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Spatial Variability of VHF/UHF Electric Field Strength in Niger State, Nigeria

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ABSTRACT

This study investigates the coverage areas of VHF and UHF signals from three television stations in Niger State, Nigeria, by quantitatively measuring the signal levels of these signals. The signal levels of the transmitters of Nigeria Television Authority (NTA), Minna, Channel 10, (210.25 MHz); NTA, Kotangora, Channel 8, (196.25 MHz) and Niger State Television, Minna, Channel 25, (503.25 MHz), and the corresponding distances were measured along some radial routes with the transmitting stations at focus. These measurements were taken using Digital Signal Level Meter and Global Positioning System (GPS). From the data obtained, Surfer 8 software application was used to draw contour maps of the signal levels around the transmitting stations to determine the coverage areas of the stations. The results obtained show that the present configurations of the transmitters of the three television stations do not give an optimal coverage of the state. Only 25.82% of the entire land mass of the state has television signal coverage. Consequently, greater percentage of Niger State is completely out of television signal coverage. So, there is need to have repeater stations at some intervals to ensure reception of television signals throughout the state.

KEYWORDS

Signal level, coverage areas, VHF, UHF, transmitter

1 INTRODUCTION

At broadcast frequencies in the VHF and UHF bands (30 MHz – 3 GHz), propagation is usually by ground waves which consist of direct wave, ground reflected and surface wave. Therefore, in these frequency bands, the electrical parameters of the ground, curvature of the earth surface, height of the antenna and weather conditions influence wave propagation. The degree to which these factors affect propagation depends primarily on the frequency of the wave and the polarization [1]. The electric field strength at a given distance from the transmitter is attenuated by these parameters, with the result that radio services in the VHF and UHF bands are limited to distances close to the transmitter.

The coverage areas of broadcast stations are usually classified into primary, secondary and fringe areas. Apart from weather conditions; the size of each of these areas also depends on the transmitter power, the directivity of the aerial, the ground conductivity and the frequency of propagation. The coverage area decreases with increase in frequency and reduction in the ground conductivity [2].

The primary coverage area is defined as a region about a transmitting station in which the signal strength is adequate to override ordinary interference in the locality at all times, and corresponds to the area in which the signal strength is at least 60 dBμV. The quality of service enjoyed in this area can be regarded as Grade A1. The appropriate value of the signal strength for this quality of service is also dependent on the atmospheric conditions and man-made noise in the locality. The signal strength also depends on whether the locality is rural, industrial or urban.

The secondary coverage area is a region where the signal strength is often sufficient to be useful but is insufficient to overcome interference completely at all times. The service provided in this area may be adequate in rural areas where the noise level is low. The secondary coverage area corresponds to the area in which the signal strength is at least 30 dBμV, but less than 60 dBμV. The quality of service enjoyed in this area can be regarded as Grade B1.

The fringe service area is that in which the signal strength can be useful for some periods, but its service can neither be guaranteed nor protected against interference. This is an area in which the signal strength is greater than 0 dBμV, but less than 30 dBμV. Such an area may be said to enjoy Grade B2 service [3].

This study investigates the coverage areas of the Nigeria Television Authority, (NTA), Minna, Channel 10 (210.25 MHz); Nigeria Television Authority (NTA), Kotangora, Channel 8 (196.25 MHz); and Niger State Television, Minna, UHF 25 (503.25 MHz), by means of quantitative measurement of the signal levels of the corresponding signals at increasing distances from each transmitter until the signals completely fade out.

2 THEORETICAL BACKGROUND

All electromagnetic waves obey the inverse-square law in free space. The inverse-square law states that the power density of an electromagnetic wave is proportional to the inverse of the square of the distance from the source. That is, if the distance from a transmitter is doubled, the power density of the radiated wave at the new location is reduced to one-quarter of its previous value. Also, the electromagnetic waves coming from a transmitter may experience three other phenomena: reflection, diffraction, and scattering. All of these factors affect the transmitted signal as it is "carried" through the air medium to the distant receiving antenna [4].

The range of a VHF transmission depends on the transmitting antenna height, transmitter power, receiver sensitivity, and distance to the horizon, since VHF signals propagate under normal conditions as a near line-of-sight phenomenon. Radio waves are weakly bent back toward the Earth by the atmosphere, so the distance to the radio horizon is slightly extended over the geometric line-of-sight to the horizon.

An approximation to calculate the line-of-sight horizon distance (on Earth) is given as [5]:

$$d = \sqrt{12.746 \times h_b} \quad \text{(km)} \qquad (1)$$

where h_b is the height of the antenna in meters.

This approximation is only valid for antennas at heights that are small compared to the radius of the Earth. In communications systems, more complex calculations are required to assess the probable coverage area of a proposed transmitter station [5].

2.1 Influence of Clear-Air Aspect of the Troposphere on VHF and UHF Propagation

In a vacuum, electromagnetic waves propagate along straight lines with velocity c (velocity of light in vacuum). The electromagnetic properties of the air are slightly different from that of a vacuum, and are characterized at each point by the refractive index, $n=c/v$, with v as the local electromagnetic wave propagation velocity [6]. Clear-air effects refer to atmospheric influences that do not involve condensed water vapour (such as cloud, rain, wet, haze, hail, and so on); but the effects of dry haze and dust particles are included [7].

Electromagnetic waves propagating through the troposphere are refracted and scattered by variations in the radio refractive index, n which in turn are caused by variation in pressure P(mb), temperature T(K), and water vapour pressure 'e' (mb) according to the formula:

$$N = (n-1)10^6 = 77.6\frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \qquad (2)$$

Here N is the refractivity which is a practical quantity often used in preference to 'n'. The refractive index at the earth's surface, denoted by 'n_s', is about 1.0003. It falls to the value of unity at great heights. The little difference in the value 'n' from unity in the troposphere is the reason for the use of practical unit N. Its value, denoted by 'N_s', at earth's surface is about 300. Values of N are often expressed in "N-units" though it is a dimensionless quantity.

The water vapour pressure '*e*' is usually calculated from the relative humidity, and saturated water vapour, using the expression:

$$e = H \times \frac{6.1121 exp\left(\frac{17.502t}{t+240.97}\right)}{100} \quad (3)$$

where H = relative humidity (%) and t = temperature (°C) [8].

The macroscopic structure of the troposphere varies much more rapidly vertically than horizontally. For this reason, the troposphere is said to be vertically stratified. The same vertical stratification may persist over a horizontal region tens or hundreds of kilometers in extent. As temperature decreases with altitude, the air above a certain level is saturated and excess moisture precipitates out. This water vapour pressure, e, decreases more rapidly with height than pressure, P, and to all intents and purposes is negligible above 2 or 3 km [9].

The net effect of the variation in pressure P, temperature T and water vapour pressure e is that N decreases with height. The average behaviour of N in the troposphere is the exponential decrease given as:

$$N = N_s exp\left(\frac{-z}{Z}\right) \quad (4)$$

where N_s is the surface value of N, z is height above the earth's surface and Z is a scale height.

The two terms in the refractivity N in equation (2) are often separated into dry term D and wet term W:

$$D = 77.6\frac{P}{T} \quad (5)$$

$$W = 3.73 \times 10^5 \frac{e}{T^2} \quad (6)$$

Both terms decay with height but at different rates leading to the bi-exponential model with corresponding surface values D_s, W_s and scale heights Z_d, Z_w respectively:

$$N = D_s exp\left(\frac{-z}{Z_d}\right) + W_s exp\left(\frac{-z}{Z_w}\right) \quad (7)$$

Values Z_d = *9 km* and Z_w = *2.5 km* are typical. The dry term D_s makes a relatively constant contribution to N_s of about 265 whilst the wet term W_s provides most of the variability of N.

The decrease of N with height bends rays towards the earth. In average conditions, N decreases by about 40 N-units/km in the lowest kilometer of the troposphere. However, the troposphere is a varying medium and quite significant deviations from average condition occur.
Over a given height range, refractivity profiles can be designated as: sub-refractive, normal, super-refractive or ducting, according to [9]:

$$\frac{\partial N}{\partial z} > -40 \quad \text{Sub-refractive} \quad (8)$$

$$\frac{\partial N}{\partial z} \approx -40 \quad \text{Normal} \quad (9)$$

$$\frac{\partial N}{\partial z} < -40 \quad \text{Super-refractive} \quad (10)$$

$$\frac{\partial N}{\partial z} < -157 \quad \text{Ducting/Trapping} \quad (11)$$

Typical propagation ray profiles under these refractivity conditions are as shown in Figure 1.

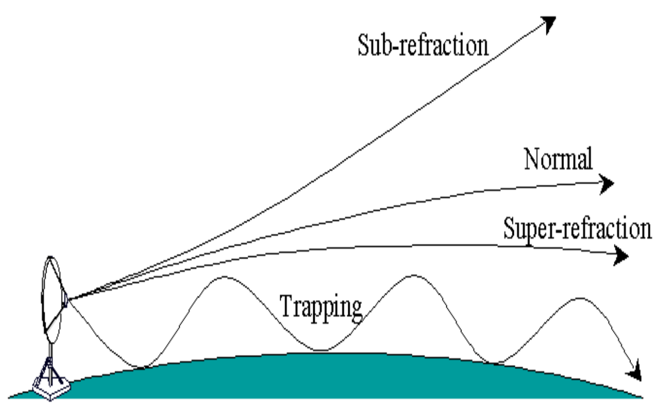

Figure 1. Four classifications of tropospheric refraction [10]

3 STUDY AREA

Niger State is a State in North central Nigeria and the largest state in the country. It is named from the River Niger and Minna is the State capital. Niger State is located between latitudes 8°20'N and 11°30'N and longitude 3°30'E and 7°20'E. Niger State is bordered to the north by Zamfara

State, to the northwest by Kebbi State, to the south by Kogi State, to the southwest by Kwara State; while Kaduna State and the Federal Capital Territory border the State to the northeast and southeast, respectively (Figure 2).

Furthermore, Niger State shares a common international boundary with the Republic of Benin at Babanna in Borgu Local Government Area of the state. Currently Niger State covers a total land area of 76,363 sq. km, or about 9 percent of Nigeria's total land area. This makes the State the largest in the country. Niger State has a population of 3,950,249 (2006 Population Census) and population density of 52/km^2 [11, 12].

Climate and Vegetation: Niger State experiences dry and wet seasons within a year. The annual rainfall varies from 1,100mm in the northern parts to 1,600mm in the southern parts. The maximum temperature is recorded between March and June which is usually not more than 37 °C, while the minimum temperature is between December and January (usually not less than 19 °C), when most parts of the state come under the influence of the tropical continental air mass which blows from the north. The rainy seasons last for about 150 days in the northern parts to about 120 days in the southern parts of the state. The fertile soil and hydrology of the state support the cultivation of most of Nigeria’s staple crops and still allows sufficient opportunities for grazing, fresh water fishing and forestry development [13].

The Southern Guinea Savannah vegetation covers the entire landscape of the state. Like in other states of similar vegetation, it is characterized by woodlands and tall grasses interspersed with tall dense species. However, within the Niger trough and flood plains are taller trees and a few oil palm trees. In some areas, traces of rain forest species can be seen [13].

Figure 2. Location of Niger State in Nigeria (10°00'N, 6°00'E) [11]

4 DATA COLLECTION AND ANALYSIS

This research was carried out for three different television stations, namely: Nigeria Television Authority (NTA), Minna, Channel 10, Nigeria Television Authority (NTA), Kotangora, Channel 8 and Niger State Television, Minna, Channel 25.

NTA Minna transmits at 210.25 MHz for video signal and 215.25 MHz for audio signal. The output power of the transmitter during the period of this work was substantially constant at 7.5 kW. NTA Kotangora transmits at 196.25 MHz for video signal and 201.75 MHz for audio signal with an output power of 2 kW. Niger State Television, Minna, transmits at 503.25 MHz for video signal and 508.75 MHz for audio signal. The output power of the transmitter in this case fluctuates between 100 and 500 W.

The signal levels of the transmitters of the three television stations were taken along some radial routes from the transmitting stations as shown in Figure 3, using Digital Signal Level Meter GE-5499. The corresponding transmitter-receiver distances, elevations above the sea level and locations were also measured using GPS 72 – Personal Navigator. Measurements were taken (at distances further from each transmitter) around the towns and villages in all the local government areas in Niger State until all the signals faded away completely. Data obtained along one of the radial routes in Minna is shown in Table 1.

From the data obtained, Surfer 8 software application was used to draw contour maps of the signal levels around the transmitting stations to determine the coverage areas of the stations. The coverage area is divided into three different areas based on the following classification of signal strength E:

i. Primary Coverage Area, E > 60 dBμV
ii. Secondary Coverage Area, 60 dBμV > E > 30 dBμV
iii. Fringe Coverage Area, 30 dBμV > E > 0 dBμV

Table 1. Data obtained along one of the radial routes in Minna, Niger State

Distance (km) (from the transmitting Station)	**Signal Levels (dBμV)**	**Location**		**Elevation (m)**
		Latitude (^{o}N)	**Longitude (^{o}E)**	
0	90.0	9.610	6.559	298
3.35	80.1	9.573	6.572	256
6.97	73.0	9.553	6.582	236
8.54	65.4	9.542	6.582	231
14.29	51.4	9.526	6.581	277
18.08	56.5	9.467	6.638	309
21.97	42.5	9.422	6.621	307
23.11	45.3	9.429	6.662	367
25.62	38.1	9.422	6.694	374
29.06	45.2	9.406	6.724	392
31.28	42.0	9.402	6.750	381
34.02	39.6	9.393	6.777	378
37.48	32.5	9.392	6.819	363
40.48	47.3	9.395	6.856	373
45.49	27.0	9.398	6.913	393
50.53	27.0	9.390	6.969	454
60.26	0	9.278	6.995	294

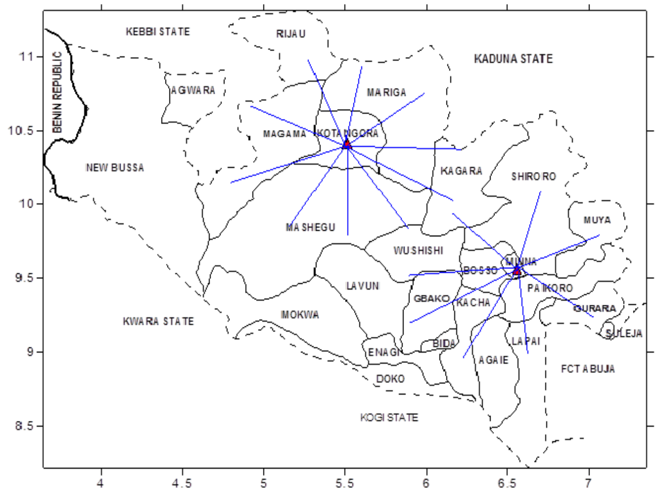

Figure 3. Map of Niger State showing the transmitting station sites and radial routes used

5 RESULTS

Figures 4 to 7 show the contour maps of the signal levels around the three transmitting stations and their coverage areas in the state, while Figure 8 shows elevation of the ground around the coverage areas of the stations under study. Tables 2 to 5 show the television signal coverage areas as percentage of the total land mass and the local government areas. The results obtained show that:

i. The present configurations of the transmitters of the three television stations do not give an optimal coverage of the state. Only 25.82% of the entire land mass of the state has television signal coverage. So, greater percentage of Niger State is completely out of television signal coverage.

ii. The contour maps show the need for repeater stations at appropriate intervals to provide reception of television signals for the entire state.

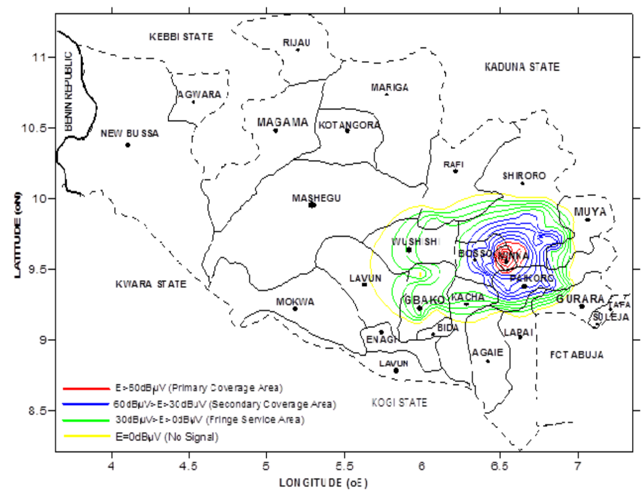

Figure 4. Coverage area of the NTA Minna in Niger State

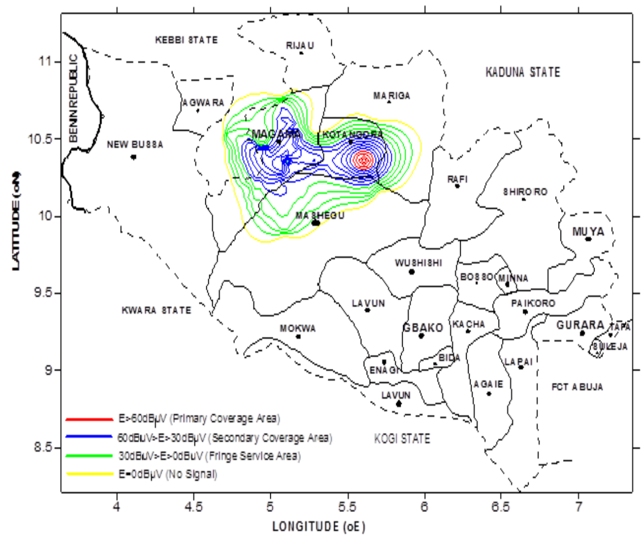

Figure 5. Coverage area of the NTA Kotangora in Niger State

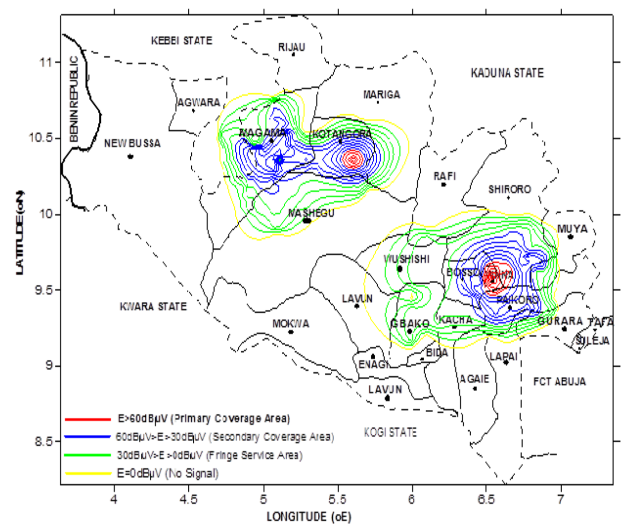

Figure 6. Combined coverage areas of the NTA Minna and NTA Kotangora in Niger State

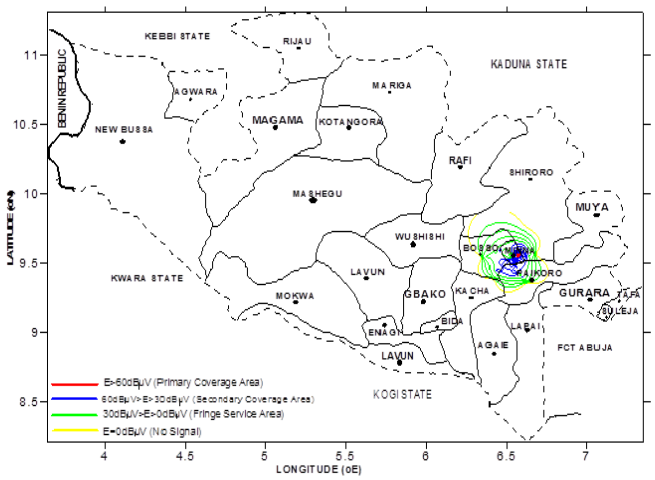

Figure 7. Coverage area of Niger State Television in Niger State

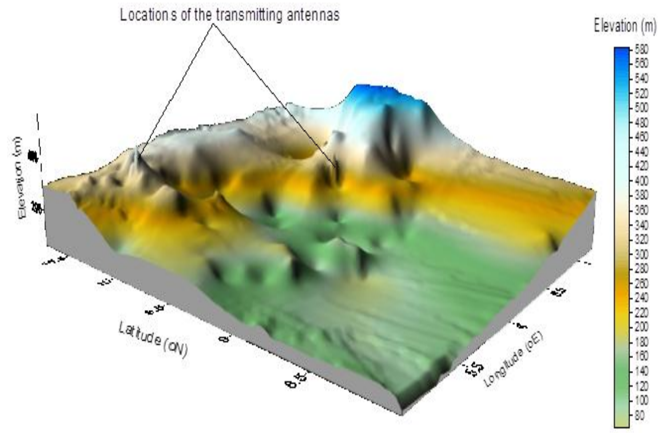

Figure 8. Surface map showing elevation of the ground above sea level around the coverage areas of the television stations in Niger State

Table 2. Percentage of the coverage areas of the television stations relative to the total land mass of Niger State

Stations	% of Primary coverage area	% of Secondary coverage area	% of Fringe coverage area	Total % of coverage area
NTA Minna	0.65%	4.15%	9.38%	14.18%
NTA Kotangora	0.22%	4.74%	6.68%	11.64%
Niger State Television	0.005%	0.32%	1.97%	2.295%

Table 3. Percentage of the local government areas covered by the NTA Minna station in Niger State

L.G.A	Average Distance (km) (from the transmitting station)	% of L.G.A. with primary coverage area	% of L.G.A. with secondary coverage area	% of L.G.A. with fringe coverage area	Total % of L.G.A. coverage area
Chanchaga	3.82	100%	-	-	100%
Bosso	16.73	7.14%	64.29%	28.57%	100%
Paikoro	30.37	3.80%	46.20%	7.70%	57.70%
Shiroro	36.06	2.80%	22.20%	19.40%	44.40%
Kaicha	44.93	-	2.27%	45.45%	47.72%
Muya	39.7	-	5.00%	2.50%	7.50%
Wushishi	54.55	-	-	69.20%	69.20%
Gurara	60.38	-	-	25.00%	25.00%
Gbako	59.3	-	-	73.10%	73.10%
Rafi	78.41	-	-	13.60%	13.60%
Lavun	99.13	-	-	5.26%	5.26%
Agaie	79.05	-	-	3.85%	3.85%
Lapai	72.79	-	-	6.70%	6.70%

Table 4. Percentage of the local government areas covered by the NTA Kotangora station in Niger State

L.G.A	Average Distance (km) (from the transmitting station)	% of L.G.A. with primary coverage area	% of L.G.A. with secondary coverage area	% of L.G.A. with fringe coverage area	Total % of L.G.A. coverage area
Kotangora	16.22	7.70%	61.50%	23.10%	92.30%
Magama	28.27	-	37.90%	27.60%	65.50%
Mashegu	26.46	-	3.60%	29.10%	32.70%
Mariga	44.63	-	2.60%	7.90%	10.50%

Table 5. Percentage of the local government areas covered by the Niger State Television station in Niger State

L.G.A	Average Distance (km) (from the transmitting station)	% of L.G.A. with primary coverage area	% of L.G.A. with secondary coverage area	% of L.G.A. with fringe coverage area	Total % of L.G.A. coverage area
Chanchaga	7.88	3.00%	47.00%	50.00%	100%
Bosso	11.93	-	3.13%	50.00%	50.13%
Paikoro	20.54	-	6.67%	20.00%	26.67%
Shiroro	25.34	-	-	7.50%	7.50%

6 SUMMARY AND CONCLUSION

The coverage areas of the transmitting stations show that less than 1% of the entire land mass of Niger State has television signals strong enough to override ordinary interference in the locality at all times, and comprise the primary coverage area. About 9.21% of the state also enjoys good television signals but not strong enough to overcome interference completely at all times, thus within the secondary coverage area. But the service provided in this area may be adequate in rural areas where the noise level is low. Also, 18% of the state is in fringe service areas. In such areas, the service can neither be guaranteed nor protected against interference, and antennas with high antenna gain and heights higher than the surrounding buildings and obstacles are needed to receive good signals. In summary, only 28.82% of the entire land mass of Niger State has television signals coverage. More than 71% of Niger State does not receive television signals from any of the three television stations in the state. Thus, the present configurations of the transmitters of the three television stations do not give optimal coverage of the total land mass of Niger State.

The rate of attenuation of the VHF and the UHF signals is very high in Niger State. This may be as result of high loss of television signals due to diffraction by some physical features like hills and vegetations covering about 60% of the entire land mass and irregular elevation of the surface of the ground. The ground elevation is extremely high in some places and extremely low in some other parts of the state as shown in Figure 8.

It is also noted that none of the two NTA coverage areas overlap at any point. Therefore, there is no town or village in Niger State that can receive television signals from the two NTA television stations at the same time. So, installation of repeater stations at certain intervals of distance to provide reception of television signals for the entire state is necessary.

The coverage areas also show that none of the television stations in Niger State constitutes potential interference to any of the television stations in the neighboring states. Hence, the stations are in compliance with the Nigeria Broadcasting Corporation (NBC) regulation.

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