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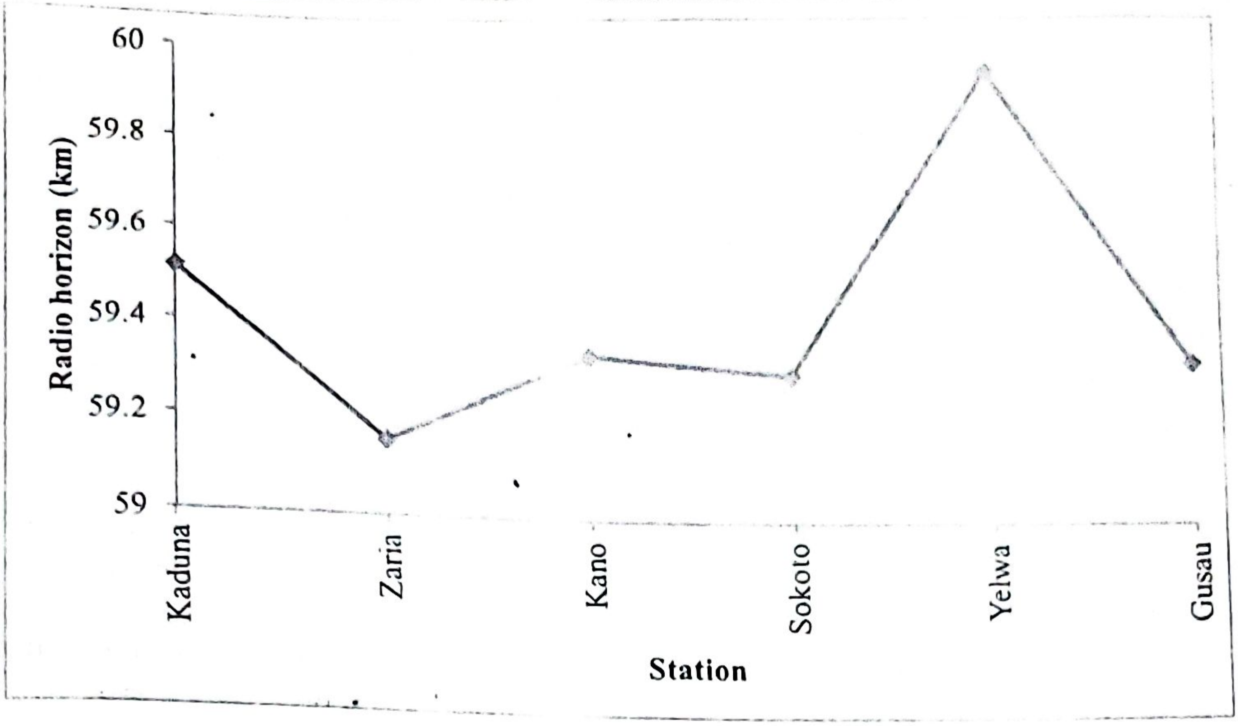

Figure 6: Radio horizon of the six stations in the North-western Nigeria (2008-2010)

4. Conclusions

The result showed that surface radio refractivity has seasonal tendencies over the North-western region of Nigeria. Surface radio refractivity increases from about 272 N-units at Zaria to about 394 N-units at Yelwa with seasonal variation of about 122 N-units in the region. Surface refractivity shows seasonal variation influenced by climate of the region with high value in the wet season and low value in the dry season. This entails that better propagation conditions prevails over the region during wet season than in the dry season; hence, longer radio coverage distance will be achieved during the wet season than in the dry season months.

The findings of this research work should be integrated in planning terrestrial communication networks in the North-western region of Nigeria for optimal link performance. Radio engineers should make use of the information derived from this research work to give appropriate fade margins in the of design GSM, cellular and other radio communication links in region for most favourable signal reception during the two distinct seasons of the year.

Acknowledgement

The authors wish to sincerely appreciate the Nigerian Meteorological Agency (NIMET), for making available these huge meteorological data used in this research work.

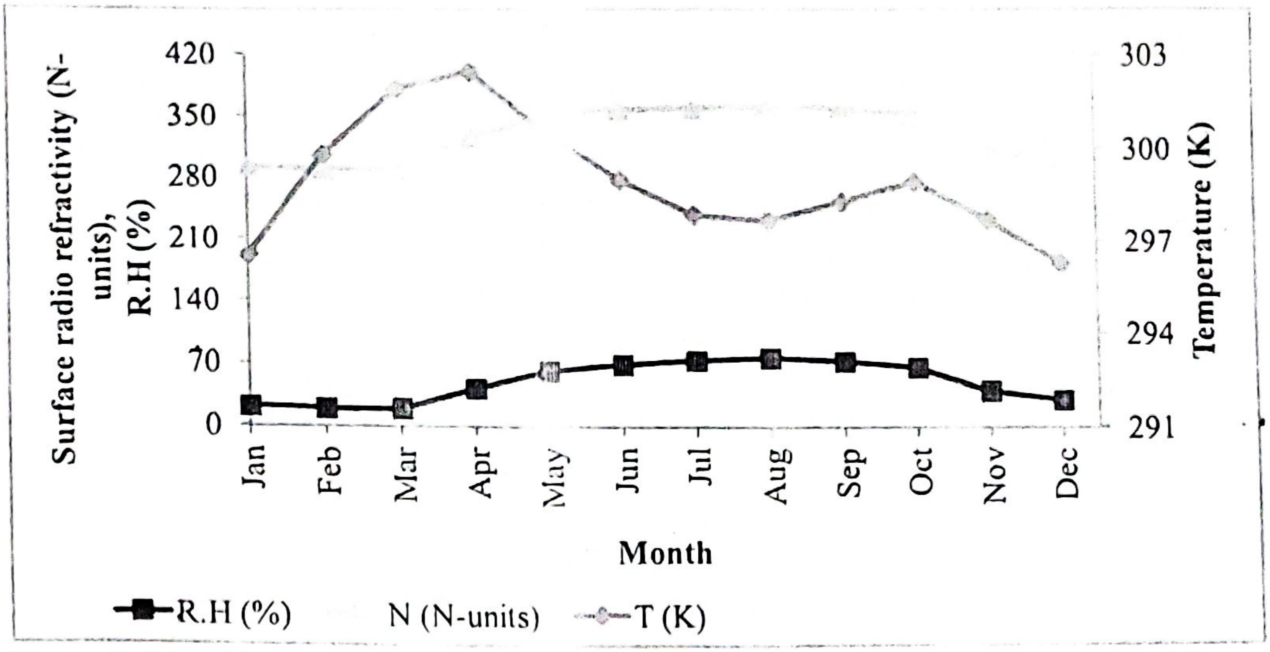

Figure 3: Monthly mean variation of surface radio refractivity with and relative humidity over Kaduna (2008-2012)

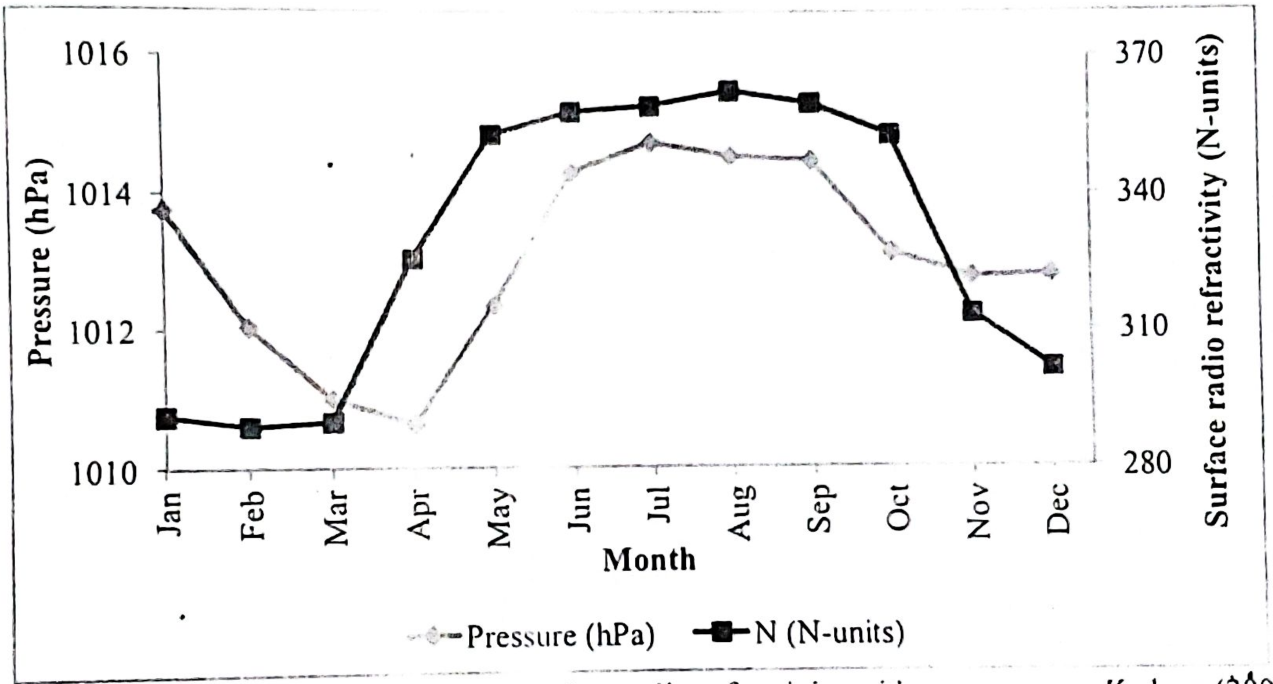

Figure 4: Monthly mean variation of surface radio refractivity with pressure over Kaduna (2008-2012)

Since several studies have shown that there is high correlation between signal strength and surface radio refractivity, monthly mean of radio horizon variation for a transmitter of 200 m height in North-western Nigeria is presented in Figure 5. Seasonal variation of radio horizon distance is observed in the region. From Figure 5, wider radio coverage distance is recorded to during the wet season (April-October) while shorter distance is recorded during the dry season (November-March). Average radio distance of about 60.46 km is recorded in wet season while 58.40 km is recorded during dry season. Seasonal radio horizon variability range of about 2.06 km is recorded in the region.

The wider radio coverage distance recorded in wet season is due to the high surface radio refractivity recorded during that season while the shorter radio coverage distance recorded in dry season is as a result of low surface radio refractivity recorded during that season. Figure 6 showed the inter-station variability of radio coverage distance across the six (6) stations in the study area for the period under review. It is observed that Yelwa recorded the longest radio coverage distance of about 59.95 km, followed by Kaduna which recorded 59.51 km and Kano 59.34 km. Gusau recorded 59.33 km, Sokoto 59.30 km, and lastly Zaria which recorded the shortest radio coverage distance of about 59.15 km. This is as a result of high surface radio refractivity prevalent over Yelwa compared to other stations in the region, and it is an indication that Yelwa could have better propagation conditions than the remaining Five (5) stations in the study area. Radio horizon variation of about 0.80 km was recorded between Yelwa and Zaria with the shortest coverage distance in the region.

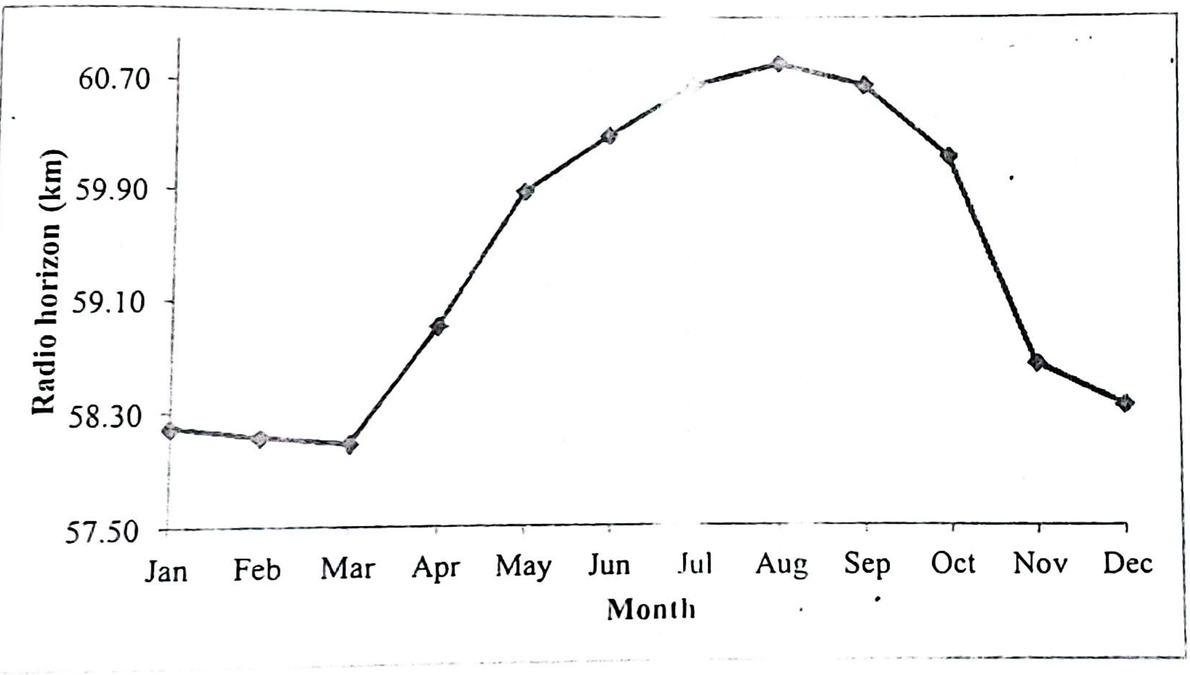

Figure 5: Monthly mean radio horizon variability in North-western Nigeria (2008-2012)

The minimum and maximum values of surface radio refractivity recorded at Sokoto station in March and August agrees with the result of Ayantunji et al, 2011. It is also observed that there are more variations of Ns during the dry season than in the wet season across all stations for the period under review. This could be attributed to the high and low humidity caused by the influence of the dry continental air mass from the Sahara Desert prevalent during dry season and the North-south migration of the Inter-Tropical Discontinulty (ITD) which saturates the atmosphere with large amount of moisture content of water vapour by the South-western winds and moisture-laden from the Atlantic Ocean during the wet season in the region.

Table 3: Annual mean of surface radio refractivity N_s (N-units) for the six stations in the North-western Nigeria (2008-2012)

Year	Kaduna	Zaria	Kano	Sokoto	Yelwa	Gusau
2008	317	311	330	315	338	323
2009	334	317	316	319	339	326
2010	329	319	328	324	345	324
2011	331	321	320	320	341	318
2012	338	329	331	339	350	331

By total mean of surface radio refractivity of the individual station, Yelwa showed the highest value of about 343 N-units which could also be because Yelwa station is more westerly located among all in the region. Zaria recorded surface radio refractivity of about 319 N-units which is the lowest value recorded in the region for the period of study.

To understand the factor responsible for the variability pattern of surface radio refractivity variation in the North-western, Nigeria, a profile of , pressure and relative humidity was plotted (Figures 3-4).

The result confirmed that surface radio refractivity variation in the dry season is mainly driven by the wet term of refractivity which is influence by humidity. The variation in wet season can be attributed to the influence of both dry and wet terms of refractivity. This is because humidity and pressure variations were both synchronous to the variation of refractivity during the wet season in the region.

However, pressure was completely out of phase with refractivity in the dry season while humidity variation remained synchronous with refractivity. Temperature variation was inconsistent with refractivity in the dry season but varied in opposite direction to the variation of refractivity during the wet season. This result aligned with the work of Ayajunji *et al*, 2011 on Sokoto station.

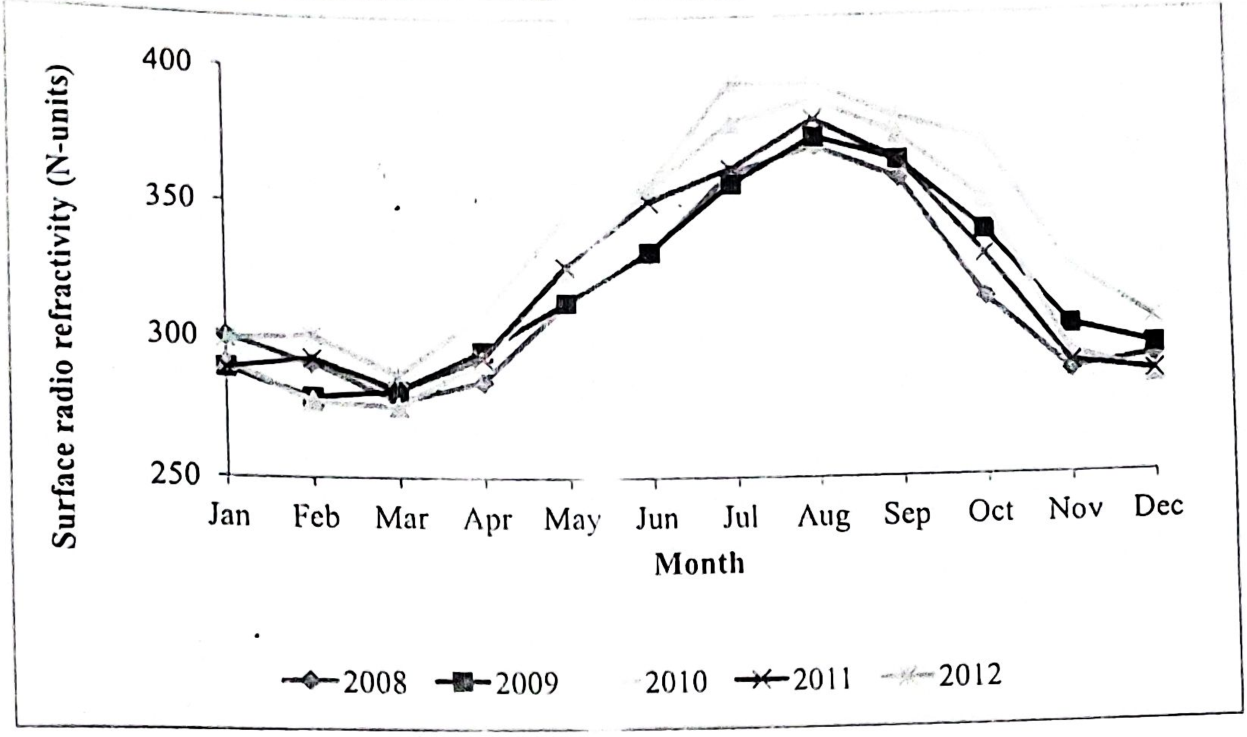

Figure 1: Monthly over Sokoto (2008-2012) variations of surface refractivity

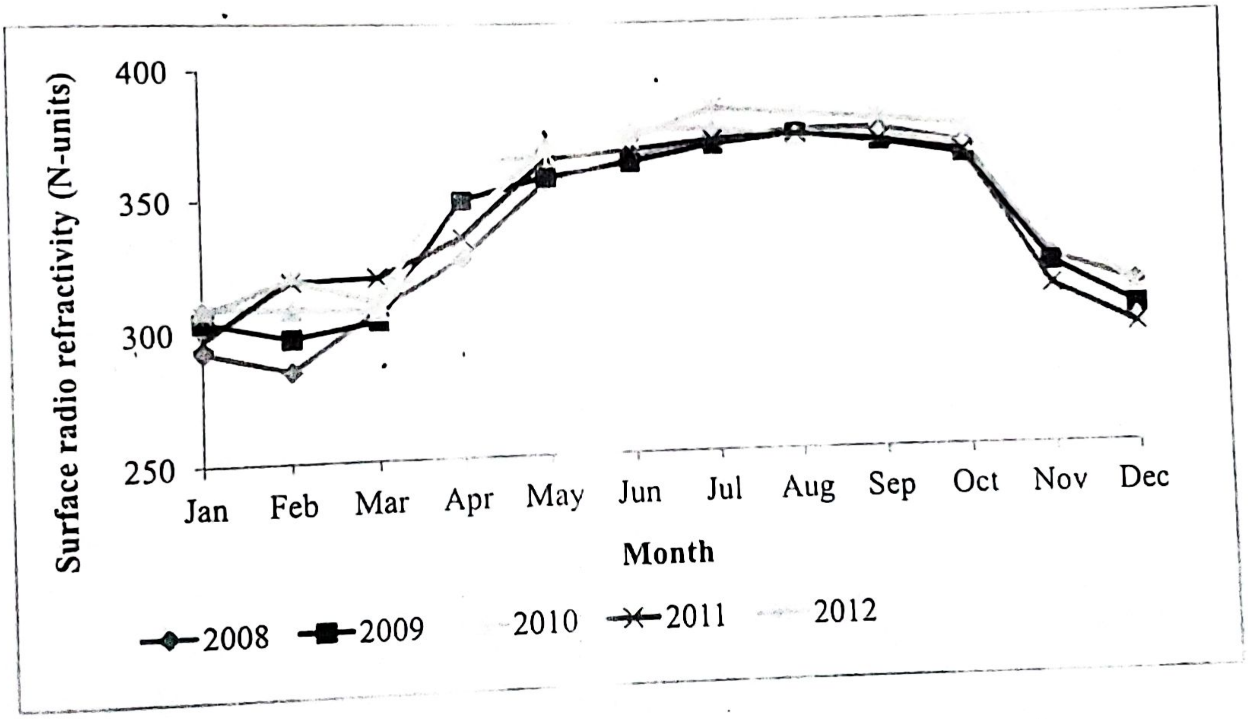

Figure 2: Monthly variations of surface refractivity over Yelwa for 2008-2012

pattern is observed in 2009 and 2010, but surface radio refractivity attained it peak value in July in 2010 while minimum values were recorded in January and March in 2011 and 2012.

Seasonal variation of surface radio refractivity over the other studied stations, (Zaria, Kano, Sokoto, Yelwa and Gusau) which fall within the same geographical and climatic region (North-western/Sahel Savannah) followed the same pattern with almost constant months of high and low values of surface radio refractivity. This result agrees with the work of Ayantunji *et al*, 2011. The maximum and minimum values of surface radio refractivity was observed in August and February for all stations for the period under investigation except in few cases where maximum and minimum values were observed in June, July, September and January, March and December respectively.

Among all stations, Sokoto station exhibited the highest value of surface radio refractivity of about 374 N-units, 388 N-units, 380 N-units and 394 N-units in 2009, 2010, 2011 and 2012 respectively, while Yelwa station recorded the highest value of about 375 N-units in 2008. The higher values of surface radio refractivity recorded in these two stations in contrast with other stations within the same climatic region could be due to close presence of the water bodies (River Rima in Sokoto and Kuwara in Yelwa) to the stations.

Table 2: Annual surface radio refractivity over the six stations in the study area

Station	2008		2009		2010		2011		2012	
	N,(min) N-units	N,(max) N-units	N,(min) N-units	N,(max) N-units	N,(min) N-units	N,(max) N-units	N,(min) N-units	N,(max) N-units	N,(min) N-units	N,(max) N-units
Kaduna	281	354	286	365	285	365	288	365	289	365
Zaria	274	355	272	357	276	358	275	363	288	365
Kano	294	373	279	361	288	373	290	365	297	377
Sokoto	277	370	278	374	275	388	281	380	286	394
Yelwa	284	375	297	373	298	376	296	373	307	383
Gusau	286	371	280	366	278	364	276	365	285	369

$$e_s = a\ exp\left(\frac{bt}{t+c}\right)\ hPa \tag{3}$$

H is the relative humidity in %, e_s is the saturated vapour pressure (hPa) at T in degree Celsius, and a,b,c are coefficients values for water and ice as: for water: a = 6.1121, b = 17.502 , c = 240.97, for ice: a = 6.115, b = 22.452, c = 272.55
Radio refractivity, N varies with height, h (km) and long-term mean dependence of refractivity upon the height h is expressed by an exponential law (Rec. ITU-R P.453-10, 2012):

$$N_s = N_o\ exp\left(\frac{-h_s}{h_o}\right). \tag{4}$$

where: h_s=height above earth's surface (km). h_o=scale height and N_s is the surface refractivity. The mean refractivity gradient in the first kilometer height ΔN is (Kolawole, 1980):

$$\Delta N = N(1) - N_s = -N_s\left[1 - \exp\left(\frac{-1}{h_o}\right)\right] \tag{5}$$

The k-factor is (Rec. ITU-R P.834-6, 2007):

$$\frac{1}{ka} = \frac{1}{a} + \frac{dn}{dh} = \frac{1}{R_e} \tag{6}$$

where: n = refractive index of the atmosphere, R_e= equivalent earth radius, a is the actual earth radius (6370 km), and k is the effective earth radius factor (k-factor)
Also radio horizon distance d is given by:

$$d = \sqrt{2R_e\,h_t} = \sqrt{2ka\,h_t}(\text{km}) \tag{7}$$

where: d= distance to the radio horizon, h_t height of the antenna (km).

3. Results and Discussion

Figures 1 and 2 depict the seasonal variations of surface radio refractivity (N_s) over Sokoto, and Yelwa for the period of 2008-2012. The result showed an increase in the values of surface radio refractivity from minimum value of about 284 N-units at Yelwa station (Figure 2) to maximum value of about 394 N-units at Sokoto (Figure 1) station in the North-western region. This result agrees with the work of Owolabi and Williams (1970).

In 2008 the surface radio refractivity at Kaduna showed gradual increase from a minimum of about 281 N-units in February until it climaxed at about 354 N-units in August before it started declining continually from September for the rest period of the year. The same variability troposphere is influenced by varieties of natural phenomena caused by some meteorological parameters such as , relative humidity and pressure (Okoro and Agbo, 2012)..The effects of the atmospheric parameters on radio wave propagation can be observed from the study of radio refractive index, which varies considerably diurnally and seasonably in the tropics (Isikwue et al, 2013).

2. Methodology

2.1. Source of Data and Processing Techniques

The data used for this research work was collected by the Nigerian Meteorological Agency (NIMET); and consists hourly/daily/monthly values of pressure and relative humidity recorded at 6 locations for years 2008-2012. Table 1 below shows some geographical information of the studied station.

Table 1: Latitudes and longitudes of the six stations in the study area

S/N	STATION	LONGITUDE	LATITUDE
1.	Kaduna	10.33°N	7.75°E
2.	Zaria	11.11°N	7.72°E
3.	Kano	11.85°N	8.51°E
4.	Sokoto	13.08°N	5.25°E
5.	Gusau	12.16°N	6.66°E
6.	Yelwa	11.79°N	4.33°E

2.2. Data Analysis Techniques

Atmospheric radio refractivity N depends on meteorological parameters such as pressure (hPa), T (K), and water vapour pressure *e* (hPa) is given by (Rec. ITU-R P.453-10, 2012):

$$N = N_{dry} + N_{wet} = \frac{77.6P}{T} + \frac{3.75\times10^{5}e}{T^{2}} \text{ (N − units)} \qquad (1)$$

where: p=atmospheric pressure (hPa), e=water vapour pressure (hPa) and T=absolute (K).
The water vapour pressure e is calculated from the relative humidity, and saturated water vapour, using the expression (Rec. ITU-R P.453-8, 2001):

$$e = \frac{He_s}{100}\ hPa \qquad (2)$$

URSI-NG Conference Proceedings (2015) 92 - 102

Surface radio refractivity variation over north-westernern Nigeria

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Abstract

Good knowledge of refractivity profile is essential for good planning of communication links; surface refractivity profile of a station is particularly required for enhanced planning and performance prediction of terrestrial radio links, especially in tropical regions where ITU-R has called for such local propagation data. The monthly and seasonal variability of surface radio refractivity over North-western Nigeria was investigated for a period of Five years (2008-2010). The monthly mean surface radio refractivity over the region is lower and more variable in the dry season, but higher and less variable in the wet season at all the study stations. About 288 N-units monthly mean surface radio refractivity (N_s) was recorded in dry season and 368 N-units in wet season. Average value of about 328 N-units is observed with annual range of 80 N-units in the North-western Nigeria. The result of the investigation also showed that relative humidity and Temperature have major influence on the variation of surface radio refractivity while pressure has relatively less influence on N_s variability. The surface refractivity profile shows that for a transmitter height of 200 metres radio horizon distance is between 60.5 km in wet season and 58.4 km in dry season in North-western Nigeria. Therefore, terrestrial radio communication links must be planned in line with the findings of this research work for best performance in the North-western Nigeria.

Keywords: Surface radio refractivity, pressure, relative humidity, radio horizon.

1. Introduction

Radio communication is the wireless transmission of radio wave signals through free air medium by electromagnetic radiation of certain frequency (significantly below that of visible light, about 30 kHz to 300 GHz). Propagation conditions in the troposphere and radio paths are governed by various properties of the under surface layer such as the physical and geographical, as well as the climatic features of the region. Changes in atmospheric propagation conditions may be manifested in the variation of the radio field strengths and the radio horizon distance (Adeyemi and Emmanuel, 2011). Thus, the propagation of radio wave signals through the

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