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Diurnal and Seasonal Surface Refractivity in Lagos, Nigeria

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Abstract

Estimation of radio refractivity in the lower troposphere is very important in the planning and design of terrestrial microwave radio links for optimal performance. The objective of this work is to estimate statistical variation of the diurnal and seasonal surface radio refractivity in Nigeria's coastal city of Lagos (6° 35′ N, 3° 45′ E). Data used for this work were obtained from National Space Research and Development Agency (NASRDA) Centre for Lower Atmospheric Research, Anyigba, based on Campell's weather instrument that logged data at every 5 minutes. The surface values of water vapour pressure, air pressure and air temperature for the years 2006-2010 were analysed to obtain the diurnal and seasonal refractivity profiles. The results obtained reveal that average surface refractivity in Lagos is 388 N-units. The most prevalent refractivity condition in this region is super-refraction and the mean refractivity gradient in the first kilometre of the troposphere is -48 N-units/km. The diurnal trend shows that surface refractivity is more pronounced in the night in the rainy season, but during the dry season it is highest in the evening time. The result also shows that refractivity is generally higher in the wet season than in the dry season. Optimal planning of Nigeria's terrestrial radio network cannot be achieved without long-term surface refractivity data for Nigerian stations. Thus, more efforts should be made in this respect, and to possibly match the derived refractivity profiles with actual propagation data.

Keywords: Surface refractivity, refractivity gradient, diurnal and seasonal variations, k-factor.

1. Introduction

Radio ray propagated through the Earth's atmosphere is influenced by variations in the atmospheric refractive index along its trajectory, which causes the ray path to curve.

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Atmospheric gases will absorb and scatter the radio path and energy, the amount of absorption and scattering being a function of frequency and altitude above sea level (Valtr and Pechac, 2005). At frequencies above 30 MHz, the troposphere has an increasing effect on radio signals and radio communication systems. Depending on prevailing conditions, radio signals are able to travel over greater distances greater than obtained by line-of-sight calculations. At times conditions change and radio signals may be detected over distances of 500-1000 km and more. At times signals may even be trapped in an elevated or surface duct and propagate in a mode referred to as tropospheric ducting. The radio refractive index of a medium is defined as the ratio of the velocity of propagation of a radio wave in free space to the velocity in the medium. At standard atmosphere conditions near the Earth's surface, the radio refractive index, n, has a value of approximately 1.0003. The radio refractivity index, n, is related to radio refractivity by the following formula (Freeman, 2007):

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

where N is Radio Refractivity. It can also be expressed by:

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

$$e = \frac{He_s}{100} \quad (3)$$

$$e_s = aexp\left(\frac{bt}{t+c}\right) \quad (4)$$

where H = relative humidity (%), t = Celsius temperature (°C), T = Absolute temperature (K) and e_s = saturation vapour pressure (hPa) at the temperature t (°C)

2. Instrumentation and Data Handling

The monthly data for atmospheric pressure, relative humidity and temperature were obtained from Nigeria Meteorological Agency in Abuja.The Nigerian Meteorological Agency (NIMET) makes use of MIDAS IV Automatic Weather Observing Station (AWOS) for the data collection over the years (Aderinto and Ibukun, 2007). The daily data were obtained from the National Space Research and Development Agency (NASRDA) Centre for Lower Atmospheric Research, Anyigba, based on Campell's weather instrument that logged data every 5 minutes.

Air pressure, relative humidity, and temperature between 2006 and 2010 for Lagos were processed with computer. The values for saturated water vapour, water vapour pressure, and refractivity were computed using Microsoft excel. The monthly and diurnal surface refractivity, field strength variability, radio horizon distance and reduced-to-sea-level refractivity were determined. The variation of diurnal surface refractivity and related atmospheric parameters were also presented as contour maps. Meteorologists and oceanographers use a technique called contour analysis to visually explain the information the data are providing. Contouring data represents an elementary step in data analysis.

3. Results and Discussion

The inter-annual seasonal surface refractivity and mean monthly surface refractivity are as shown in Figure 1 and Figure 2 respectively. It can be observed from the graphs that surface refractivity in Lagos from the year 2006 to the year 2010 show the influence of rainy and dry seasons. There was sharp increase of the surface refractivity from April to July and slight decrease in August, which indicates the August break in the wet season. The Month of January experienced the least values of refractivity, except in the year 2008 and 2010 when compared to the values in other months. In the year 2008, the lowest value was experienced in October, and in 2010, the lowest value was in July.

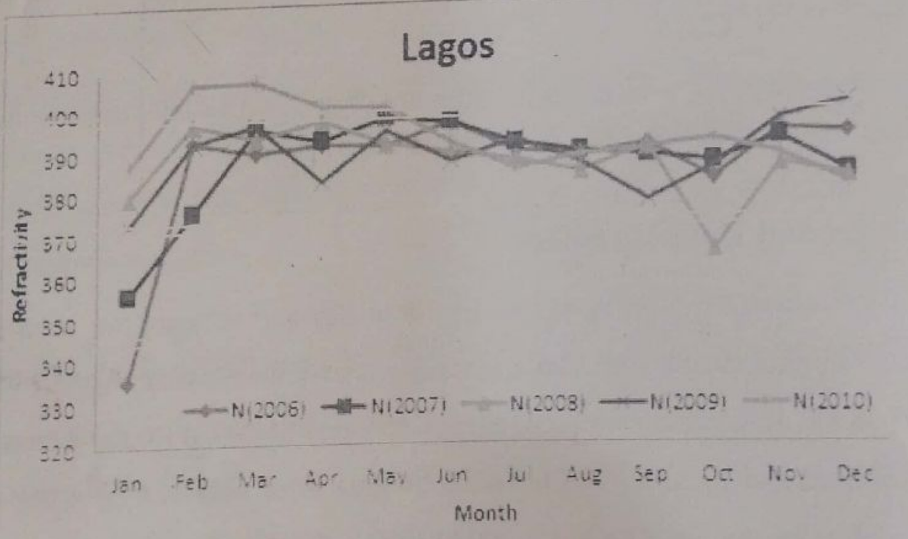

Figure 1: Inter-annual seasonal variation of refractivity

Figure 2 show that Lagos has lowest refractivity of 366 N-units in January and highest refractivity of 396 N-units in March. The average refractivity in Lagos was 388 N-units. In January, all regions north of 4°N in Nigeria are under the influence of the dry continental tropical (cT) air mass. Conditions are generally such that little or no precipitation is experienced and refractivity values are low, and show marked decrease from the coast to inland areas. During March and April, the ITD position would be between 10°N and 15°N or at lower latitudes meaning that the regions are now beginning to experience little amount of rainfall making variability in the refractivity values to be higher. The implication of the result is that signal strength would be higher in the dry season than in the rainy season (Famoriji and Oyeleye, 2013).

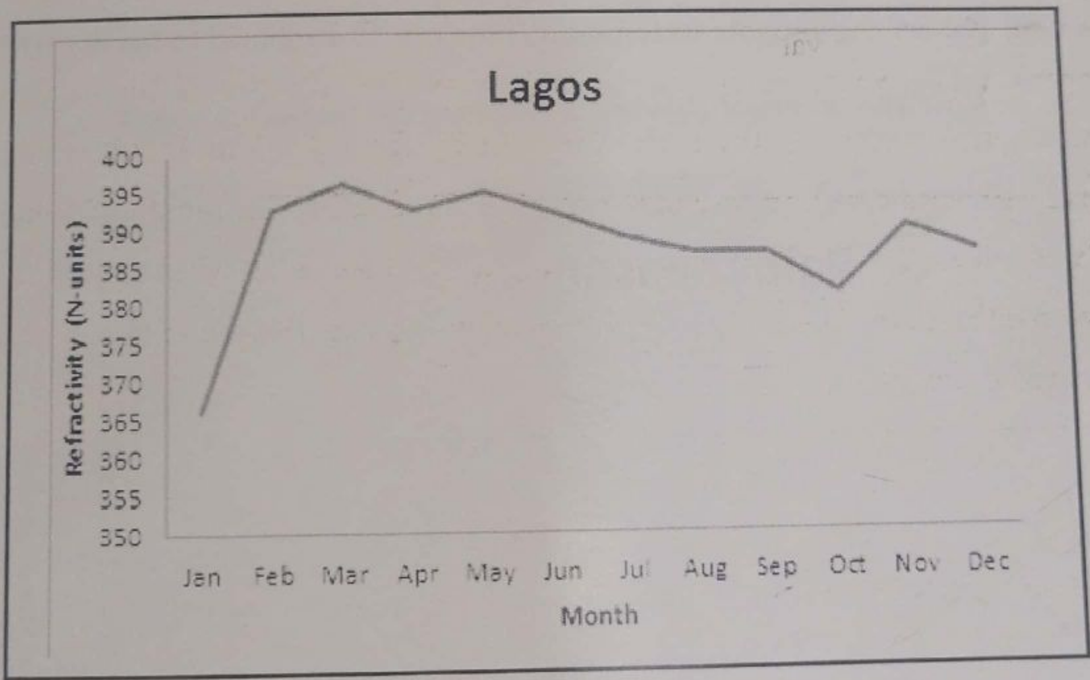

Figure 2: Mean Monthly variation of refractivity

The daily surface refractivity for both wet season and dry season are obtained at intervals of one hour for the whole 24 hrs of the day. The dry months include November, December, January, February and March, while the rest are wet months. The time considered to be early morning is between 00:01 to 05:59 hrs, morning is between 06:00 to 11.59 hrs, noon is 12:00 hrs, afternoon 12.01 to 17:59 hrs, evening is between 18:00 to 19:59 hrs, night is 18:00 to 23:59 hrs and Mid-night is 00:00 hr.

Figure 3 shows diurnal variation of N_s in rainy season of the year. It can be inferred from the graph that refractivity increases over time, between 1:00 to 15:00 hrs and falls slightly from 07:00 to 12:00 hrs of the day. It reaches the maximum of 396 N-units at 15:00 hrs and falls for the rest of the time. To fully understand the diurnal behaviour of refractivity and the variation during the rainy season in Lagos, the related meteorological parameters involved were considered with refractivity in the rainy season in Figures 4 to 6. Figure 5 shows the diurnal variation of refractivity with atmospheric temperature. It can be observed that in the early morning, temperature is low as well as pressure in Figure 6, but humidity is high as illustrated in Figure 4; this implies that the slight increase experienced at the early hour of day is influenced by wet term of the refractivity. Between 13:00 to 20:00 hrs, the refractivity is more pronounced than in the early morning, this is expected because the temperature as well as pressure is also high during this period. The driving variable factor at this time can be attributed to the dry term of the refractivity.

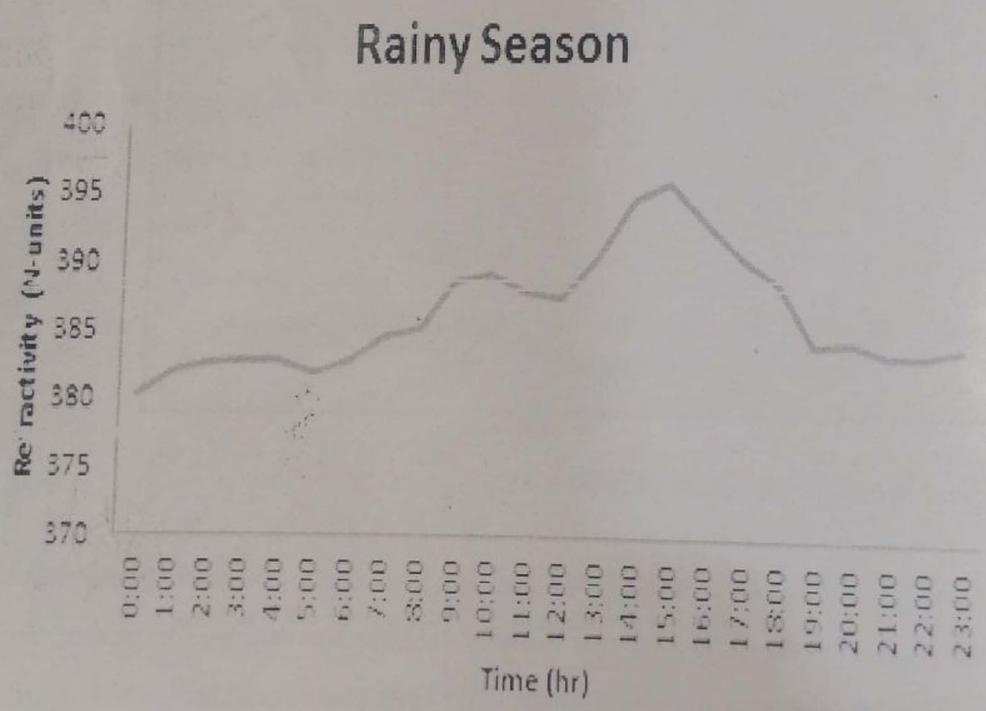

Figure 3: Diurnal Variation of Surface Refractivity

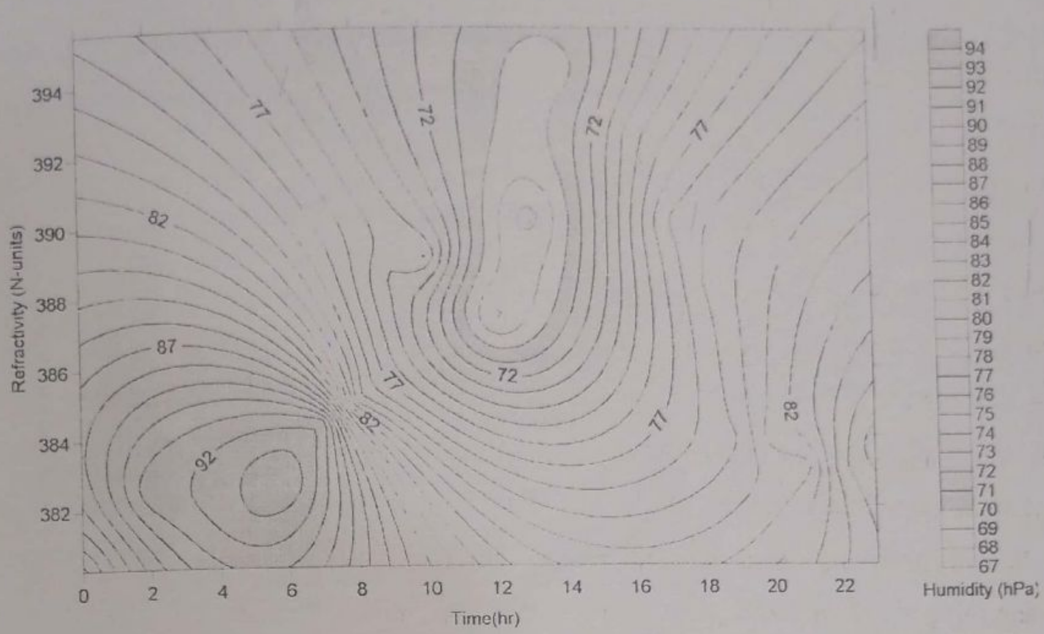

Figure 4: Diurnal Variation of N_s and H in Rainy Season

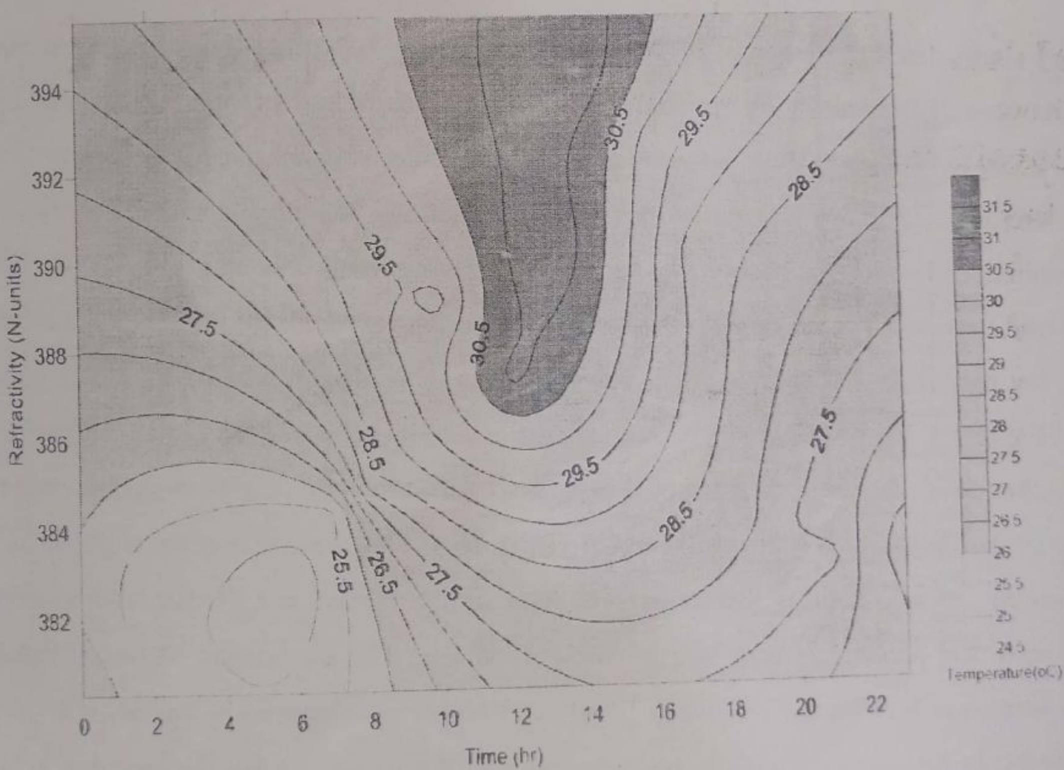

Figure 5: Diurnal Variation of N_s and T in Rainy Season

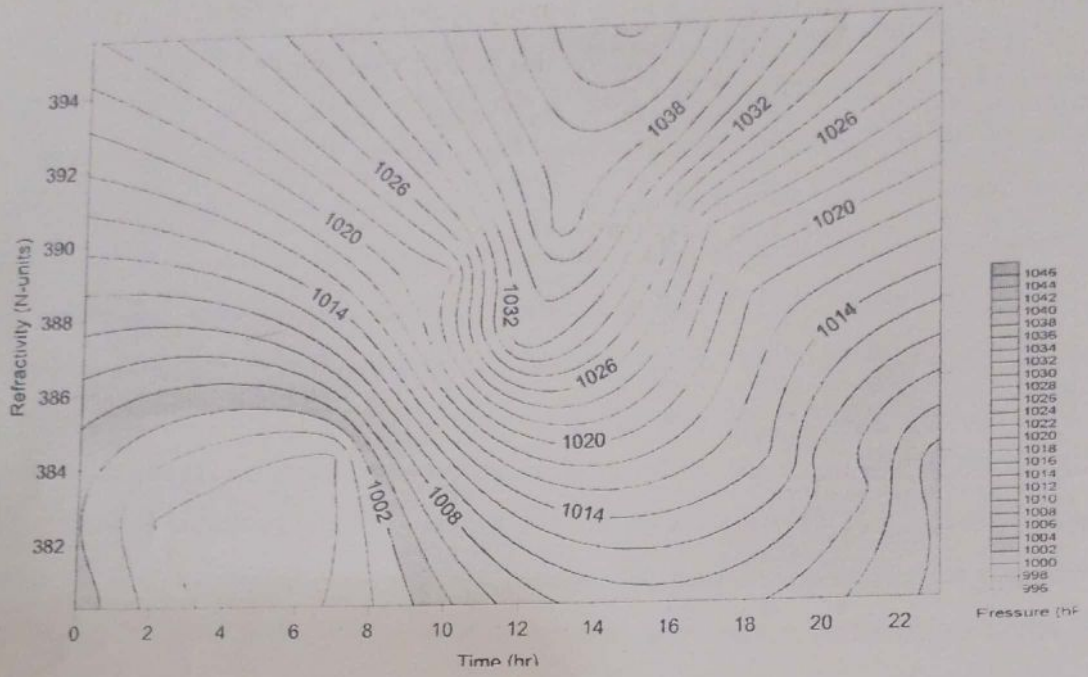

Figure 6: Diurnal Variation of N_s and P in Rainy Season

Figure 7 shows diurnal variation of surface refractivity in Lagos during the dry season. At early hour between 01:00 and 05:00 hrs there is slight increases in refractivity, which later falls around 05:00 to 08:00 hrs. There is steady increase in the afternoon but this is cut short at 17:00 hr; N_s later rises again and reaches its maximum value of 392 N-units at 18:00 hrs of the day. The minimum value of 377 N-units was experienced during the first hour of the day. To fully understand the diurnal behaviour of refractivity and the forcing factor during the dry season in Lagos, the meteorological parameters involved were considered with refractivity in dry season in the Figures 8 to 10. Figure 9 shows diurnal variation of refractivity with atmospheric temperature. It can be observed that in the early hour, temperature is low as well as pressure in Figure 10, but humidity is high as illustrated in Figure 8. This implies that the slight increase experienced at early hour is driven by wet term of the refractivity. In the afternoon, the temperature and pressure is high but the humidity is low. The implication of this is that the steady increment in refractivity between 12:00 to 17:00 hrs is influenced by the dry term of the refractivity. In the evening hours, the pressure and temperature are low but the humidity is high. The driving factor at this time can be attributed to the wet term of the refractivity. Figure 11 shows the relationship between the surface refractivity in dry season and wet season. The result reveals that refractivity is higher in the wet season than dry season except at the early evening time. This is in agreement with previous studies on this work (Ayantunji and Okeke, 2011). Thus, there would be better signal strength in wet season than in dry season.

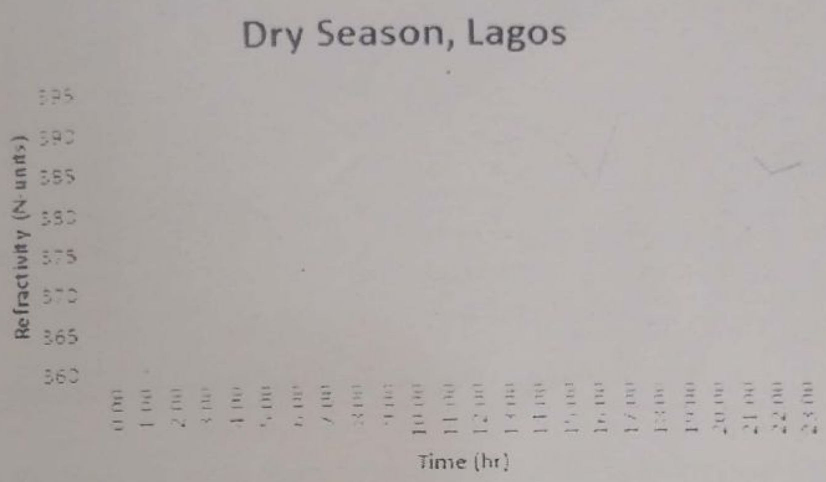

Figure 7: Diurnal Variation of Surface Refractivity in Dry Season

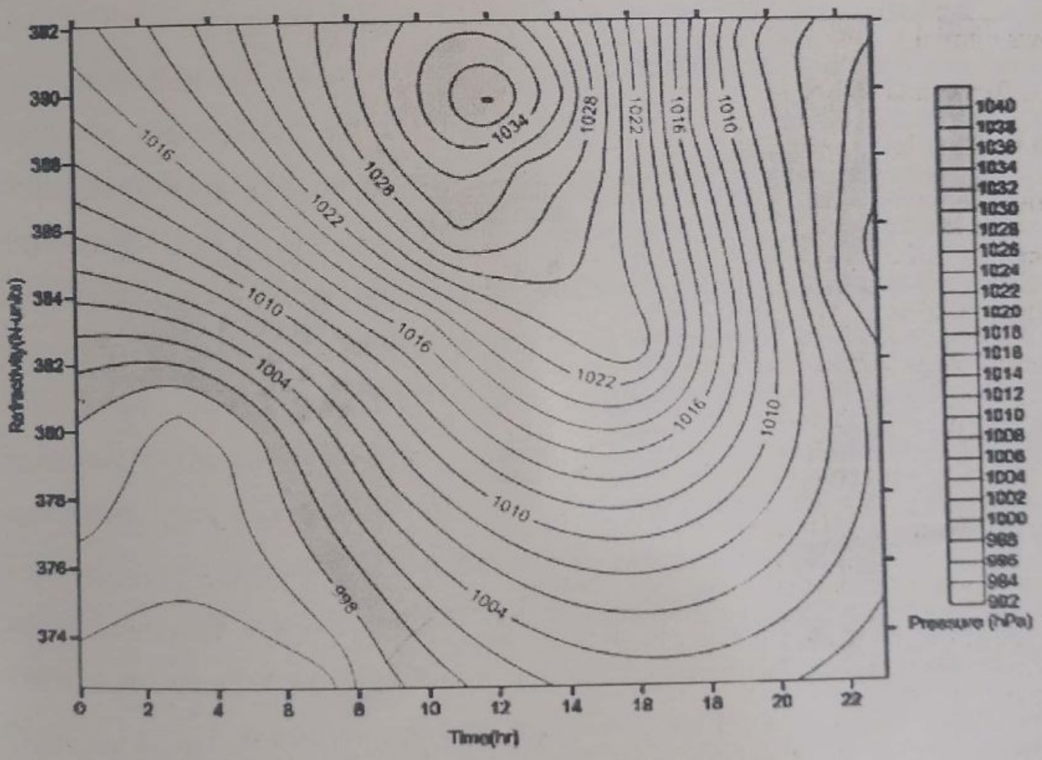

Figure 8: Diurnal Variation of N_s and P in Dry Season

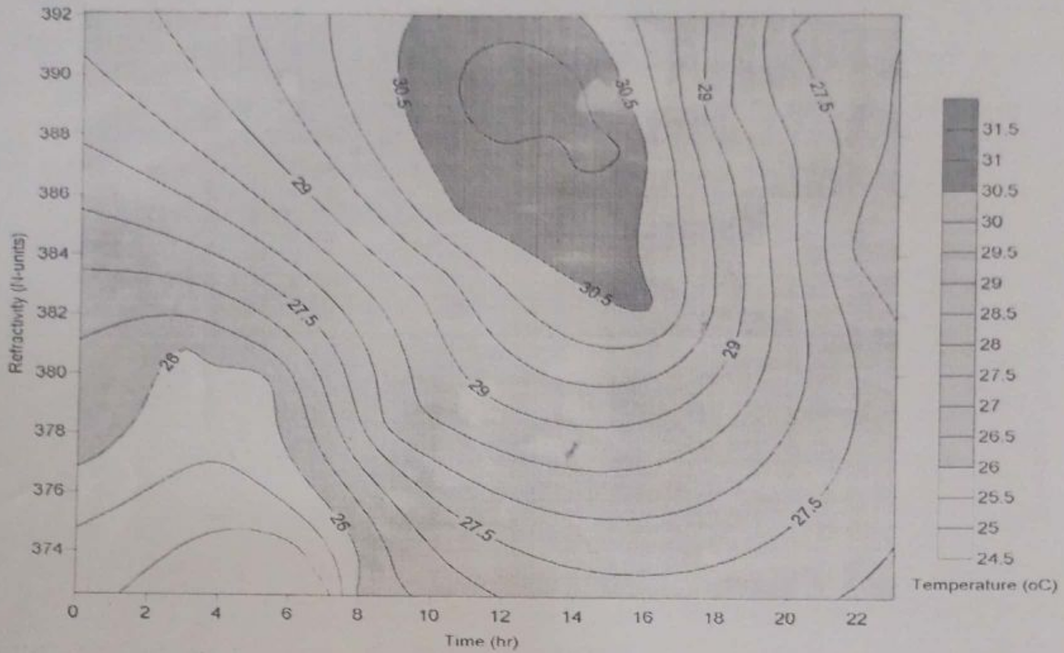

Figure 9: Diurnal Variation of N_s and T in Dry Season

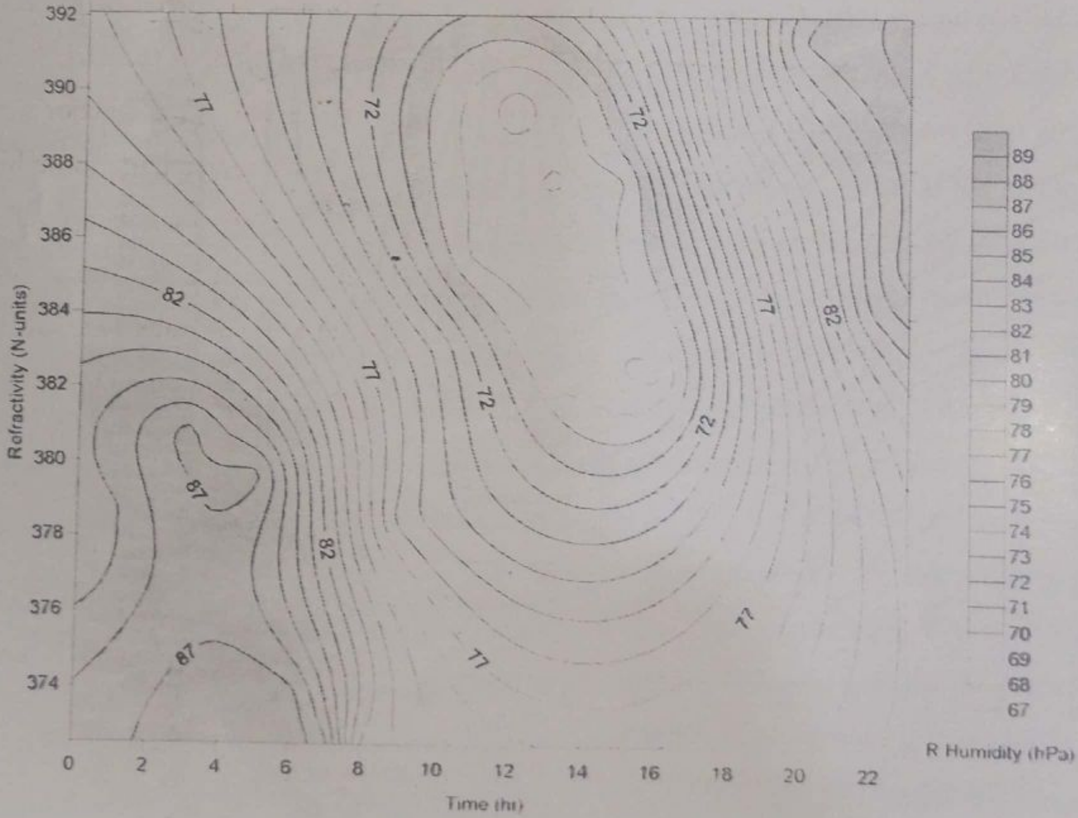

Figure 10: Diurnal Variation of N_s and H in Dry

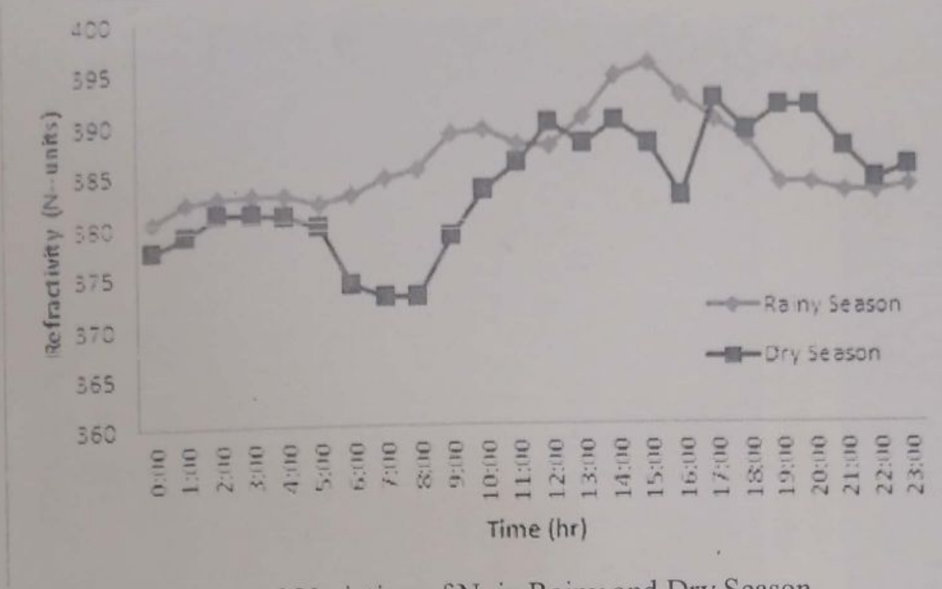

Figure 11: Diurnal Variation of N_s in Rainy and Dry Season

Figure 12 shows the mean diurnal variation of surface refractivity in Lagos. In early morning and morning period refractivity is low, but later rises from 09:00 hrs until i' reaches its peak value of 392 N-units at 15:00 hrs and 16:00 hrs in the afternoon. The slight increase in the early morning (0:00 to 5:00 hrs) could be as a result of increases in water vapour at the early hours due to the response of the earth to reduced solar insolation (at night) which is the major force behind the weather condition observed. The solar insolation causes the temperature to be high and humidity to be low during the day, and vice versa at night. The fall in refractivity observed at 07:00 hrs could be associated with the decrease in the air moisture as the sun starts rising, which neutralises the effect of the wet term in the results at 09:00 hrs. The minimum value of 379 N-units is realised around 00:00 hr in the early morning while the maximum of 392 N-units is realised in the afternoon. The maximum refractivity during the day is connected to the dominating factor (dry term) of the refractivity which is the driving force around this time. Figure 13 shows the monthly variation of the effective Earth Radius Factor in Lagos. The average value of the k-factor is 1.44, which implies that radio propagation condition in this station is mostly super-refractive. Figure n shows the contour of seasonal variations of N_s and k-factor in Lagos. It can be inferred from the contour that the higher the k-factor, the higher the surface refractivity and the lower the k-factor the lower the refractivity.

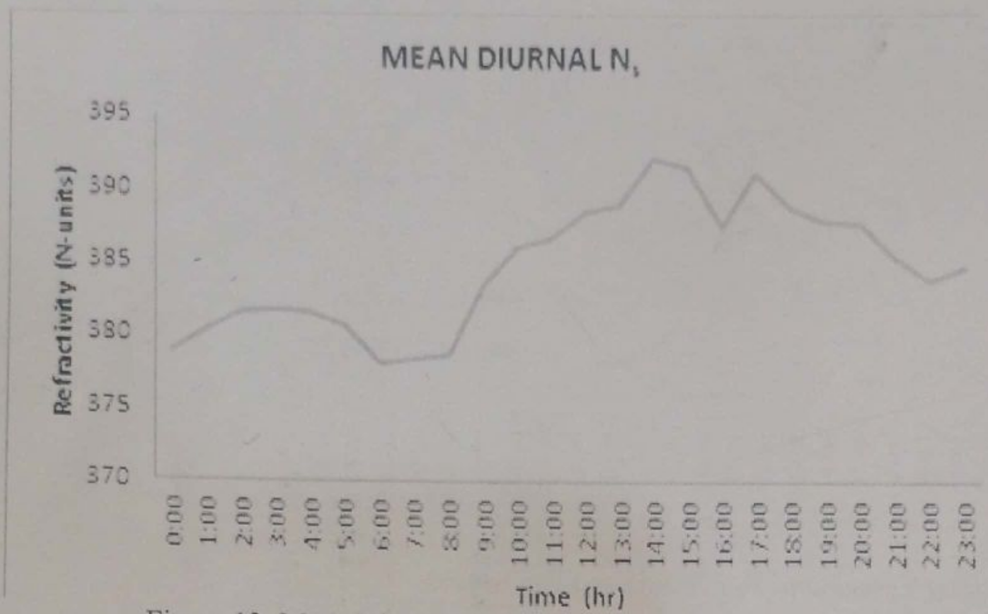

Figure 12: Mean Diurnal Variation of N_s

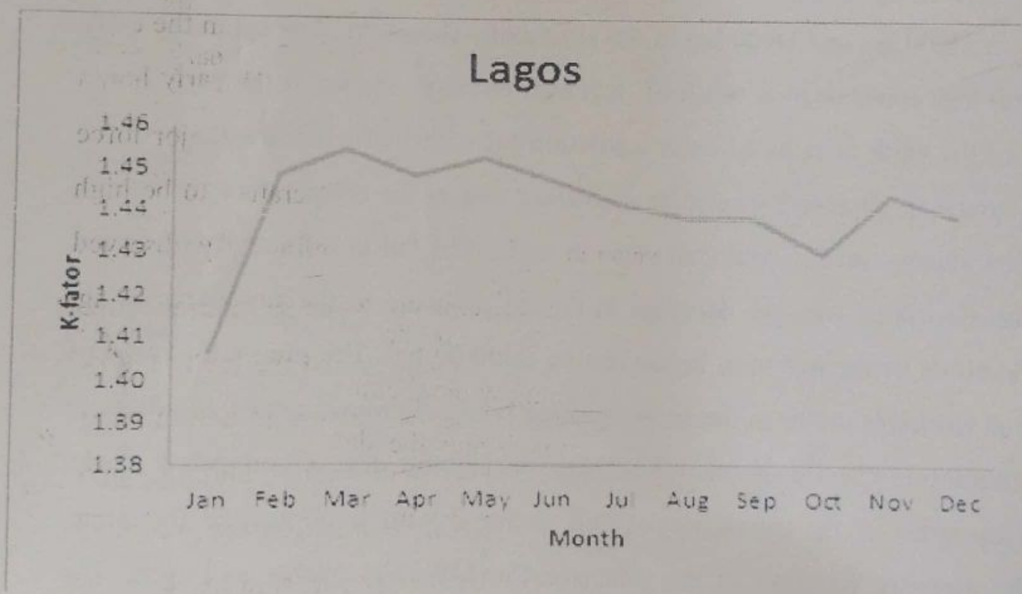

Figure 13: Seasonal Variations of Earth Radius

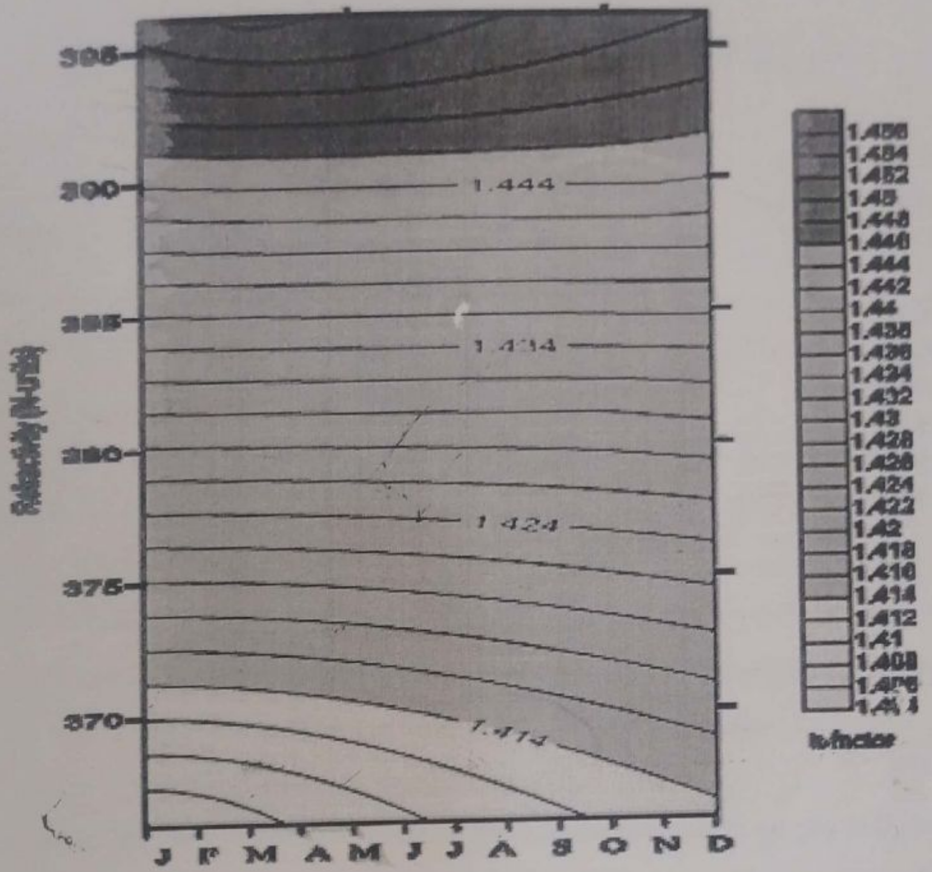

Figure 14: Contour of k-factors Versus N_s

Figure 14 shows the contour map of k-factors versus surface refractivity. It can be inferred from the contour that the higher the k-factor, the higher the surface refractivity and the lower the k-factor the lower the refractivity. k-factor is one of the most essential factors in determining obstacle clearance in the path of propagating LOS signal. Maximum and minimum radio horizon distance for 100 m transmitter antenna height and the seasonal variations are presented in Figures 15. It can be observed that maximum radio horizon distance is observed in March as 30.44 km and the minimum observed in January is 29.93 km. Thus, allowance must be made for fluctuation of about 510 m for the coverage distance of a transmitter of 100 m height while designing radio links within Lagos.

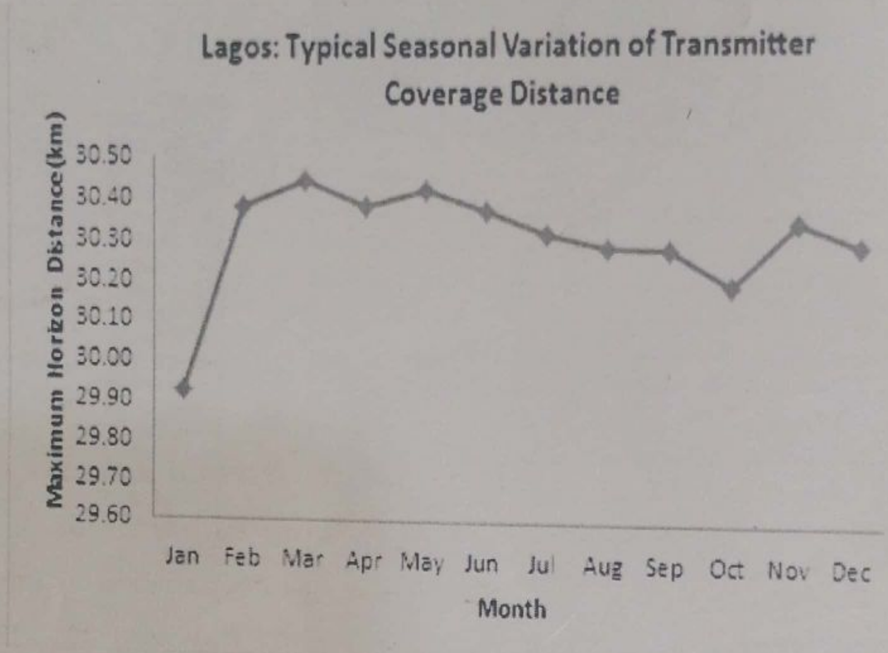

Figure 15: Seasonal Variation of Radio Horizon

4. Conclusion

The salient points that can be deduced from this work are as outlined below. The mean surface refractivity for Lagos is 388 N-units and the refractivity change over the first 1 km is -48 N-units/km. Surface refractivity shows seasonal variations with high values in rainy season and low values in dry season. The diurnal variation seems to be driven by the dry component in the rainy season and wet component in the dry season. The average value of the k-factor is 1.44, which implies that radio propagation condition in this station is mostly super-refractive. It is further revealed that the higher the k-factor, the higher the refractivity; so the better the signal reception. An allowance of 510 m in the coverage distance of a transmitter of 100 m height while designing terrestrial radio links in Lagos.

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