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Daily and Seasonal Variations of Tropospheric Radio Refractivity at Akure in South-West Nigeria using Campbell Scientific Automatic Weather Instrument

[1]Agbo, G. A., [2]Onuorah, L. O., [3]Okoh, D.

[1,2]Industrial Physics Department, Faculty of Science, Ebonyi State University, Abakaliki, Nigeria

[2]Department of Physical & Geosciences, Faculty of Natural Sciences & Environmental Studies, Godfrey Okoye University, Enugu, Nigeria

[3]Centre for Atmospheric Research, National Space Research and Development Agency, Abuja, Nigeria

***Abstract* - Tropospheric radio refractivity over Akure in South–West, Nigeria has been studied using meteorological data such as relative humidity, temperature and pressure from January 2014 – December 2016. The Campbell Scientific Automatic Weather Instrument was used for data collection and data was logged using the CR100 data logger. Measurement and data collection was done at a five minute interval. The records cover 24 hours each day starting from 00:00 hours to 23:55 hours local time. The overall three years data were averaged and used for the analysis. Results of the analysis show that the percentage contributions of the wet term of radio refractivity (which is a function of relative humidity) and dry term of radio refractivity (which is a function of pressure) were 29% and 71%, respectively. This revealed that variation of tropospheric radio refractivity over Akure is attributed to the contribution of the wet and dry terms of radio refractivity. The results also revealed that a regression statistical model can be used to predict radio refractivity in Akure using the available data.**

Keywords: Troposphere, Meteorological data, Radio Refractivity, Regression and percentage.

I. Introduction

Electromagnetic radiation can be said to be waves of the electromagnetic field, propagating through space, and carrying electromagnetic radiant energy. It includes, radio waves, microwaves, infrared, light, ultraviolet, x-rays and gamma rays. However, the study of the tropospheric radio refractivity has stimulated much interest because of its influence on radio wave communication in the lower atmospheric layer (troposphere). Korak (2003) stated that in the troposphere, the propagation of electromagnetic waves is mostly affected by the composition of the atmosphere. The atmospheric water molecules are polar, which means they have dipole moments. Other atmospheric gases such as nitogen, argon, methane, carbon-dioxide etc are non polar, meaning that the dipole moments are induced in their molecules only when electromagnetic radiation propagates through them. This attributes to the variation in the radio refractivity that contributes to reflection, polarization and scattering of the incident radiation (Raju, 1999).

According to Adediji and Ajewole (2008), radio wave propagation is determined by changes in the refractive index of air in the troposphere. Relative humidity, temperature and pressure, among others are factors that influence the tropospheric radio frequency or radio wave signal propagation. Thus, the refractivity variation in the troposphere is a function of relative humidity, pressure, and temperature (Saha, Raju and Parameswaran, 2005; Tomar, 2012). The radio wave behaviour depends mostly on the radio refractive index of the troposphere. For this reason, the tropospheric surface refractivity is tremendously important in any communication system that uses electromagnetic radiation (Kurt, 1960; Hall, 1966; Ippolito, 1981; Muop, 1999).

Variation of surface refractivity in Nigeria has been studied widely using extrapolated data from radiosonde measurements. Adeyemi and Kolawole (1992) conducted in-situ measurements of surface refractivity in Akure. From the results of the measurements, it was reported that the main contributor to the seasonal and diurnal variations in surface radio refractivity comes from the wet term. Other researchers such as Oyinloye (1987); Oyedum and Gambo (1994); Falodun and Kolawole (2006); Adeyemi and Ewetumo (2006) also worked on surface refractivity variations over Nigeria using extrapolated radiosonde data. The results from these studies show a consistent trend of high value of refractivity during the rainy season and low values during the dry season.

The meteorological parameters such as relative humidity, temperature and pressure used in computation of refractivity vary daily, monthly and seasonally. These variations cause

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variation in the tropospheric radio refractivity that fluctuates, and affects communications. Ojo (1977) observed that water vapour, one of the greenhouse gases, affects radio wave propagation in the atmosphere.Kolawole (1983) also observed that water vapour, in estimation of radio refractive index of air for radio meteorological studies, is responsible for large fluctuations in tropospheric radio refractivity.

Babalola (1998) stated that permanent dipole moments possessed by atmospheric water vapour are important in the propagation of the atmospheric radio waves. Studying the influence of some meteorological factors on tropospheric radio refractivity over a tropical location in Nigeria, Adediji, Ajewole, Ojo, Ashidi, Ismail and Mandeep (2013) noted that most previous research on radio refractivity in Nigeria focused on surface refractivity and are based on radiosonde data. Using other instruments such as Davis 6162 wireless Vantage Pro2 with the Integrated Sensor Suite (ISS), a solar panel with battery source and wireless console, they observed in the lowest atmosphere that water vapour has the most significant effect on radio refractivity whereas variations in pressure have least effect on refractivity change.

This work focuses on daily and seasonal variations of tropospheric radio refractivity in Akure, south-west, Nigeria using Campbell scientific automatic weather instrument.

II. Data Collection

The data used for this work were obtained from the Centre for Atmospheric Research (CAR), Kogi State University Campus, Anyigba, which is an activity centre of the National Space Research and Development Agency (NASRDA), Abuja, Nigeria. We studied the daily and seasonal variations of tropospheric radio refractivity in Akure, south-west Nigeria using January 2014 – December 2016 surface data collected by means of Campbell scientific automatic weather instrument. The CR1000 data logger type is used. Measurement and data collection was done at a five-minute interval. The records cover 24 hours each day starting from 00:00 hours to 23:55 hours local time.

III. Theoretical Background

The refractive index of the troposphere is tremendously important in predicting performance of terrestrial radio links. The variation of refractivity in the troposphere is determined by the variations of temperature, relative humidity and pressure. The temperature in Kelvin (K), relative humidity in percentage (%) and pressure in millibar (mb) were the input parameters used to calculate the radio refractivity (N-units).

The atmospheric radio refractivity can be computed using the ITU-R (2016): formula

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right)(N - units) \quad 1$$

The dry term, N_{dry}, of radio refractivity is given by:

$$N_{dry} = 77.6\frac{P}{T} \quad 2$$

And the wet term, N_{wet}, by:

$$N_{wet} = 373256\frac{e}{T^2} \quad 3$$

Where P is the pressure in millibar (mb), e is the water vapour pressure in hectoPascal (Pa), and T is temperature in Kelvin (K).

The water vapour pressure, e is given by

$$e = \frac{RH\,e_s}{100} \quad 4$$

Where RH is the relative humidity in percentage (%) and e_s is the saturated vapour pressure.

The saturated vapour pressure, e_s is given by

$$e_s = 6.1121 exp\left\{\frac{17.502t}{t+240.97}\right\} \quad 5$$

Where t is the value of the temperature in degree Celsius (^{0}C). The refractive index, n and refractivity, N are related by the equation:

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

IV. Methods

Meteorological data such as temperature, relative humidity and pressure values collected from January 2014 - December 2016 were used to calculate the radio refractivity value using the refractivity expression in equations 1-3 above to give twenty four (24) data points representing hourly radio refractivity values for each day of the year. The water vapour pressure, and the saturated vapour pressure, was determined using the expressions in equations 4 and 5 respectively. The hourly data for each day is averaged to give a data point for the day and the hourly averages were further averaged in daily bins to obtain the daily values of tropospheric radio refractivity over all the years investigated. Furthermore, the daily averages were averaged in monthly, and then seasonal bins and these were used to investigate the monthly and seasonal variations of the radio refractivity parameter over Akure.

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A correlation between the tropospheric radio refractivity and the three meteoological parameters (relative humidity, temperature and pressure) was done using regression statistical analyses on the excel software. This was achieved by using the regression model on the data analysis tool, taking the measured radio refractivity value as the input Y range and all the three meteorological parameter values as the input X range. The software is then requested to compute the correlation coefficients, R and the coefficients of determination, R2 by closing the dialogue box. The correlations results were determined and the comparison between the actual (measured) and estimated tropospheric radio refractivity values were plotted. The analyses were all achieved using Microsoft excel and Matlab softwares.

V. Results and Discussion

The results of the investigation are graphically presented in Figures 1-9. The average day to day (hourly) variation of radio refractivity, relative humidity, temperature and pressure, respectively plotted against time for January 2014 – December 2016 is presented in Figure 1, 2, 3 and 4, respectively. The plot shows that the parameters exhibit day – night cycles. Figure 1 shows that radio refractivity value increases slightly from the 00:00 hours to a value of 357.2 N units at 01:00 hours local time. It then decreases uniformly until it reached a value of 356.7 N units at 06:00 hours local time from which it slightly increased to a peak value of 357.4 N units at 08:00 hours local time. It thereafter decreases uniformly around 15:00 hours local time reaching a minimum value of 336.5 N units after which it rose steadily until 23:00 hours local time, to complete the day's cycle.

The variation of relative humidity as depicted in Figure 2 shows that humidity increases from 00:00 hours local time until it reached a peak value of about 88% at 07:00 hours local time. It thereafter decreasing uniformly until it reached a minimum value of 49% at 15:00 hours local time from which it rises till 23:00 hours local time, to complete the day's cycle. The variation of temperature (Figure 3) follows a pattern that is opposite to that of humidity. The minimum and peak values for temperature are around 07:00 hours and 15:00 hours local time with values of 21.5°C and 31°C, respectively. The variation of pressure is presented in Figure 4. The plot shows that pressure value slightly decreases from 00:00 hours local time until it reached a minimum value of 968.7 mb at 04:00 hours local time and after which it slightly increases to a peak value of 971.2 mb at 10:00 hours local time. It thereafter decreases uniformly until another minimum value of 967 mb at 17:00 hours local time before rising for the rest of the day.

From the results we observed that the peak values for refractivity, relative humidity and pressure occur between 07:00 – 10:00 hours local time. On the other hand, the temperature is a minimum at about the same time. This is rather surprising, given that the pressure of a given gas is directly proportional to its temperature. However, the relative humidity and pressure are partially in phase with refractivity, while temperature is in anti-phase with relative humidity, pressure as well as refractivity. The percentage contributions of the wet term of radio refractivity (N_{wet}), which is a function of relative humidity, and the dry term of radio refractivity (N_{dry}), which is a function of pressure, are 29% and 71%, respectively. The percentage result shows that the N_{dry} is about thrice as high as that of N_{wet}. It could be said that refractivity in Akure is highly dependent on relative humidity and pressure with little contribution from temperature. Therefore the daily variation of radio refractivity at Akure is mostly influenced by the contribution of both dry and wet terms of refractivity. This does not agree with the work of Adeyemi and Kolawole (1992) who reported from their results that the main contributor to diurnal variation of radio refractivity comes from the wet term.

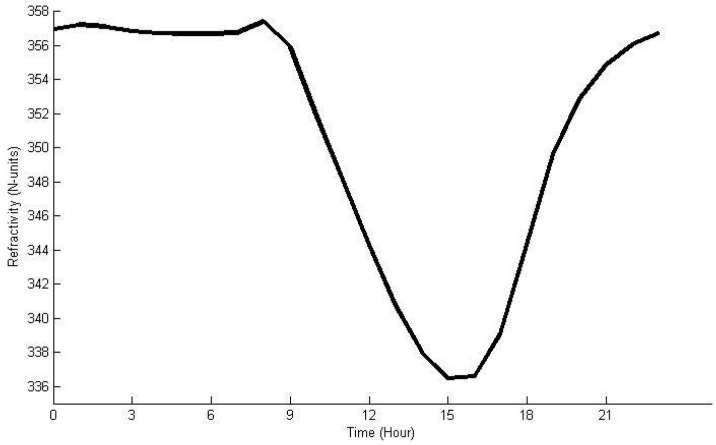

Figure 1: Average Diurnal Variation of Radio Refractivity over Akure

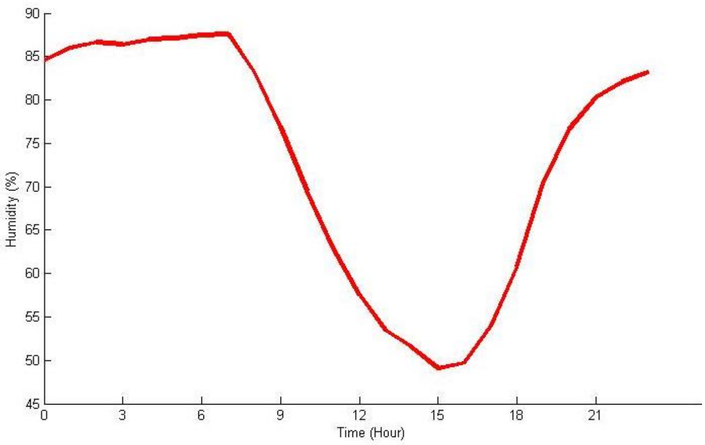

Figure 2: Average Diurnal Variation of Humidity over Akure

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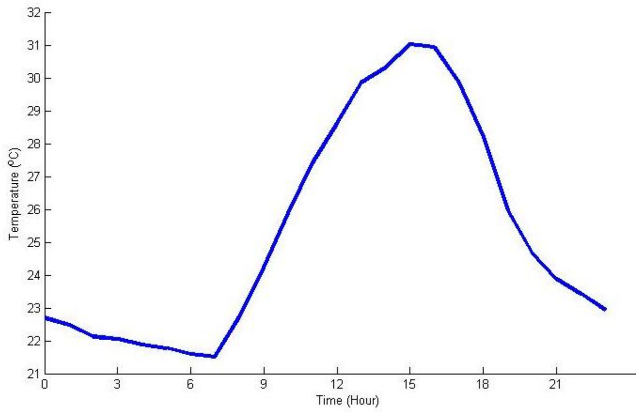

Figure 3: Average Diurnal Variation of Temperature over Akure

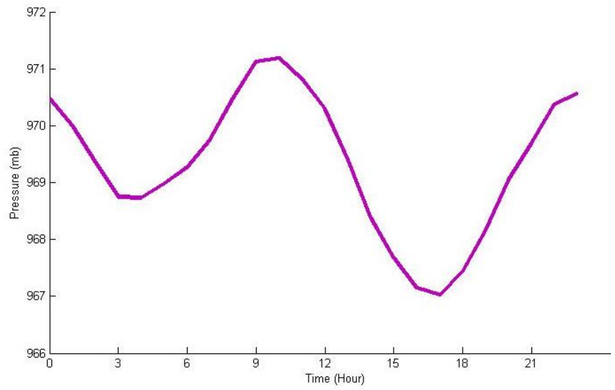

Figure 4: Average Diurnal Variation of Pressure over Akure

The mean monthly variation of radio refractivity presented in Figure 5 shows high values of refractivity in the months of March to October and the period coincided with the rainy season period in Akure. The minimum and maximum values of refractivity were observed in the months of December and May, respectively. The value of refractivity increases from a minimum of about 341.3 N units in January to a maximum at about 360.9 N units in May. Thereafter, it slightly decreases from June and rising again in September before gradually dropped until the month of December with a minimum value of 331.7 N units.

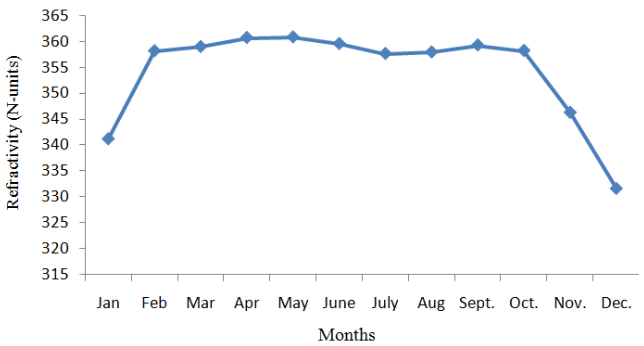

Figure 5: Average Monthly Variation of Radio Refractivity over Akure

The average seasonal variations of radio refractivity, relative humidity, temperature and pressure plotted against time for the dry and rainy seasons of January 2014 – December 2016 are presented in Figures 6 and 7, respectively. Figure 6 shows the average seasonal variation of radio refractivity, relative humidity, temperature and pressure over Akure for the dry season. The refractivity shows a steady increase from early hours of the day until it peaked at about 352.4 N units around 08:00 hours local time. It thereafter decreases from then to a minimum at about 320.6 N units around 16:00 hours local time from which it rises till the end of the day. This variation pattern is in line with what is expected when the refractivity variation is being influenced by the variation of relative humidity.

The average seasonal variation of radio refractivity, relative humidity, temperature and pressure over Akure for rainy season is depicted in Figure7 The refractivity showed a steady decrease from early hours until it reaches about 361.3 N units around 05:00 hours local time. It thereafter rises from then until it peaked at about 362.4 N units around 08:00 hours local time from which it steadily dropped to a minimum of 352.1 N units around 15:00 hours local time before rising for the rest of the day.

The variation of relative humidity at Akure showed a steady increase from early hours of the day till 07:00 hours local time. It thereafter decreases from then until it reaches a minimum around 15:00 hours local time from which it rises till the end of the day. The variation of temperature followed opposite trend as that of the relative humidity. The temperature showed a decrease from the early hours of the day till 07:00 hours local time. It thereafter increases from then to a maximum around 15:00 hours local time from which it dropped for the rest of the day. The variation of pressure showed a steady decrease from the early hours of the day to around 04:00 hours local time (first minimum). It thereafter increases slightly from then until it peaked around 10:00 hours local time from which it decreased to another minimum around 17:00 hours local time before rising again till the end of the day.

The combination of these three meteorological parameters can be used to explain the radio refractivity variation at Akure during the dry and rainy seasons. The variation of relative humidity shows a pattern that synchronized with variation of refractivity in the dry season. Moreover, the variation of pressure also contributed to the refractivity variation in the dry season. This is evident in the steady decrease in refractivity from 09:00 hours local time to a minimum around 16:00 hours local time and suddenly increased for the rest of the day. The decrease in refractivity during the early hours of the rainy

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season can be attributed to the minimum pressure at this time of the day. The radio refractivity variations during the day and evening hours were influenced by the contribution of both the humidity and pressure variations. This is also evident in the steady decrease in refractivity from early hours to around 05:00 hours local time with slight increase from then to around 08:00 hours local time which is consistent with the drop and rise in pressure at these times of the day. The lowest value of refractivity around 15:00 hours local time is consistent with relative humidity, and steadily increased for the rest of the day. This is consistent with both variations of relative humidity and pressure.

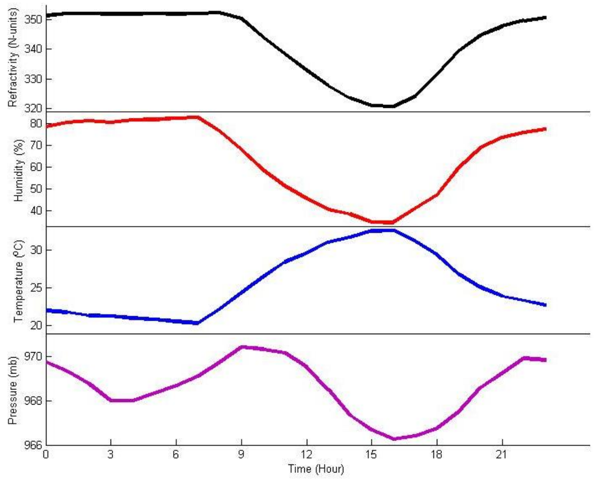

Figure 6: Average Seasonal Variation of Radio Refractivity, Relative humidity, Temperature and Pressure over Akure for Dry Season

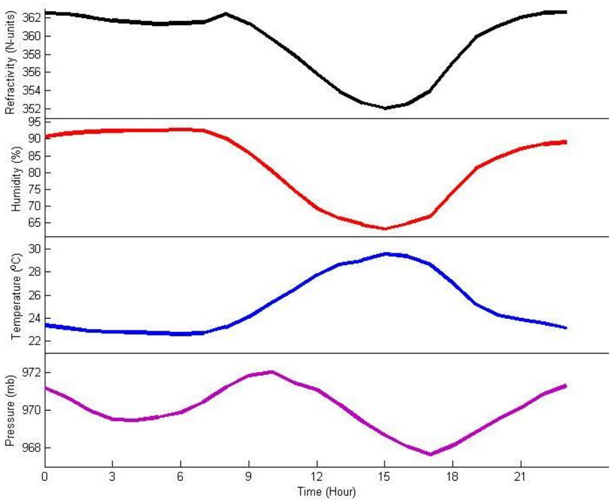

Figure 7: Average Seasonal Variation of Radio Refractivity, Relative humidity, Temperature and Pressure over Akure for Rainy Season

In other word, the seasonal variation of surface radio refractivity at Akure for the dry and rainy seasons is a contribution of both variations of relative humidity and pressure, which are functions of wet and dry terms of refractivity. This result does not agree with the findings of Adeyemi and Kolawole (1992) who showed that the main contributor to seasonal variation of radio refractivity comes from the wet term.

Furthermore, the results also showed that the highest value of radio refractivity recorded was about 362.4 N units observed in the rainy season and the lowest value of radio refractivity was about 320.6 N units, observed in the dry season.

The contour plot in Figure 8 presents the summary of the average seasonal and diurnal variations of surface radio refractivity. It can be clearly seen from the plot that the high values of refractivity occur between March and October which corresponds to the period of rainy season. The highest refractivity value was identified to be in the month of May as can be seen on the plot. The noticeable drop which was observed in the month of August can be attributed to a period of scanty rainfall during rainy season commonly known as the August break.

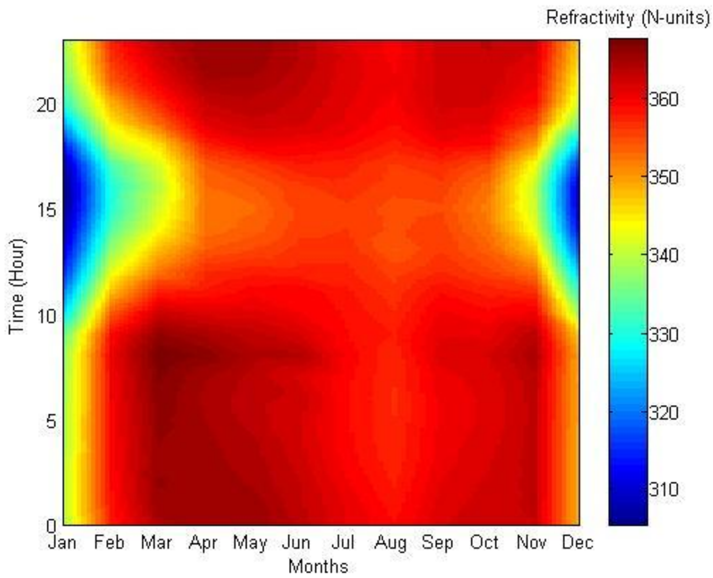

Figure 8: Average Seasonal Variations of Surface Radio Refractivity with Time over Akure

The regression statistical analysis was used to determine the correlation between the refractivity and three meteorological parameters namely relative humidity, temperature and pressure. This was done in order to estimate the extent to which these three meteorological parameters correlate with the refractivity and to predict the value of refractivity based on the value of the three parameters. The results show that; the correlation coefficients, R which explains that the combination of independent variables (temperature, relative humidity and pressure) gives the result of the dependent variable (predicted refractivity) is 0.99, the

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coefficient of determination; R2 that shows the output of regression analysis is 0.99.

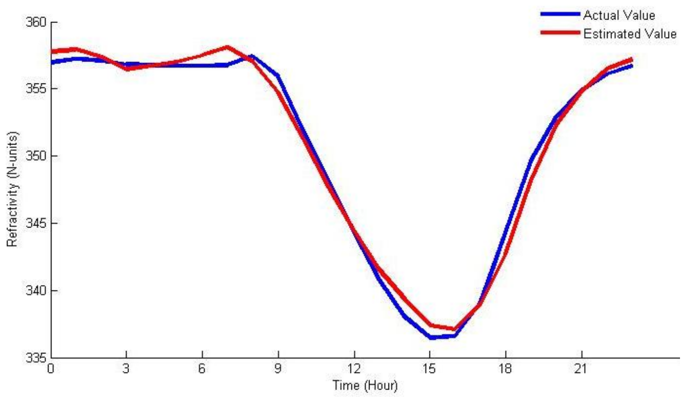

Figure 9: Comparison between actual and predicted Radio Refractivity over Akure

Figure 9 presents the comparison between the actual tropospheric radio refractivity values and the estimated tropospheric radio refractivity values. It can be seen from the plot that the actual and estimated values followed the same pattern. The absolute value or deviation determined gives a value of -0.07 and percentage error gives a value of -0.02. The negative value of error shows that the predicted value is higher than the actual value. The percentage contribution from R2 shows that the parameters contributed 99% of the tropospheric radio refractivity variation in Akure while the remaining 1% may be caused by other factors such as clouds, precipitation etc.

From the results of the analysis we concluded that the relationship of the three meteorological parameters (relative humidity, temperature and pressure) in generating the radio refractivity at Akure gives a strong positive correlation.

VI. Conclusion

The analysis of results revealed that the variation of tropospheric radio refractivity over Akure is influenced by the contribution of the N_{wet} and N_{dry} of radio refractivity which are functions of relative humidity and pressure, respectively. The results also revealed that the radio refractivity value is higher during the rainy season than the dry season. The results from statistical regression analysis show a strong positive correlation between refractivity and the three meteorological parameters (relative humidity, temperature and pressure). This implication means that the statistical regression model can be used to estimate the tropospheric radio refractivity from the actual data in Akure, south-west, Nigeria.

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