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Investigation of the Effects of Atmospheric Conditions on Atmospheric Refractivity in Tropical Savannah Region of Nigeria

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Abstract: In this work, the effects of Atmospheric conditions such as Relative Humidity, Atmospheric pressure, Temperature is being investigated on the Refractivity values of the savannah region of Nigeria. Gombe and Adamawa were used as case study for this research work. These regions have tropical climate marked by both dry and rainy seasons. Atmospheric conditions seriously affect radio wave propagation when transmitted. The need to have a study of the effects of these Atmospheric conditions on Atmospheric Refractivity (N) in the region is therefore paramount. The values of the weather conditions were gotten from NIMETS at Federal Airport Agency of Nigeria in the region for the period of three years, from January 2021 to December 2023. The obtained data were computed in a general equation used to determine the Refractivity values (298-410 N units) and plotted against each Atmospheric condition. The results shows that the Refractivity values are directly proportional to Atmospheric pressure, Humidity and inversely proportional to Temperature. At minimum and maximum Temperatures, Refractivity values vary significantly. These findings are in agreement with other related works that were conducted in other regions within the country. The results of this work can be used to determine refractivity gradient and proper purchase and installation of telecommunication equipment's.

1. Introduction

When a radio wave is radiated, it moves away from the source spreading out in the form of a sphere. The curvature of the earth and the condition of the atmosphere can refract electromagnetic waves either up, away from, or down toward the earth's surface (Nor *et al.*, 2015). Virtually all-weather factors that affect signal transmission take place in the atmosphere that extends from the surface of the earth to a height of about 6 km at the poles and 18 km at the equator (Smith, 1957). The temperature in this region decreases rapidly with altitude, clouds form, and there may be much turbulence because of variations in temperature, density, and pressure (Abraham *et al.*, 2015). Refraction is the ability of a substance to refract Light. In Telecommunication, Refractivity is the ability of the Atmospheric conditions and layers to refract radio wave signal according to (Samuel, 2010; Norin, 2023; Scholz & Förster (2003).

Studies have shown that precipitation such as those of rain, harmattan dust and so on, absorb and scatter electromagnetic energy (Luomala and Hakala, 2015). Temperature and humidity among others also lead to attenuation in the signal strength of radio waves that are transmitted (Dajab, 2006). All radio stations and other telecommunication equipment's are not exempted to such hazard that is caused by those factors year in year out on radio wave propagation (Famoriji, 2016; Otto *et al.*, 2022; Pham *et al.*, 2022). The parameter measured and computed in this work is Refractivity.

The research work covered a period of three years from January 2021 to December 2023. This was done to take care of both rainy and dry seasons and other climatic conditions such as harmattan, cloud and rainfall. The obtained data from the Nigerian Meteorological Service (NIMETS) of the Federal Airport Authority of Nigeria (FAAN) helped the study by providing information that is vital for the work. As stated earlier, the work took care of some atmospheric conditions these parameters were simulated in a relevant equation which help in studying the effects of these atmospheric conditions on refractivity (Yu *et al.*, 2024). The objective of the work is to investigate the variation of Refractivity with Atmospheric Pressure, Temperature and Relative Humidity within the savannah region.

Despite a lot of contributions on the effects of atmospheric factors in different locations of the globe on Refractivity, there is a need for such study in tropical savannah region of Nigeria. The region should have updated information that coporate bodies can use in the procurement of latest communication equipment that are reliable, and can have enough coverage in terms of transmission. The work can serve as a gateway for more research on information and communication technology (ICT) in the region.

The study Area

Gombe and Adamawa are the center of the tropical savannah region of Nigeria. The climates are marked by both dry and rainy seasons (Pascal *et al.*, 2018) and (Okoro, 2023). The rainy season commences in April and ends late October while the wettest months are August and September. There is also the harmatan period from November to March when the dust-laden North-Eastern Trade Winds from the Sahara-desert have a marked effect on the climate these states (Maigida, 2016). These periods are sometimes cold, dry and hot. Although temperatures vary, the average recorded minimum temperature is 17.7^{o}C while the maximum is 41.7^{o}C (Pascal *et al.*, 2018).

2. Methodology

2.1 Materials

The equipment used in conducting this research work includes the following:

- Computer system
- Microsoft Excel software
- Data from Federal Airport Authority of Nigeria.

2.2 Methods

According to (Dajab, 2006), there are different ways of evaluating weather effects on communication systems, namely mathematical analysis, computer simulations and measurement. Two methods were employed in this work; the mathematical analysis and computer simulations was carried out to compute the values of refractivity and using the data collected from the Meteorological Department of the Federal Airports Authority of Nigeria (FAAN) The desired atmospheric parameters of minimum and maximum temperature, humidity, atmospheric pressure were collected from the NIMETS for a period of 3 years on monthly base. January 2021-December 2023 so that it covers all the atmospheric conditions in both rainy and dry seasons.

2.2.1 Computation of Refractivity

The Refractivity was computed using the equation given by (Abraham *et, al.*, 2016) The Refractivity (N) is given by eqn. 1

$$N_{(P,T,e)} = N_{dry}+N_{wet} = \frac{77.6P}{T} + 3.732\times10^{5}\frac{e}{T^{2}} \qquad \textbf{eqn. 1}$$

Where P is the Atmospheric pressure in Hectopascal (HPa), and T is the absolute Temperature (K), e is the water vapor. The stated equation can be used for radio frequency of up to 100 GHz with error less than 0.5%

The water vapor e is given by eqn. 2

$$e = \frac{H_R e_s}{100} \qquad \textbf{eqn. 2}$$

Where H_R is the Relative Humidity, and e_s is the Saturation Vapor Pressure (HPa) at a given Temperature, t (°C) is given by eqn. 3 as:

$$e_s = a\times\exp\left(\frac{bt}{(t+c)}\right) \qquad \textbf{eqn.3}$$

Where a=6.1121 HPa, b=17.502 and c=240.97 °C

But $e = \frac{H_R e_s}{100}$

3. Results and Discussion

The result of the experiments performed by the various methods show how the efficiency of the work is. The data collected from FAAN for the period of three years from 2021 to 2023 was computed using eqn. 1 to determine the Refractivity. The values of the refractivity by the Tables 1-4 given below while the values of fog density is computed to be 0.003767 and visibility given by 0.9KM as collected from NIMETS department of FAAN. Various graphs of Atmospheric conditions were plotted against Refractivity and their effects being carefully examined.

Table 1: Calculated Average Monthly Refractivity values for the year 2021 at Minimum Temperature.

Month	Minimum Temperature(°C)	Atmospheric Pressure(Hpa)	Relative Humidity(%)	Refractivity(N)
JAN	17.7	991.2	37	297.67
FEB	23.1	990.1	34	300.37
MAR	24.8	988.6	43	314.24
APR	20.5	988.7	48	311.54
MAY	25.7	989.9	60	340.02
JUNE	23.7	991.3	70	346.21
JUL	23.0	993.1	81	357.25
AUG	23.3	992.9	82	359.91
SEPT	23.1	992.4	83	359.91
OCT	23.9	991.3	75	353.25
NOV	21.8	990.7	53	320.2
DEC	18.1	992.3	41	302.01

Table 2: Calculated Average Monthly Refractivity values for the year 2022 at Minimum Temperature

Month	Minimum Temperature(ºC)	Atmospheric Pressure (Hpa)	Relative Humidity (%)	Refractivity(N)
JAN	19.8	993.6	33	296.76
FEB	21.9	989.7	27	290.87
MAR	26.9	987.7	37	310
APR	28.7	989.2	51	336.75
MAY	26.8	989.4	70	358.5
JUNE	25.7	991.8	78	365.38
JUL	24.1	992.6	81	362.03
AUG	24.2	992.6	85	367.6
SEPT	23.7	992.5	82	361.43
OCT	24.4	991.6	76	356.72
NOV	21.7	991.6	55	322.44
DEC	20.6	995.0	37	301.84

Table 3: Calculated Average Monthly Refractivity values for the year 2023 at Minimum Temperature

Month	Minimum Temperature (ºC)	Atmospheric Pressure (Hpa)	Relative Humidity (%)	Refractivity(N)
JAN	18.9	993.9	35	297.68
FEB	21.8	991.7	27	291.32
MAR	26.4	988.9	31	300.72
APR	27.8	987.7	29	298.13
MAY	26.2	990.9	51	329.29
JUNE	25.1	992.6	67	348.04
JUL	24.5	992.6	74	354.82
AUG	23.8	992.7	82	361.93
SEPT	23.7	992.4	83	405.03
OCT	23.9	990.6	77	355.58
NOV	22.5	990.3	47	314.79
DEC	19.4	991.4	45	308.28

Table 4: Calculated Average Monthly Refractivity values for the year 2021 at Maximum Temperature

Month	Maximum Temperature(ºC)	Atmospheric Pressure (Hpa)	Relative Humidity (%)	Refractivity(N)
JAN	36.1	991.2	37	335.24
FEB	37.6	990.1	34	332.71
MAR	39.8	988.6	43	365.08
APR	39.2	988.7	48	375.77
MAY	35.6	989.9	60	385.66
JUNE	33.4	991.3	70	394.26
JUL	31.7	993.1	81	405.17
AUG	30.0	992.9	82	395.74
SEPT	31.5	992.4	83	407.36
OCT	34.0	991.3	75	408.62
NOV	36.8	990.7	53	376.17
DEC	35.4	992.3	41	342.22

Table 5: Calculated Average Monthly Refractivity values for the year 2022 at Maximum Temperature

Month	Maximum Temperature(ºC)	Atmospheric Pressure(Hpa)	Relative Humidity(%)	Refractivity(N)
JAN	33.6	993.6	33	319.44
FEB	39.0	989.7	27	318.60
MAR	39.9	987.7	37	348.57
APR	40.2	989.2	51	389.10
MAY	39.4	989.4	70	437.18
JUNE	35.1	991.8	78	423.21
JUL	33.3	992.6	81	416.36
AUG	31.8	992.6	85	413.28
SEPT	30.9	992.5	82	401.56
OCT	33.7	991.6	76	408.69
NOV	36.4	991.6	55	379.00
DEC	34.8	995.0	37	331.94

Table 6: Calculated Average Monthly Refractivity values for the year 2023 at Maximum Temperature

Month	Maximum Temperature(ºC)	Atmospheric Pressure (Hpa)	Relative Humidity(%)	Refractivity(N)
JAN	33.5	993.9	35	323.59
FEB	31.5	991.7	27	302.97
MAR	40.7	988.9	31	334.74
APR	41.7	987.7	29	331.87
MAY	36.6	990.9	51	370.37
JUNE	33.7	992.6	67	390.26
JUL	32.1	992.6	74	394.37
AUG	31.5	992.7	82	405.57
SEPT	32.0	992.4	83	410.86
OCT	35.0	990.6	77	470.91
NOV	38.1	990.3	47	367.84
DEC	35.8	991.4	45	352.51

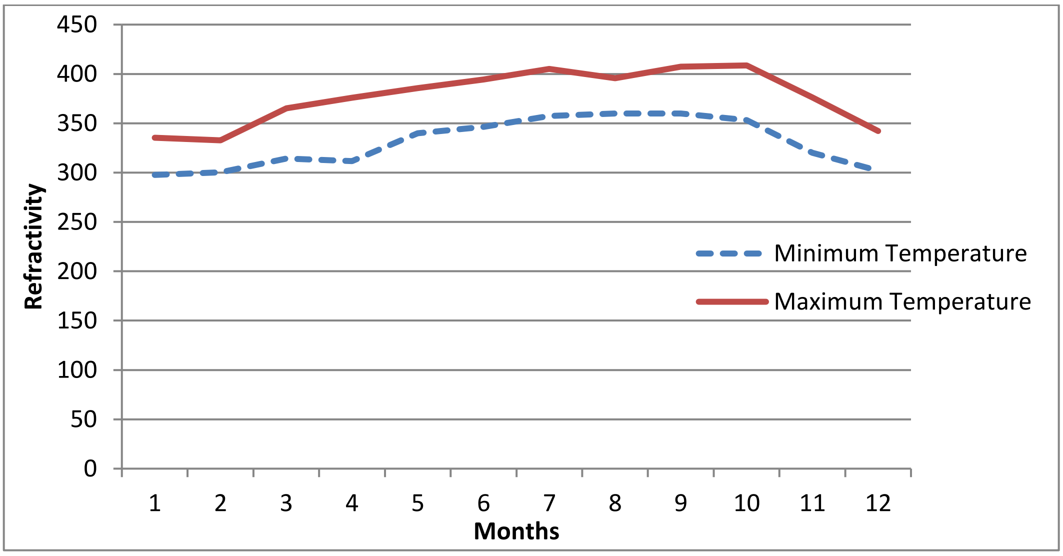

Figure 1: The graph of Refractivity for the year 2021 for Minimum and Maximum Temperature on Monthly bases

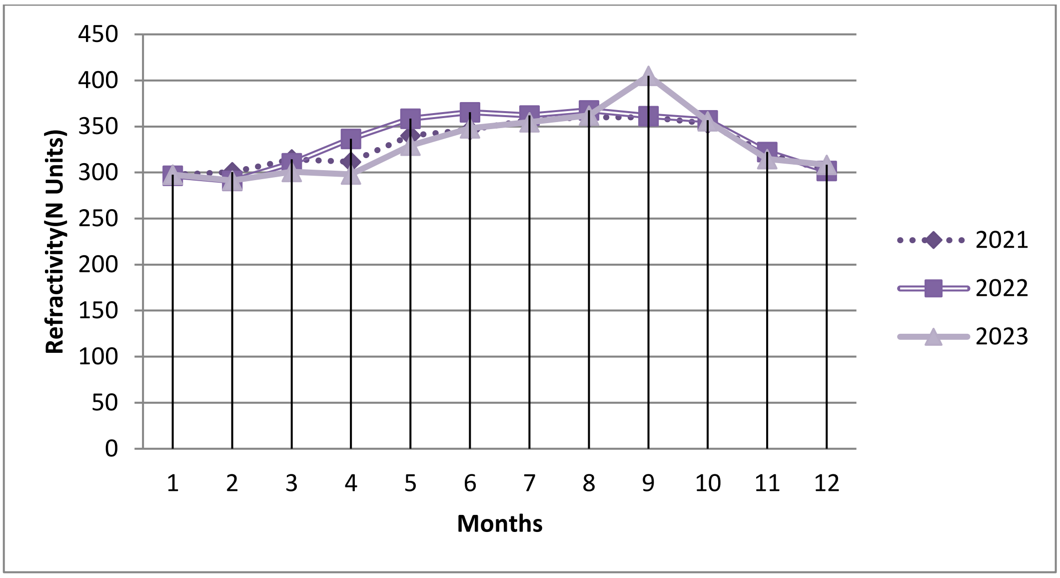

Figure 2: Graph of Refractivity for Minimum Temperature of the Three years (2021, 2022, and 2023)

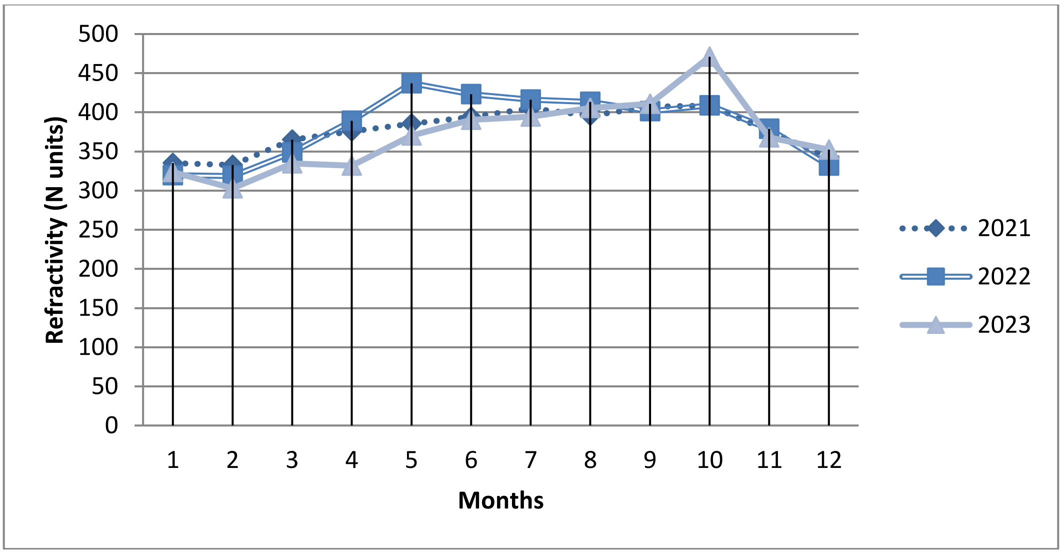

Figure 3: Graph of Refractivity of Maximum Temperature for the Three Years (2021, 2022, and 2023)

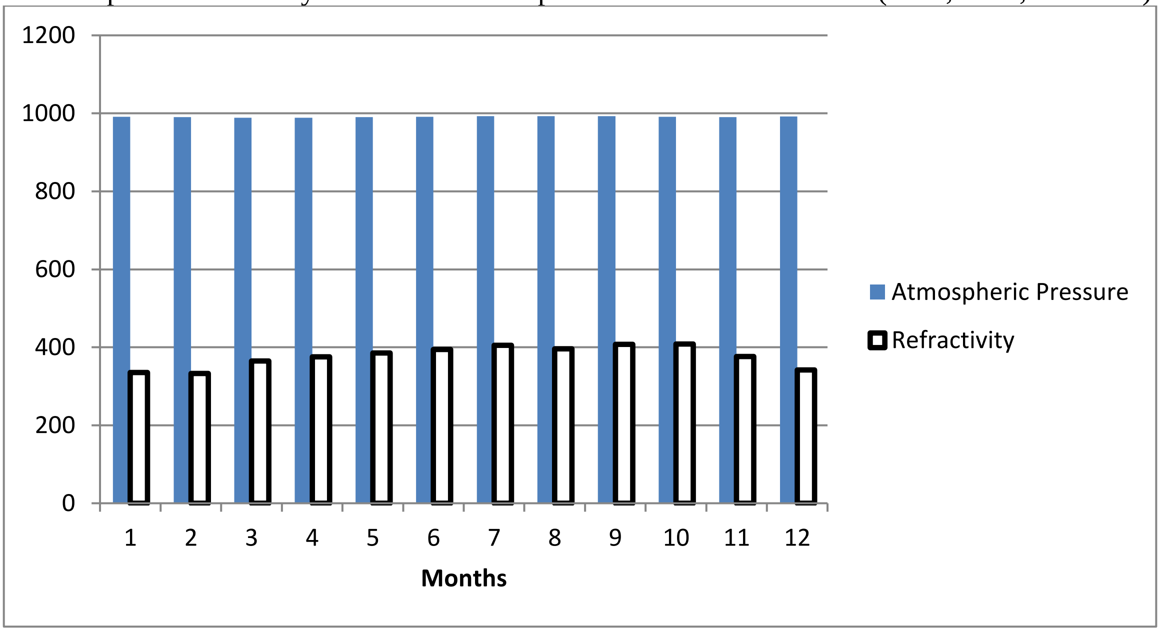

Figure 4: Bar chart of the variation of Atmospheric Pressure and Refractivity for the year 2023 on Monthly bases

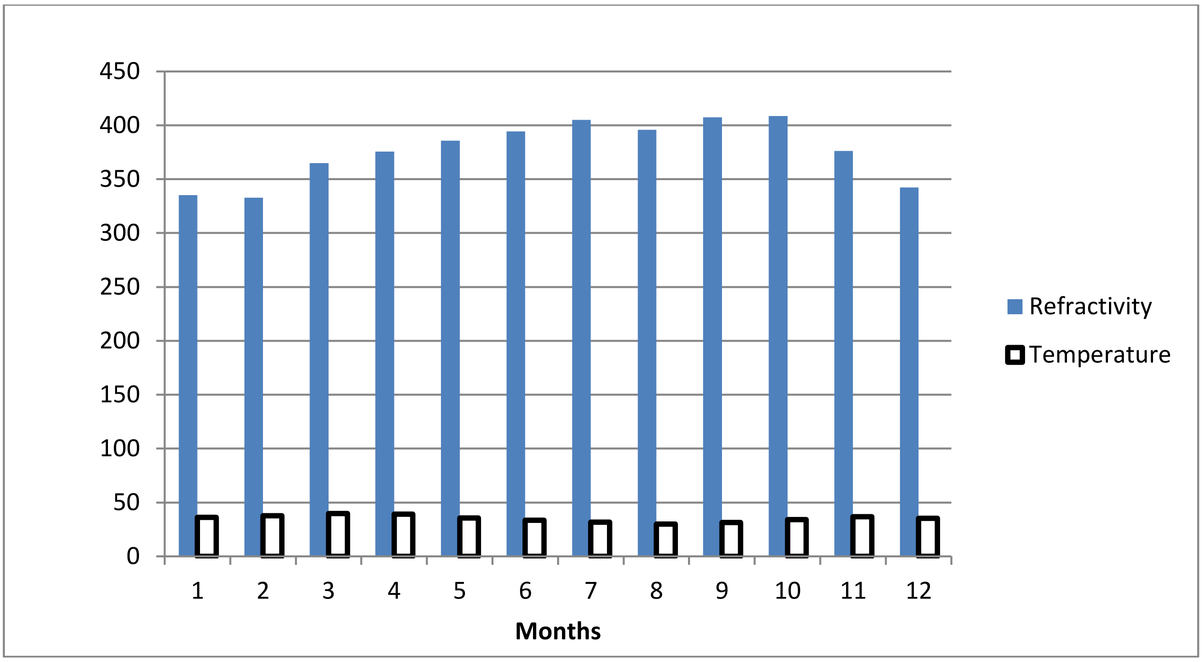

Figure 5: Bar chart of the variation of Temperature and Refractivity for the year 2023 on Monthly bases

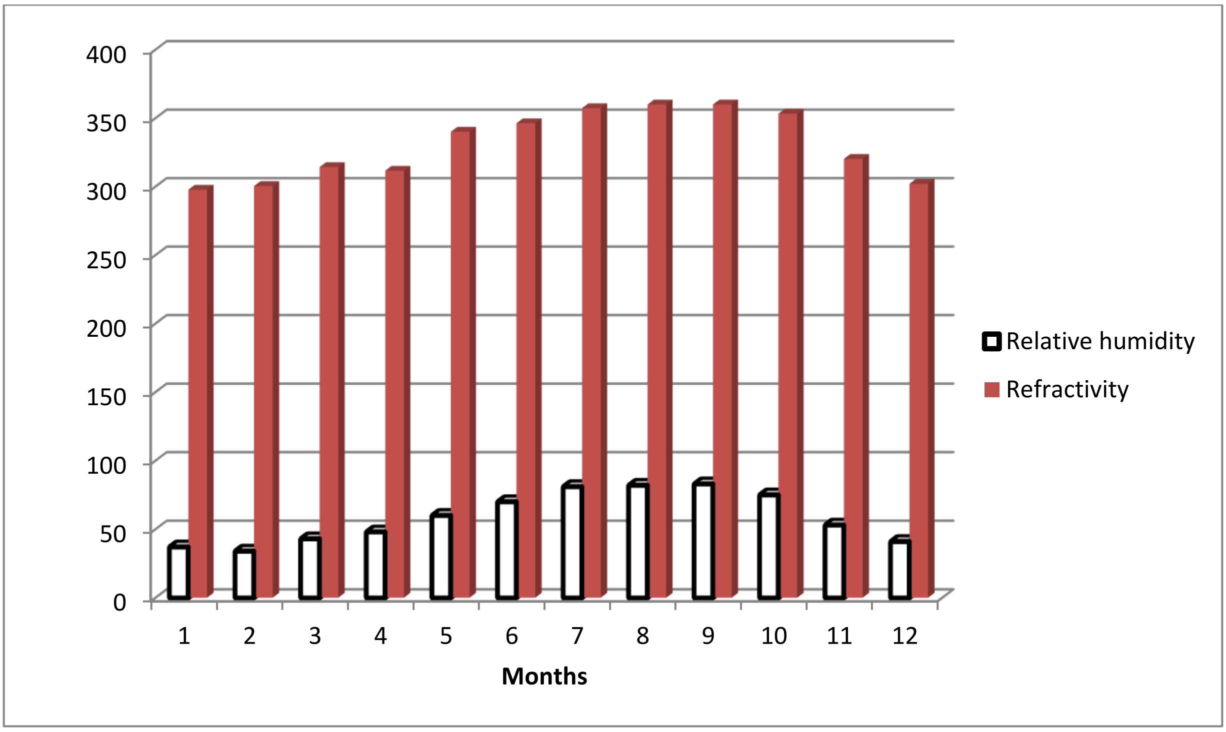

Figure 6: Bar chart of the variation of Relative Humidity and Refractivity for the year 2023 on monthly bases.

Tables 1-3 show the Refractivity values of the years 2021, 2022 and 2023 obtained for the minimum temperatures the least temperature being 17.7^{o}c in the month of January 2021 also has the least refractivity value of 297.7. While Table 4-6 shows the computed values of Refractivity for the same years at maximum Temperature. April 2023 recorded the highest temperature of 41.7 while October 2023 has the highest refractivity value of 470.91 units.

Figure 1 is the graph of Refractivity for the year 2021 for minimum and maximum temperature on monthly basis compared side by side. Based on the graph, it means that the refractivity values of higher temperatures are greater than those of lower values of temperature. Figure 2 and 3 compares the refractivity values for the three years both at minimum temperature and at maximum temperature and show that the year 2023 in the month of October has the highest refractivity value, while February 2022 has the lowest.

Figure 4 shows the graph of atmospheric pressure plotted against refractivity for the year 2021, based on the graph, refractivity depends directly on atmospheric pressure. Figure 5 is the plot of temperature against refractivity but here, temperature is inversely proportional to refractivity. Figure 6 is the plot of relative humidity against refractivity and depends directly on relative humidity.

Conclusion

Finally, based on this research work, atmospheric conditions such as temperature, atmospheric pressure and relative humidity and so on play a vital role in Refractivity within the Savannah region. The work has shown that the more the impacts of the atmospheric conditions, the less radio wave can be propagated and the less the impact of the atmospheric conditions the more radio wave is being transmitted or propagated in the atmosphere. Which serve as the major transmission path of the radio waves. These factors have helped in enhancing the negative effect of these atmospheric conditions on the proper propagation of radio signal in the region. The work has succeeded in investigating the effects of the atmospheric parameters on refractivity and is in agreement with several other works.

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