Radio Refractive Index Variation with Related Weather Parameters at Surface Level in Ilorin, North Central Nigeria

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Statistical analysis of surface radio refractive index and related atmospheric parameters over Ilorin (8°32" N, 4°34" E), North Central Nigeria, is presented. One minute interval measurement of temperature, pressure and relative humidity for a period of five years was obtained from the Baseline Surface Radiation Network (BSRN) of the University of Ilorin observatory. The diurnal and seasonal variations of these meteorological parameters especially in the tropics contribute to the analysis of refractivity variations and are needed for the design of efficient radio communication systems. Apart from the conventional deduction of low refractivity values in the dry season and high values in the wet season, the interrelationship of surface refractivity and related weather parameters were explored. The regression analysis carried out shows that mean monthly humidity and refractivity are well correlated with a correlation coefficient of 0.97 while the regression equation for predicting mean monthly refractivity N from the mean monthly relative humidity h is $N = 0.881\,h + 279$.

Keywords: Refractivity, Temperature, Pressure, Humidity

Introduction

Radio signal transmissions of frequencies above 30 MHz in the troposphere are prone to the fluctuations of weather and climate. This is because water vapor molecules with their permanent electric dipole moments account for the atmosphere having a complex dielectric constant and hence a complex refractive index (Hall, 1979).

Variation in the radio refractive index which in turn is caused by variation in pressure, temperature and water vapor pressure results in the refraction and scattering of electromagnetic waves propagating through the troposphere (Hall and Barclay, 1991). Therefore, in the propagation of radio waves through the atmosphere, the radio refractivity of air is an important parameter to be considered because its space-time distribution results in scattering, sub-refraction, super-refraction, ducting, and absorption phenomena (Batueva *et al.*, 1998).

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In the lowest layer of the atmosphere, the statistics of the vertical gradient of radio refractivity is an important parameter for the estimation of path clearance and propagation associated effects, such as ducting on transhorizon paths, surface reflection and multipath fading and distortion on terrestrial line-of-sight links (ITU-R, 2003). The radio engineer involved in the design of radio communication systems operating in the above frequency bands (30 MHz and above), normally subjects long term data relating to atmospheric refractive index and its properties to statistical analysis in order to be able to predict these parameters (Aro and Willoughby, 1992).

Among the earliest radio scientists that worked in this field were Bean and Thayer (1959). They observed that a correlation existed between monthly means of surface refractivity, N_s, and monthly means of refractivity decrease in the first kilometer, ΔN, above the ground. Also, Adebanjo (1977) determined an empirical relation of the form $\Delta N = -25 \exp (0.0022 N_s)$ to indicate the average change in refractivity between surface and the first kilometer over Nigeria. This relationship was based on the data for the same stations in Nigeria for which Owolabi and Williams (1970) computed N_s values. The ΔN values were obtained from a world atlas of atmospheric radio refractivity published by Bean *et al.* (1966). Although the contributions of these scientists to radio science especially in the African region are invaluable, they could not explore the diurnal trend of refractivity because of a dearth of atmospheric data. Therefore, recent efforts (Adedeji and Ajewole, 2008; and Oyedum *et al.*, 2009 and 2010) including this work explore the diurnal and seasonal trends of surface refractivity, temperature, pressure and humidity.

Data Acquisition

The data used for this work was obtained from the University of Ilorin observation station operating under the radiometric network known as the Baseline Surface Radiation Network (BSRN). Pressure was measured with a CS105 analogue barometer incorporating a Vaisala Barocap silicon capacitive pressure sensor, while a combined temperature-relative humidity sensor of model HMP35C probe was used to measure the temperature and relative humidity. These instruments were connected to a module with a data logger that stores the measured data. Downloading is done thrice a month (at 11 days interval). While downloading, the module is removed from the data logger and connected to a computer where the data is transferred to the hard disk. For each instrument, there are 1,440 records for every 24 h. The data used was for a period of five years from 2000 to 2004.

Radio Refractivity, N

The atmospheric radio refractive index, n can be computed by the following formula:

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

where N is radio refractivity expressed by:

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

The 'dry term' of radio refractivity is given by:

$$N_{dry} = 77.6\frac{P}{T} \quad ...(3)$$

while the 'wet term' is given by:

$$N_{wet} = 3.73 \times 10^5 \frac{e}{T^2} \quad ...(4)$$

where,

P is the atmospheric pressure (hPa)

e is the water vapor pressure (hPa)

and T is the absolute temperature (K) (ITU-R, 1999)

The vapor pressure, e is given as:

$$e = \frac{H \times e_s}{100} \quad ...(5)$$

where H is the relative humidity and e_s is the saturated vapor pressure.

e_s is calculated from:

$$e_s = 6.11\exp\left[(19.7t)/(t+273)\right] \quad ...(6)$$

where t is the temperature in °C (Hall, 1979).

Results and Discussion

Diurnal Variation of Surface Refractivity

The hourly variation of surface refractivity for a typical dry season month (January) is presented in Figure 1a. It is observed that during the early morning hours, mean refractivity values vary between 300 *N*-units and 312 *N*-units but N_s values begin to decrease sharply around 8-9 a.m. This decrease continues until a minimum of 279 *N*-units is reached at about 3 p.m. local time, before it begins to rise again. In comparison with a typical wet season month (May), there is relatively no change in N_s from early morning hours till around 10 a.m. Values are constant at 366 *N*-units. However, a decrease is noted from 11 a.m. until a minimum of 338 *N*-units is reached around 5 p.m. (Figure 1b).

On the average, the dry season refractivity values vary from 290 *N*-units in the afternoon to about 304 *N*-units in the late evening and early morning hours, while the wet season values vary from about 358 *N*-units in the afternoon to about 370 *N*-units in the early morning and late evening hours. Also, an average minimum N_s value of about 280 *N*-units in the dry season and about 355 *N*-units in the wet season are observed between 2 p.m. and 5 p.m. local time. Maximum values are noted at different times of the morning between 6 a.m. and 9 a.m., and at night between 11 p.m. and 12 p.m. local time. This is shown in Table 1.

Figure 1a: Surface Refractivity Variation for a Typical Dry Month

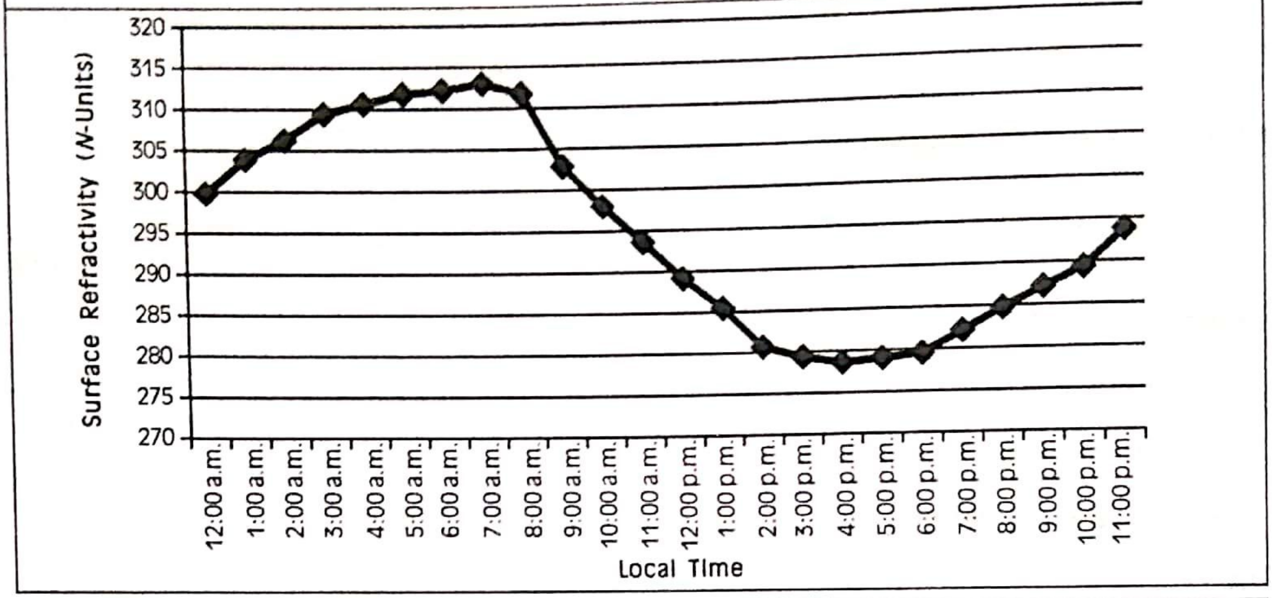


Figure 1b: Surface Refractivity Variation for a Typical Wet Month

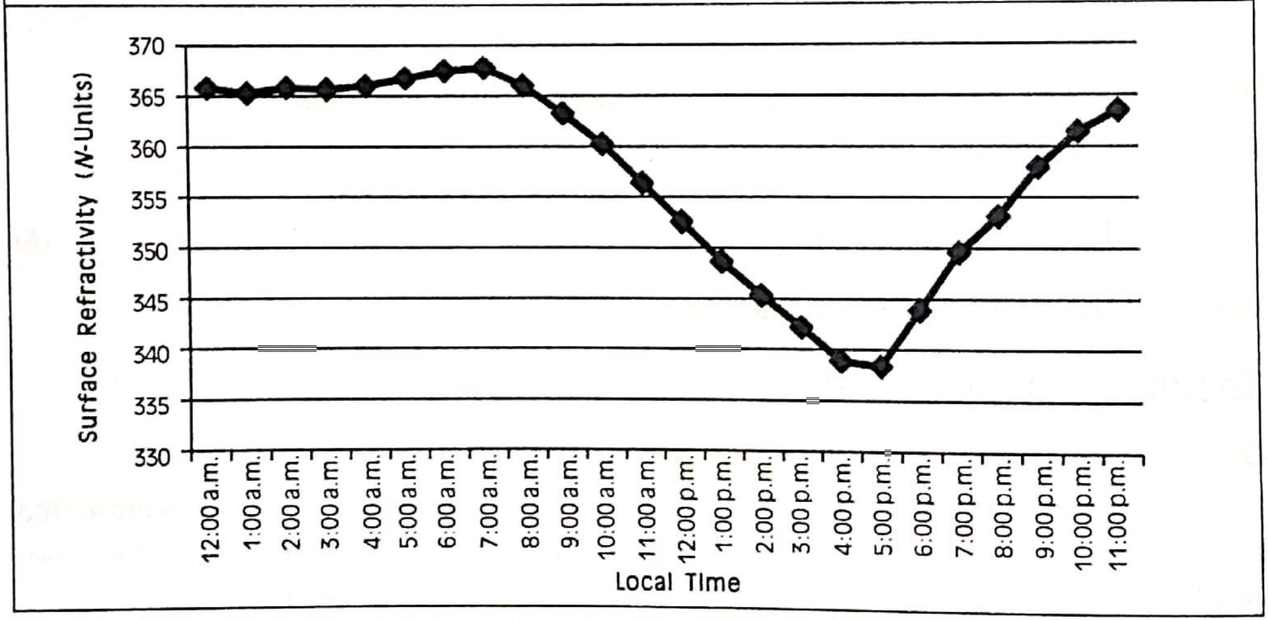


Table 1: Average Diurnal Refractivity Values for Dry and Wet Seasons

Average Dry Season Refractivity Values (*N*-Units)				Average Wet Season Refractivity Values (*N*-Units)			
Afternoon	Evening/ Morning	Minimum	Maximum	Afternoon	Evening/ Morning	Minimum	Maximum
290	304	280	340	358	370	355	367

Variability of Surface Refractivity

In order to investigate the degree of variability of surface refractivity for both climatic seasons, standard deviation was calculated and the plots for some selected months are presented in Figures 2a and 2b. From the figures, it was observed that variability is higher in the dry season than the wet season. The wet term factor given by Equation (4) is responsible for this variability. It varies from an average minimum of 12 *N*-units in December to an average maximum of 45 *N*-units in February for the dry season months and an average minimum of 5 *N*-units in April to an average maximum of 13 *N*-units in May for the wet season months.

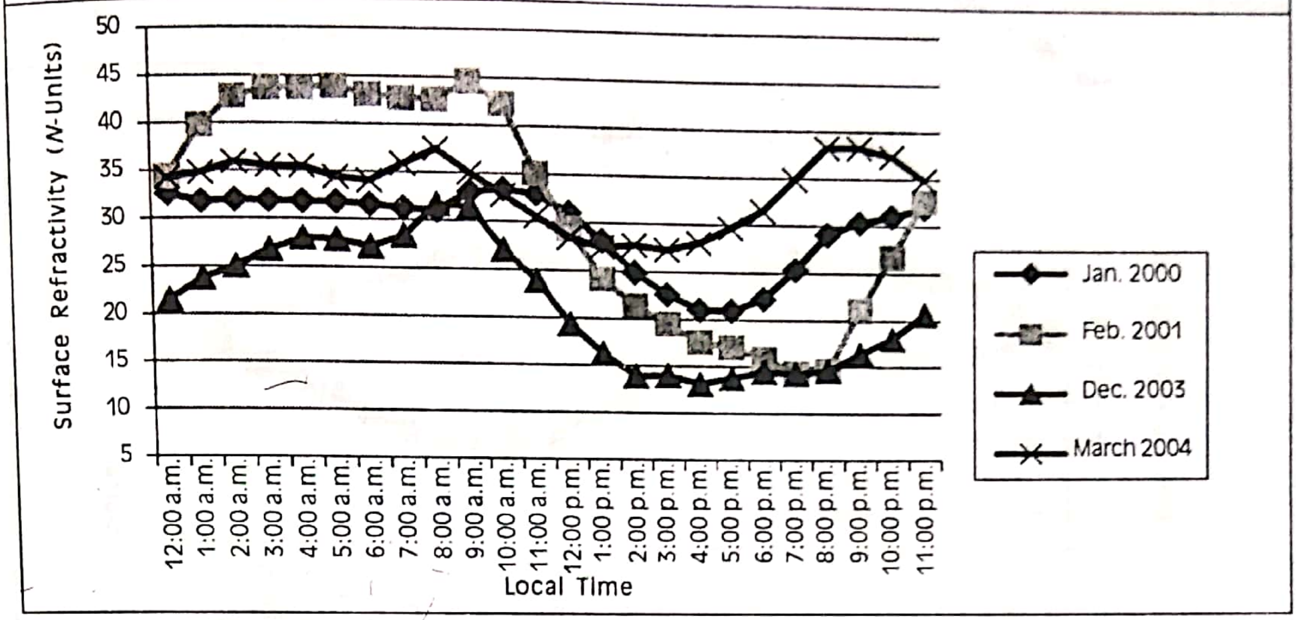


Figure 2a: Standard Deviation of Surface Refractivity for Dry Months During the Period 2000-2004

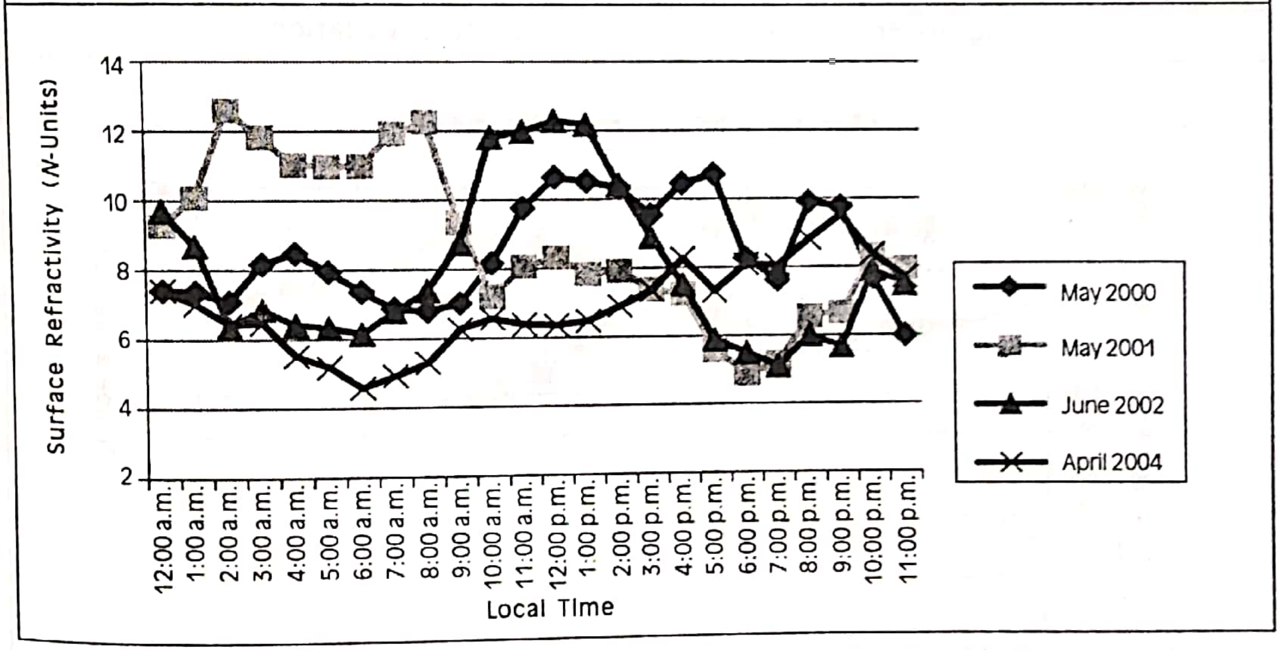


Figure 2b: Standard Deviation of Surface Refractivity for Wet Months During the Period 2000-2004

Variation of Atmospheric Parameters with Refractivity

The interrelationship of surface refractivity and related parameters was examined and the results are hereby presented.

Temperature with Humidity

Surface temperature and relative humidity variation is shown in Figure 3a. From the graph, it was observed that both parameters are out-of-phase. Around 9 a.m. local time, mean hourly temperature has a minimum value of 22 °C when relative humidity peaks at 77%.

Also, temperature peaks at 34 °C around 4 p.m. local time while humidity has a minimum of 26% around the same time. Figure 3b shows the variation of surface refractivity with temperature. The trend is similar to Figure 3a. This is in agreement with Equation (2) which shows refractivity to be inversely proportional to temperature.

Figure 3a: Temperature and Relative Humidity Variation

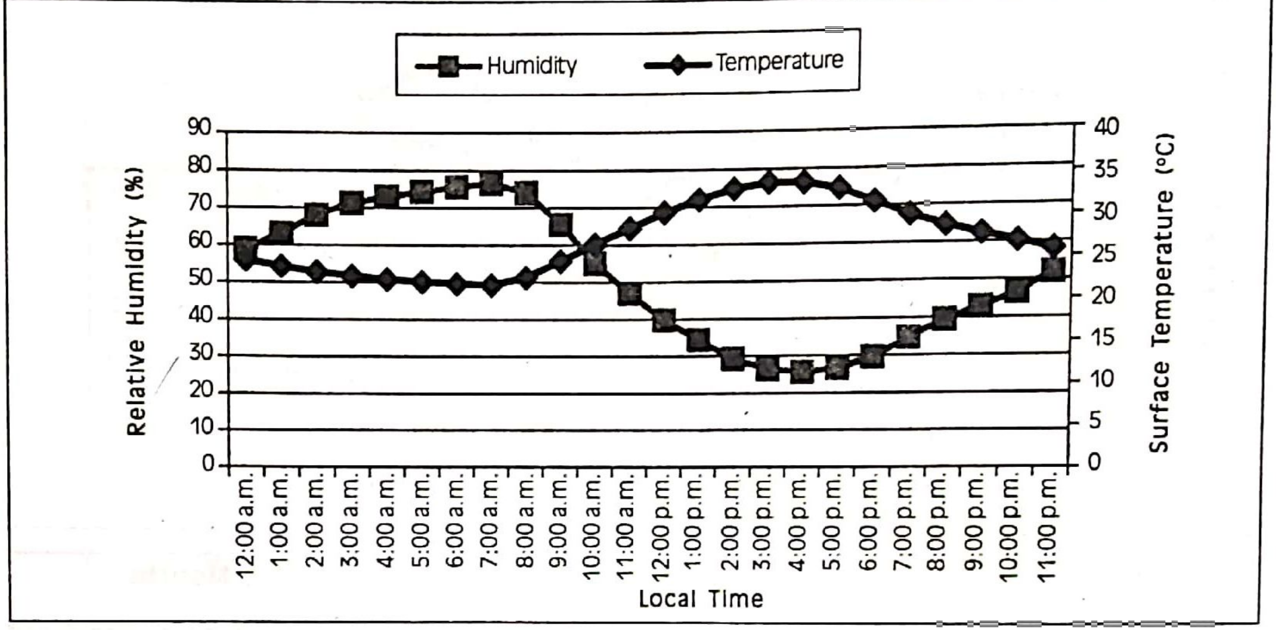
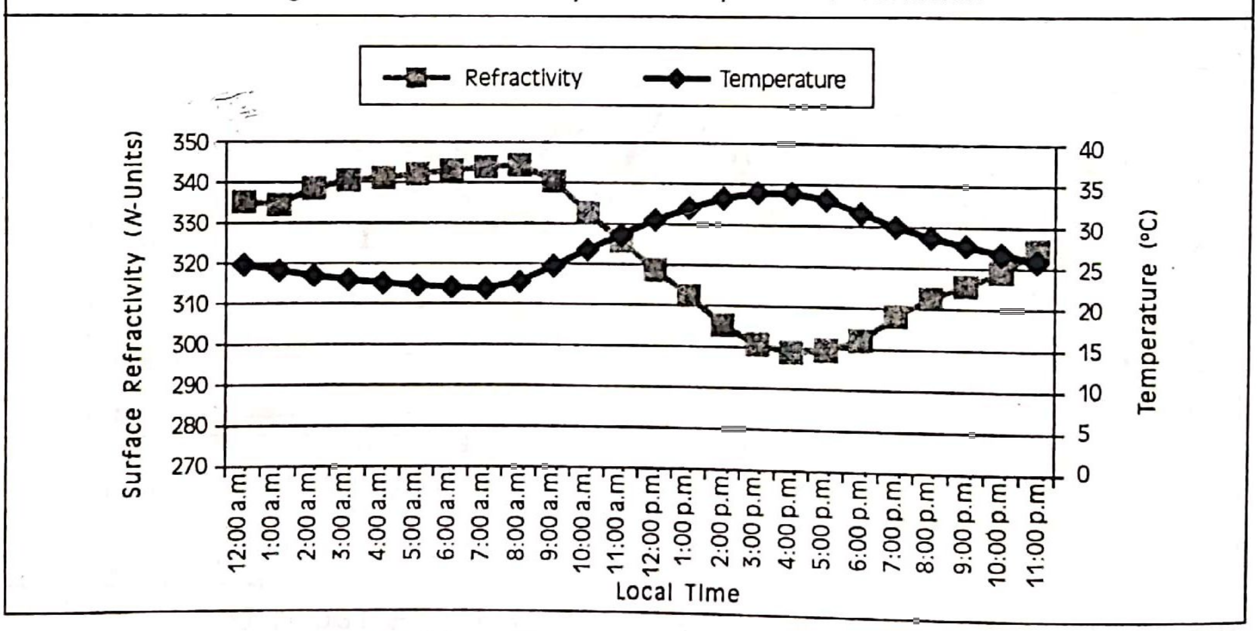


Figure 3b: Refractivity and Temperature Variation



Surface Refractivity Profile with Humidity and Pressure

Figure 3c shows the plot for surface refractivity and relative humidity. It is clearly seen here that surface refractivity has a diurnal trend with humidity and they are both in-phase with each other. Consequently, humidity peak of 77% around 9 a.m. is immediately followed by refractivity peak of 344 *N*-units at exactly the same time; while humidity minimum of 26% around 6 p.m. is followed by refractivity minimum of 299 *N*-units at the same time. The diurnal profile of surface refractivity and surface pressure was also examined and it is observed that they are out-of-phase during the early morning hours, but closely follow each other during the afternoon/evening hours (Figure 3d). Pressure has a minimum of 968 hPa around 4-7 a.m. local time when surface refractivity peaks (327-336 *N*-units) occur. Also, refractivity peak of 336 *N*-units around 10 a.m. is followed by a pressure peak of 970 hPa at 11 a.m. thereby having a time lag of 1 h while the refractivity minimum of 289 *N*-units around 6 p.m. local time is followed by a pressure minimum of 966 hPa at the same time. Moreover, in order to estimate the extent to which humidity correlates with surface refractivity, regression analysis was carried out. The analysis shows that monthly mean of humidity and refractivity are well correlated with a correlation coefficient of 0.97. It also shows that monthly surface refractivity, N values can be predicted by mean monthly values of humidity using the equation $N = 0.881\,h + 279$ where N is refractivity in *N*-units and h is the humidity in % (Figure 3e).

Figure 3c: Refractivity and Humidity Variation

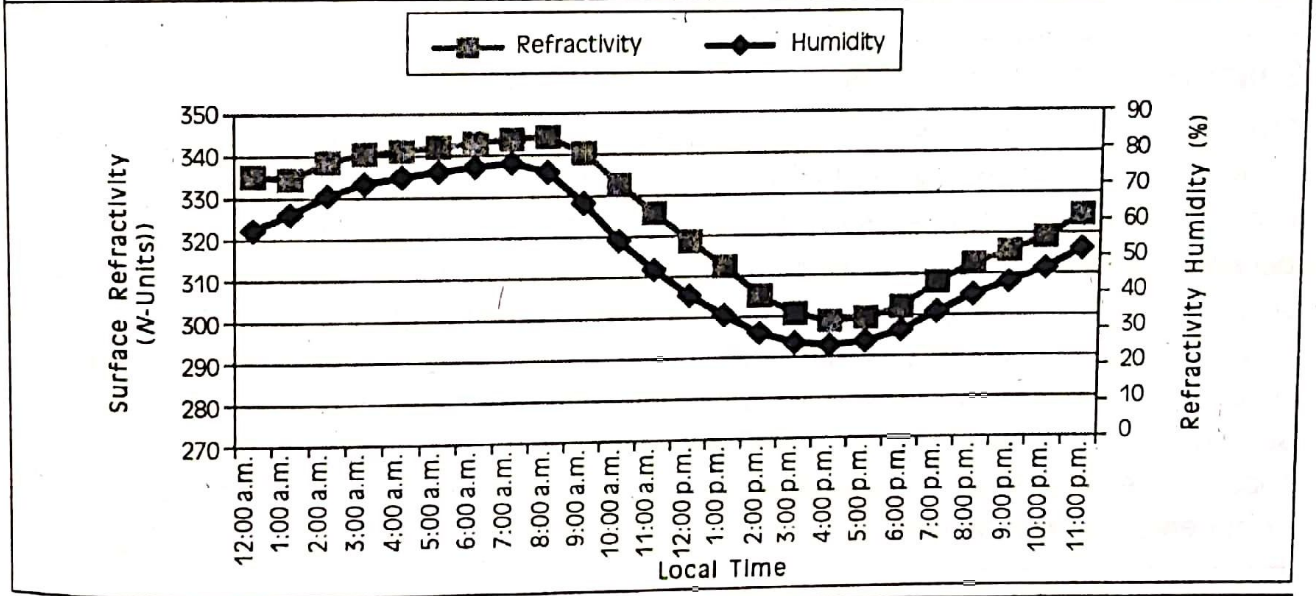


Figure 3d: Refractivity and Pressure Variation

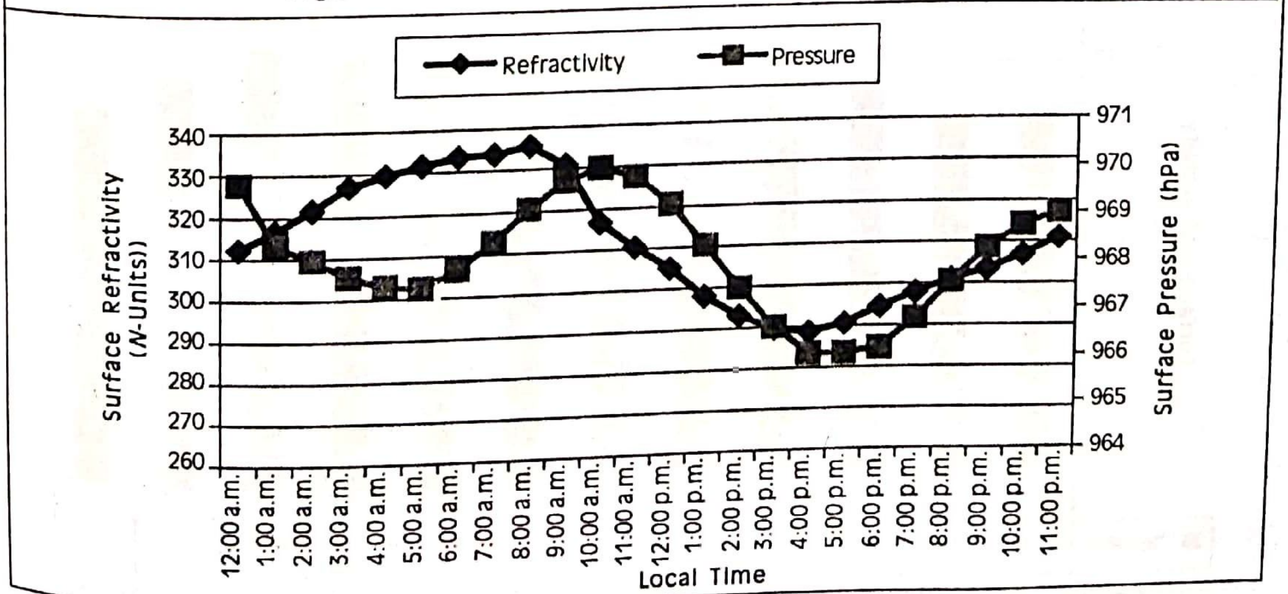
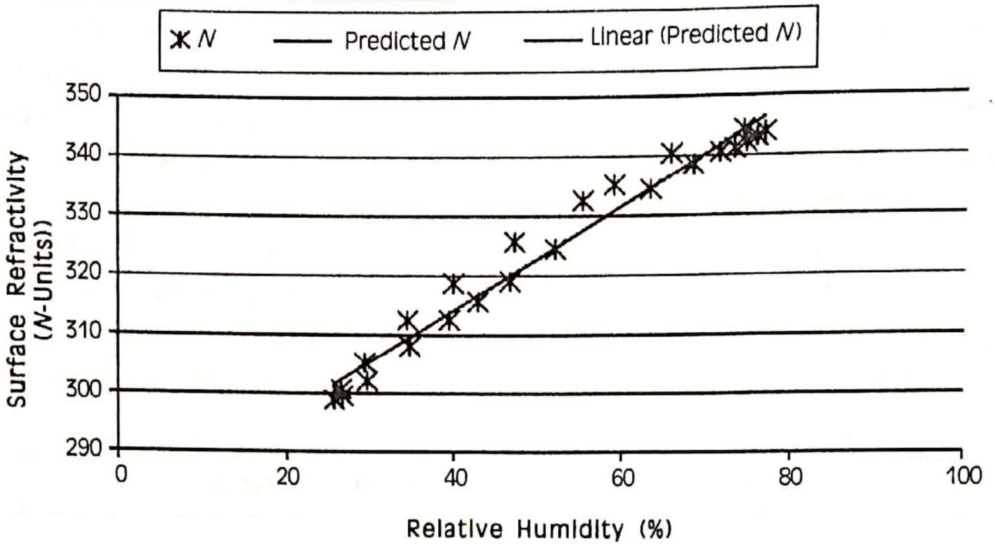


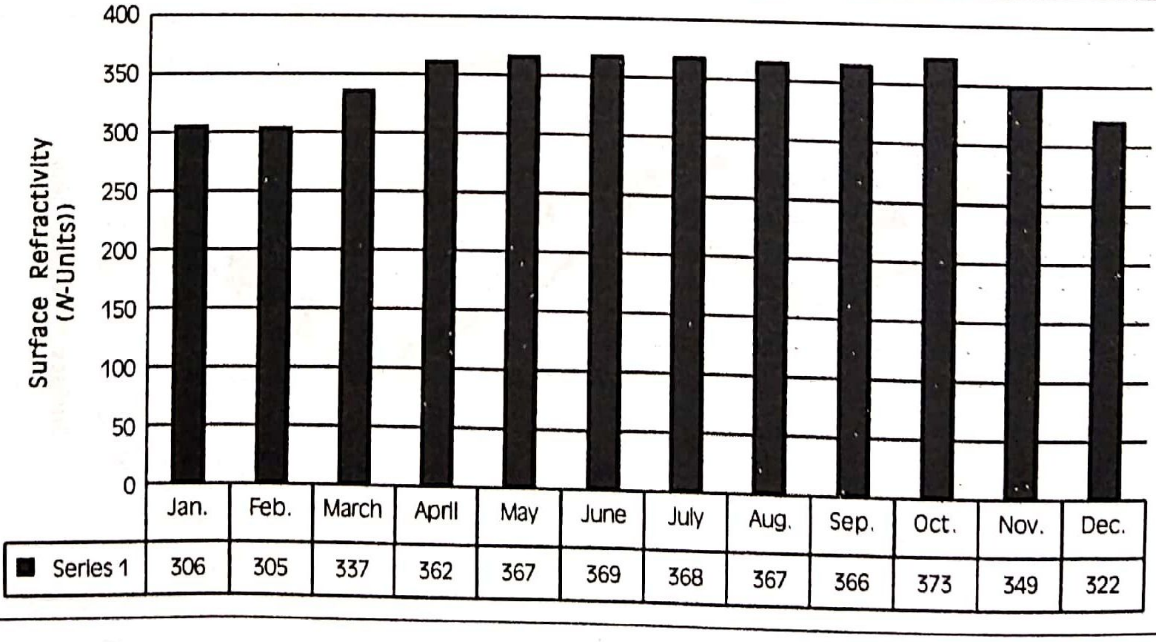
Figure 3e: Linear Regression on Surface Refractivity and Relative Humidity



Seasonal Variation of Surface Refractivity

The five years monthly mean profile of surface refractivity is shown in Figure 4. Minimum values occur in the dry season (November to March) while peak and more constant values occur in wet season. During the wet season (April to October), refractivity values only vary between 360 and 370 *N*-units. By November when the dry harmattan sets in, N_s values fall sharply steadily reaching the lowest values by January and February (306 *N*-units and 305 *N*-units respectively). This is followed by a steeper rise from February to March (337 *N*-units) thereby, indicating more variability. The low refractivity values recorded in the dry season is a consequence of the combined effect of low humidity and high temperatures that reduce the moisture content of the atmosphere. Also, the strong influence of dry continental air mass prevalent during this season in this part of the globe contributes, while

Figure 4: Five Years Seasonal Variation of Surface Refractivity



	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
■ Series 1	306	305	337	362	367	369	368	367	366	373	349	322

the higher values recorded during the wet season is as a result of the characteristic heavy rainfall in this region brought about by a south-westerly, tropical maritime air mass from the southern hemisphere.

Conclusion

The statistical analysis of radio refractive index and its related atmospheric parameters for a period of five years over Ilorin shows diurnal and seasonal trends. Results obtained reveal that surface radio refractivity over Ilorin is more variable in the dry season than the wet season thereby, resulting in variation in field strength in the Very High Frequency (VHF) band in this region. It was also observed that dry season months exhibited lower refractivity values ranging from 272 *N*-units to 367 *N*-units in comparison with the wet season months values of 354 *N*-units to 373 *N*-units. The diurnal variation showed that dry season refractivity values varied from 290 *N*-units in the afternoon to about 304 *N*-units in the late evening and early morning hours, while the wet season values varied from about 358 *N*-units in the afternoon to about 370 *N*-units in the early morning and late evening hours. Also, the relationship between diurnal profile of surface refractivity and related atmospheric variables of temperature, humidity and pressure show that refractivity and temperature are out-of-phase with each other while refractivity and humidity are in phase with each other, refractivity and surface pressure was observed to be out-of-phase during the early morning hours but closely follow each other during the afternoon/evening hours. The regression analysis carried out shows that monthly mean humidity and refractivity are well correlated with a correlation coefficient of 0.97. It also shows that monthly mean surface refractivity, *N* values can be predicted by monthly mean values of humidity with the equation $N = 0.881\ h + 279$.

References

1. Adebanjo T I (1977), "A Semi-Empirical Radio Refractive Index Variation Over Nigeria", *Nig. Inst. Phys.* Vol. 2, No. 2, pp. 69-78.
2. Adedeji A T and Ajewole M O (2008), "Vertical Profile of Radio Refractivity Gradient in Akure, South-West Nigeria", *Progress in Electromagnetics Research C*, Vol. 4, pp. 157-168.
3. Aro T O and Willoughby A A (1992), "Some Characteristics of Radio Refractive Index in the First Kilometer of a Tropical Troposphere", *Proceedings of Wave Propagation and Remote Sensing*, June 8-12, pp. 10.5.1-10.5.14, Ravenscar North Yorkshire, UK.
4. Batueva E V, Darizhapov D D and Tarbazheeva O L (1998), "Vertical Distributions of Radio Meteorological Parameters of Troposphere of Far East of Russia" *Proceedings of the 8th URSI Commission F Triennial Open Symposium*, September 22-25, pp. 196-199, Aviero, Portugal.
5. Bean B R and Thayer G D (1959), "Models of Atmospheric Radio Refractive Index", *Proceedings of IRE*, Vol. 47, No. 5, pp. 740-755.

6. Bean B R, Cahoon C A, Samson C A and Thayer G D (1966), *A World Atlas of Radio Refractivity*, Monograph No. 1, Environmental Sciences Services Administration, US Government Printing Office, Washington DC.

7. Hall H P M (1979), *Effects of the Troposphere on Radio Communication*, pp. 1, 14 and 22, Peter Peregrinus Ltd. UK and US.

8. Hall H P M and Barclay L W (1991), *Radiowave Propagation*, p. 150, Peter Peregrinus Ltd., UK.

9. ITU-R (1999), "The Radio Refractive Index: Its Formula and Refractivity Data", *Recommendation ITU-R*, Vol. 453, No. 7, p. 1.

10. ITU-R (2003), "The Radio Refractive Index: Its Formula and Refractivity Data", *Recommendation ITU-R*, Vol. 453, No. 9, p. 7.

11. Owolabi I E and Williams V A (1970), "Surface Radio Refractivity Patterns in Nigeria and the Southern Cameroons", *Journ. of West African Sci. Assoc.*, Vol. 15, pp. 3-7.

12. Oyedum O D, Igwe K C, Eichie J O and Moses A S (2009), "Preliminary Results of Surface Refractivity in Minna, Niger State, Nigeria", *Proceedings of the Annual Conference of Nigeria Union of Radio Science (NURS)*, pp. 19-24.

13. Oyedum O D, Ezenwora J A, Igwe K C *et al.* (2010), "Diurnal and Annual Cycles of Surface Refractivity and Related Atmospheric Parameters in Minna, Nigeria", Proceedings of Workshop on African Participation in IHY and ISWI (WAPII), Abuja, Nigeria (in press).

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