. The month of July has the highest value of surface refractivity and as such regarded as the month of regular rain showers while the month of January has the lowest value. This shows that N_s have greater effects in wet season than in dry season in Awka.

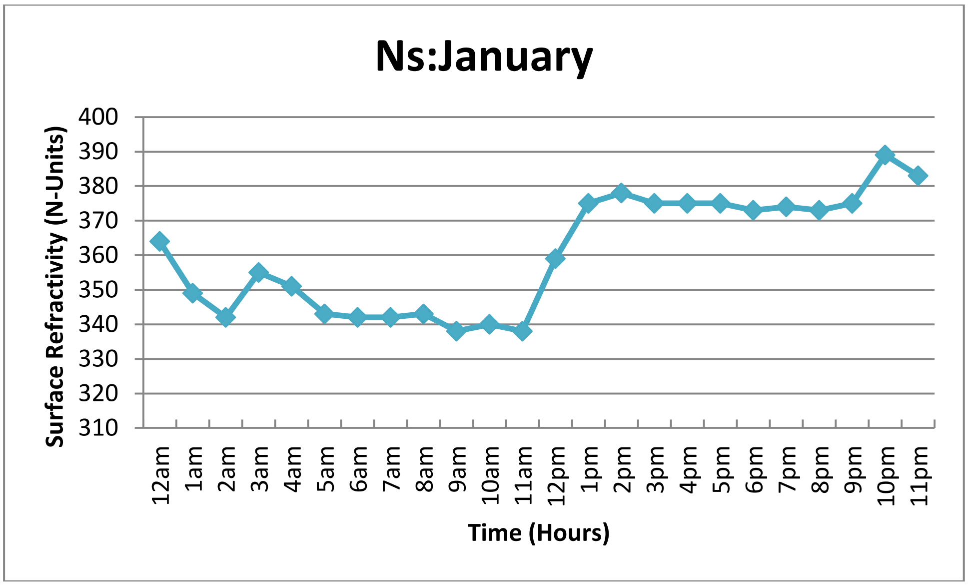

Fig. 5: Mean diurnal variation of Surface Refractivity in January

Fig. 5 shows mean diurnal variations of surface refractivity which drops from 12 midnight to 2.am of that night. The undulation continues to a minimum value of 338 N-units by 11.am of that day. There is a rise in the value of N_s from that time to a value by 2.pm on that day. Between 2.pm and 9.pm refractivity values are fairly constant. It then rises to a maximum value of 389 N-units by 10.pm.The drop in values of N_s from 12 midnight to a minimum value in the day time is attributed to low values of T, e and e_s which combine to give low contribution from N_{wet}. Also, there is a penetrating influence of the dry north-easterly winds which generates Harmattan in that period. Higher values of N_s which are less than that in typical rainy season (July) are attributed to high moisture content which saturates air around the city of Awka in those hours of the day and night [9].

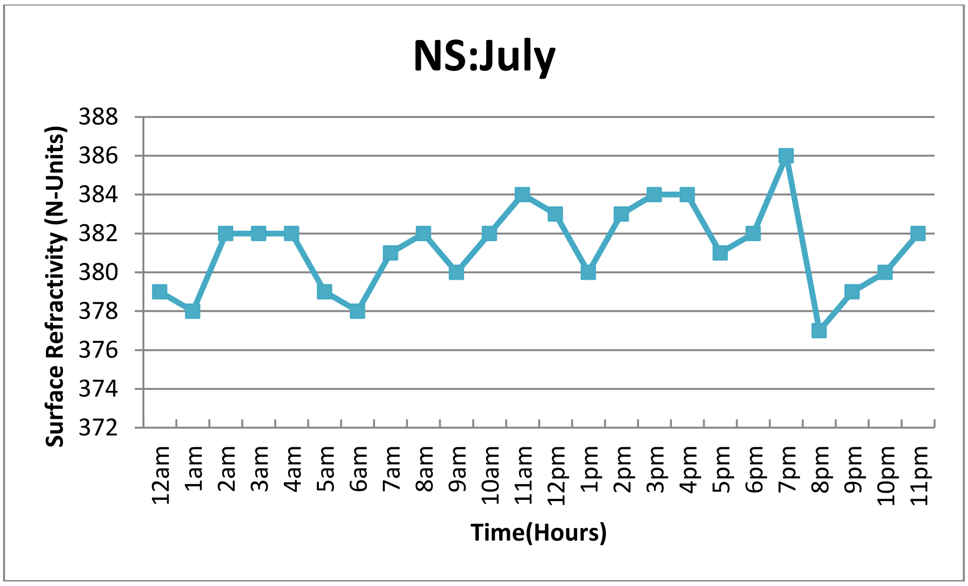

Fig. 6: Mean diurnal variation of Surface Refractivity in July

The plot of refractivity profile of hourly variations has refractivity range of 377 N-units to 386 N-units. The values are more or less stable throughout the night and day at higher refractivity values than a typical dry season month, January. The month of July in Awka is a typical rainy season period associated with moisture-laden south westerly winds which increasingly saturates the air. However, there are higher contributions from N_{wet} following the fairly stable higher values of H, e and e_s which combined together.

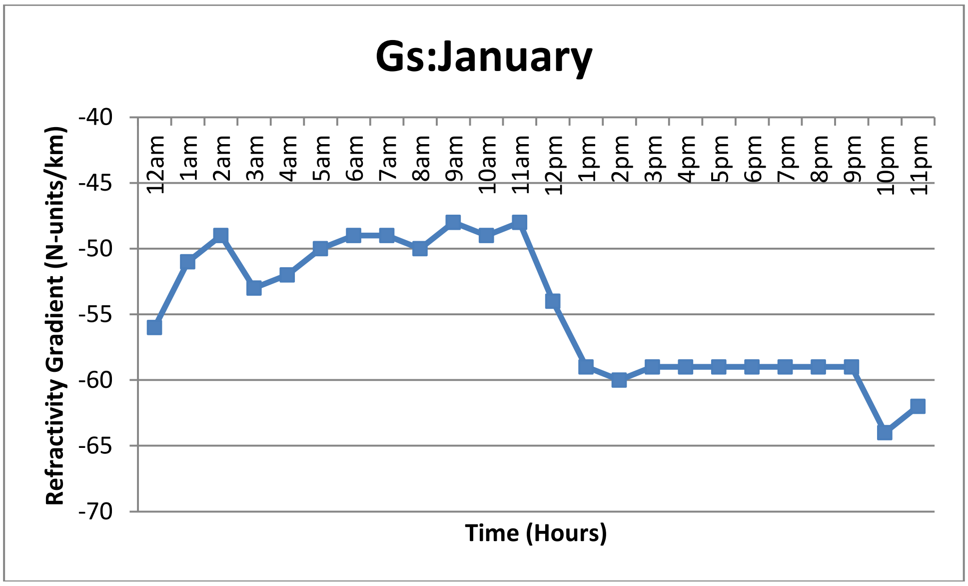

Fig.7: Mean diurnal variation of radio refractivity gradient in January

From fig.7, refractivity gradient ranges from the minimum value of -64 N-units/km to a maximum value of -48 N-units/km. There is increasing undulation from 12 midnight to the peak value of -48 N-units/km by 11am in the day time. This is due to penetrating influence of dry north easterly winds that give rise to strong harmattan in those hours of night and day. G_s value drops from 11 am to a minimum value by 11pm in the night. There is fairly stable lower G_s value between 2 pm and 9 pm as a result of higher constant signal strength because the more negative the G_s value becomes for super-refractive conditions, the stronger the signal strength. So the drop in G_s value in those hours of day and night is due to increasing signal strength in the city of Awka.

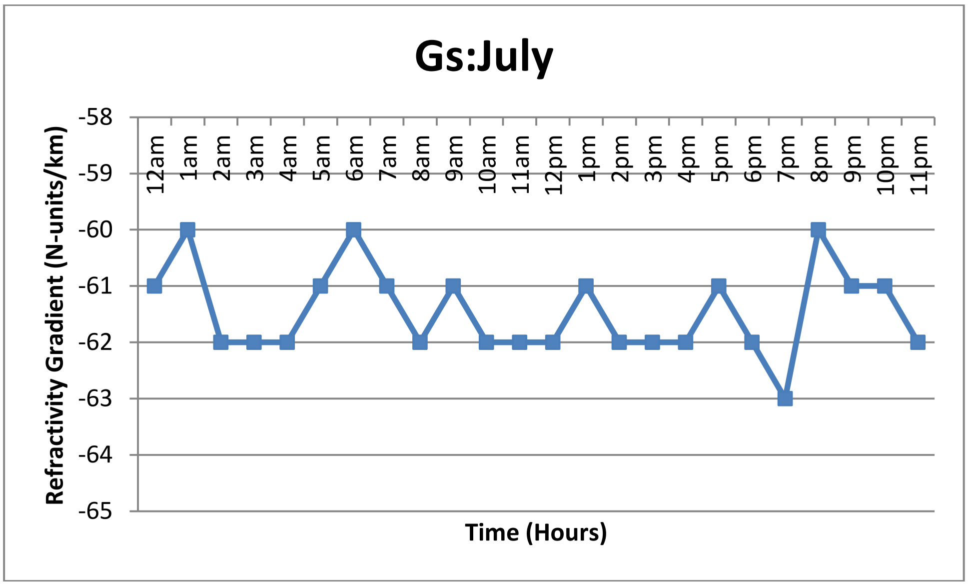

Fig.8: Mean diurnal variation of radio refractivity gradient in July

Fig.8 shows refractivity gradient range of -61 N-units/km to -63 N-units/km. There are more or less fairly stable lower values of refractivity gradient throughout night and day in the month of July. The lower negative values are attributed to higher signal strength and hence more super-refractive condition in that locality [9].

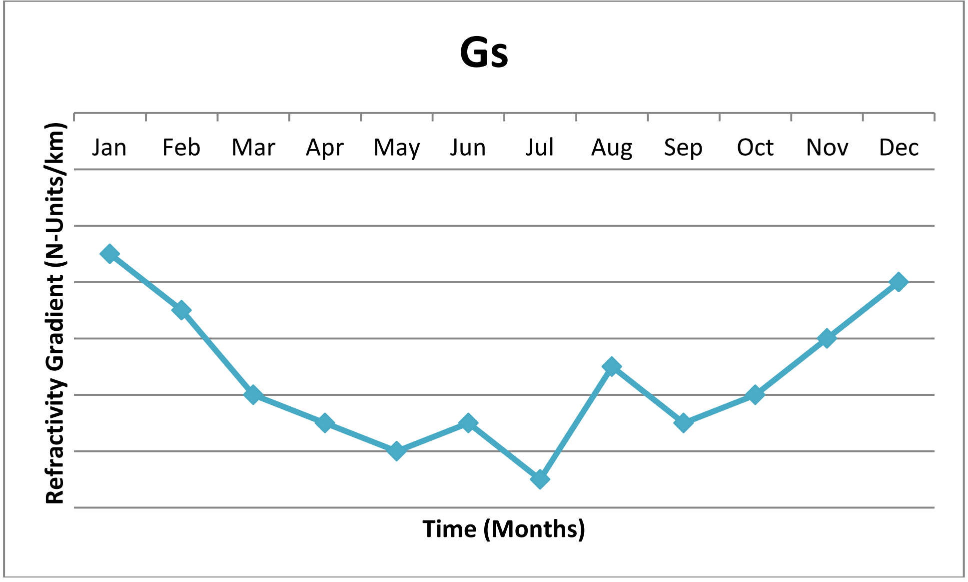

Fig.9: Mean monthly radio refractivity gradient over Awka for 2013 and 2014

From fig.9, it is observed that the mean refractivity gradient for the two-year period varies from the minimum value of -63 N-units/km to a maximum value of -55 N-units/km in the month of July and January respectively. The mean gradient value for the period is -59 N-units/km. Also, the wet season surface refractivity gradient varies from -60 N-units/km to -63 N-units/km while the dry season values vary from -55 N-units/km to -60 N-units/km during same period. The large negative values during the period show that the propagation conditions are mostly super-refractive because the refractivity gradient is less than -40 N-units/km and as such improved signal strength is obtained. The month of July has the higher signal strength because of the lower mean gradient value. The propagation implication bearing in mind that the more negative the refractivity gradient becomes the more super-refractive the troposphere, and the better the propagation conditions.

CONCLUSION

The work has shown that the surface radio refractivity gradient has lower values in wet season and higher values in dry season for the two-year period over Awka and environs. The propagation conditions could be mostly super refractive and the city of Awka is likely to obtain higher signal strength for radio propagation through the troposphere.

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