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THE STUDY OF DIURNAL AND SEASONAL REFRACTIVITY VARIATIONS AND ITS INFLUENCE ON VHF/UHF SIGNAL FIELD STRENGTH PROFILE OF LAPAI, NIGERIA.

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ABSTRACT

The study of diurnal and seasonal variation of surface radio refractivity N_s over Lapai (9.625°N / 6.570°E) Niger State, Nigeria was carried out using 3-year meteorological data collected with Integrated Sensor Suite (ISS-Vantage Pro2) weather instrument installed at surface level in Ibrahim Badamasi Babangida University, Lapai, Niger State. The data used were collected from 2010 to 2012. The seasonal variations were calculated using the data obtained at 5-minutes interval and the result showed that mean value of radio refractivity during the rainy season months (April to October) is greater than the mean N_s value of the dry season months (November to March) for the location and years of the study. The computed mean diurnal N_s over Lapai in the first 1 km of height is 342 N-units, which give the refractivity gradient$\left(\frac{dN}{dh}\right)$ of -46 N/km; this shows that the station is on average characterised by low scale super-refraction, which was used to calculate both the k-factor and the mean Field Strength Variability (FSV) over Lapai in the first 1 km of height as 1.38 and 5.52dB respectively. The mean reduced to sea-level refractivity (N_o) over Lapai is 357 N-units. The radio horizon distance within 1 km height for a transmitter height of 100 m over Lapai is 41.93 km. The seasonal N_s variations with respect to atmospheric parameters of temperature, pressure, humidity and time in Lapai were shown using 2-D contouring. These results give broader insight into how N_s values directly affect VHF/UHF signal field strength profile in Lapai.

Keywords: Seasonal Refractivity Variations, VHF/UHF Signals.

INTRODUCTION

Line - of - sight (LOS) microwave links are prone to severe fading due to refraction of the transmitted waves along the propagation path. Hence, refractive fading can significantly impair service on terrestrial LOS microwave transmission. Microwave propagation through the troposphere is affected by varieties of natural phenomena caused by variation in some meteorological parameters, such as pressure, temperature and relative humidity at Ultra high frequencies (UHF) and microwave frequencies (Adeyemi and Emmanuel, 2011). These effects are analysed from the study of radio refractive index derived from these parameters of Humidity, Temperature and Pressure. These parameters vary considerably diurnally and seasonally in the tropics. Therefore, the knowledge of the refractivity is essential for the design reliable and efficient radio communication (terrestrial and satellite) systems. Thus, the refractive index of the troposphere is very important for estimating the performance of terrestrial radio links (Isikwue *et al.*, 2013). At frequencies above 30MHz, the ionosphere does not normally reflect radio energy, and changes in the refractive index of the atmosphere affect radio frequencies above 30MHz, although these effects become significant at frequencies greater than about 100MHz in the lower atmosphere (Ayantunji *et al.*, 2011). Hence, the refractive index, n of the troposphere is of major concern in the propagation of radio waves at these frequencies. The value of refractive index n at the earth's surface is slightly greater than unity and gradually decreases towards unity with increase in altitude. At the earth's surface, radio refractive index is usually between 1.00025 and 1.00035. This is report presents an easy method for calculating radio refractivity and enhances understanding of the concept signal variations between the dry and rainy seasons in Lapai.

METHODOLOGY

Source of Data

Data used for this work is from 3 years record of measurements at 5-minutes interval data collected with Integrated Sensor Suite (ISS-Vantage Pro2) instrument installed at surface level in th Geography Department of Ibrahi Badamasi Babangida University, Lap between 2010 and 2012.Lapai is th headquarter of Lapai Local Governme area located within this coordinat (9.625°N / 6.570°E) as shown in Figure 1 one of the twenty-five local governments Niger state, Nigeria.

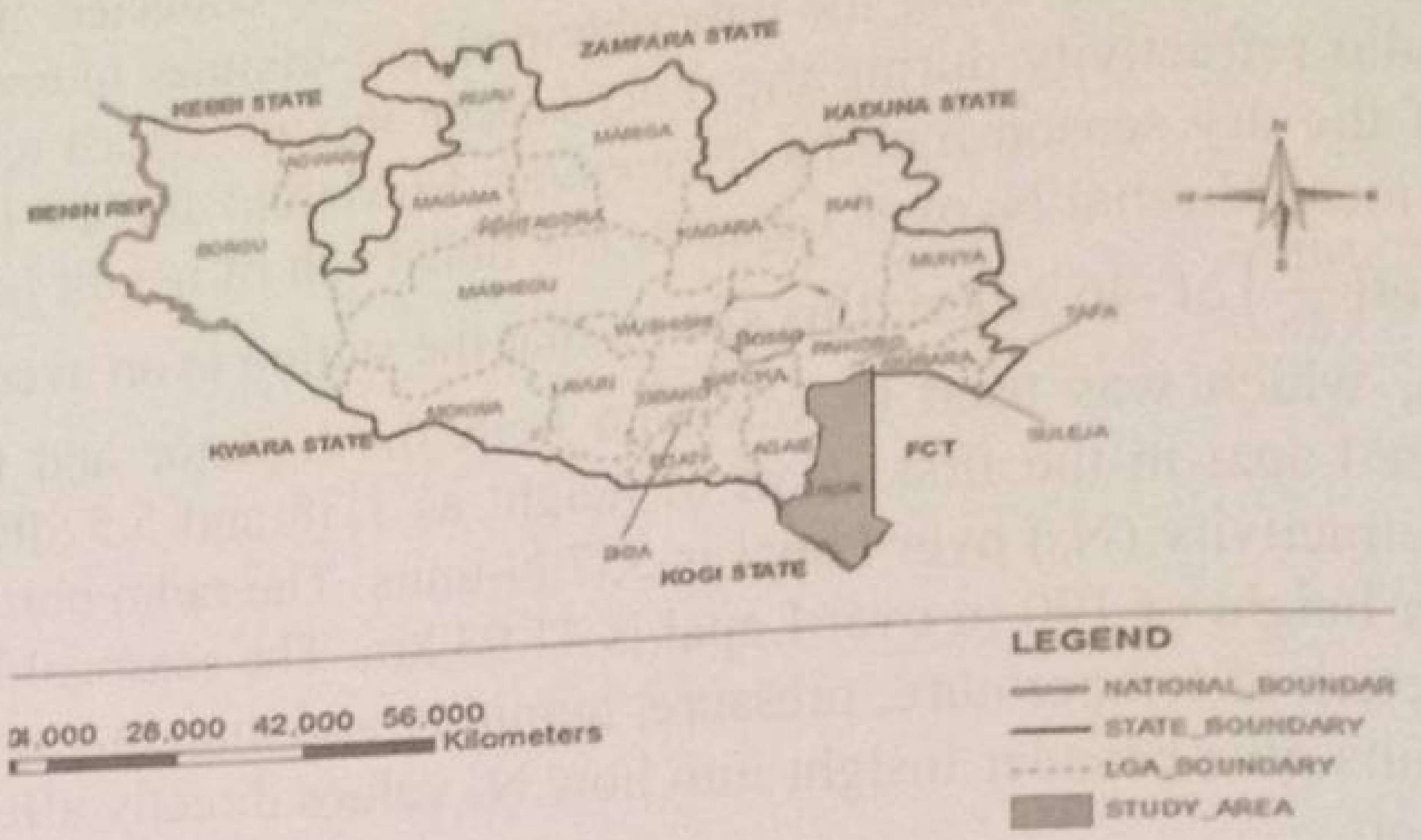

Figure 1: Map of Niger State showing Lapai Local government, the study area.

Analysis of Data Collected

The table 1 shows a typical sample data used for the analysis

Table 1. Daily sample data over Lapai.

IBBU LAPAI	56111	Main	
TIME STAMP	RH	T107_C_Avg	Bar Press. Avg.
	%	Deg C	Mbar
10/3/2010 21:25	86	31.03	988
10/3/2010 21:30	86.4	30.99	988
10/3/2010 21:35	86.2	30.96	988
10/3/2010 21:40	85.7	30.93	988
10/3/2010 21:45	86.2	30.9	988
10/3/2010 21:50	86.3	30.87	988
10/3/2010 21:55	86.8	30.84	988

Diurnal mean five minutes data for Lapai was used to compute surface refractivity (N_s) for the station. Annual mean of refractivity reduced-to-sea level (N_o) of the study station was also computed. Analysis was done using Surfer11 software application. This software was used to contour the refractivity values.

Calculations of Radio Refractivity N

Radio refractivity N is evaluated using the relation defined by Hall, (1979):

$$N = (n - 1) \times 10^6 \qquad (1)$$

where n is the refractive index of air

For instance, when n = 1.000350, then N = 350. N is strictly the refractivity, but sometimes referred to as refractive index. For frequencies up to about 30 GHz, the radio refractivity of clear air is given by the formula (Smith and Weintraub 1953):

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

where P is the atmospheric pressure in millibars (mb), e is the water vapour pressure in mb and T is the absolute temperature in Kelvin. Equation (2) may be split into two and rewritten as:

$$N = \frac{77.6}{T}P + \frac{3.73\times10^5 e}{T^2} \qquad (3)$$

The first and second terms are representing the dry (N_{dry}) and wet (N_{wet}) components of refractivity, respectively. While the dry term contributes about 70% to the total value of N, the wet term is responsible for a major part of the variation in N at a given location of the atmosphere. At very low temperatures, N_{wet} reduces to a very small value even for saturated air and this makes refractivity, N almost independent of relative humidity. An increase in temperature will force N_{dry} to decrease but at the same time causes a rapid increase in the saturated value $N_{wet.max}$. At high temperatures, value of $N_{wet.max}$ may become larger than, N_{dry} so that N will vary with relative humidity. When both temperature and relative humidity are high, N becomes very sensitive to small changes in temperature and relative humidity. Consequently, the variability of water vapour content in the atmosphere (and hence the refractivity) in tropical areas is far greater than that of cold climate (Hall, 1979). The atmospheric radio refractivity is an important factor in the propagation of radio waves in the very high frequency (VHF) and higher frequency bands. The path and general characteristics of the signals are very much tied to the refractive conditions of the troposphere (Oyedum and Gambo, 1994).

The refractivity, N (which is actually the refractive index in excess of unity in part per million) are as given in equations (1) to (3).

The vapour pressure, e is estimated from (Hall, 1989)

$$e = (R.H\times e_s)/100 \qquad (4)$$

where R.H is relative humidity and e_s is the saturated vapour pressure.

e_s is calculated from(Hall, 1989)

$$e_{s} = 6.11\exp[(19.7t)/(t+273)] \qquad (5)$$

where t is the temperature in °C

Computation of reduced-to-sea level refractivity (N_o) at Lapai and its environs

According to Smith & Weintraub, (1953),the null refractivity (N_o) was computed using the relation:

$$N_o = N_s\exp\left(\frac{h_s}{h_o}\right) \qquad (6)$$

where N_o is the average value of atmospheric refractivity extrapolated to sea level, N_s is the surface refractivity calculated using equation (3) above, h_o is the scale height in (km) and $h_s$is the height of the earth's surface above the sea level (km).

Computation of Gradient (dN/dh) and k-factor

Seybold (2005) reported that the Gradient (dN/dh) and k-factor can be computed via equation 7 which is expressed as:

$$N = N_s e^{(-h/H)} \qquad (7)$$

where h is the height above the surface, which is taken to be 1 km for the surface refractivity calculations . H is the scale height; H is 7 km, as obtained for tropical conditions (Kolawole and Owonubi, 1982). N_s is the calculated surface refractivity from equation (3) But $\frac{dn}{dh}$ is expressed as:

$$\frac{dn}{dh} = \left(\frac{dN}{dh}\right) 10^{-6} \quad \text{(N-Units/km)} \qquad (8)$$

Therefore, the equation for obtaining the gradient $\left(\frac{dN}{dh}\right)$ parameter is further expressed as:

$$\left(\frac{dN}{dh}\right) = \left(\frac{-N_s}{H}\right) e^{(-h/H)} \qquad (9)$$

Meanwhile, the k-factor is giving as (Kolawole *et al*., 1981):

$$k = \frac{1}{\left(1 + a\left(\frac{dN}{dh}\right)10^{-6}\right)} \qquad (10)$$

where k is the k-factor, and a, is the earth radius and the term $\left(\frac{dN}{dh}\right)$ is the gradient given in equation (9).

Field Strength Variation (FSV)

Using the formula in equation (11) as established by (Bean and Dutton 1968), the field strength variation is defined as:

$$FSV = (N_{Smax} - N_{Smin}) \times 0.2dB \qquad (11)$$

where N_{Smax} and N_{Smin} are the maximum and minimum values of surface refractivity respectively.

Radio Horizon Distance (d_{RH}) Calculation

Furthermore, Bean and Dutton (1968) also reported that the radio horizon distance (d_{RH}) can be obtained via equation (12):

$$d_{RH} = \sqrt{2kah} \qquad (12)$$

where k is the effective earth's radius factor, a is the equivalent earth's radius and h is the transmitter height.

N_s Contouring

The confirmation of the calculated N_s variation was achieved using surfer 11 software applications to contour the values of surface refractivity (N_s) with respect to other variables which include: month, time, temperature, humidity and pressure.

RESULTS

The results obtained from the sampled data used for the analysis were as presented in Figure 2, 3 and 4 respectively. Figure 2 shows the graph of three years mean hourly surface refractivity for dry season months in Lapai, while, Figure 3 shows the three years mean hourly N_s variations for the wet season months in Lapai and Figure 4 shows the three years mean Field Strength Variability (FSV) for the period of study in Lapai.

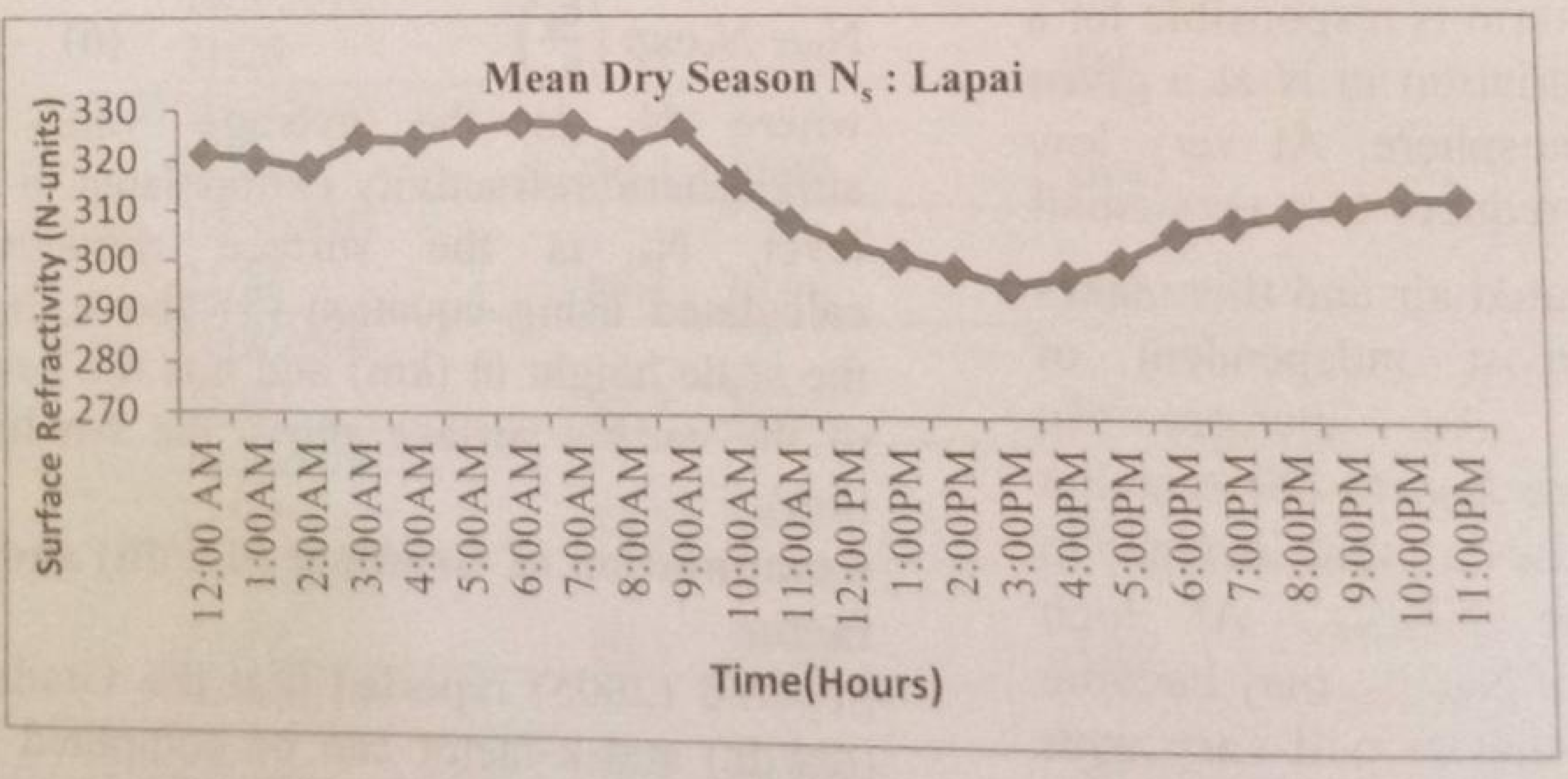

Figure 2: Three Years Mean Hourly Surface Refractivity for Dry Season (November to March) in Lapai

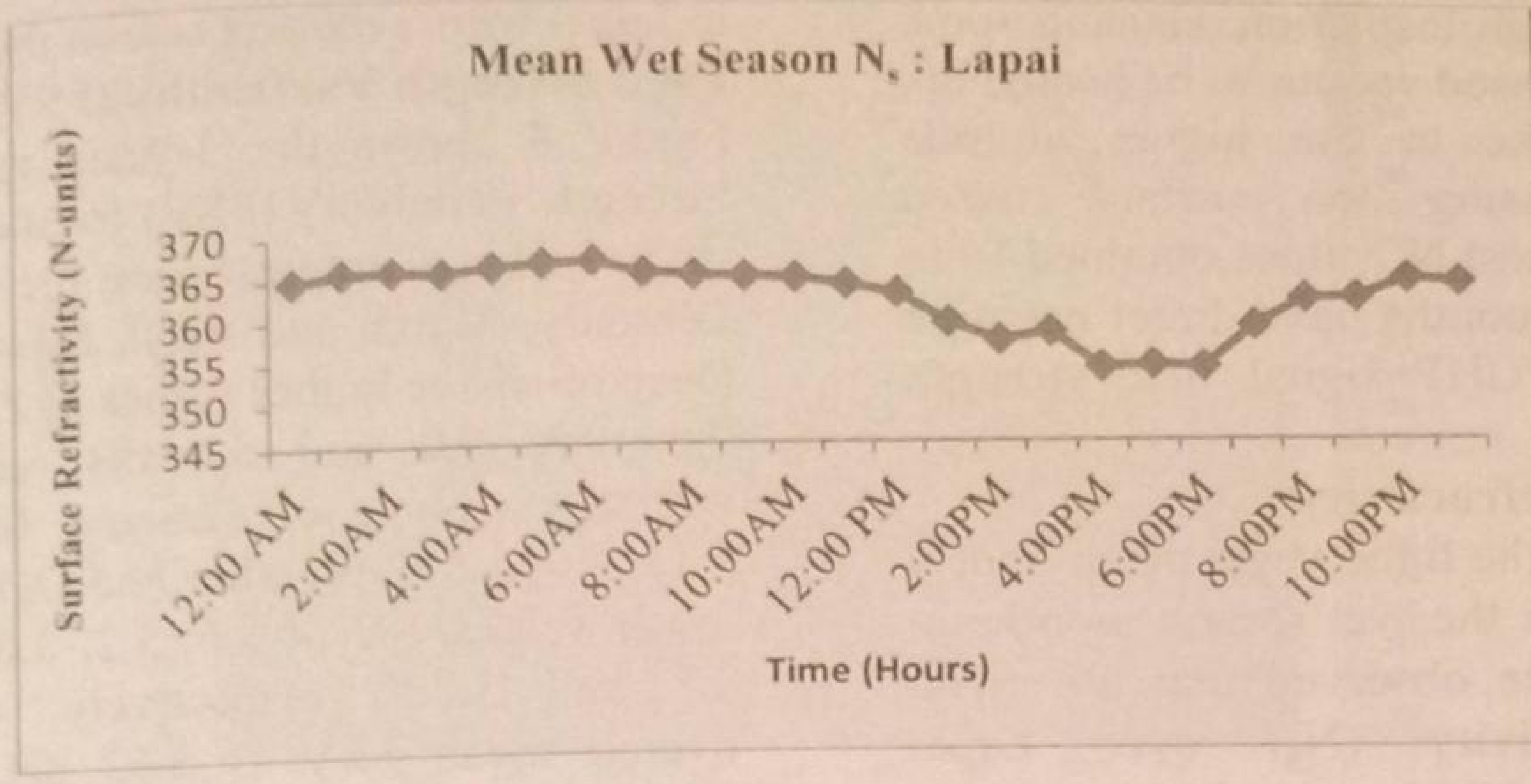

Figure 3: Three years Mean Hourly Surface Refractivity for Rainy Season (April to October) in lapai.

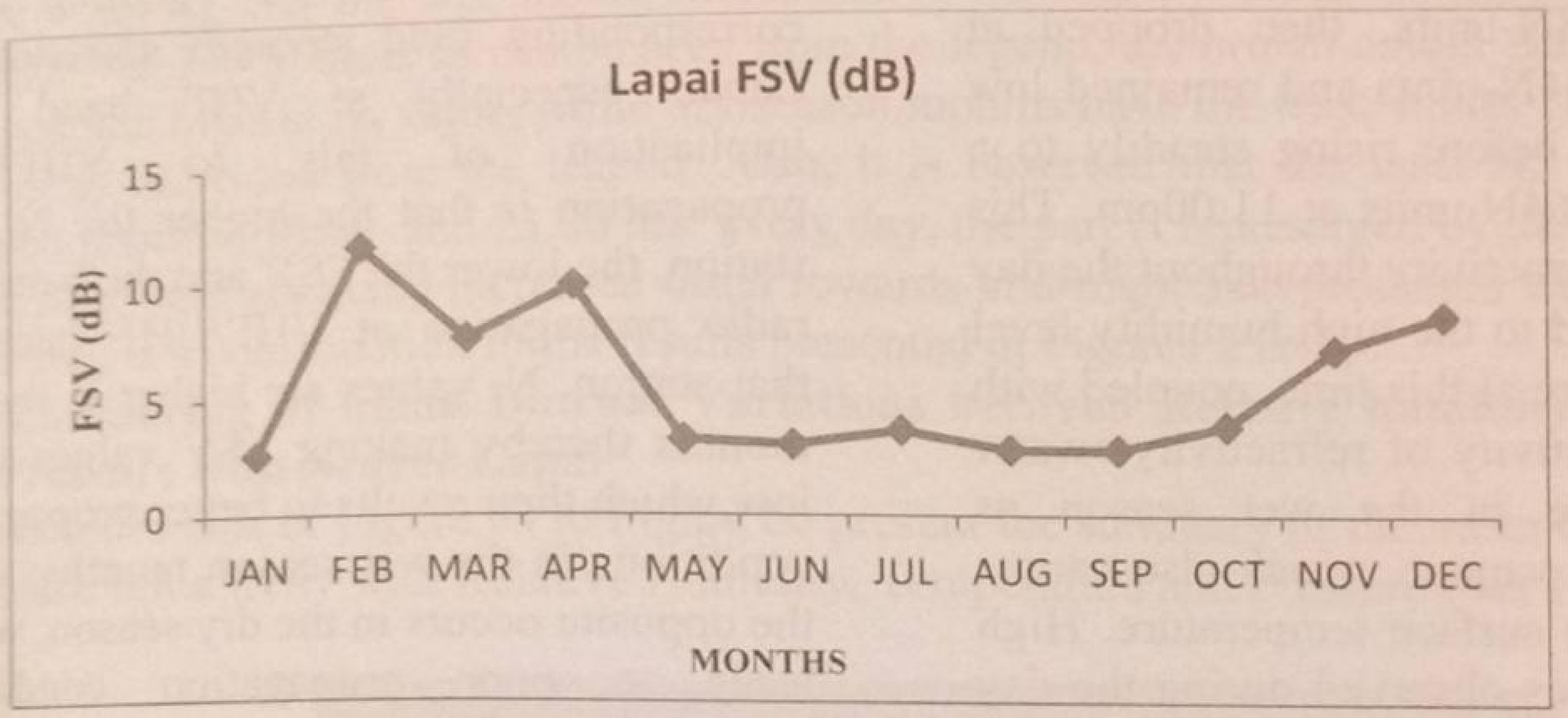

Figure 4: Three Years Mean Monthly Field Strength Variability (FSV) for the period of study in Lapai.

DISCUSSION OF RESULTS

The data obtained from climatic observations at 5 minutes interval of time in Lapaiwere utilized together with relevant mathematical tools to compute the values of surface refractivity due to dry and wet terms. These measurements were carried for three consecutive years from 2010 to 2012 and they cover weather conditions for both seasons (rainy and dry seasons) occurring in Lapai.

Dry Seasons Refractivity

Figure 2 shows the graph of three years mean hourly surface refractivity for dry season months in Lapai. Considering Figure 2 the hourly refractivity, It can seen that N increased from 320N-units at 12:00am to a peak of 326N-units at 9:00am and then decreased gradually to the least value of 295N-units at 3:00pm after which it increased gradually again all through 11:00pm to a value of 313N-units. This trend of high refractivity in the morning and late at night can be attributed to the high humidity level in the atmosphere at this time coupled with the higher sensitivity of refractivity to water vapour partial pressure in the dry season at such times. Low refractivity values observed during the day is due to the high insolation, causing some of the surface-based vapour to be heated up, expand and rise to the higher altitude thereby decreasing the surface based moisture. The least N_s values obtained from the dry season months have direct negative effect on VHF/UHF signal field strength profile in Lapai.

Wet Seasons Refractivity

Figure 3 shows the three years mean hourly N_s variations for the wet season months in Lapai.It could be observed that the mean surface refractivity (N_s) over Lapai decreased from 12:00am at 365N-units to 2:00pm at 357N-units, increased slightly till 3:00pm at 358N-units, then dropped at 4:00pm with 354N-uints and remained low up till 6:00am before rising steadily to a high value of 364N-units at 11:00pm. This trend of high refractivity throughout the day can be attributed to the high humidity level in the atmosphere at this time, coupled with the higher sensitivity of refractivitytowater vapour pressure in the wet season as increased water vapour, which also causes reduction in the surface temperature. High refractivity values observed during the day is due to the low insolation, causing the surface-based vapour not to be heated up, not to expand and thus remain at the lower altitude thereby increasing the surface based moisture content. The high N_s values obtained from the wet season months have direct positive effect on VHF/UHF signal field strength profile in Lapai, because it enhances terrestrial communication in Lapai, causing reduced energy loss from transmitter to receiver, thus a greater efficiency of radio propagation is observed in Lapai within the wet season months.

Field Strength Variability (FSV)

Figure 4 shows the 3-years mean Field Strength Variability (FSV) for the period of study in Lapai, representing the months of February, March and April. November and Decemberhave higher values of FSV - 11.6, 7.6, 9.8, 7.0 and 8.4 dB respectively, whilethe months of January, May, June, July, August, September and October have lower valuesFSV of 2.6, 3.2, 3.0, 3.6, 2.8, 2.8 and 3.8dB respectively, while the overall mean FSV is 5.52 dB over the period of study in Lapai. The observed diurnal and seasonal Ns variation cause corresponding field strength variations in Lapai, especially at VHF band. The implication of this to VHF/UHF propagation is that the higher the N_s in a station, the lower the FSV and the better the radio propagation at VHF/UHF bands in that station. N_s values are higher in the wet months thereby making FSV values to be low,which then results to better propagation conditions in the wet season months, while the opposite occurs in the dry season, which leads to poor propagation conditions experienced in the dry season months.The low FSV of 2.6 dB in January, may be due to reduced insolation caused by harmattan haze

Contouring of Diurnal and Seasonal Variation of N_s over Lapai

The contour maps of Figure 5 present the summary of the seasonal and diurnal variation of surface refractivity over the station under study.

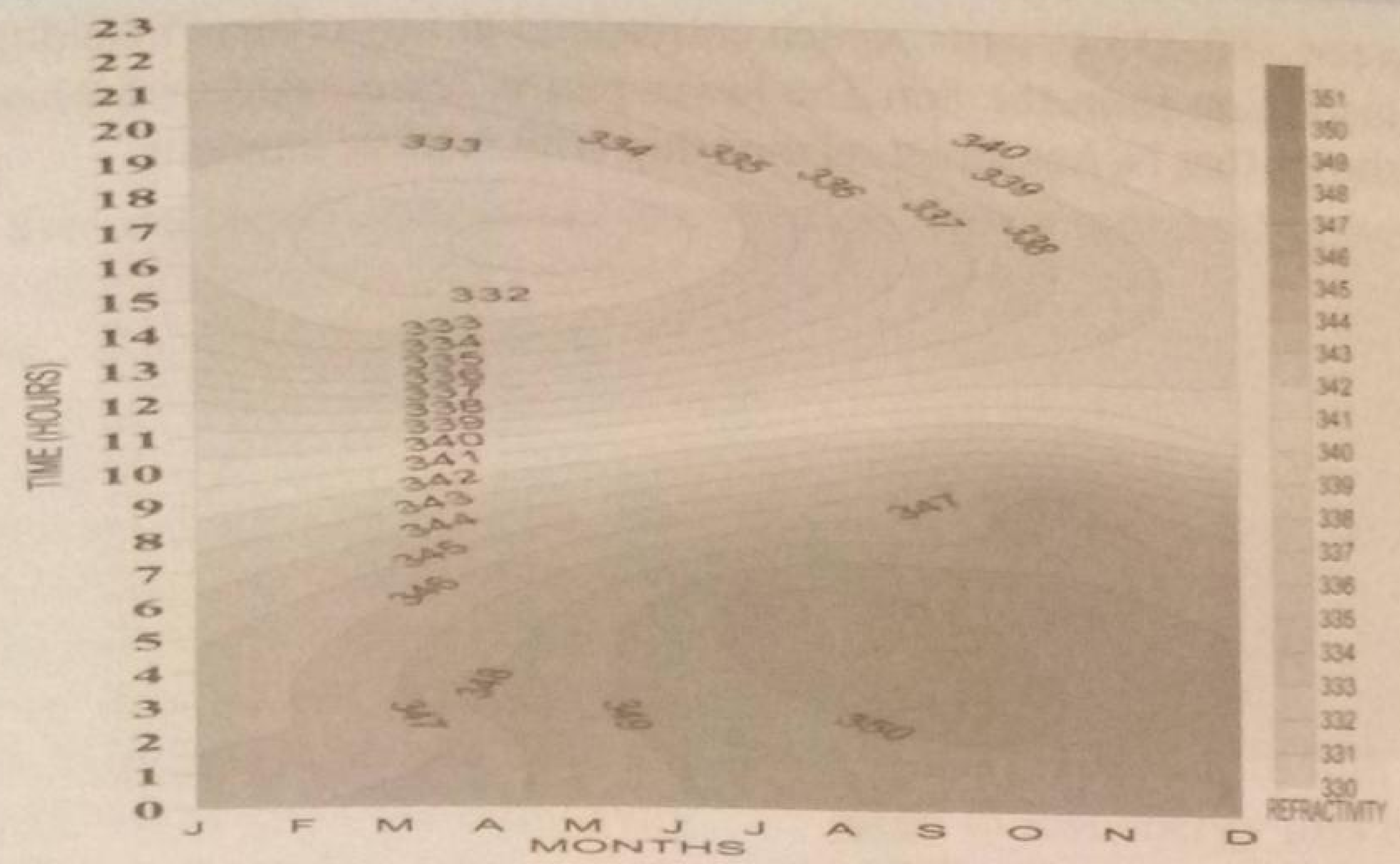

Figure 5: Diurnal and Seasonal Variation of N_s over Lapai

Figure 4 shows that the wet season months have the higher values of N_s; the N_s values are between 348-350 N-units as can be seen from the legend, the brown colour part of the contour represent the highest N_s value, while dry season months have the least values between 330-347 N-units as indicated from the legend. Also, it is observed that the least N_s value occurred between hours of 18:00 and 23:00 hrs every day, the part is represented by the white colour in the contour and gradually increased faster towards mid-night as represented with green colour. This result is a confirmation of the results presented in Figures 2 and 3.

The Contouring of Mean Diurnal Variations between Relative humidity, Temperature and Pressure with N_s over Lapai

The contour maps of Figure 6a to Figure 6c present the summary of the mean diurnal variation of surface refractivity with Relative Humidity, Temperature and Pressure over Lapai

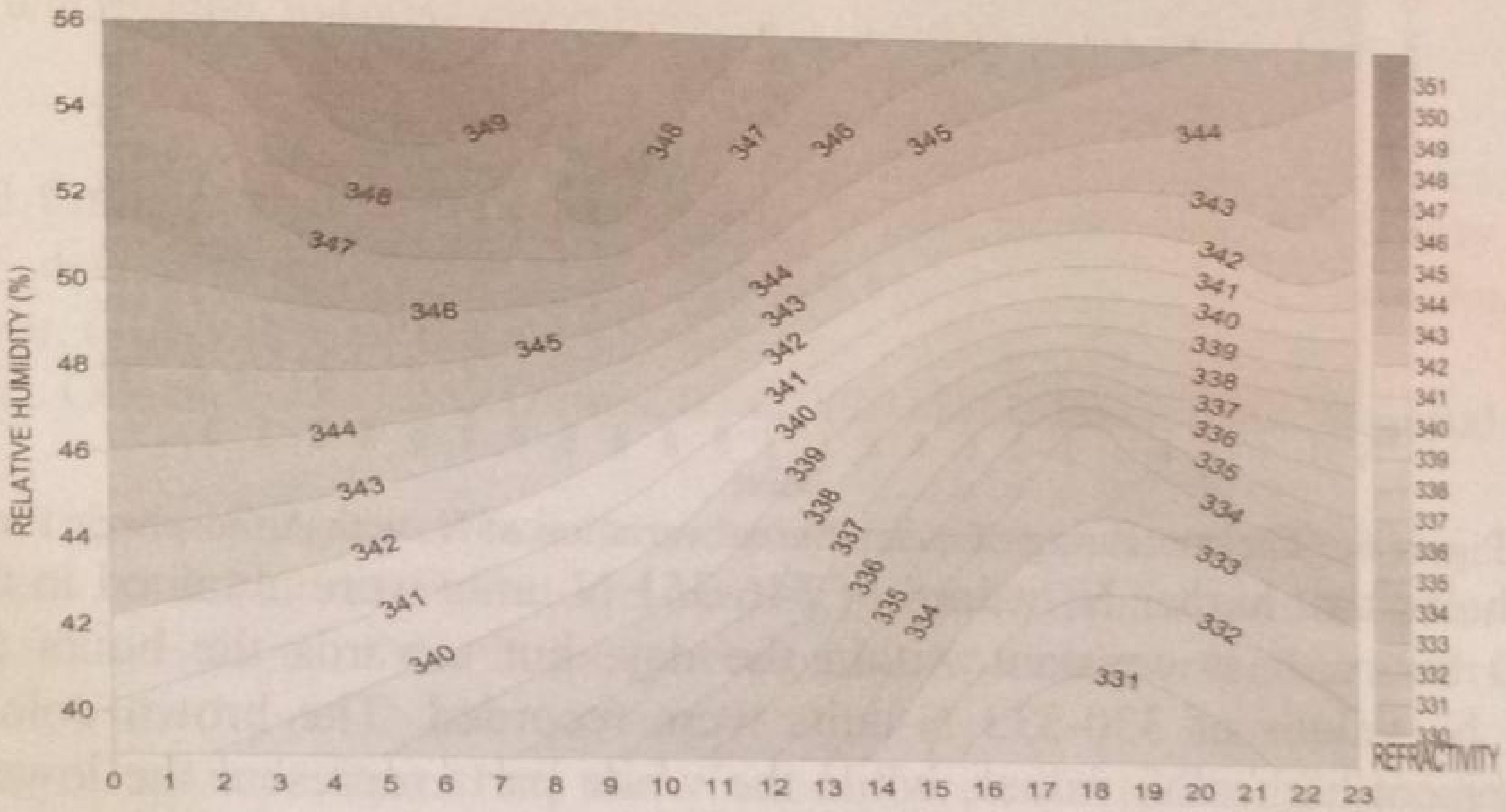

Figure 6a: The contouring of mean diurnal variation of N_s with Relative Humidity

Figure 4a shows that morning hours of the day have higher values of N_s due to high relative humidity values. The N_s values are between 346 - 351 N-units, as can be seen from the legend, the brown colour part of the contour represents the higher N_s values, which correspond to high relative humidity values. Towards the hours 14:00 – 23:00 hrs of the day, the least N_s values are recorded between 330-333 N-units, which correspond to low relative humidity values. This could be due to insolation from the Sun.The lower part is represented with white colour from the legend. This shows that N_s has direct relationship with relative humidity.

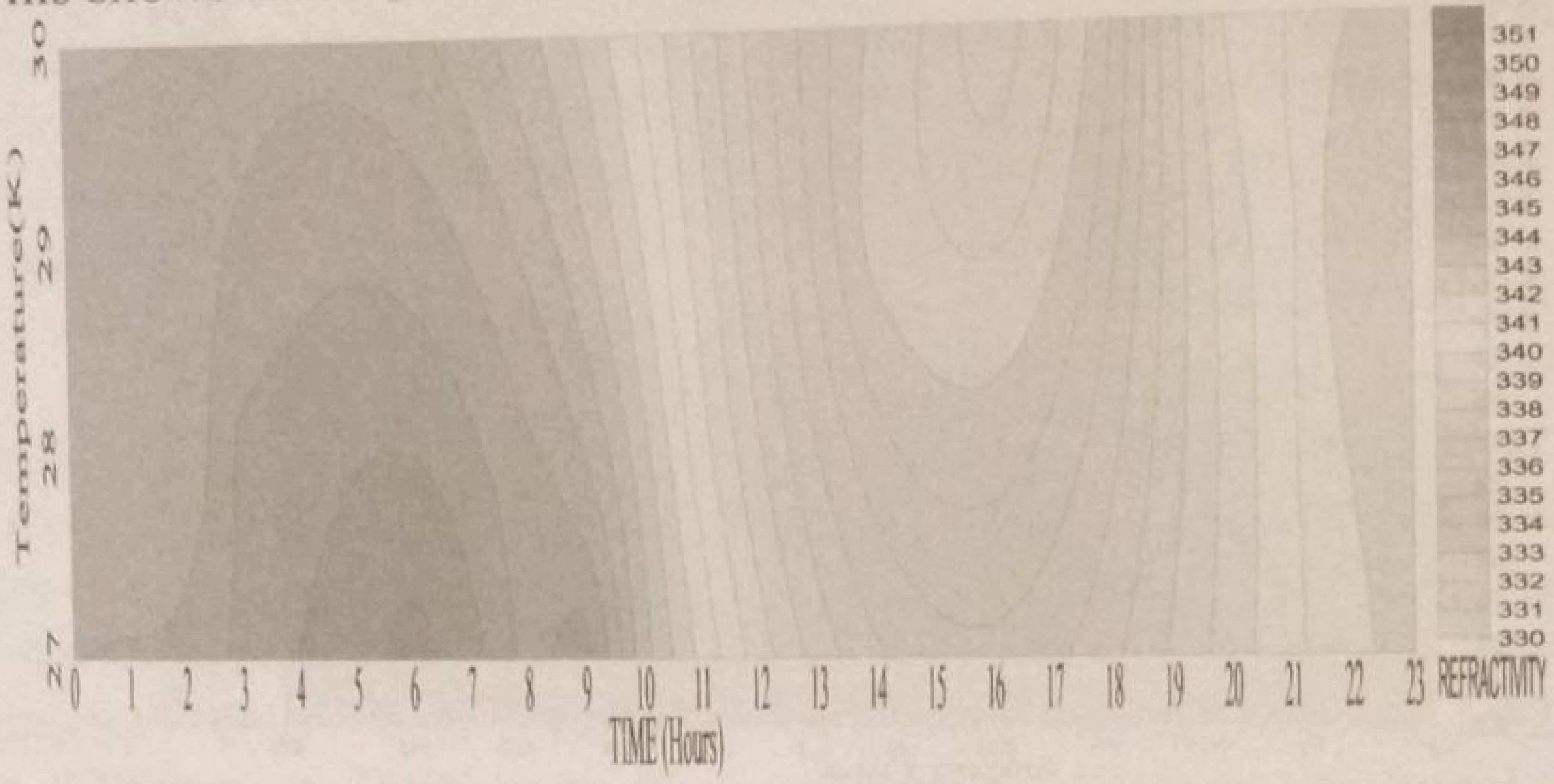

Figure 6b: The contouring of mean diurnal variation of N_s with Temperature

Figure 6b shows that the morning hours of the day, between 07:00 – 11:00 hrs, have highe values of N_s, due to low temperature. N_s values are between 345-351 N-units, as can be seen from the legend.The brown coloured parts of the contour represent higher N_s values.Toward the hours of 14:00-17:00 hrs of the day, low N_s values were recorded, between 330-333 N units, which correspond to high temperature values. This could be due to insolation from the Sun; the lower part is represented with white colour from the legend. This shows that N_s have indirect/inverse relationship with temperature.

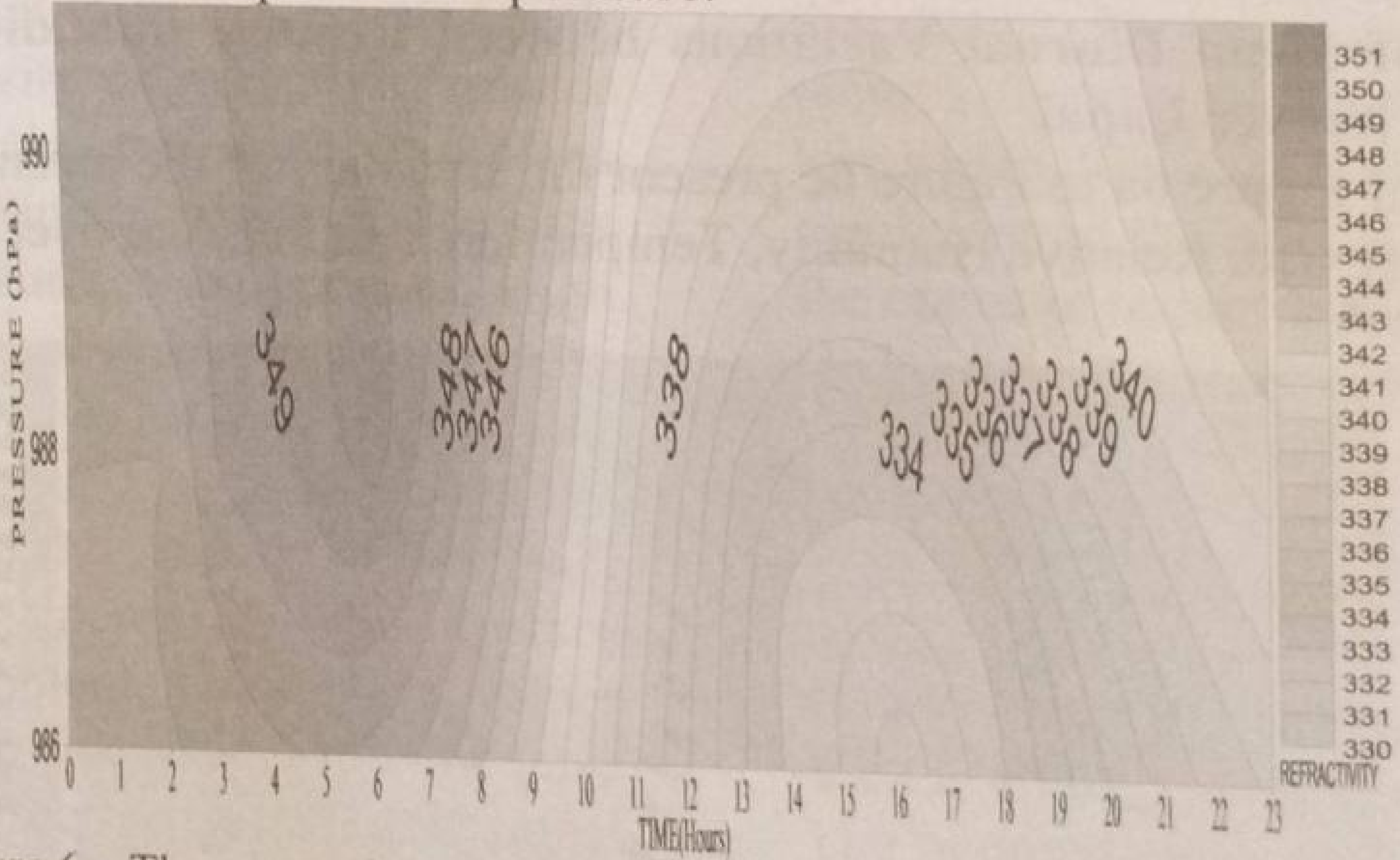

Figure 6c: The contouring of mean diurnal variation of N_s with Atmospheric Pressure

Figure 6c shows that higher N_s values of 346-351 N-units were obtained in the morning hour of 00-10:00 hours. It is constant within the day, but towards the hours of 14:00 – 18:0 hrs,reduced N_s values of 330-333 N-units were recorded. The brown coloured parts of th contour represent higher N_s values, while the white parts represent the lower N_s values. Th shows that Atmospheric Pressure has less effect on refractivity values obtained. The result reported in this study are in line with works of Oyedum et al., 2009 and Oyedum et al., 201 The author did work on both Northern and Southern parts of Nigeria.

CONCLUSION AND RECOMMENDATIONS

Conclusion

Generally, from the results obtained, the refractivity value in Lapai is between 290 to 390 N-units. The diurnal variations of refractivity are driven by the dry component in the rainy season and the wet term component in the dry season. The refractivity shows a seasonal variation with higher values in the rainy season and lower values in the dry season.The computed mean diurnal N_s over Lapai in the first 1 km is 342 N-units, which gives the refractivity gradients $\left(\frac{dN}{dh}\right)$ of -46N/km,and this shows that the station is averagely characterized by low levelsuper-refraction.The k-factor over Lapaiwithin the first 1 km is 1.38. The mean Field Strength Variability (FSV) in first 1 km of height in Lapai is 5.52 dB. The Radio Horizon distance within 1 km height for a transmitter height of 100 m over the station is 41.9 km.

Since higher the refractivity values, the better would be the performance of radio wave propagation, radio signals are better received in the wet season months than in dry season months. The results provide useful information needed by radio engineers to set up new(or improve an existing) terrestrial radio propagation links in Lapai, North-Central Nigeria. The results obtained from this study will be particularly useful in planning communication links in the region, especially at VHF, UHF and microwave frequencies since several studies have shown that there is a very high correlation between signal strength and surface refractivity. Higher refractivity values observed in the rainy season will lead to less energy loss of the signals at the VHF range and above, thereby improving the signal strength received by the receiver.

Recommendations

There is need to install several surface weather monitoring measuring locations over more parts of the region, especially the radiosonde stations to obtain upper air data with which N at higher levels can be derived as inline with ITU-R P.453 (2013), which recommends the need for local reference data on refractivity and refractivity gradients all over the world.

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