ESTIMATION OF RADIO HORIZON DISTANCE USING MEASURED METEOROLOGICAL PARAMETERS OVER SOME SELECTED LOCATIONS IN NIGERIA

ABSTRACT

In this study, results of the variation of maximum and minimum radio horizon distance derived from the computation of surface refractivity through measurement of temperature, relative humidity and pressureacrosssevenlocations((Akure *(*7.15ºN*,* 5.12ºE*)*, Lagos (6.30ºN, 3.20ºE), Abuja (7.10ºN, 9.25º E), Jos (9.50ºN, 8.50ºE), Makurdi (7.30ºN,8.53ºE), Port-Harcourt(4.20ºN,7.00ºE), and Nsukka (6.90ºN,7.67ºE)) in Nigeria are presented. Two years (Jan., 2011–Dec., 2012) archived data as provided by Tropospheric Data Acquisition Network (TRODAN) of the Centre for Atmospheric Research Anyigba, Kogi State were utilized for the study. Results showed that the values of surface refractivity (N_s) were low during the dry season months and high during the wet season months and also there was high value of N_S at the coastal areas compared with the inland areas. It was also deduced that the mean value of N_S for Abuja, Akure, Jos, Lagos, Markurdi, Nsukka and Port-Harcourt is 355, 362, 303, 391, 375, 361 and 399 N-units respectively. Results showed that the Radio Horizon Distance (R_{DH}) values were generally low during the wet season months and high during the dry season months. The variability of radio horizon distance of transmitting antennas is higher in the Northern part of Nigeria than the southern part.

Keywords: Refractivity, Radio Horizon distance, Transmitting Antenna, Meteorological parameters, Troposphere.

1.0 INTRODUCTION

Radio wave propagation is the sending out of electromagnetic energy from a transmitter to a receiver and it is affected by the rate of change of the radio refractivity*,* *N* with altitude of air in the troposphere [1, 2]. The propagation environment is the geographical area over which the wave spreads between a transmitter and a receiver. This environment is generally described by the physical parameters of the medium, like humidity, pressure, temperature or refractive index. Refractive index of a medium is the ratio of the velocity of propagation of radio wave in a vacuum to its velocity in the specified medium. Moreover, how far a radio signal will travel within the radio horizon is determined by the distribution of the radio refractivity. Mobile communication systems employ the microwave frequency bands because of its broad bandwidth [3,4].

The radio horizon is the locus of points at which direct rays from an antenna are tangential to the surface of the Earth. It is theoretically the maximum distance an unobstructed radio signal will travel from the transmitter before grazing the surface. For a receiver to be effective, it must be installed within that distance. The radio horizon of the transmitting and receiving antennas can be added together to increase the effective communication range. Optical horizon is the locus of points at which a straight line from the given point becomes tangential to the earth’s surface. Figure 1 shows the relationship between the optical horizon distance and radio horizon distance.

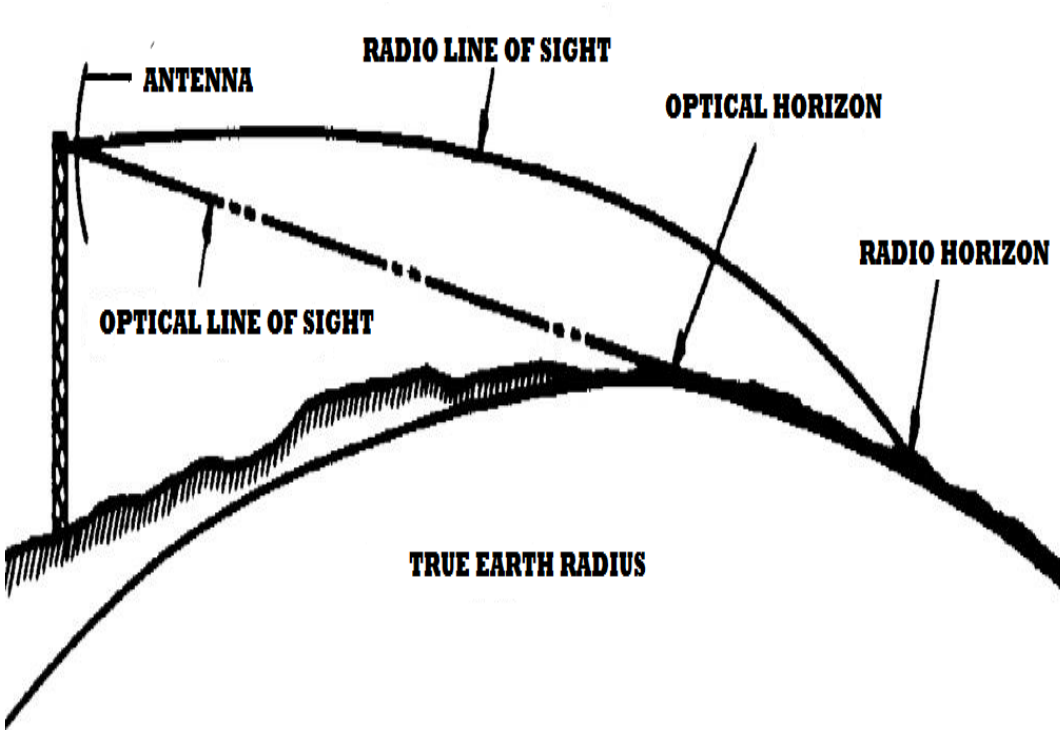

Fig .1. Relationship between optical horizon and radio horizon. [5]

Several researchers have studied Electromagnetic wave (EMW) medium interaction processes and the propagation implications over Nigeria, especially the study of variation of radio field strength and radio horizon distance over few stations in Nigeria [2, 4]. This is not enough to generalise the variation of radio field strength and radio horizon distance over Nigeria, due to variation of meteorological parameters in each geographical location. Hence, this work studied the variation of radio field strength over seven locations in Nigeria covering the different climatic conditions. Two years data of atmospheric variables: temperature, pressure and relative humidity obtained for Abuja, Akure, Jos, Lagos, Markurdi, Nsukka and Port-Harcourt locations were employed. The data were used to compute the surface radio refractivity which was then used to study the seasonal variability of radio horizon distance over Nigeria.

1.1 CLIMATIC CHARACTERISTICS OF NIGERIA.

Nigeria lies between latitudes 4°N and 14°N and longitude 3°E and 15°E, covering an area of about 924000 km^2. The climate of Nigeria is broadly equatorial and tropical continental. Movement of t he Inter Tropical Discontin-uity (ITD) complemented by aspects of ocean atmosphere coupling make Nigeria's climate truly tropical with generally high temperature ranging from 24℃ to 27℃ and annual mean temperature of 27℃ in the tropical rainforest down south but higher mean value in the sub-Sahel up north. Tropical maritime air mass (south-westerlies) and tropical continental air mass (North-Easterlies) constitute the main wind system over the country. While the former fills the troposphere with moisture in the wet season, the latter brings a lot of Harmattan dust from the Sahara during the dry season. The climatic characteristics of the study locations is shown in table 1

The Northern part of Nigeria experiences a long dry season (October to mid- May) followed by a short rainy season (June –September), during which annual mean is about 50 cm. However, the southern part experiences a long rainy season (March-October) with maximum in June/July with a short dry period of about 2-3 weeks in August and a long dry season from mid- October to Early March. Annual mean along the South-Eastern Atlantic coast is about 400 cm. These rainfall regimes endow Nigeria with two broad vegetation belts that comprise the Forest to the south and the savannah to the north [4,6]. Figure 2 shows the map of Nigeria indicating the locations considered for this study

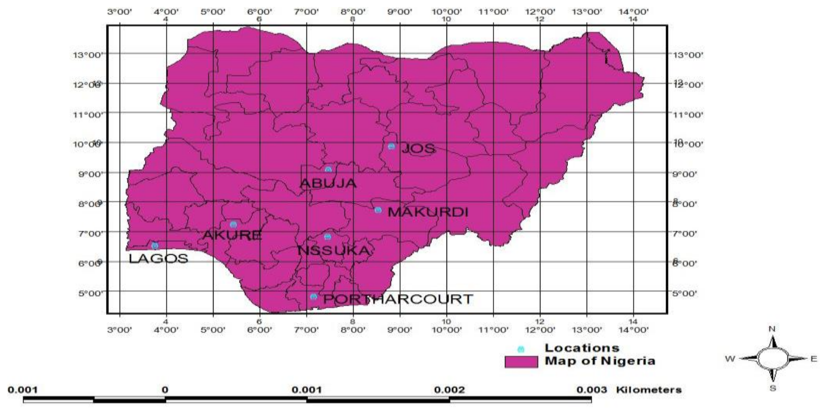

Fig. 2. Digitized map of Nigeria showing the study areas.

Table 1: Characteristics of the study locations.

LOCATIONS	LATITUDE ($°N$)	LONGITUDE ($°E$)	ELEVATION (m)	CLIMATE
ABUJA	7.10	9.25	840	Guinea Savannah
AKURE	7.25	5.21	396	Tropical Maritime
JOS	9.88	8.86	1217	Sahel Savannah
LAGOS	6.30	3.20	41	Monsoonal savannah
MAKURDI	7.73	8.53	104	Guinea Savannah
NSUKKA	6.90	7.67	552	Tropical-Rain Forest/Savannah
PORT-HARCOURT	4.82	7.05	27	Swampy

Source: [7, 8]

2. **Theory and Method**

Two-year (2011-2012) meteorological variables (pressure, temperature and relative humidity) were obtained from the archived data of Akure (7.15ºN, 5.12ºE), Lagos (6.30ºN, 3.20ºE), Abuja (7.10ºN, 9.25ºE), Jos (9.50ºN, 8.50ºE), Makurdi (7.30ºN, 8.53ºE), Port-Harcourt (4.20ºN, 7.00ºE), Nsukka (6.90ºN, 7.67ºE). Each of the locations is equipped with complete wireless weather equipment as provided by Tropospheric Data Acquisition Network (TRODAN). The radio refractivity, N is related t o radio refractive index and from the data collected, radio refractivity and field strength are computed [9] as;

$$N = (n-1) \times 10^6 = \frac{77.6}{T}(p + \frac{4810 \times e}{T}) \tag{1}$$

where T (K) is the air temperature, P (hPa) is air pressure and e (hPa) is water vapour pressure. Eq. (1) consists of two terms: the dry term and the wet term.

$$N_{dry} = \frac{77.6\, p}{T} \tag{2}$$

$$N_{wet} = \frac{3.73\times10^5}{T^2}e \quad (3)$$

the dry term contributes about 70% to the total value of refractivity while the wet term is mainly responsible for its variability [10, 11].

Surface refractivity correlates highly with radio field strength, especially at the VHF bands. In the frequency range 30–300 MHz, a factor of 0.2 dB change in field strength may be adopted for every unit change in N_s [12, 13]. Using Ns values obtained in a given calendar month, maximum (N_s(max)), and minimum (N_s(min)) values of N_s are determined, from which the monthly range is obtained as;

$$\text{Monthly range} = N_{S(max)} - N_{s(min)} \quad (4)$$

Thus, an assessment of field strength estimation (FSE) in a given location is explored from monthly ranges of N_s using the relation;

$$FSE = N_{S(max)} - N_{s(min)} \times 0.2 \text{ dB}. \quad (5)$$

The radio horizon distance (R_{DH}) in each station was also calculated using the relation [15]:

$$R_{DH}= \sqrt{2kah_t} = \sqrt{2a_e h_t} \quad (6)$$

$$K= (1 + a\Delta N \times 10^{-6})^{-1} \quad (7)$$

$$a_e=ka=[1 + a(-1.46exp(0.00981N_s)) \times 10^{-6}]^{-1}a \quad (8)$$

where:
k - earth radius factor, a =earth's radius

a_e –Equivalent earth radius
h_t –Transmitter height and ΔN - Refractivity gradient.

2.1 INSTRUMENTATION

The instrument used for the measurement of the atmospheric parameters used for this study is the wireless weather station shown in Figure 3, which consists of a solar panel which converts the sun rays in to electrical energy, a rain collector that measures the amount of rainfall and a tipping bucket rain gauge that measures the rain rate, sensors that measure temperature, pressure, relative humidity, UV index dose, solar radiation, anemometer that measures wind speed and direction. It is calibrated to measure the weather parameters in 5 minutes integration time. The data is stored in the data logger and then copied to a computer for analysis. The equipment was installed in all the locations considered for this study by the Centre for Atmospheric Research, (CAR) Anyigba, Kogi state. The centre is one of the activity centres of the National Space Research a nd Development Agency, (NARSDA) in Abuja Nigera. Tropospheric Data Acquisition Network (TRODAN) is a unit of CAR.

Fig. 3. Tropospheric Data Acquisition Network (TRODAN) set up at a location.

3.0 RESULTS

3.1**Seasonal Variation of Surface Refractivity over the Stations**.

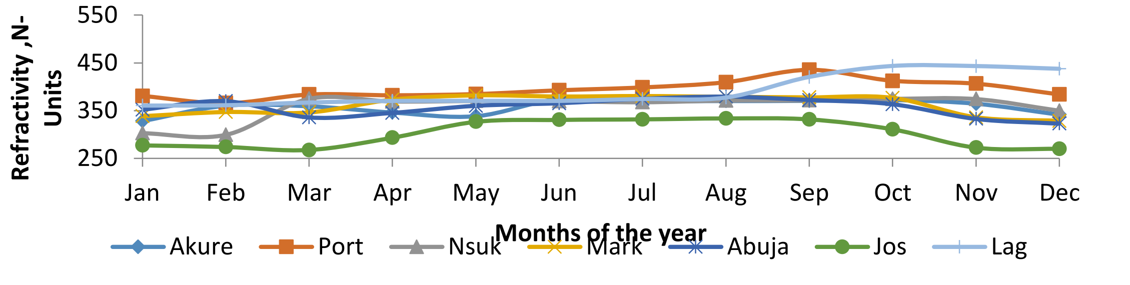

Fig. 4. Seasonal variation of surface refractivity over the stations for year 2011.

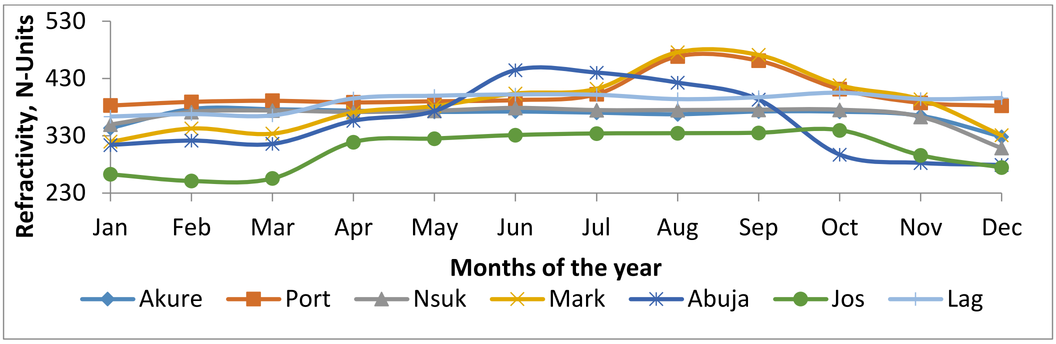

Fig. 5. Seasonal variation of surface refractivity over the stations for year 2012.

Seasonal Variation of Surface Refractivity over the Stations

Figures 4 and 5 showed the seasonal variation of refractivity for the study areas over the periods of two years (2011-2012) considered for this study. It is observed from the result that the result agreed with the works of [12, 13, 15, 16]. There is seasonal variation of refractivity at all the stations studied an increase in the value of refractivity from minimum value of about 250.9 N-units at Jos station to maximum value of about 469 N- units in Port-Harcourt. This result compare favourably well with the works of [9, 12,] where they obtained 270 N-units as a minimum value of surface refractivity in Sokoto and 390 N-units as the maximum value in Lagos. It can also be seen that in 2011, Lagos has the maximum value of refractivity of 436 N- units in December which is expected to be low. This is due to the influence of the Atlantic Ocean on the station and also high humidity and water vapour. Jos has the minimum value of refractivity 269 N-units in December. In 2012, Port-Harcourt has the maximum value of refractivity of 468 N-units in August. The mean value of surface refractivity for the stations, Akure, Lagos, Abuja, Markurdi, Port-Harcourt, Jos and Nsukka for the two years are 361.86 N-units, 390.87 N-units, 354.74 N-units, 371.41 N-units, 396.91 N-units, 323.76 N-units and 360.35 N-units. The result of Akure station compares favourably well with the works of [4, 17] where they obtained mean value of surface refractivity for five years to be 364.74 N- units and 369 N-units respectively. Similarly, [18] obtained a mean value of surface refractivity of 365 N-units and 367 N-units for years 2007 and 2008 respectively over Akure. It is seen form the results of the mean value of surface refractivity that Jos has a very low value of refractivity. This is may be due to the altitude which is ~1217 m above sea level. At this altitude pressure variation seems insignificant. It is also shown from the figures 4 and 5 that the value of refractivity depicted seasonal variation with high values during the rainy season and low value during the dry season. This result is in agreement with the result by [8, 12, 19], It is also shown that the surface refractivity has high value at the coastal areas compared with the inland areas. This is due to the influence of the Atlantic Ocean on the coastal areas. This result supports the work of [20]. This result is in agreement with the result obtained by [19] which was produced as world atlas for refractivity variation.

3.2 SEASONAL VARIATION OF RADIO HORIZON DISTANCE OVER THE STATIONS

Maximum and minimum radio horizon distances for different transmitter antenna heights and their seasonal variations are shown in Figures 6–19 for the seven locations over Nigeria. From the Figures, for a 200 m high antenna in each of the seven locations, the maximum radio horizon distance expected is about 1.86, 1.91, 2.67 1.70, 1.88, 1.97 and 1.74 km and the minimum of about 0.95, 1.07, 1.57, 0.70 1.00, 1.09 and 1.74 km in January, the peak of dry season. Thus, when designing radio links in any of these locations for the month of January, an allowance of about 0.91, 0.84, 1.10, 1.00, 0.88, 0.88 and 0.82 km respectively for the coverage area of a transmitter of antenna height of 200 m must be made for fluctuations of radio signal. In July, the peak of the rainy season, the locations experience a maximum and minimum radio horizon distances of 1.43, 1.42, 1.78, 1.35, 1.37, 1.41 and 1.30 km and 0.98, 1.08, 1.18, 0.60, 1.00, 0.97 and 0.93 km for 200 m transmitter antenna giving a range of about 0.45, 0.34, 0.60, 0.75, 0.37, 0.44, 0.37 km respectively. This range of fluctuations is quite significant and could make a lot of difference in the success of a radio links especially in mountainous or built-up areas, therefore, adequate fade margins should be provided.

Moreover, in 2012, Abuja, Akure, Jos, Lagos, Markurdi, Nsukka and Port-Harcourt at 200 m in January, the maximum and minimum radio horizon distances are 1.87, 1.90, 2.16, 1.80, 1.86, 1.92 and 1.71 km and 1.08, 1.02, 1.42, 1.00, 1.02, 0.81 and 0.95 km, this gives a range of 0.79, 0.88, 0.74, 0.80, 0.84, 1.11 and 0.76 km respectively .Also in July, the maximum radio horizon distance is 1.80, 1.40, 1.98, 1.31, 1.30, 1.41 and 1.30 km while the minimum is 0.48, 1.08, 1.20, 0.92, 0.84, 1.03 and 0.86 km, thus giving a range of 1.32, 0.32, 0.78, 0.39, 0.46, 0.38 and 0.44 km. It is therefore deduced that the required allowance for fluctuation of radio horizon distance in Akure is slightly lower than that of every other locations at the same transmitter antenna height. These values could cause disruption on a terrestrial line-of-sight (LOS) link if not properly taken care of at the design stage of the radio link. Examples of such disruptions are absorption, scattering, frequency dispersion, fading, atmospheric scintillation, multipath effects, and reduction in antenna gain and so on. From Figures 6–19, therefore, it can be deduced that the seasonal variation of the minimum and maximum radio horizon distances are low in the wet season months and maintain a progressive slight increase in the dry season months.

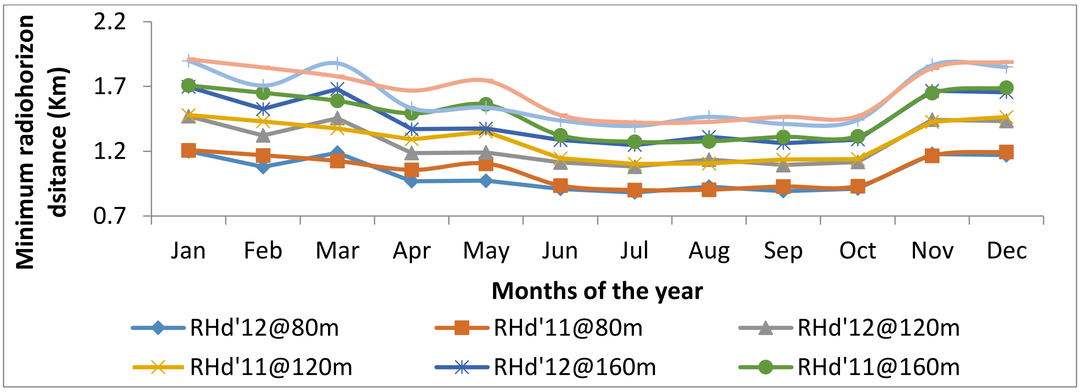

Fig. 6. Seasonal variation of minimum radio horizon distance over Akure at various transmitter heights of 80–200 m for the period of the study (2011-2012).

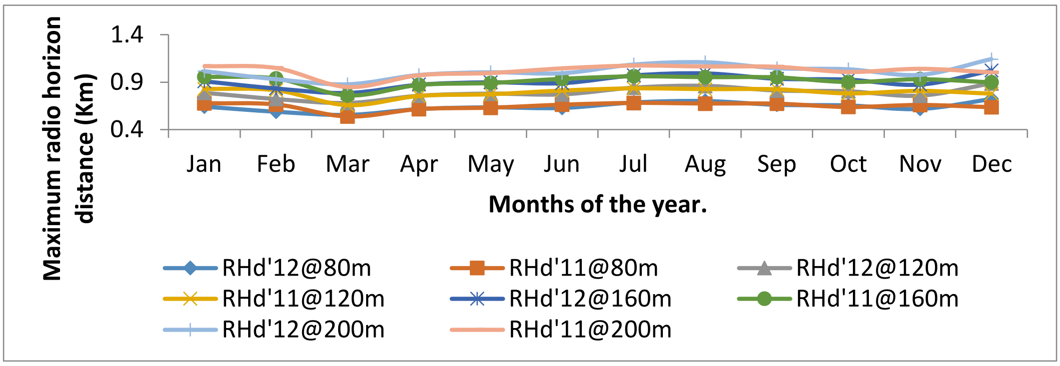

Fig. 7. Seasonal variation of maximum radio horizon distance over Akure at various transmitter heights of 80 – 200 m for the period of the study (2011-2012).

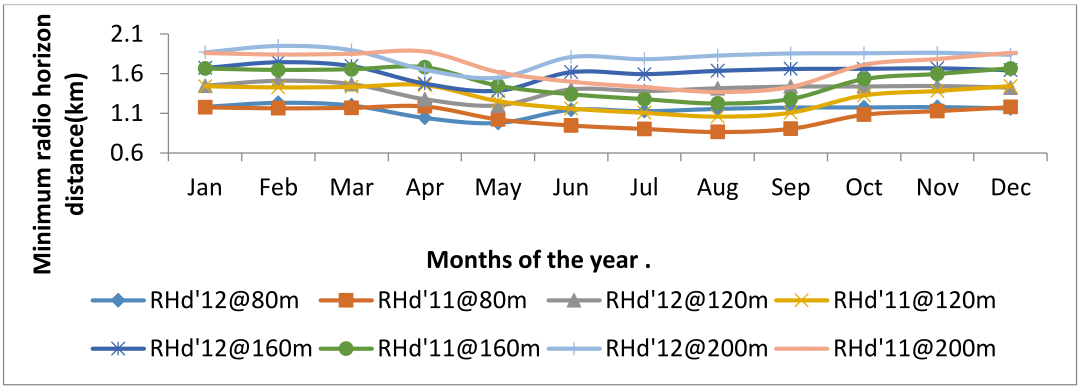

Fig. 8. Seasonal variation of minimum radio horizon distance over Abuja at various transmitter heights of 80–200m for the period of the study (2011-2012).

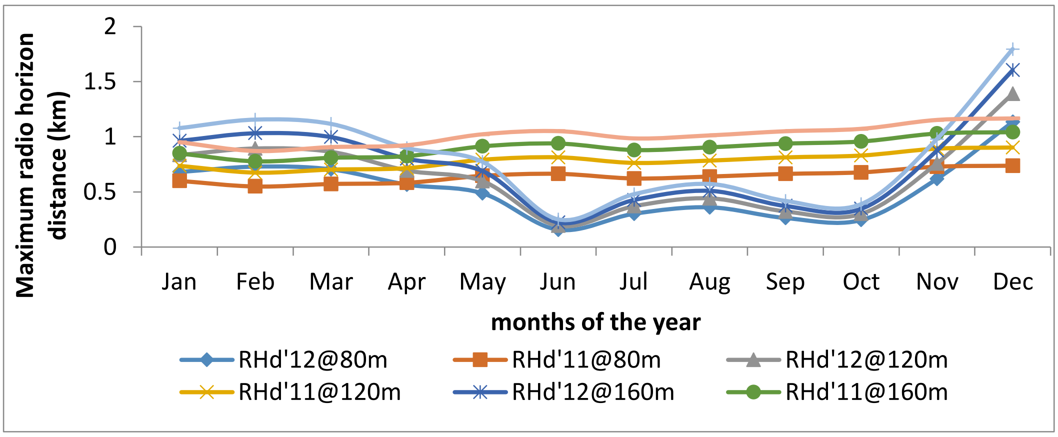

Fig. 9. Seasonal variation of maximum radio horizon distance over Abuja at various transmitter heights of 80 - 200 m for the period of the study (2011-2012).

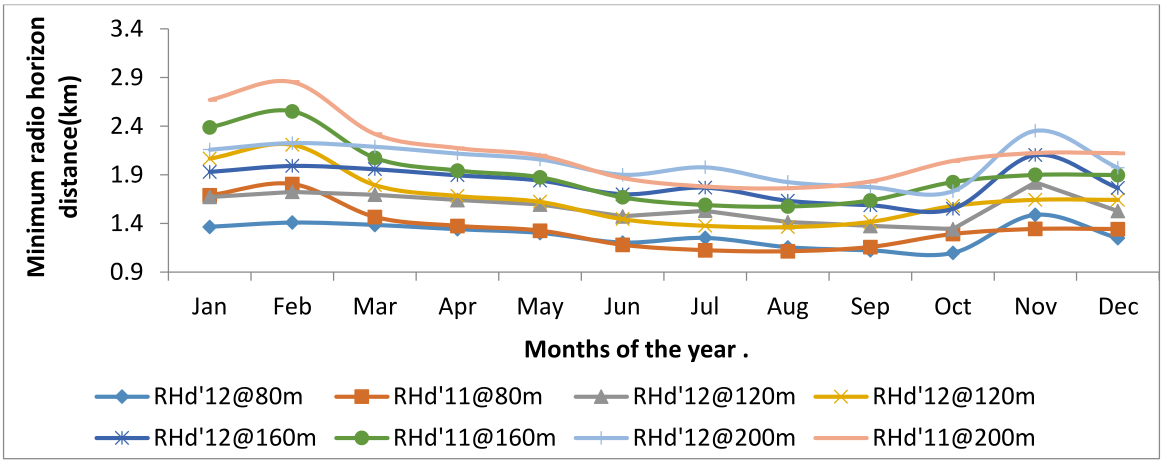

Fig.10. Seasonal variation of minimum radio horizon distance over Jos at various transmitter heights of 80 - 200 m for the period of the study (2011-2012).

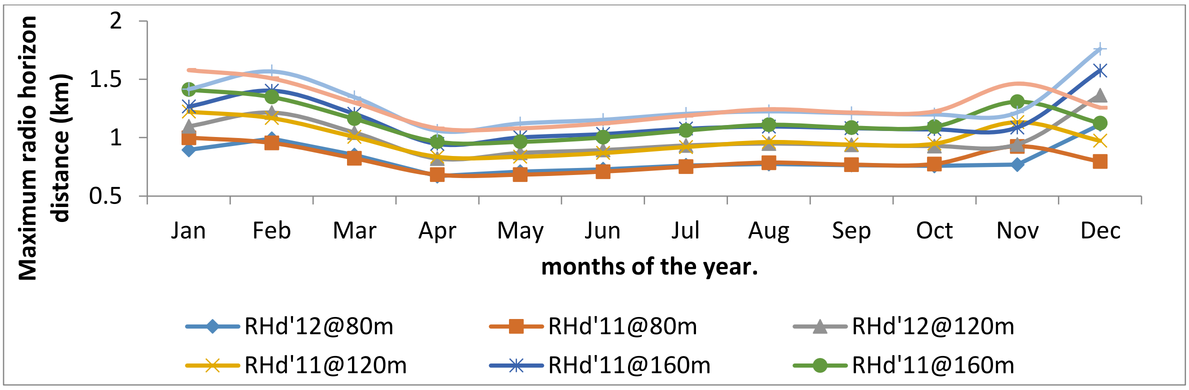

Fig.11. Seasonal variation of maximum radio horizon distance over Jos at various transmitter heights of 80 - 200 m for the period of the study (2011-2012)

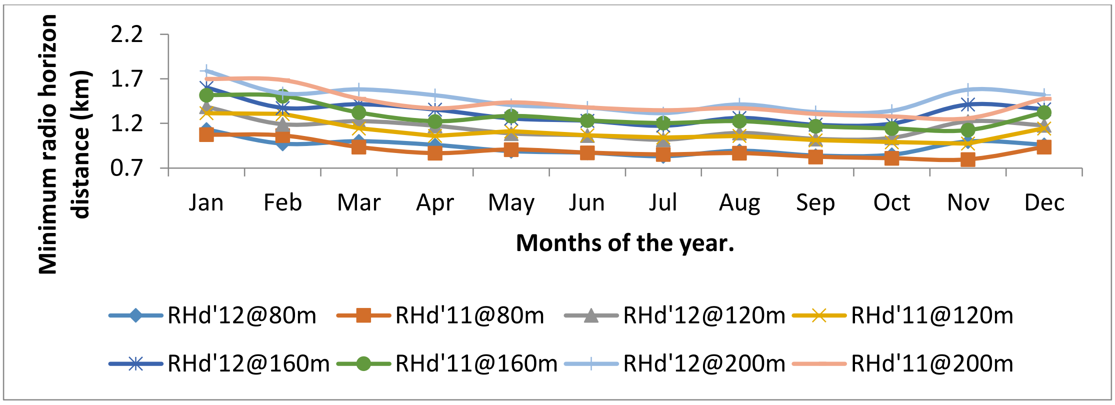

Fig. 12. Seasonal variation of minimum radio horizon distance over Lagos at various transmitter heights of 80 - 200 m for the period of the study (2011-2012).

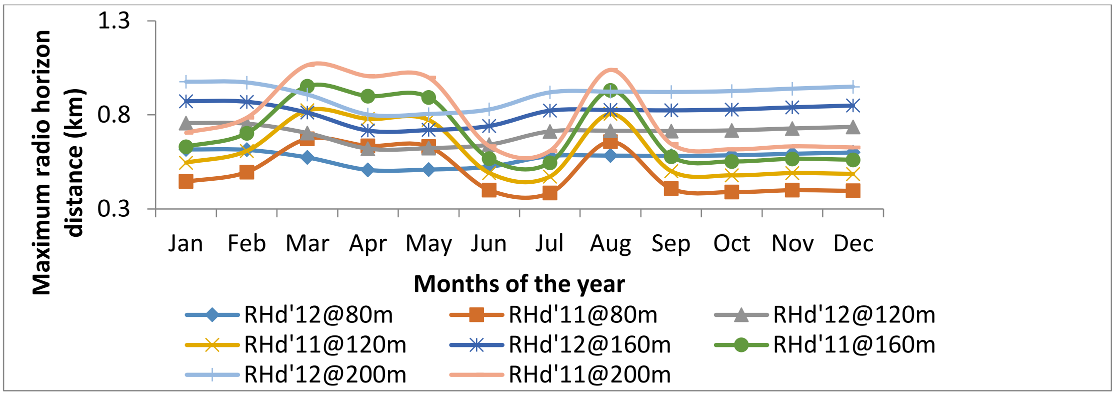

Fig.13. Seasonal variation of maximum radio horizon distance over Lagos at various transmitter heights of 80 - 200 m for the period of the study (2011-2012)

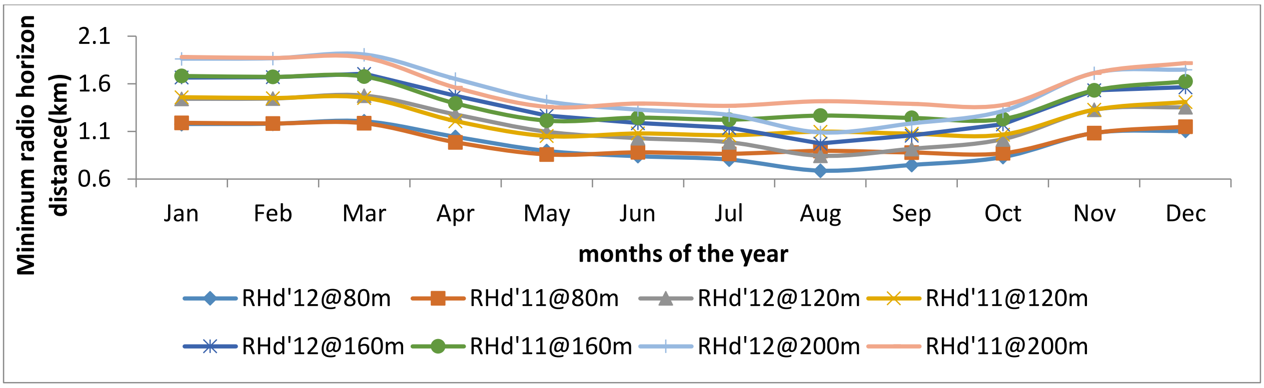

Fig. 14. Seasonal variation of minimum radio horizon distance over Markurdi at various transmitter heights of 80 - 200 m for the period of the study (2011-2012).

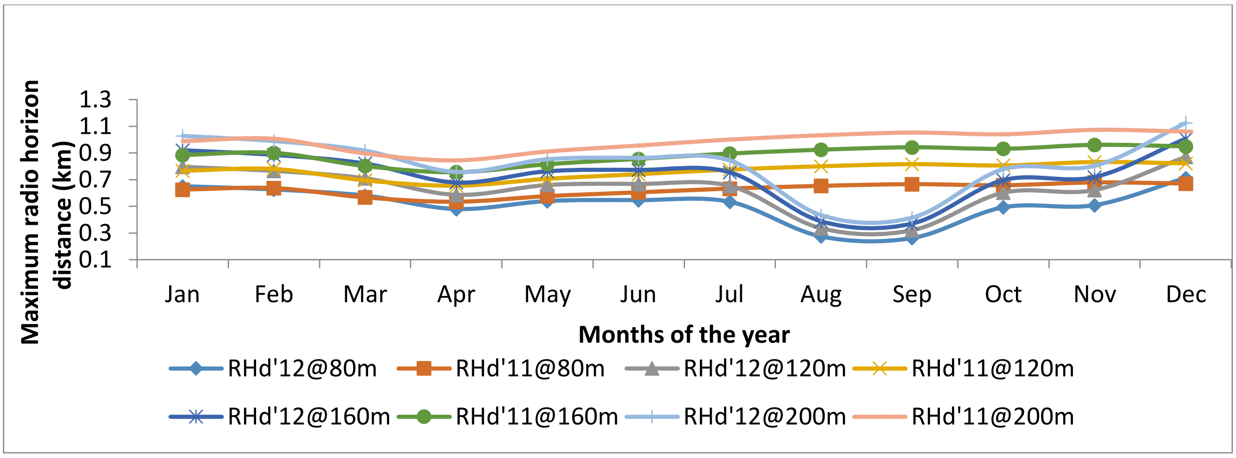

Fig. 15. Seasonal variation of maximum radio horizon distance over Makurdi at various transmitter heights of 80 - 200 m for the period of the study (2011-2012).

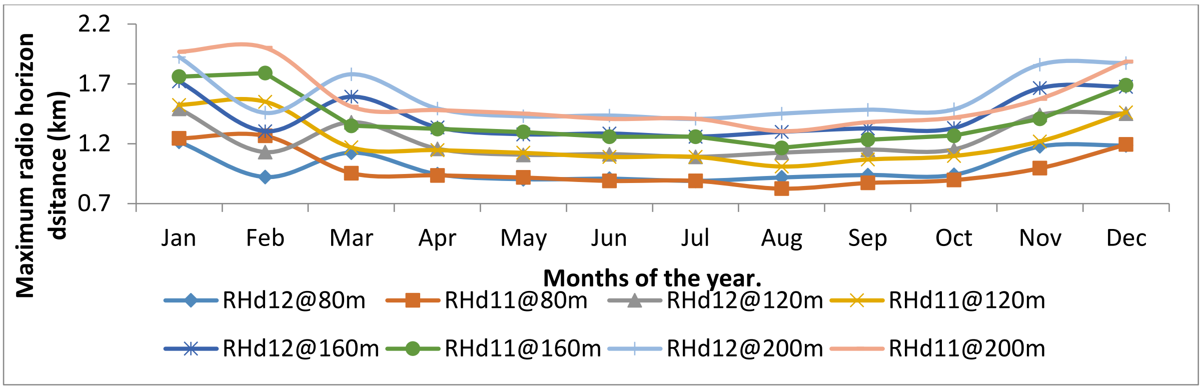

Fig. 16. Seasonal variation of maximum radio horizon distance over Nssuka at various transmitter heights of 80 - 200 m for the period of the study (2011-2012).

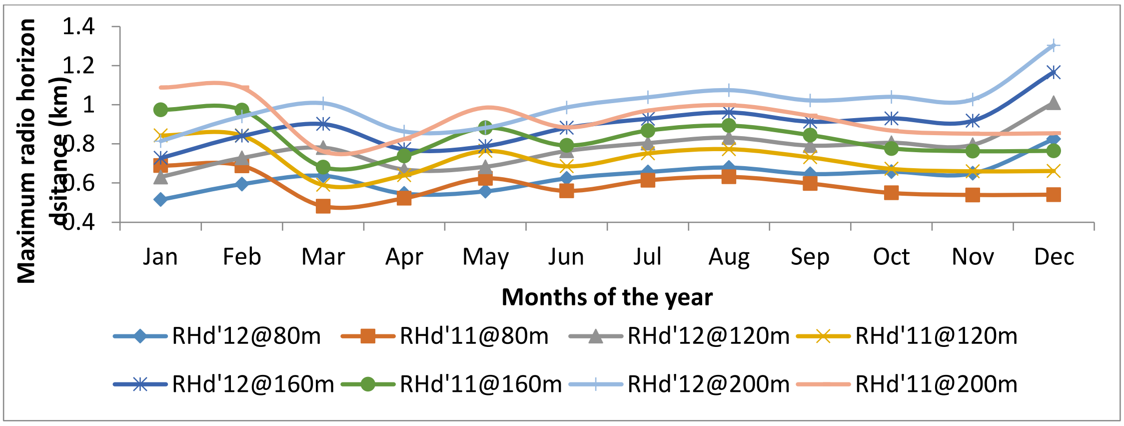

Fig. 17. Seasonal variation of minimum radio horizon distance over Nssuka at various transmitter heights of 80 - 200 m for (2011-2012).

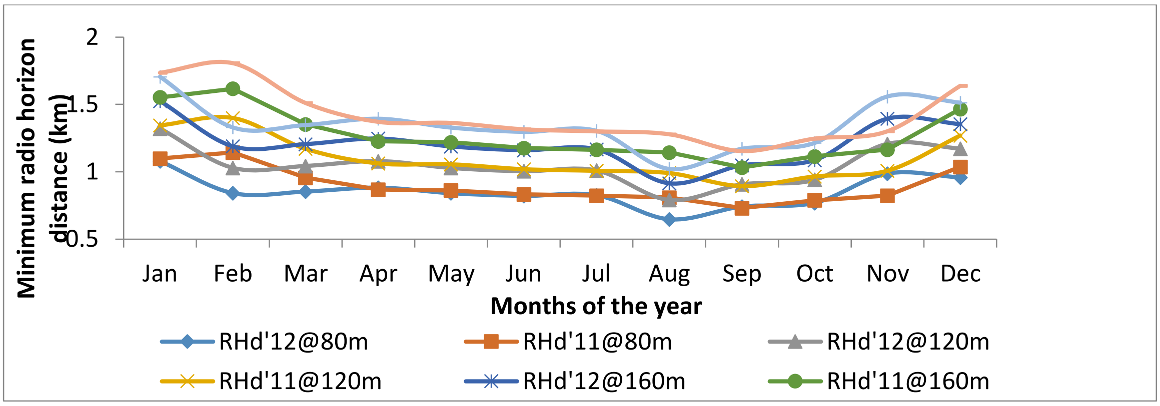

Fig. 18. Seasonal variation of minimum radio horizon distance over Port-Harcourt at various transmitter heights of 80 - 200 m for the period of the study (2011-2012).

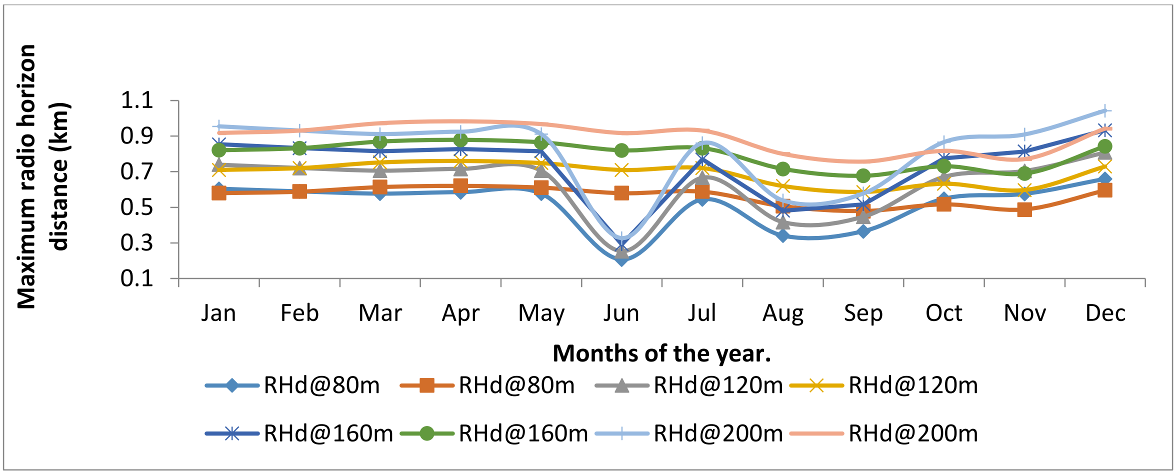

Fig. 19. Seasonal variation of maximum radio horizon distance over Port-Harcourt at various transmitter heights of 80 - 200 m for the period of the study (2011-2012).

Conclusions

Two-year (Jan. 2011-Dec. 2012) archived data of atmospheric variables: temperature, pressure and relative humidity obtained for Abuja, Akure, Jos, Lagos, Markurdi, Nsukka and Port-Harcourt locations were employed in this study. The data were used to compute the surface radio refractivity which was then used to study the seasonal variability of radio horizon distance. However, some of the main findings in the study are as follows: The surface refractivity were high at the early hours of day and very low between the hours of 12:00 LT and 16:00 LT and also high at late night in all the locations for this study. Surface refractivity value over Nigeria increases from about 250.9 N-units in the Northern part to about 469 N-units in the Southern part. Seasonal surface refractivity shows a seasonal variation with high values in the wet season months and low values in the dry season months over Nigeria. The mean surface refractivity value was highest in Port-Harcourt with 404 N-units and lowest in Jos with 302 N-units. The difference in the values of the surface refractivity over Nigeria is attributed to the meteorological influence of the semi- permanent climatological features, such as ITD, Sub-Tropical High Pressure (STHP) and associated monsoonal flow pattern. The variability of radio horizon distance of transmitting antennas is higher in the Northe-rn part of Nigeria than the southern part.

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