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Field Strength Variability Mapping of Nigeria

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Abstract

The analysis of the field strength variability using the meteorological parameters (temperature, pressure and relative humidity) retrieved from the archive of National Aeronautical and Space administration (NASA) was conducted for 61 locations between 2016 and 2020 to check for the spatial and seasonal variation. The result shows a seasonal variation with higher field strength variability during the dry season and lower field strength variability during the wet season. The spatial variation shows a significant difference between stations in the drier locations up north and those in the coastal areas. This could be attributed to the moisture contents of the atmosphere. Further analysis of the Inter-Tropical Discontinuity (ITD) position during the study period has confirmed this assertion where we discovered the northward movement of the ITD brings along with it more moisture and consequently a weak field strength. The variation in the high grounds is not manifesting because of the fact that pressure has little influence on the field strength variability. A careful study of the pressure contour explains that. The mean field strength is found to be between 2.8 dB and 17.9 dB. This implies that the output of the receiving antenna should be less than 2.8 dB and can be as high as 17.9 dB.

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1. Introduction

Atmosphere is a non-homogenous space having different layers exhibiting different physical behavior in terms of density, temperature, humidity and pressure. This erratic behavior has a significant impact on the propagation of radio as it travels from a transmitter to a receiver. In comparison to other communication channels, the notion of radio wave communication over time has been used to a higher extent. The wireless communication links are used for phone, data, and video services. The terrestrial radio link and mobile telecommunication can be deployed using the point-to-point radio line-of-sight link [1]. These areas of application are being deployed for both civil and military missions around the world.

An important system in the radio propagation is the transmission channel. This could be the atmosphere, optic fiber, or coaxial cable. The extent of signal distortion during the propagation within a chosen transmission channel determines the integrity of the information received. The variation in refractive index is a factor that determines the refraction in the lower part of the atmosphere. The ratio of the speed of propagation of a radio wave in a vacuum to its speed in a specific medium is known as the radio refractive index. The changes in this refrac-

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tive index determines the propagation of the radio wave in the troposphere [2]. Radio wave propagation in the atmosphere is largely influenced by the variation in relative humidity, temperature, and atmospheric pressure. Therefore, radio refractivity variation in the troposphere is a direct function of relative humidity, temperature, and pressure [3, 4]. However, it is worthy of note that large percentage of the values of refractivity can be determined by temperature in the wet season compared to dry season which is largely driven by relative humidity [5].

The radio wave propagation in the troposphere is broadly impacted by the properties of the earth and atmosphere [6]. The curvature of the earth and the condition of the atmosphere are responsible for the electromagnetic wave multi-directional refraction. The refractive index of the medium through which the electromagnetic wave travels determines the clearing of the microwave route.

Surface refractivity correlates negatively with the radio field strength, especially at very high frequencies [7]. A study by [8] concluded that radio refractivity is synchronous with the seasonal moisture in the atmosphere. Higher field strength are recorded when the refractivity is low. This corresponds to a time when there is less humidity and moisture. For every unit change in surface refractivity (Ns), a factor of 0.2 dB change in field strength can be used in the frequency range 30 – 300 MHz [9]. For the characterization of radio channels, surface and elevated refractivity data are frequently required. Surface refractivity, in particular, is highly useful for predicting propagation effects [10].

The condition of the atmosphere is very important for the proper planning of terrestrial radio links, navigation and remote sensing installations like RADAR. The field strength variability determines the sound level of a signal antenna. This will determine the height of the antenna and the distance between successive antennas. The basic principle of this research is Snail's law of refraction where the ratio of the angle of incidence to that of refraction is equal to unity.

This paper for the first time analyzed field strength variability for 61 locations in Nigeria compared to previous studies. Our decision to analyze 61 locations is to achieve significant spread. The period of the study (2016 – 2020) was decided for convenience.

2. Data and Methodology

Satellite meteorological data comprising of temperature (^oC), relative humidity (%), and pressure (hPa) were obtained from the US National Aeronautics and Space Administration (NASA) at 2-meter height [11]. While the Inter-Tropical Discontinuity (ITD) position data was obtained from the Nigerian Meteorological Agency (NiMet) for the period of five years (2016-2020). These data are however obtained daily.

The analysis of the surface radio refractivity depends on relative humidity, air temperature, and pressure. The atmospheric refractivity N (N-units) is analyzed using the equation from [12]:

$$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \quad (1)$$

where P is atmospheric pressure (hPa), T is absolute temperature (K), and e is the atmospheric water vapour pressure (hPa). The water vapour pressure can be determined from [2]:

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

$$e = H \times \frac{6.1121exp\left(\frac{17.50t}{t+240.97}\right)}{100} \quad (3)$$

where t is temperature in Celsius (^oC), and H is the relative humidity.

The Field Strength Variability (FSV) can be analyzed from the monthly maximum and minimum of surface refractivity obtained from equation 1. The FSV is determined from the monthly ranges of surface refractivity (N_S) as expressed in equation 4. The 0.2 dB is a factor adopted for a frequencies between 30 – 300 MHz [9]:

$$FSV = [N_s max - N_s min] \times 0.2 \quad (4)$$

Equations 1, 2, and 3 were used to compute the surface radio refractivity after which the equation 4 was used to compute the field strength variability: the surface refractivity was computed daily, this was to enable us obtain the monthly range of the surface radio refractivity which will subsequently be used to compute field strength variability using equation 4. The monthly mean and the study period mean where obtained for final plotting using Surfer software.

2.1. Study Area

The study was undertaken from the 61 stations within Nigeria, as shown on Figure 1. These stations were sampled for convenience from the five geo-climatic regions in the country using the definition of [13], these stations are:

- **Sahel**: Gusau, Sokoto, Maiduguri, Katsina, B/Kebbi, Damaturu, Nguru and Abadam.
- **Sudan Savannah**: Yelwa, Maru, Zaria, Giade, Dutse and Potiskum and Kano.
- **Guinea Savannah**: Abuja, Bida, Jalingo, Kaiama, Wase, Ilorin, Jos, Lafia, Lokoja, Makurdi, Minna, Ibi, M/Plateau, Yola, Kaduna, Bauchi, Gombe and Shaki.
- **Tropical Rainforest**: Abeokuta, Ado-Ekiti, Akure, Ibadan, Iseyin, Ondo, Oshogbo, Benin, UsiEki, Abakaliki, Asaba, Umuahia, Owerri, Awka, Enugu, Ogoja, Obudu and Ikom.
- **Coastal**: Ijebu-Ode, Ikeja, KokaMarine, Calabar, Eket, Onne, Port Harcourt, Uyo, Yenagoa and Warri.

3. Results and Discussion

3.1. Field Strength Variability of Nigeria

The results from this study can be seen as displayed in Table 1 as well as on Figure 2 to Figure 7. The field strength variability is found to be prevalent in the dry season and lower in the

Table 1: Field Strength Variability (*dB*) of the study area (2016-2020).

Region	January	February	March	April	May	June	July	August	September	October	November	December
Sahel	5.6	8.1	14.2	17.7	14.0	8.5	4.7	3.5	4.1	13.1	8.2	5.5
Sudan	6.1	9.2	16.0	17.9	8.7	5.1	3.9	3.5	3.2	10.5	9.2	5.6
Guinea	9.6	12.3	14.3	10.0	4.3	3.9	3.1	3.2	3.3	6.0	9.3	7.9
Rainforest	12.4	12.9	4.8	4.0	3.6	4.1	3.2	3.2	3.1	3.6	5.6	8.6
Coastal	10.0	9.5	3.3	3.3	3.3	3.6	3.1	2.8	2.6	3.2	3.5	7.4

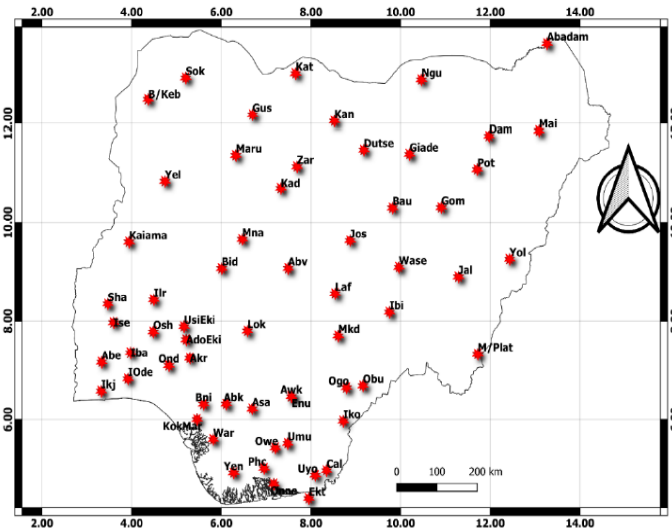

Figure 1: Map of the study area.

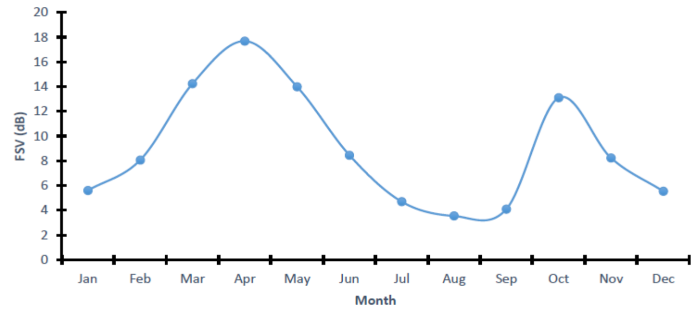

Figure 3: Field Strength Variability of Sahel zone of Nigeria.

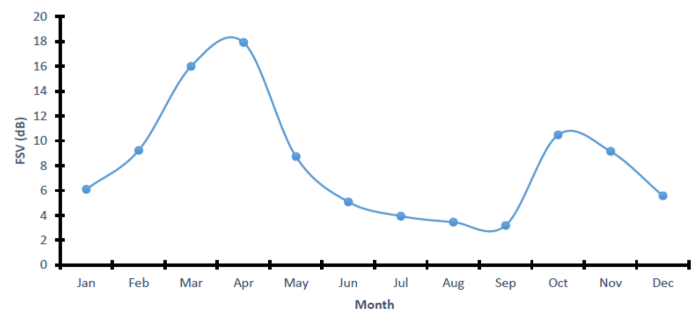

Figure 4: Field Strength Variability of Sudan Savannah of Nigeria.

rainy season. A negative correlation between the field strength and the moisture content in the atmosphere has been established at -0.90, unlike the refractivity which correlated positively at 0.93. More moisture means less field strength variability hence the rise in the dry season. Having higher field strength variability in the dry season is directly as a result of elevated surface temperature, low humidity and almost constant pressure. The field strength variability values in a particular location determines the output of the receiving antenna in that location.

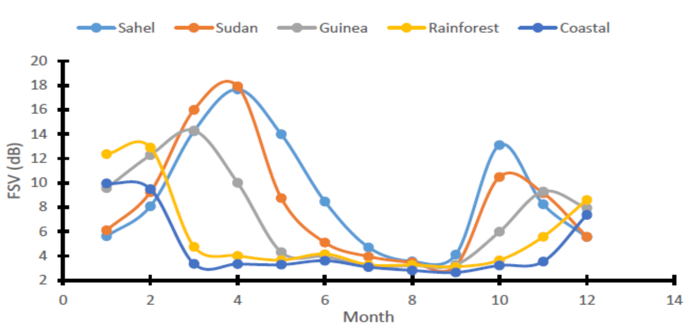

Figure 2: Field Strength Variability of Nigeria.

3.2. Seasonal Variation

A seasonal variation has been observed in this study of field strength variability. This work agrees with [6, 7], which all confirmed that field strength variability varies with season. Figure 2 revealed elevated values in the early and late part of the year except in stations within Sudan and Sahel areas where elevate values are also recorded in the April. The general pattern of field strength variability variation in the tropics is exhibiting higher values in the dry season and lower values in wet season.

The field strength variability in the Sahel stations in this study as shown in Figure 3 is found to rise from January at 5.6 *dB* to a peak of about 17.7 *dB* in April. It further declined sharply to about 3.5 *dB* in August. The elevated values were recorded in the dry season while the lower values in the rainy season. The curve did not completely follow the expected trend due to erratic nature of rain in the zone where the period is short with heavy rainfall. The output of antenna in this zone can be as high as 17.7 *dB* but should not be lower than 3.5 *dB*.

The electric field strength in this zone followed the same pattern as the Sahel zone. Careful observation of Figure 4 shows a sudden rise from January at about 6.1 *dB* to a peak of about 17.9 *dB* in April. The fall is as sudden as the rise to a dip of about 3.2 *dB* in September accounting for the lowest value in the zone. The output of the antenna in this zone is at the same range as that of the Sahel which is expected to be between 3.2 *dB* and 17.9 *dB*. This confirmed the similarities between the two zones.

The field strength variability in the Guinea Savannah of

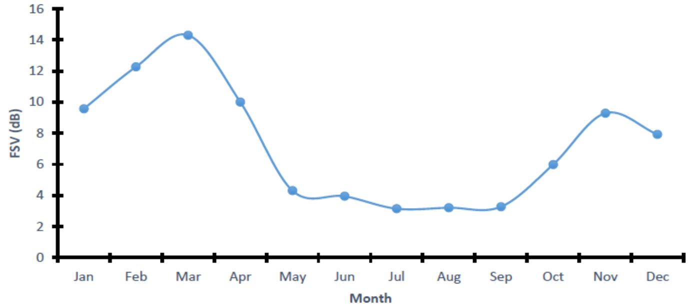

Figure 5: Field Strength Variability of Guinea Savannah of Nigeria.

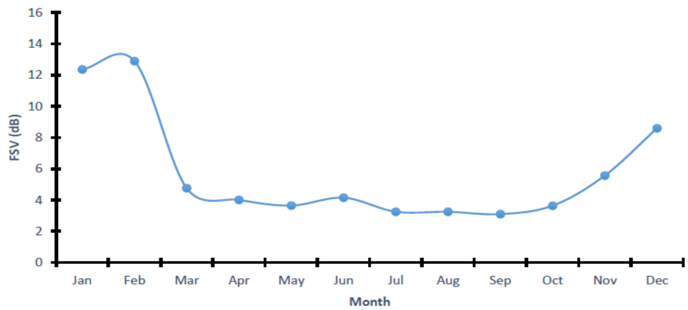

Figure 6: Field Strength Variability of Tropical Rainforest of Nigeria.

Nigeria is displayed in Figure 5. The maximum field strength is measured in March at about 14.3 dB and the minimum in July at about 3.1 dB. The curve showed a little deviation from those of the Sahel and Sudan showing nearly flat bottom from May at about 4.3 dB to September at about 3.3 dB. This clearly the months where maximum rain and atmospheric refraction is recorded in the zone. For planning of radio link and RADAR network in this zone, the output of the antenna can be as high as 14.3 dB but should not be less than 3.1 dB.

Figure 6 revealed the outcome of the study on the field strength studied in the Tropical Rainforest zone of Nigeria. Elevated values are recorded in the month of January and February at about 12.4 dB and 12.9 dB respectively. December, January and February are known to be dry months in this zone. A near consistent low values within the range of about 5 dB is recorded between March and November confirming the length of wet season in the zone. From the curve we can suggest that antenna output in the zone should as high as 12.9 dB and not lower than 3.1 dB.

The field strength of Coastal stations in this study as shown in Figure 7 is found to follow the same pattern as that of the Tropical Rainforest zone. The maximum value in this zone is recorded in January at about 10 dB declining sharply to about 3.3 dB in March. A near consistent low values are recorded from March to November at the range of about 2 to 3.5 dB. This is in agreement with the established length of wet period in the zone. The output of the receiving antenna in this zone can be as high as 10 dB but should not be less than 2.6 dB when planning RADAR network and terrestrial radio link.

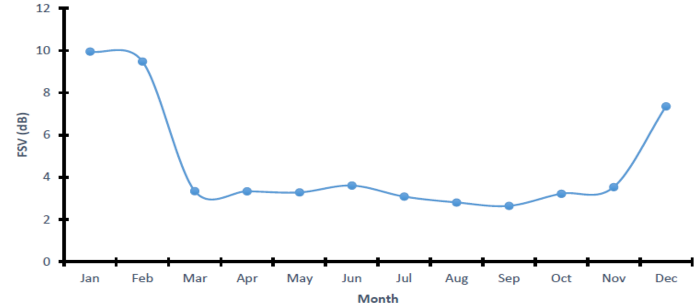

Figure 7: Field Strength Variability of Coastal Areas of Nigeria.

3.3. Spatial Variation of Electric Field Strength Variability

The variation of field strength variability across the study stations within the geo-climatic zones is shown in Figure 9 to Figure 12. For convenience, we divided the years under study into: First dry quarters (December, January & February), Second dry quarter (March, April & May), First rain Quarter (June, July & August) and Second rain quarter (September, October & November).

The spatial variation of field strength variability in the first dry quarter (December, January & February) is revealed in Figure 9. The approximate position of the ITD during this quarter as revealed in Figure 8 is around 8.3 ^oN with more than half of the country north of the imaginary line. During this period we expect a rise in the field strength variability due to reduced moisture and humidity in the atmosphere as showed in the humidity contour. The minimum value recorded in this quarter was in Giade, a station in Sudan Savannah at about 4.0 dB. While the maximum value was recorded in Benin a station in the Tropical Rainforest zone at about 15.1 dB. Lower values are found to strangely dominate the Sahel and Sudan Savannah zone during this quarter with most of the higher values in the lower part of the guinea Savannah into the Tropical Rainforest. This could be attributed to high range of atmospheric radio refractivity in the Tropical Rainforest zone.

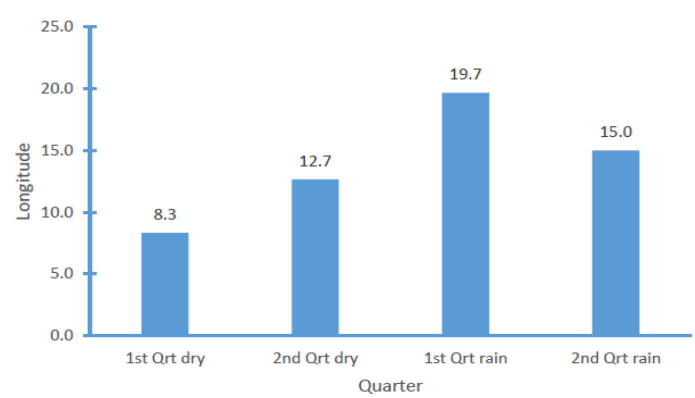

Figure 8: Average ITD position during the study period.

Showing in Figure 10 is the field strength variability during the second dry quarter. This is in consistent with the natural behavior of field strength variability where higher values are recorded in the dry regions and lower values in the wet regions.

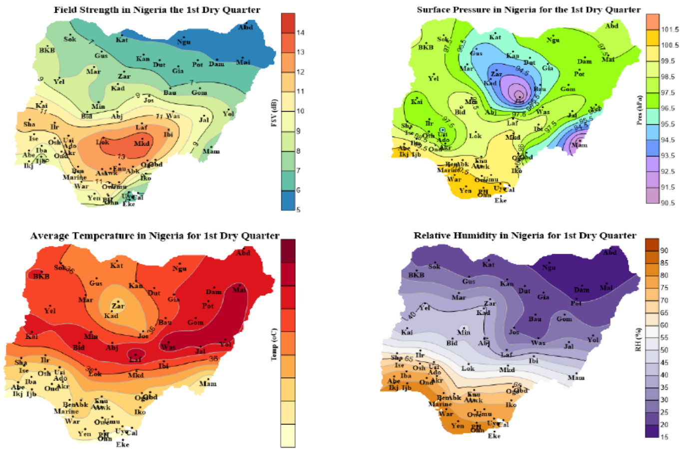

Figure 9: Spatial variation of FSV of Nigeria in first dry quarter (December, January & February).

The nearness of the Coastal and the Tropical Rainforest to the Atlantic Ocean led to higher atmospheric refraction which adversely affects the values of field strength variability in those regions. About half of the country accounts for the higher values of field strength variability especially in March and April. This could be attributed to lower refraction recorded during this periods all over the country. A maximum of about 21.5 dB was recorded in Potiskum, a station in the Sahel zone while the minimum of about 2.6 dB was recorded in Eket, a station in the Coastal zone. This agrees completely with the established trend of the field strength variability. Higher temperature give rise to higher field strength variability while the reverse is the case with humidity as can be seen on the temperature and humidity contours. The ITD position during this quarter is about 12.7 ^oN as can be seen in Figure 8. This puts more than half of the country under the line.

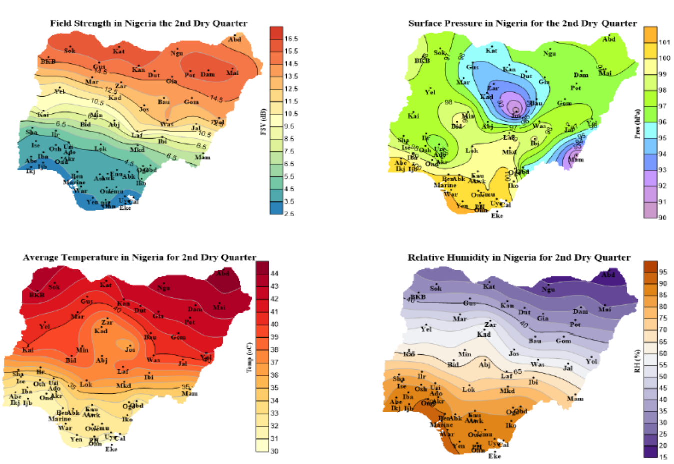

Figure 10: Spatial variation of FSV of Nigeria in second dry quarter (March, April & May).

The variation in the first rain quarter as depicted in Figure 11 revealed elevated values at Abadam an extreme north eastern flank of the Sahel zone at about 16.0 dB and lowest values at Eket in the Coastal zone at about 2.0 dB. During this period, the large part of the country is dominated by lower values except the extreme north of the Sahel where higher values were recorded. This confirms the facts that June, July and Aug as wet months of the year. The approximate position of the ITD during this quarter is around 19.7 ^oN putting the entire country under the influence of south westerly moisture laden wind. This consequently rise the atmospheric refractivity of the entire country. As the south westerly monsoon wind intensifies, it pushes the elevated values northward as can be seen clearly from the chart. The average minimum and maximum field strength variability during this period is about 2 dB and 16 dB respectively.

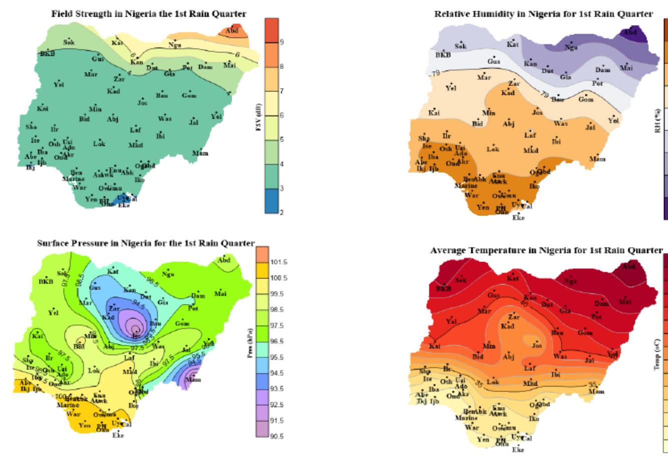

Figure 11: Spatial variation of FSV of Nigeria in first rain quarter (June, July & August).

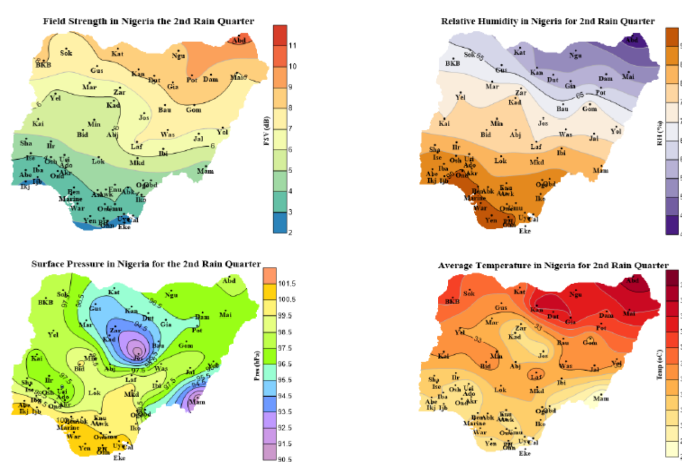

Figure 12: Spatial variation of FSV of Nigeria in second rain quarter (September, October & November).

The spatial variation of field strength variability of Nigeria for the second rain quarter (September, October & November) is shown in Figure 12. This is the period when rainfall dominate the Tropical Rainforest and Coastal areas while receding in the Sahel, Sudan Savannah, and Guinea Savannah. Looking at the months of October and November it shows the dominance of values in most part of the country. The ITD position in this quarter is approximately around 15 ^oN It is clear that the imaginary meteorological line is retreating southward due to the push from the North-Easterly trade wind. The retreat will continue until the whole country in under the influence of north easterly trade wind. For every southward retreat of the ITD, an increase in the field strength variability is recorded. The maximum field strength variability was recorded in Abadam at about 16.8 dB and the minimum in Eket at about 2 dB.

4. Conclusion

The field strength variability of Nigeria studied from 2016 to 2020 has revealed both seasonal and spatial variation. The seasonal variation has revealed a dominance in the dry season and a decline in the wet season. This is believe to be due moisture variation in the atmosphere during these two seasons. The presence of moisture in the atmosphere is believed to dampen the field strength, hence the prevalence of higher values in the dry season. The stations in the Sahel recorded higher field strength while stations in the coastal area recorded the least field strength. This further buttress the fact that field strength depend largely on the moisture content of the atmosphere. The value of field strength found during the study was between 17.9 dB to 2.8 dB. The implication of the field strength variability values in this study is that the output of a receiving antenna in Nigeria may generally be not less than 2.8 dB, but can be as high as 17.9 dB.

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