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An Empirical Analysis of Atmospheric Radio Refractivity Effect on Signal Quality at UHF Band in a Tropical Environment

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Abstract

This study analyzed the impact of atmospheric parameters on UHF signal strength in a tropical environment using Gusau, North West, Nigeria as a case study. The analysis exploited year 2018 meteorological data measured simultaneously with UHF signal strength from instruments situated at Federal University, Gusau (6^0 78' N, 12^0 13' E). The refractivity values were computed using ITU-R model. The results show that the average daily variation of refractivity is large due to variations in Humidity, while refractivity reveals seasonal variations with high values in the rainy season (April to October) and low values in the dry season (November to March). Minimum value of 272 N-Units was observed in January. Regression analyses gave UHF signal strength and Relative humidity correlations of 0.633 and 0.85 for December and January, and -0.728 and -0.639 for August and September. Also, the correlation between UHF signal strength and Temperature are -0.597 and -0.890 for December and January, and 0.782 and 0.556 for August and September respectively. Lastly, the correlation between UHF signal strength and radio refractivity are 0.530 and 0.864 for December and January, and 0.311 and 0.364 for August and September. These results indicate that environmental factors have effects on signal quality.

Keywords - *Radio Refractivity, Atmospheric parameters, Ultra High Frequency*

I. INTRODUCTION

In free-space, electromagnetic waves propagate in straight lines without absorption, scattering, refraction, diffraction and attenuation. Free-space, however, is an idealization that is only approximated when RF or microwaves energy propagates through atmosphere or in the presence of Earth. In practice, the performance of any communication system may be seriously affected by propagation effects such as reflection, refraction, diffraction or attenuation. It's important to realize that propagation effects generally cannot be quantified in any exact or rigorous sense, but can only be described in term of their statistic [10]. Whenever radio waves are propagated through the troposphere, multipath effects arise due to large scale variation in the atmospheric refractive index, such as horizontal layers with very different refractivity [11] and [14]. The effect becomes apparent when the same signal takes different paths to its target, the rays arriving at different times and hence interfering with each other. The consequence of this large-scale variation in the atmospheric refractive index is that radio waves propagating through the atmosphere become progressively curved towards the earth [5]. In order to able to design a reliable and efficient communication system (terrestrial and satellite), a quantitative knowledge of atmospheric parameters (Temperature, Pressure and Relative humidity) and consequently refractive index of the lower atmosphere are required, especially in the tropical regions where the atmosphere is subject to variation daily and seasonally. Dearth of propagation data in tropical environment, especially in Sub-Saharan Africa means that radio link design in this environment is mostly done using extrapolated data from temperate region. This study is an attempt to cover this data gap. Several studies have been carried out on the impact of atmosphere on UHF signal strength in this region in recent time by the following researchers namely; [16], [1], [20], [2], [3], [15] and [17]. Non of this studies covers the arid or semi arid region of Nigeria. They locations are mostly along the coast. This study will further checked if the result in the coastal region can be applied to the arid or sem arid region.

II. REFRACTIVE INDEX AND REFRACTIVITY OF THE TROPOSPHERE

The radio refractive index is defined as the ratio of the speed of propagation of radio energy in a vacuum to the speed in a specified medium. [7] and [21]. Due to the minute difference between the value of refractive index in the troposphere (about 1.0003) and that of free space (n = 1.0) it is more convenient to refer variations in refractive index in terms of a parameter called refractivity N [22], which is defined as the measure of deviation of refractive index, n of air from unity which is scaled-up in parts per million to obtain more amenable figures. Thus, N is dimensionless quantity defined as measured in N units [12]. The Refractivity, N, is related to refractive index of air [13] as follows;

$$\boldsymbol{N = \langle n - 1\rangle \times 10^{-6}} \qquad 1$$

Where *N* is radio refractivity expressed by

$$\boldsymbol{N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right)} \qquad 2$$

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

$$\boldsymbol{N_{dry} = 77.6\frac{P}{T}} \qquad 3$$

and the 'wet term' given by

$$\boldsymbol{N_{wet} = 3.732 \times 10^5\,\frac{e}{T^2}} \qquad 4$$

where: P is atmospheric pressure (hpa), e is water vapor pressure (hpa) and T is absolute temperature (K). This expression may be used for all radio frequencies (for frequencies up to 100GHz; the error is less than 0.5%) for representative profiles of temperature, pressure and water vapour pressure [9]. The water vapor pressure, e, can be calculated from relative humidity as ;

$$\boldsymbol{e = \frac{He_s}{100}} \qquad 5$$

Where e_s is defined as

$$\boldsymbol{e_s = EF \cdot a \cdot exp\left\{\frac{\langle b - \frac{t}{d}\rangle \cdot \mathrm{t}}{t + c}\right\}} \qquad 6$$

And:

$$\boldsymbol{EF_{water} = 1 + 10^{-4}[7.2\mathrm{P}(0.00320 + 5.9 \cdot 10^{-7} \cdot \mathrm{t2}} \qquad 7$$

Where e_s is the water vapour partial pressure, t is temperature in Celsius, H is the humidity, and constants for water are *a* = 6.1121,*b*= 18.678, *c* = 257.14 and *d* = 234.5 **[13]**

III. MATERIAL AND METHOD

A. Material

The Instrument used for the measurements of atmospheric parameters and UHF signal strength are Vantage Pro 2 automatic weather station and UHF signal strength measuring devices respectively. The wirelessVantage Pro 2 automatic weather station used in this study has two components; the Integrated Sensor Suite (ISS) and Console (receiver). The ISS collect outside weather data and sends the data to a vantage Pro2 console. The ISS contains a rain collector, temperature sensor, humidity sensor, anemometer, solar radiation sensor and an ultra violet (UV) sensor. Temperature, pressure and humidity sensors are mounted in a passive radiation shield to minimize the impact of solar radiation on the sensor readings. The data from the ISS then transmits to the console via radio signal and stored on the data logger. The console is connected to a computer, through which the stored data are collected. The UHF measuring device were designed and constructed by the research group using available networks, the device has two modules, the external and internal. The external module received the UHF signal strength from the GSM networks and transmits to the internal module. The internal module is connected to a computer, through which the stored data are collected

B. Method

Surface values of Temperature, Pressure and relative humidity as well as UHF signal strength used for this study were extracted from the measurements made using Davis Vantage pro2 automatic weather station and UHF signal strength measuring device located at the ground surface of Federal University, Gusau *(6^0 78' N, 12^0 13' E)* North West Nigeria. The weather stations have thirty-minute integration time while the UHF signal strength measuring device hasfive-minute integration time. Data collected for the year 2018 for both weather parameters and signal strength were averaged over each hour to give twenty-four data points representing diurnal variations for each day and average were taken over the month to give a 24 data point for the month. The data were used to compute the diurnal variations refractivity and signal strength as well as the correlation between weather parameters and signal strength.

IV. RESULT AND DISCUSSION

A. Sensitivity Analysis of Radio Refractivity

Differential of equation (2) dictates the role played by temperature (T) atmospheric pressure (P) and water vapor pressure (e) in the variation of Radio Refractivity.

$$dN = 77.6\frac{dN}{T} - \left(77.6\frac{\mathrm{p}}{\boldsymbol{T^2}} + 7.46 \times 10^5\,\frac{e}{T^3}\right)\mathrm{dT} + 3.73 \times 10^5\,\frac{e}{T^2}\,(\mathrm{N\ unit}) \qquad 8$$

For normal atmospheric condition

P = 1000hpa, RH = 60%, T= 290k and e = 13.7 hpa.

$$dN = 0.268dp - 1.289dT + 4.435de \qquad 9$$

This clearly indicates the contribution of e is large relative to T and p in the gradient of N. The reason behind this is the fact that water vapor polarizes on interaction with the radio signal. This effect causes the dielectric constant of the water vapor to rise resulting in a relatively larger contribution in N than T and p in standard atmosphere [4]. Figure 1.0 depicts the sensitivity to atmospheric temperature and Relative humidity at constant pressure. As the relative humidity increases the value of N also increases. It can be seen from the figure that 1°C change in temperature result in about 2N unit change in refractivity at standard atmospheric condition. For example, consider the graph of R.H = 60% the value of N at 20°C is about 300 N units while at 30°C is about 320 N units, Figure 1.0 This clearly shows that 10°C change in temperature causes an approximate change of 20 N units in refractivity.

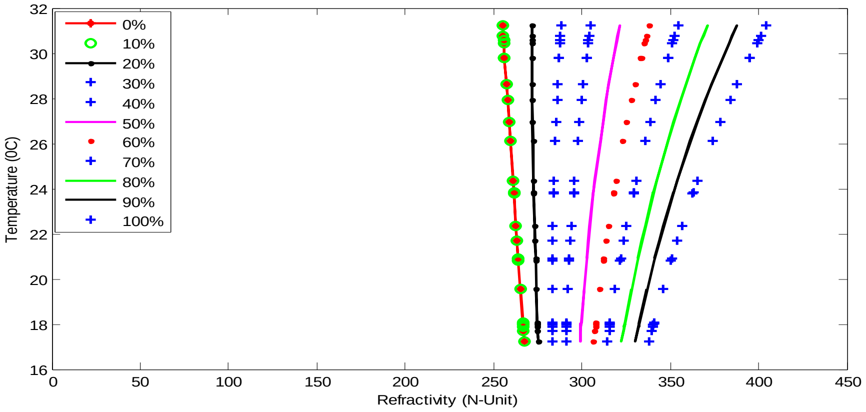


Figure 1.0: Variation of Refractivityto Temperature and Relative Humidity at assume constant Pressure

The Dry and Wet term in refractivity depend on temperature and water vapor pressure as seen in equation 3 and 4. In case of normal water vapor content in the atmosphere, an increase in the temperature would decrease the wet term faster than the dry term in equation 2. Hence, contribution of wet term is relatively small to the value of N. However, in case of high-water content in the atmosphere, the contribution of N wet to N is higher. This is due to the fact that decrease in its value due to temperature is more than compensated by the increase due to the higher water vapor content. Consequently, the contribution of N wet in the value of N is relatively larger over the period of time when atmosphere has high vapor content [4]. From figure 1.1 the below effects could also be observed, where the contribution of the wet term to N for the month of June to September is relatively high than the rest of the months in the year. Thus, dry part of refractivity contributed larger portion to the refractivity than the wet part N_{wet}, the largest contribution is in the month of (August and September), this is connected to the high rainfall during the months in the region.

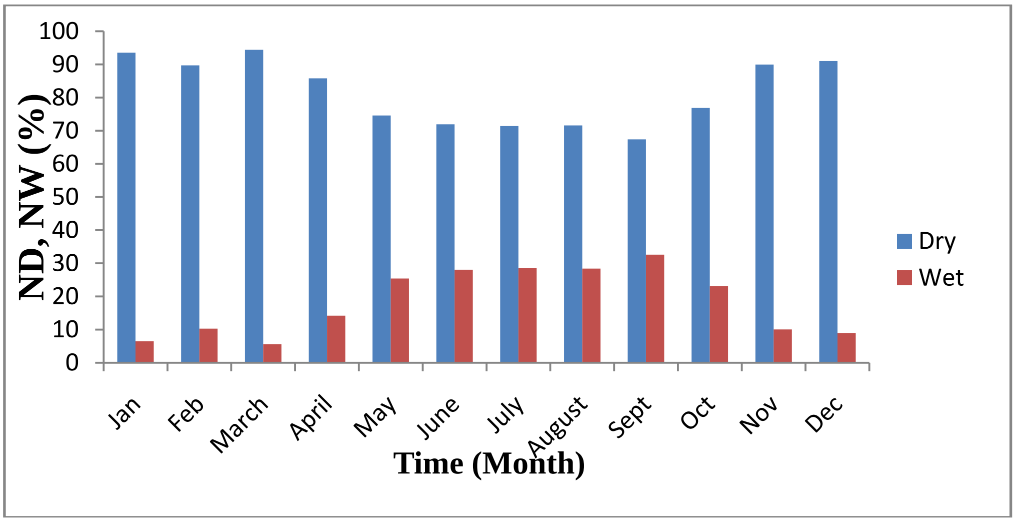


Figure 1.1: Monthly values of Wet and Dry part of N

B. Diurnal Variation of Radio Refractivity

Fig. 1.2 depicts the average hourly variations of surface radio refractivity, over Gusau for dry season month, the surface radio refractivity, shows strong dependence on the wet term (Humidity) of refractivity with high values in the morning and late in the evening and low values in the day time. This is attributed to the response of the earth to solar isolation which is the major force behind the weather condition observed. The solar isolation causes the temperature to be high and humidity low during the day. The highest value is 293 N-units and the lowest value is 277 N-units. The average daily variations of surface refractivity over Gusau for rainy season is depicted in Fig. 1.3, shows a maximum in the afternoon with a sudden rise pre-noon and sudden drop just at the noon. The maximum value is about 402 N-unit which occur at 12:00hr local time and the lowest value is about 373 N-unit.

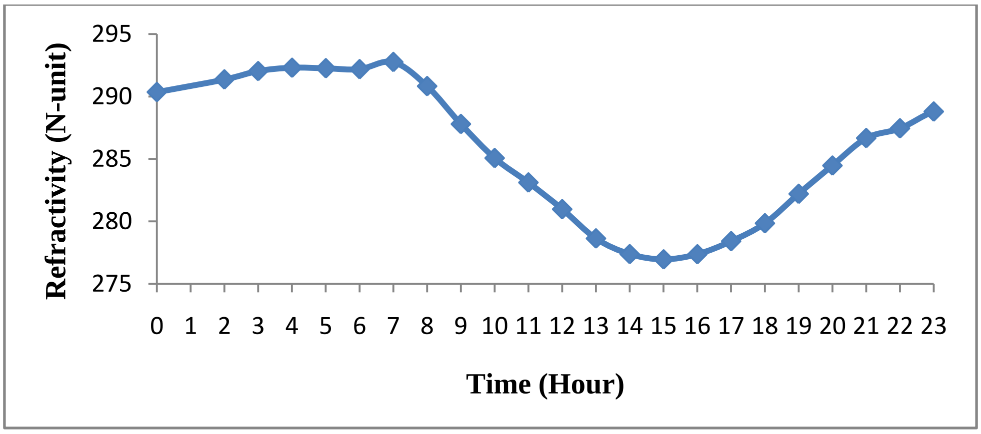


Figure 1.2: Variation of Refractivity with Time for Dry Season

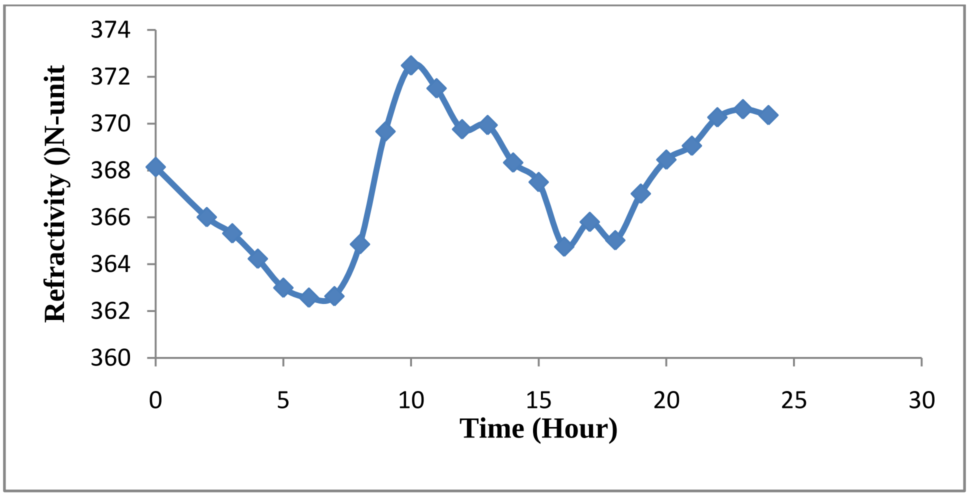


Figure1.3: Variation of Refractivity with Time for Rainy Season

C. Seasonal Variation of Radio Refractivity

Figures 1.4 depict the seasonal variations of refractivity at Gusau, North-West, Nigeria. The value of radio refractivity at this location is generally low in the dry months (November to March) compared with the values for rainy months. The minimum values of 272 N-units were also observed in January. The difference between the minimum and maximum for rainy and dry seasons were observed to be 117 N-units. This shows that the influence of relative humidity is more pronounced at this location. A slight drop in the values of refractivity was observed in the months of March and August in this location. The drop in March was attributed to the onset of rainy season while that of August was as a result of slight cessation of rainfall, which is usually experienced in August in the location and is referred to as August Break. The minimum value of refractivity was observed in the month of March which coincides with the Harmattan season Month at the location. The Harmattan season is associated with the northeasterly wind, which passes over the Sahara Desert with its attendance dryness. This result agrees with the work of [6], [18] and [19]. Results from this study show that the climatic condition is the main driver of seasonal variations of refractivity and further emphasizes the need for local study of this phenomenon with in-situ data.

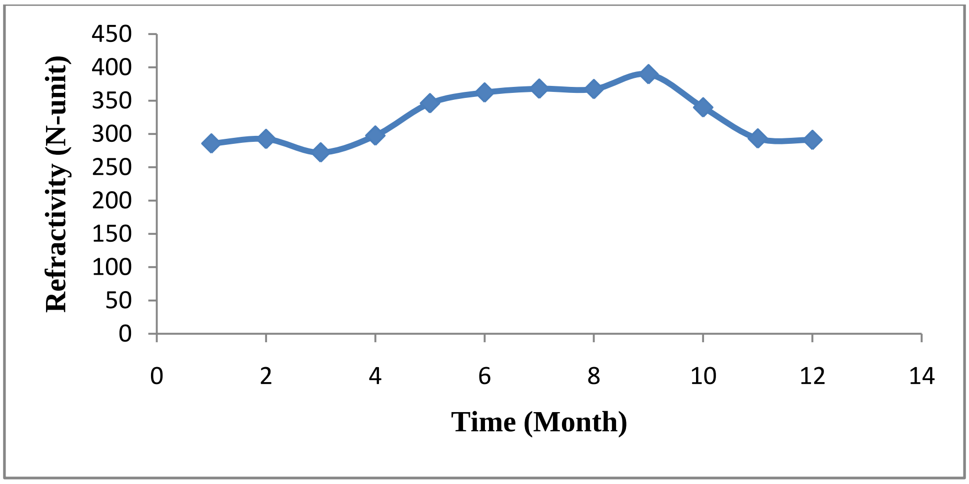


Figure1.4: Seasonal Variation of Refractivity

D. Signal Strength Variation with Weather Parameters

1. Correlation between Signal Strength and Relative Humidity

Figure 1.5 and 1.6 depicts the graph of the variation of signal strength with Relative humidity for dry season months (December and January) respectively. Figure 1.5 shows a slight increase with the increase in the value of Relative Humidity in some hours of the day with a correlation of 0.633. The correlation for the month of January between the Signal Strength and Relative Humidity is 0.85 as shown in Figure 1.5. This result also agreed with the earlier result obtained for the Month of December shown in figure 1.6.

Figure 1.7 and 1.8 depicts the graph of the variation of signal strength with Relative humidity for rainy season months (August and September) respectively. Figure1.7 shows the relationship between signal strength and relative humidity for the month of August with correlation coefficient of -0.728. The signal strength decreases with the increase in relative humidity and this is attributed to the month of August being the peak of the rainy season in the study Area and this cause the relative humidity be high. The month of September also experienced high rainfall comparable to August in the study area, the correlation between the signal strength and relative humidity was found to be -0.639 (Fig.1.8). This agreed with the previous month of August studied. The diurnal variation of signal Strength for August and September followed different pattern as previous months of December and January studied. In dry season, when the relative humidity is low, the signal strength increases with the increase in the value of relative humidity while in the rainy season, when relative humidity is high almost close to 100%, the signal strength decreases with the increase in the value of relative humidity. Future research will focus on finding the threshold humidity at which the signal begins to deteriorate. The results from this study as presented in Figure 1.5 to 1.8 shows that the relative humidity affect signal strength. The signal quality is better at lower humidity. This result agrees with previous studies [3] and [16].

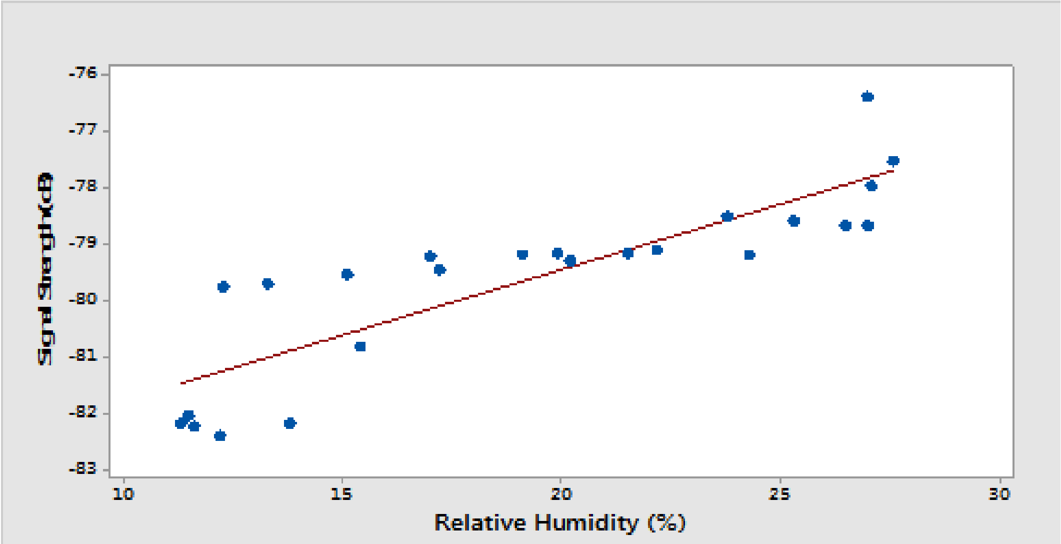
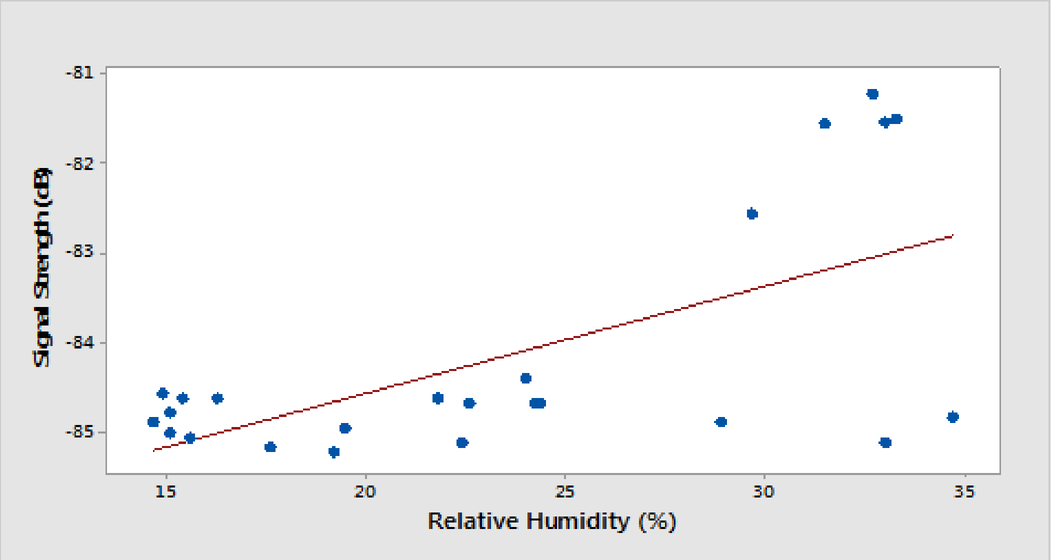


Figure1.5: Variation of Signal Strength with Relative Humidity for the month of January



Fgiure 1.6: Variation of Signal Strength with Relative humidity for the month of December

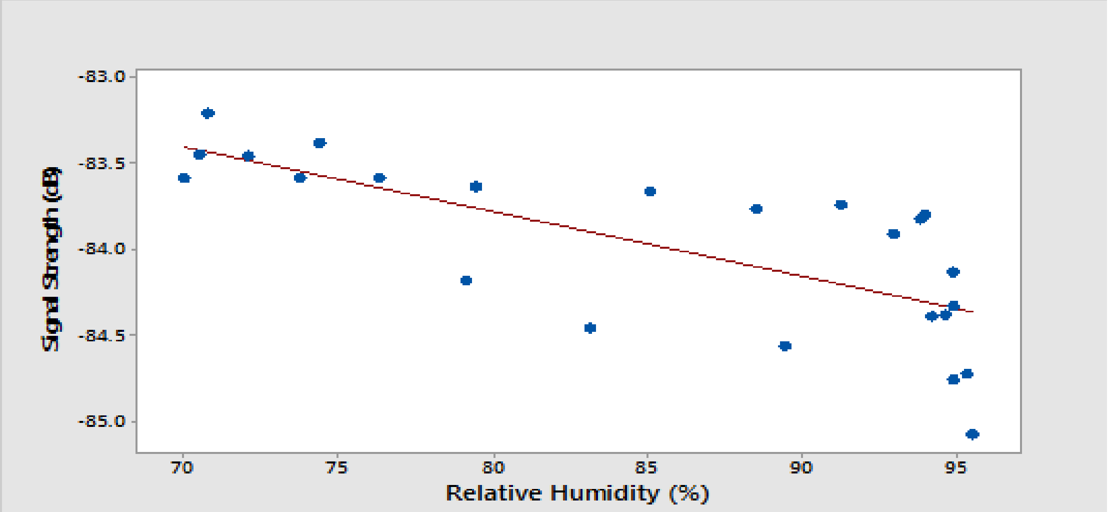


Figure 1.7:The variation of Signal Strength with Relative Humidity for the Month of August

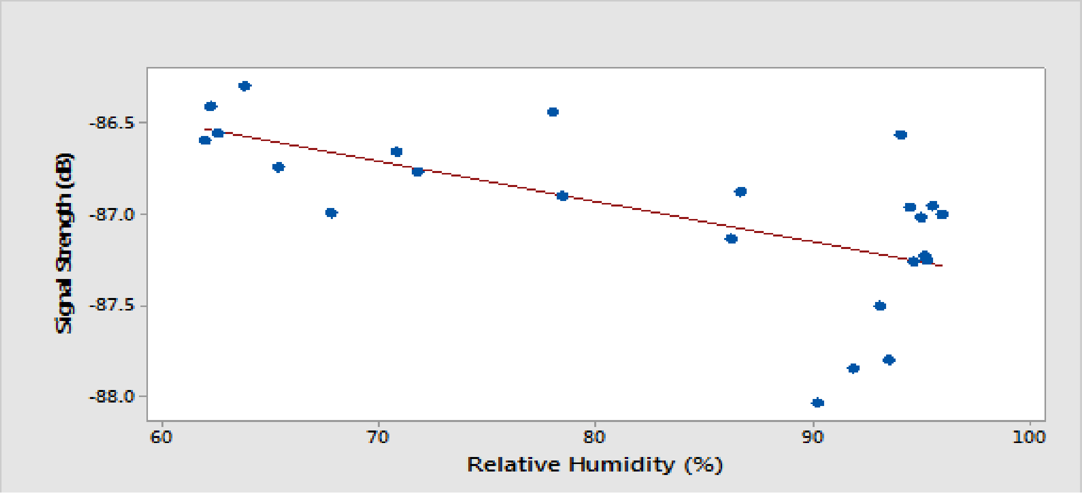


Figure1.8: Variation of Signal Strength with Relative Humidity for the Month of September

2. Correlation between Signal Strength and Temperature

Figure 1.9 and 2.0 depicts the graph of the variation of signal strength with temperature for dry season months (December and January) respectively. Figure 2.0 shows a slight decrease in signal strength with the increase in the value of Temperature for the month of December with a correlation of -0.597. The correlation for the month of January between the Signal Strength and Temperature is -0.890 as shown in Figure 1.9. This result also agreed with the earlier result obtained for the Month of December.

Figure 2.1 and 2.2 depicts the graph of the variation of signal strength with Temperature for rainy season months (August and September) respectively. Figure 2.1 shows the relationship between signal strength and Temperature for the month of August with correlation coefficient of 0.782. The signal strength increases with the increase in Temperature. The month of September (Fig. 2.2) also followed the same trend with the month of August and recorded a correlation of 0.556.

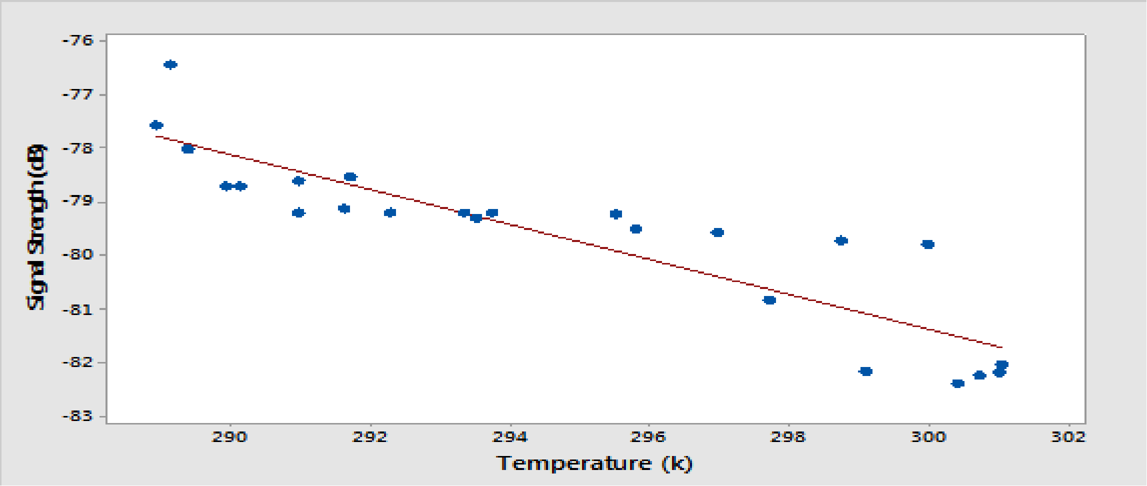


Figure1.9: Variation of Signal Strength with Temperature for the month of January

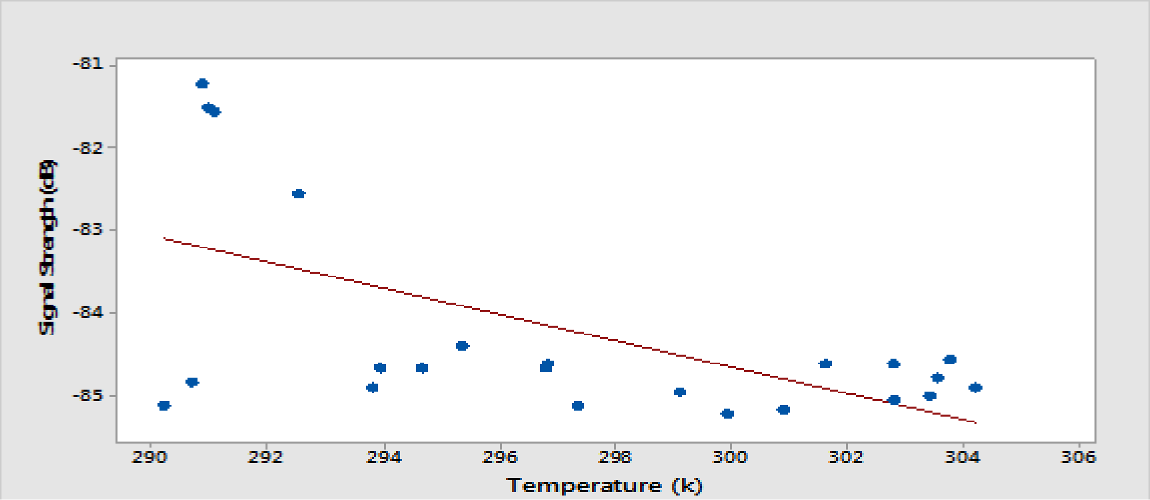


Figure 2.0 Variation of Signal Strength with Temperature for the month of December

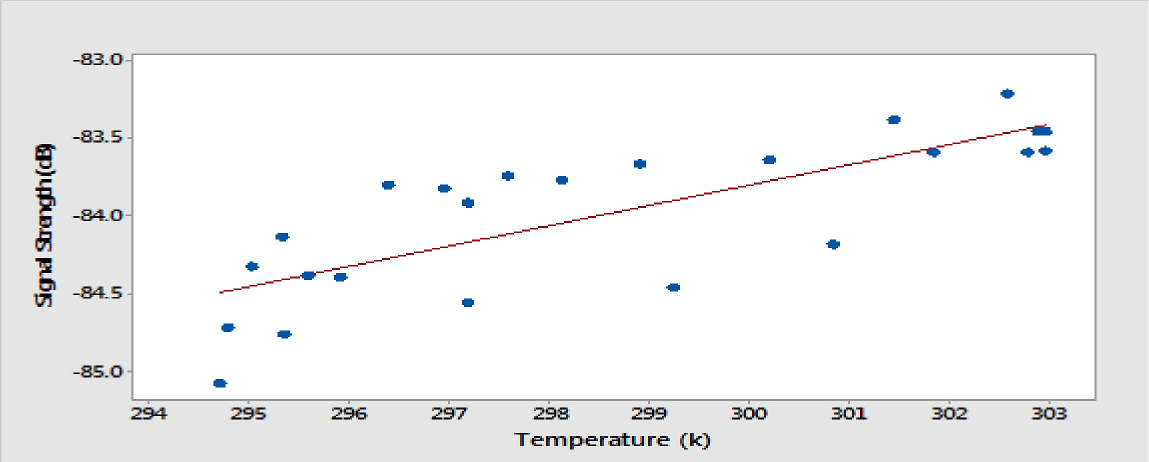


Figure 2.1: Variation of Signal Strength with Temperature for the Month of August

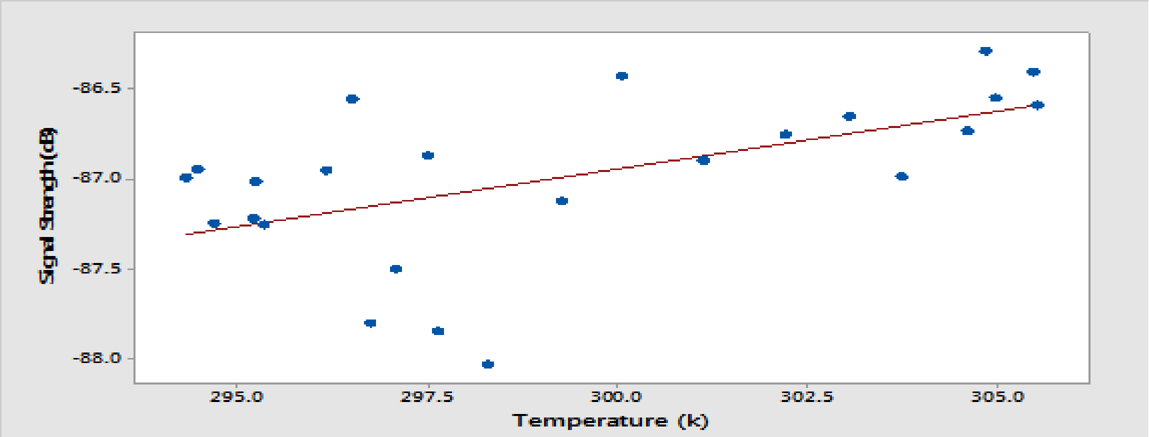


Figure2.2: Variation of Signal Strength with Temperature for the month of September

3. Correlation between Signal Strength and Radio Refractivity for Dry Season

Fig. 2.3 and 2.4 depicts the graph of the variation of signal strength with refractivity for dry season months; the signal strength shows significant increase with the increase in the value of refractivity with the positive correlation of 0.864 and 0.530 for the month of January and December respectively. Fig. 2.5 and 2.6 depicts the graph of the variation of signal strength with refractivity for rainy season months, it followed the same trend with the dry season month with weak correlation of 0.311 and 0.364 for the month of August and September respectively.This result contradicts previous researches show that refractivity and UHF signal strength has inverse relationship [17] and [2]. More observation would be carried out over a long period of time to clear this contradiction.

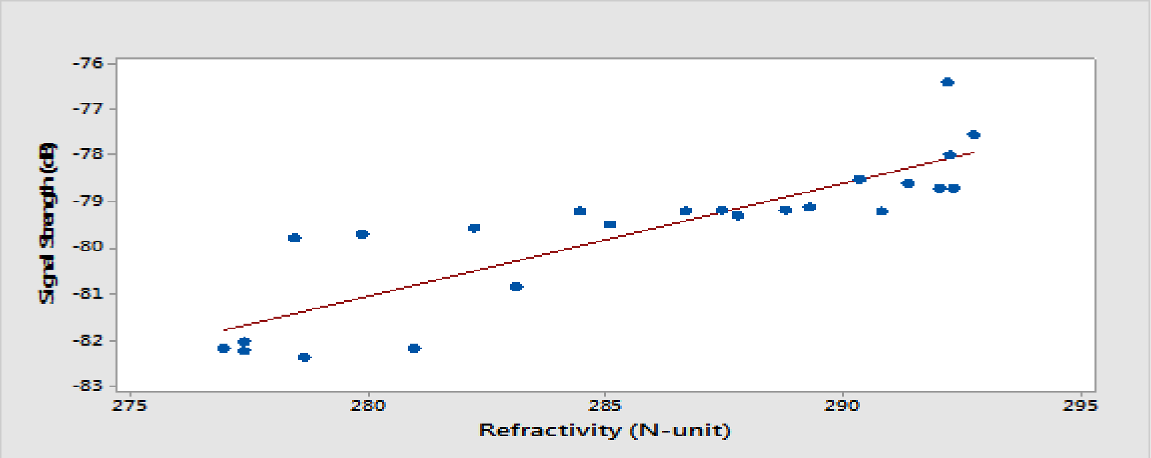


Figure2.3: Variation of Signal Strength with Refractivity for the month of January

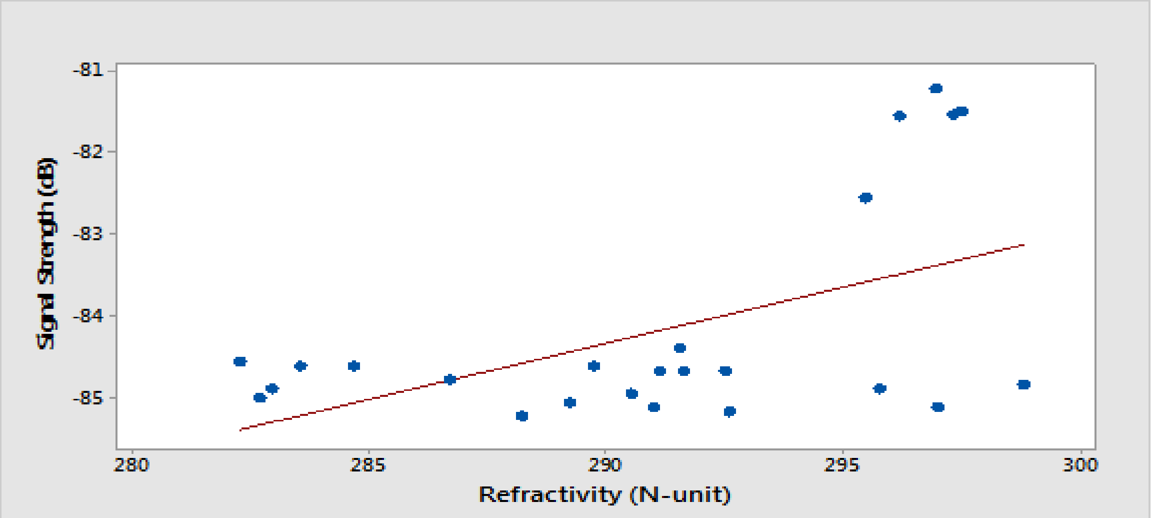


Figure 2.4:Variation of Signal Strength with Refractivity for the month of December

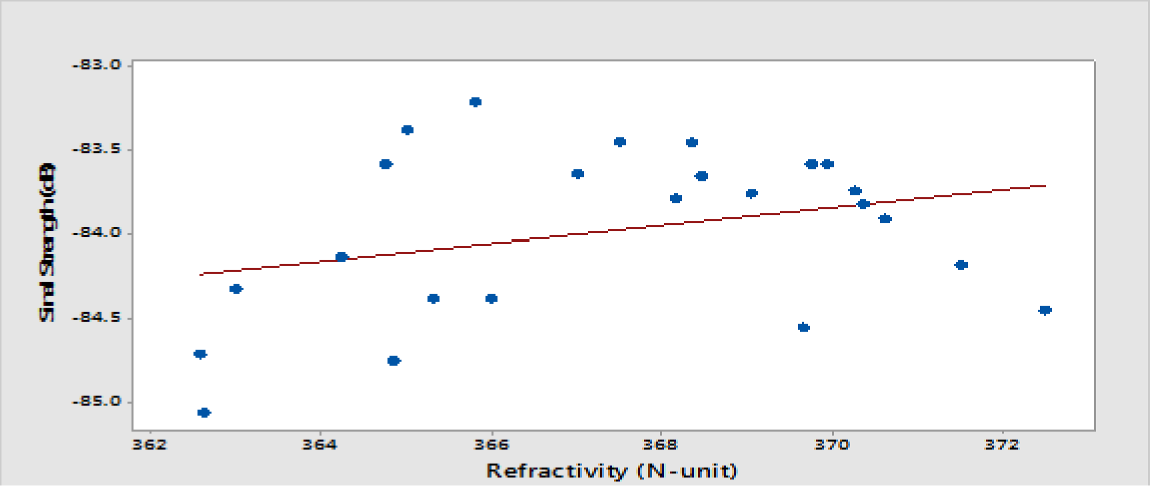


Figure 2.5: Variation of Signal Strength with Radio Refractivity for the month of August

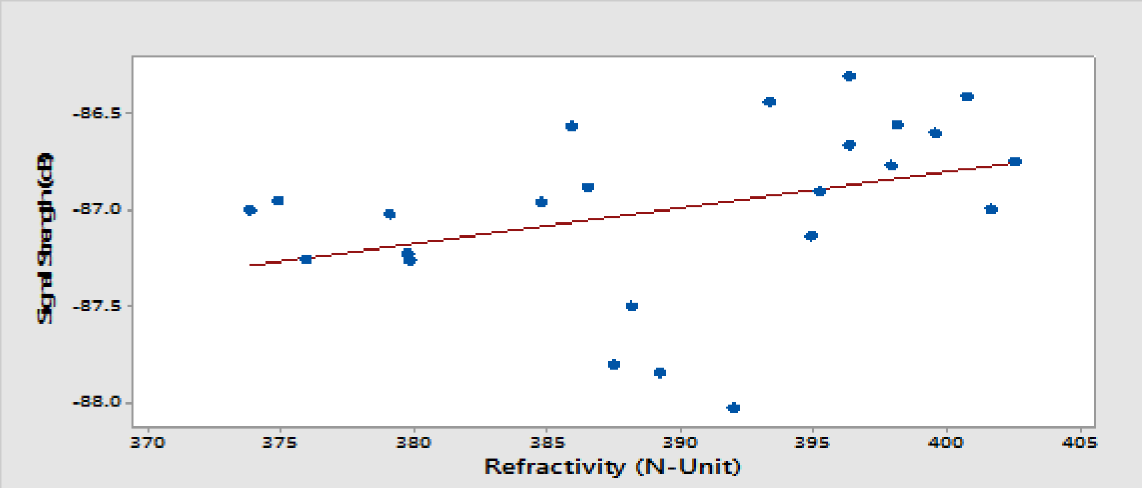


Figure 2.6: Variation of Signal Strength with Refractivity for the month of September

V. CONCLUSION

Measurement of atmospheric parameters (Temperature, pressure and Relative humidity) simultaneously with UHF signal strength were made on the premises of Federal University, Gusau, North-West, Nigeria with the objective of examining the impact of atmospheric parameters on UHF signal strength in the lower atmosphere in the year 2017. The weather parameters were used to compute the surface radio refractivity using ITU-R model, while regression analysis shows a strong correlation between signal strength and weather parameters. Hence, the following summations were made. The average daily variation of refractivity is largely as a result of the variations of the wet (Humidity) component of refractivity. Refractivity reveals seasonal variations with high values in the rainy season month and low values in the dry season month in the location. There is an appreciable impact of atmospheric parameters on the transmitted UHF signal. Observations indicate a significant impact of weather parameters in the UHF receiver performance, especially between 1100 to 1500 local time.

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