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Research Article

INVESTIGATING THE IMPACTS OF COSMIC RAY FLUX ON TROPOSPHERIC REFRACTIVITY OVER NIGERIA

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ABSTRACT

A comparative research on the effects of cosmic ray flux on tropospheric refractivity variations and its implication on radio communication in Nigeria wasinvestigated. The atmospheric data (Temperature, Pressure and Relative Humidity) for five locations across Nigeria, Akure (6°57'50.85"N, 4°36'17.19"E), Anyigba,($7^0$45'N, $6^0$45' E),) Nsukka (6°51'28.14"N, 7°24'28.15"E), Port - Harcourt (4^0 48'N, 7^0E) and Yola ($9^0$11' N, $12^0$30' E) was acquired from Centre for Atmospheric Research Kogi State while Cosmic rays data was downloaded from Mexico Cosmic ray Observatory. Five years' data were employed in each case while atmospheric data were used for the computation of tropospheric refractivity. The integration time for the data is in two minutes. Diurnal and seasonal variations of tropospheric refractivity across the five stations were determined to identify zones that have more impact of cosmic rays on radio communication. It was observed that diurnal variations of refractivity in the rainy season was caused by changes in the dry component refractivity while the diurnal changes in dry season was as a result of wet component of refractivity in all the stations except Yola which is in Northern part of Nigeria. There were series of signal fluctuations experienced between the average atmospheric parameters and cosmic ray fluxes. Careful application of correlation test was carried out between the variations of cosmic ray and tropospheric refractivity. The degree of correlation between cosmic ray fluxes and the variation of the average Earth's atmospheric parameters in each of the stations was found to differ according to the season and zone. The impacts of cosmic rays on radio communication were found in all the stations, although the pattern of its effect differs from one station to the other. The results show that the impact of cosmic rays on radio communication during rainy season is greater than the results in dry season. This is as a result of refractivity variation pattern in both seasons which is driven by variations in meteorological parameters.

INTRODUCTION

The propagation of electromagnetic waves in the atmosphere (mainly the troposphere) is greatly affected by the composition of the atmosphere (Korak, 2003). This is due to the fluctuations of atmospheric parameters primarily at the troposphere (the lower part of the earth's atmosphere). Consideration of the refractive properties of the lower atmosphere is of importance when planning and designing terrestrial communication systems mainly because of multi-path fading and interference due to trans− horizon propagation.

It is has been shown that the refractivity fluctuation in the lower atmosphere (troposphere) is a function of atmospheric parameters (Ekpe *et al.,*).Radio signals can be reflected, refracted, scattered, and absorbed by different atmospheric constituents (Chinelo and Chukwunike, 2016).

However, the degree of atmospheric effects on radio signals depends mainly upon the frequency/power of the signal and on the state of the troposphere through which the radio wave propagates. The characterization of tropospheric variability has great significance to radio communications, aerospace, environmental monitoring, disaster forecasting *etc.* The quality of transmitted radio waves to a receiving antenna mostly depends on performance and reliability of the links (Serdege and Ivanovs, 2007).

Generally, for radio link design, the measured data for signal strength at a particular location under study is required by radio

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planning engineers (Ali *et al*., 2012). Consequently, a radio propagation model is required to be used for the evaluation of signal level variations that occur at various locations of interest over different times of the year. An important element of such type of radio propagation model is the variation of radio refractivity in the troposphere (Gao*et al*., 2008).

According to Serdege and Ivanovs (2007), The variation of refractive index is due to various phenomena affecting the propagation of radio signal, which for instance include refraction, bending, ducting and scintillation, range and elevation errors in radar acquisition and radio station interference (Freeman, 2007, Grabner and Kvicera, 2003, Tom, 2006). Radio–wave propagation is determined by changes in the refractive index of air in the troposphere (Adediji and Ajewole, 2008). At standard atmospheric conditions near the Earth's surface, the radio refractive index is approximately 1.0003 (Freeman, 2007).

Changes in the value of the troposphere radio refractive index can curve the path of the propagating radio wave. In the troposphere, the refractive index is influenced by temperature, pressure and water vapour. Refractive index is small at the earth's surface and as a result, it becomes convenient to use refractivity N, when modeling variation of refractive index in the atmosphere. Refractivity, N is related to refractive index, n, as (Ekpe*et al.,* 2009):

$$N = (n - 1) \times 10^{6} \quad (1.1)$$

In terms of meteorological parameters, the refractivity is expressed as

$$N = 77.6\frac{P}{T} + 3.75 \times 10^{6}\frac{e}{T^{2}} \quad (1.2)$$

Where P is the pressure (hPa), T is the temperature in Kelvin and e is the water vapour pressure determined by

$$e = \left(\frac{R.h}{100}\right)e_{s} \quad (1.3)$$

and

$$e_{s} = 6.11\exp\left[17.5t/(t+240.97)\right] \quad (1.4)$$

Wheree_s is the saturated vapour pressure, t is temperature in degree Celsius, R.h is relative humidity expressed in percentage (%). The variation of the refractive index with height has a considerable influence on radio wave within the frequency range of 30MHz and above. Bending of radio signals as they propagate through the troposphere can cause a lot of problem in systems such as the accuracy of tracking radio source (such as stars) with radio telescope, tracking of satellites (such as GPS satellite), missile range *etc*.The lower atmosphere scatters electromagnetic radiation over a vast range, including radio waves. This effect is known as tropospheric scatter, or troposcatter.

Several Researchers (Usoskin*et al*., 2004; Umahi*et al*., 2016; Chima*et al*., 2015) have shown that cosmic rays have a lot of impact on lightening in Africa and consequently on the atmosphere. These studies did not establish its effect on radio communication, especially in Nigeria which this research tends to investigate. In this study the influence of cosmic ray variation on tropospheric radio refractivity will be examined. The study intends to statistically analyze the variations of cosmic ray flux and the tropospheric refractivity and correlate the variations both diurnally and seasonally using some statistical analyses such as SPSS (Statistical Package for Social Sciences). The study will also seek to establish a worst-case scenario of the cosmic ray effect on radio communication.

Data Source

The cosmic ray data for this work were obtained from the Mexican Cosmic Ray Observatory Center, while the atmospheric data were obtained from Center for Atmospheric Research (CAR), National Space Research and Development Agency (NASRDA), Anyigba, Kogi State, Nigeria.

METHOD

Series of analysis and procedures were carried out before arriving at our conclusion.Four different statistical tools were used in analyzing these data which include the following: Excel program, MatLab, Origin Pro 8 software and SPSS (Statistical Packages for Social Science).

The year was divided into rainy and dry months. This was done due to the inconsistencies in the commencement and cessation of rainy and dry season over Nigeria in recent years. Microsoft Excel and MatLabwere employed to calculate the refractivity variations in all the stations used for this study.Origin Pro was employed to plot the entire graphs, while, ISPS was employed to find the correlation coefficient between cosmic rays and atmospheric parameters. Pearson's Product Moment Correlation Coefficient (r) was employed to find the relationship between cosmic rays and atmospheric parameters and to ascertain the level of impact it will have on radio communication in Nigeria during rainy and dry seasons. The correlation coefficient of atmospheric parameters and cosmic rays using Pearson's formula is given as:

$$r = \Sigma(\times - \times)(\boldsymbol{y} - \bar{y})/\sqrt{\boldsymbol{\Sigma}(\times - \times)^{2}.\boldsymbol{\Sigma}(\boldsymbol{y} - \bar{y})^{2}} \quad (3.1)$$

Where, x = independent variable

y = dependent variable
x¯ = mean of the independent variable
ȳ = mean of the dependent variable

RESULTS

Diurnal Variation of Surface Refractivity

The Diurnal variation of refractivity at Akure in the dry season is shown in figure 1. The refractivity value ranges from about 340N to 345N during the early hours of the day and late in the evening. The value of refractivity started dropping about noon and reached a minimum of about 333N around 20:00hr local time. This variation was attributed to the response of the earth to solar insolation which is the major forcing behind the weather condition observed. The solar insolation caused the temperature to be high and humidity to be low during the day. The result shows that the refractivity over Akure for dry season is as a result of variation in the wet term of the refractivity. This result is in agreement with previous studies (Ayantunji*et al*., 2011, Falodun, 2004, Falodun and Ajewole, 2006, Bawa*et al*.,2015).

The variation of refractivity over Akure for rainy season is shown in figure 2. The refractivity increased to a first peak of about 362N around 9:00 hr local time. It gradually decreases to 356N around 12:30 hr local time. It then increases to about 360N around 17:00 hr local time before increasing for the rest of the day. While the variation of temperature and humidity showed the expected pattern, the pressure variation showed a pattern that is synchronous with refractivity variation. It is therefore deduced that the pressure (dry term) is the major driver of the refractivity variation over Akure in the rainy season.

Figure 3 shows diurnal variation of refractivity at Anyigba in the dry season. The refractivity drops to about 282N 18:00hr before increasing to 290N in the early hours. The value of refractivity decreased at noon and reach a minimum of about 280N around 13:00 hr local time. When the refractivity variation is put side by side with humidity variation during the same season, it shows that the refractivity is driven by the wet term.

The variation of refractivity over Anyigba for rainy season is shown in figure 4. The refractivity variation reflects the influence of the large water body in the proximity of the study area. The refractivity at the beginning of the day was about 355N and drops gradually to about 345N around 9:00 hr local time. It gradually increases to 354N around 12:30hr local time. It then decreased to a minimum of about 330N drops around 15:00hr local time and then increase gradually for the rest the day. The influence of both pressure and humidity on refractivity variation in Anyigba for rainy season shows that the wet and dry component combine are the driver of the variation.

The variation of refractivity over Nsukka for dry season as depicted in figure 5 showed a noisy pattern that is not consistent with any of the stations that had earlier been presented, probably due to altitude of the station. The station showed a post noon minimum which is consistent with refractivity variation driven by the wet term. Therefore, the refractivity variation over Nsukka for dry season can be said to be driven by the wet term.

The refractivity variation for rainy season over Nsukka as depicted in figure 6 showed low value in the early hours of the day which gradually increased and reached maximum of about 350 N around 11:00 hr local time before gradually dropping to a minimum of about 345 N around 20:00 hr local time and rise till the end of the day. The variation of pressure as depicted in figures 4.32 – 4.35 shows almost a synchronous pattern except slight differences at 2:00 hrs local, 10:00 hr local time and 16:00 hr local time. These discrepancies are attributed to the contribution of the humidity (wet term of refractivity). The refractivity variation over Nsukka for rainy season is therefore driven by the combination of the dry and wet terms of refractivity.

The diurnal variation of refractivity over Portharcourt for dry and rainy season is depicted in figures 7 and 8 respectively. Figure 7 showed that the refractivity value is high in the early morning and late in the evening with maximum value of about 352 N and low during the day with minimum value of about 315 N between the 8:00 hr and the 20:00 hr local time. This is in agreement with what is expected when the refractivity variation is being driven by the wet term. The variation in figure 8 shows a sudden rise pre-noon and sudden drop post-noon. The maximum value of 368N was observed around noon.

This maximum valuesat noon can be explained as a result of the contribution of the dry term of refractivity and the variation during the remaining period and the sudden rise and fall at noon is attributed to the contribution of the wet component. Anyigba and Port – Harcourt have series of similarities which could be attributed to the presence of large water body as explained earlier.

Figures 9 and 10 depict the Diurnal variation of refractivity over Yola for dry and rainy seasons respectively. Figure 9 shows a variation with high value during the early hours of the day which drops gradually from noon and reached a minimum of 274 N around 22:00 hr local time for dry season. Figure, 10 showed a variation that peaked to 340 N at noon for rainy season. The variation in the dry season can be attributed to the influence of the wet term of refractivity which is majorly influenced by the humidity. While the maximum value of refractivity at noon can be attributed to the contribution of pressure variation at this time of the day. The refractivity variation in the early hours and late hours of the day are driven by the combination of the wet and dry terms.

This is evident in the gradual rise of refractivity from early morning to about 5:00 hr local time which is consistent with the humidity profile (wet term) with slight drop from 4:00 hr local time to 6:00 hr local time which is consistent with drop in pressure (dry term) and with lowest value of refractivity at around 17:00hr local time and gradual rise till the end of the day which is consistent with both humidity (wet term) and pressure profile (dry term). In other word, the variation of refractivity over Yola in rainy season is as a result of the combination of both wet and dry terms.

For all the stations studied, the study of diurnal refractivity variation showed that the dry term is the major cause of refractivity variation in rainy season and the wet term is the major cause of refractivity variation in dry season except Yola. In Yola the result was found to be opposite and it is attributed to the fact that in dry season the humidity is almost zero while in rainy season the pressure seems to be almost constant but the temperature fluctuates rapidly and consequently the humidity.

The study also shows that there exists a variation between rainy and dry season refractivity and that higher refractivity is experienced during the rainy season as observed in all stations in Nigeria than during the dry season. Hence, higher radio power losses should be expected during the rainy season as stated in the literature (Daniel *et al.,* 2015). Radio signal transmission efficiency is expected to be higher in areas with low refractivity such as Yola and as was observed in previous studies such as Gabriel and Temitope (2016)andAdegboyega, (2013).

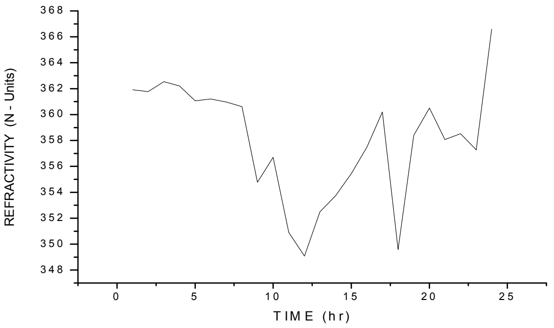

Figure 1 Diurnal Refractivity variations over Akure during the dry season from 2012 – 2016.

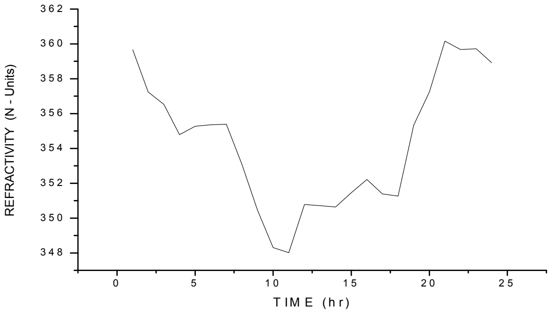

Figure 2 Diurnal Refractivity variations over Akure during the Rainy Season from 2012 – 2016.

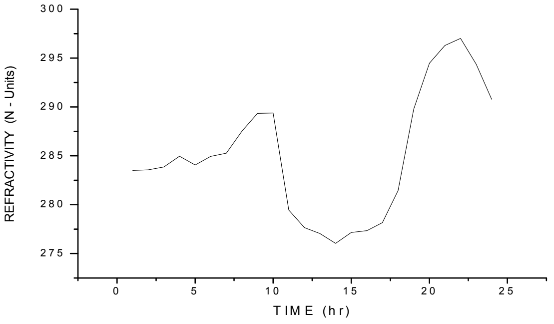

Figure 3 Diurnal Refractivity variations over Anyigba for dry season from 2012 – 2016.

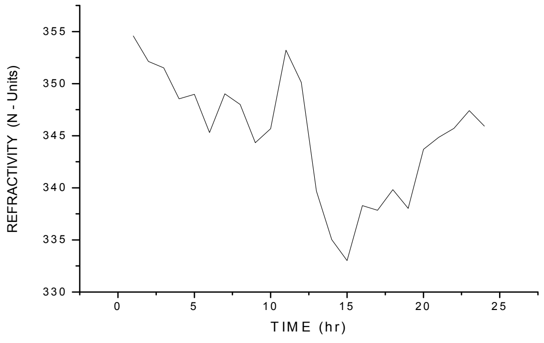

Figure 4 Diurnal Refractivity variations over Anyigba for rainy season from 2012 – 2016.

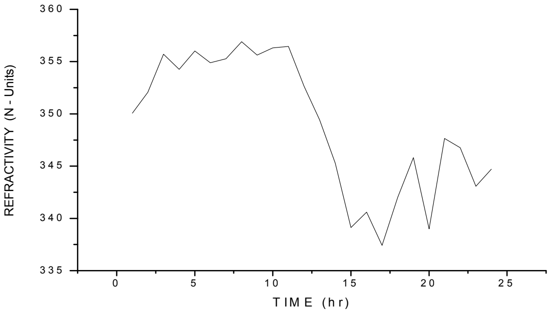

Figure 5 Diurnal Refractivity variations over Nsukka for dry season from 2012 – 2016.

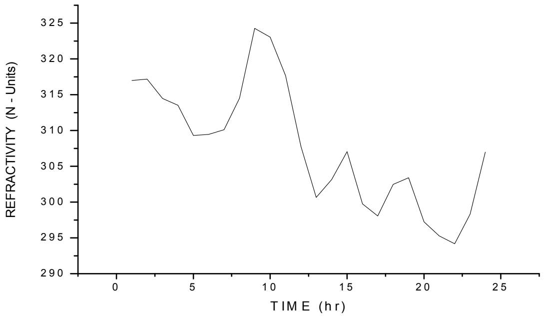

Figure 6 Diurnal Refractivity variations over Nsukka for rainy season from 2012 – 2016.

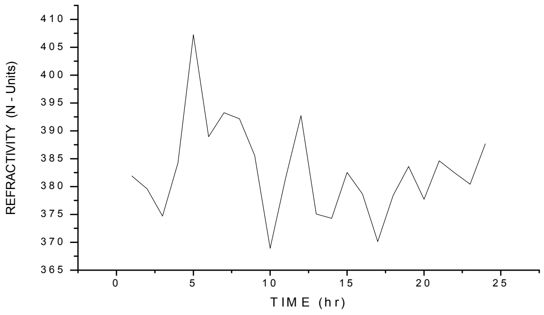

Figure 7 Diurnal Refractivity variations over Port - Harcourt for dry season from 2012 – 2016.

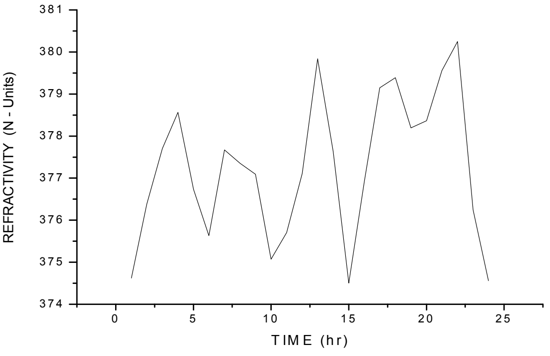

Figure 8 Diurnal Refractivity variations over Port - Harcourt for rainy season from 2012 – 2016.

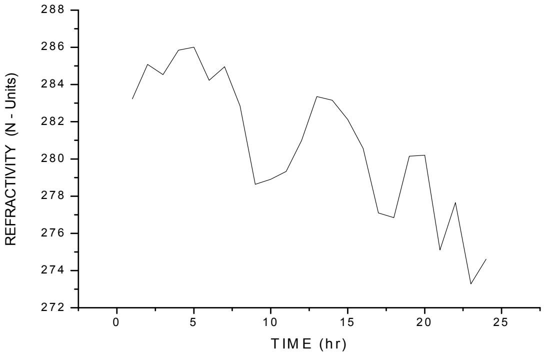

Figure 9 Diurnal Refractivity variations over Yola for dry season from 2012 – 2016.

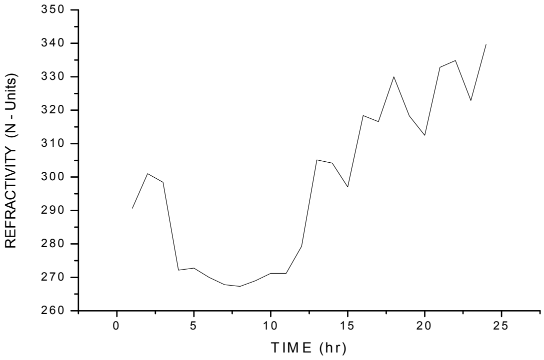

Figure 10 Diurnal Refractivity variations over Yola for rainy season from 2012 – 2016.

Impact of Cosmic Rays on Atmospheric Parameters in all the Five Stations Used.

Figure 11 to figure 20 presents the statistical analysis of the impact of Cosmic rays on refractivity. This was to determine the impact of Cosmic rays on radio communication based on the dependence of radio communication on refractivity as established from the literatures. The scatter diagrams were used to determine the correlation coefficient of cosmic rays on refractivity at all the stations. The correlation coefficient for rainy and dry seasons is presented for all the stations in Table1

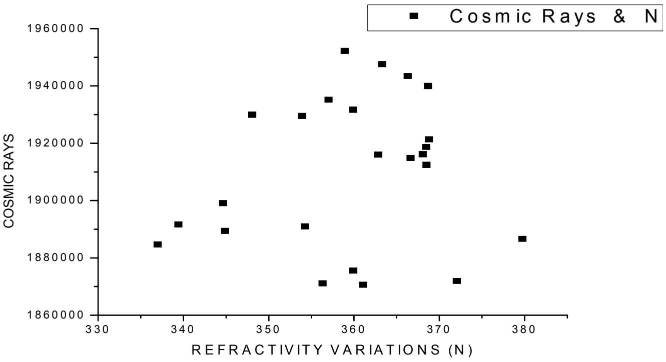

Figure 11 Dependence of refractivity on cosmic rays in Akure during rainy season from 2012-2016

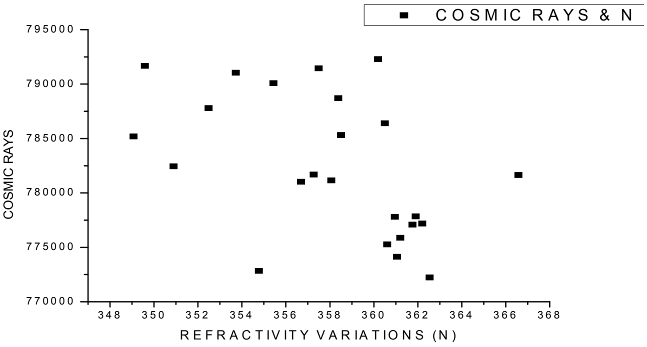

Figure 12 Dependence of refractivity on cosmic rays in Akure during the dry season from 2012 - 2016

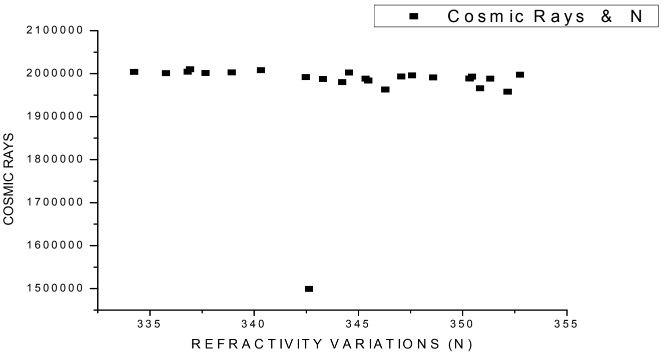

Figure 13 Dependence of refractivity on cosmic rays inAnyigba during the rainy season from 2012 - 2016.

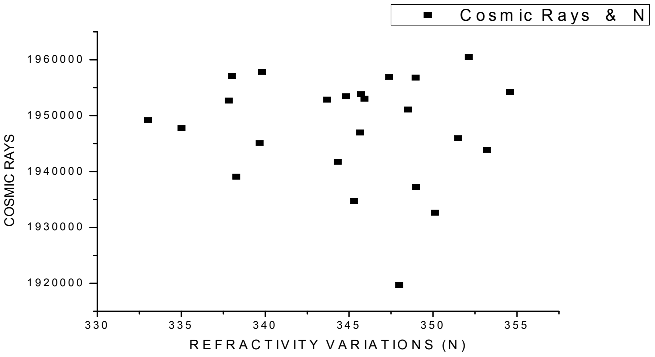

Figure 14 Dependence of refractivity on cosmic rays in Anyigba during the dry season from 2012 – 2016.

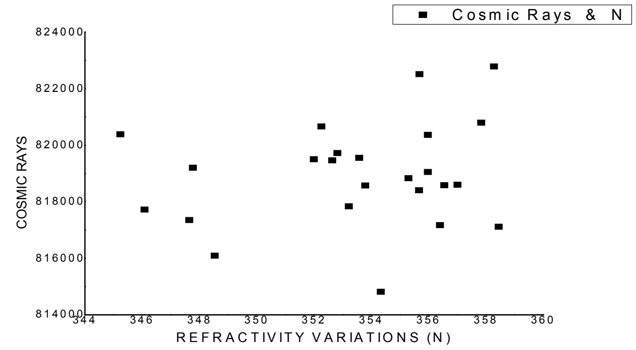

Figure 15 Dependence of refractivity on cosmic rays in Nsukka during rainy season from 2012 – 2016.

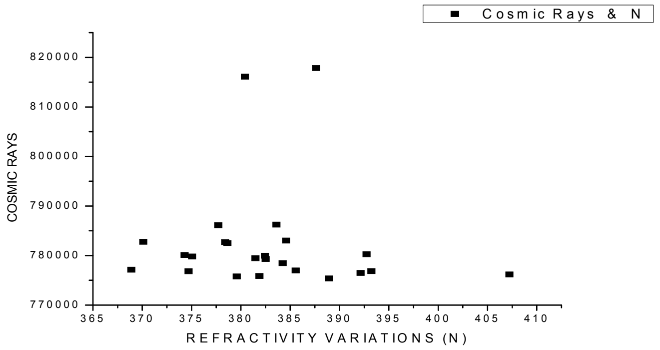

Figure 16 Dependence of refractivity on cosmic rays in Nsukka during dry season from 2012 - 2016.

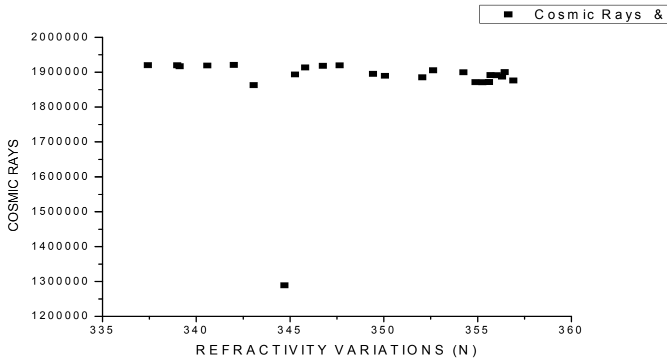

Figure 17 Dependence of refractivity on cosmic rays in Port - Harcourt during rainy season from 2012 - 2016.

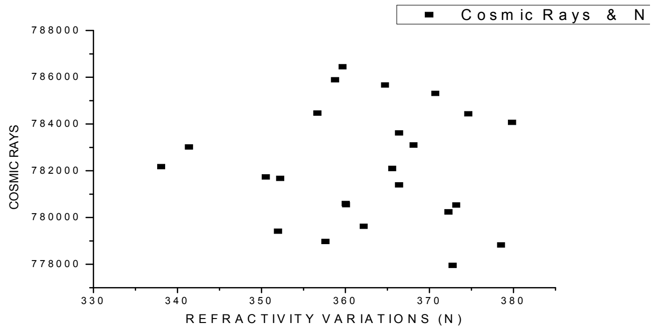

Figure 18 Dependence of refractivity on cosmic rays in Port - Harcourt during dry season from 2012 - 2016.

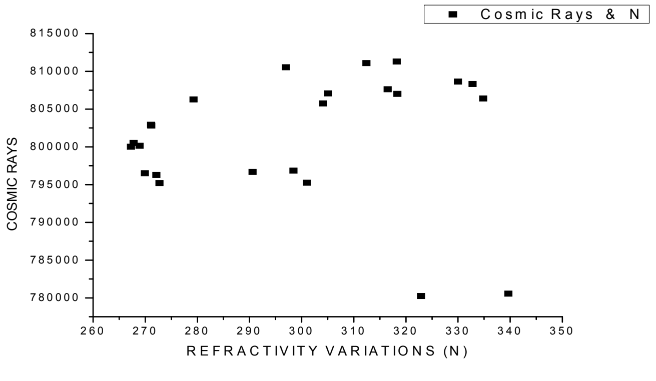

Figure 19 Dependence of refractivity on cosmic rays in Yola during rainy season from 2012 - 2016

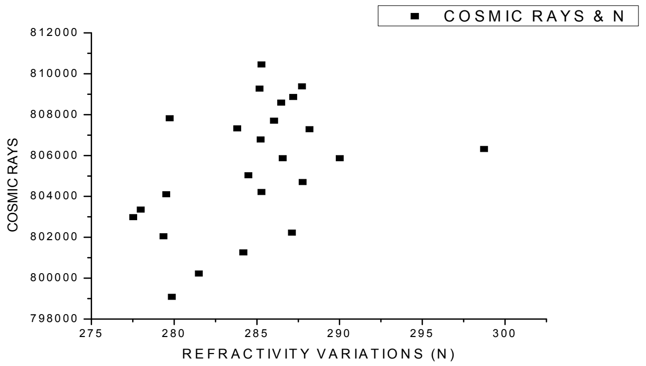

Figure 20 Dependence of refractivity on cosmic rays in Yola during dry season from 2012 – 2016

DISCUSSION

Table 1 Values of the Correlation Coefficient on the Dependence of the Variations of Cosmic Rays on Refractivity for all the Stations Used in this Research

Stations	Rainy season	Dry season
Akure	0.23	0.47
Anyigba	0.15	0.63
Nsukka	0.27	0.65
Port – harcourt	0.09	0.36
Yola	0.44	0.67

Generally, Cosmic rays seem to have stronger correlation with refractivity in dry season. In Akure correlation is 0.23 and 0.47 for rainy and dry seasons respectively. It is 0.15 and 0.63 for dry and rainy seasons at Anyigba, 0.27 and 0.65 at Nsukka, 0.09 and 0.36 at Portharcourt and 0.44 and 0.67 at Yola. The results indicated that the impact of cosmic rays on refractivity is higher during rainy seasons.

It was established in previously that the refractivity variation in the dry season is largely driven by the wet term in all the stations considered. The wet term of refractivity was also shown to depend on humidity and temperature. This result shows that cosmic rays plays a lot of roles in atmospheric processes, especially atmospheric temperature, which is in agreement with result obtained by Devendraa and Singh (2010). The variation of the correlation coefficient from one station to another also affirms the latitudinal dependence alluded to above.

The slight correlation variations in Akure suggest that the variations lead to a positive correlation relationship throughout the months of observations. This shows that an increase in rainfall leads to decrease of cosmic ray's variations; this is the reason why we have strong correction with refractivity in dry season which signifies that cosmic rays have influence on temperature, pressure and humidity. These relationships are in agreements with the findings of other results (Badruddin and Aslam, 2014), which talks about Influence of cosmic-ray variability on the rainfall and temperature.

In Anyigba, the variation of cosmic rays and refractivity showed a positive correlation coefficient of 0.63 during the dry season and 0.2 during rainy season. In rainy season we have a weak positive correlation and this is due to the presence of large water bodies in Anyigba as already explained. This result shows that the amount of local meteorological condition plays a significant role in the amount of Cosmic ray radiation received at any given time and this result is in agreement with that of Adedoja *et al., (*2015).

In Nsukka region, Chima *et al.,* 2015 worked on this region and observed that the average temperature of the Earth's atmosphere and the cosmic rays have positive correlation which implies that cosmic rays trigger the variation in temperature of the Earth's atmosphere and can easily affect radio communications. Cosmic rays are one of the parameters that enhance the ionization and the temperature variation of the atmosphere. The inconsistency in the variation shows that cosmic rays may not be the only source of ionization in the earth's atmosphere which is in line with the result obtained Umahi (2016).

Portharcourthas similarity with Anyigba in term of weather because both have the highest refractivity variations compare to other zones involved in this study, this is as a result of abundance of large water bodies in this area.

In Yola, the correlation coefficient of 0.67 during the dry season and 0.44 during the rainy season was found. These values mimic the nature of the zone because these zone experience inconsistencies in their weather conditions and has low refractivity variation with just slight increase around June and July.

CONCLUSION

This study examined the impact of cosmic ray on radio communication across Nigeria. Five zones out of the six-geopolitical zone we have in Nigeria were studied. The scatter diagram was employed to check the dependence of atmospheric parameters on cosmic rays. The strong correlation of cosmic ray's variation and refractivity variation in dry season and weak correlation in the rainy season indicates that the effect is high in dry season.

Findings from this study if harnessed will benefit radio wave propagation researches, including radio astronomy observations, space science, wireless communication, satellite, antenna and mobile communication. In considering factors that affect radio communication in Nigeria, cosmic rays should be looked into for its effect has been established from this research which is in affirmation with those of other authors (Umahi, 2016, Chima *et al.,* 2015, Dickinson and Robert 1975, Sloan *et al.,* 2011).

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