IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 18, Issue 6, Ser. I (Nov. – Dec. 2023), PP 22-29
www.iosrjournals.org

Variations Of Electric Field Strength Of Radio Waves Propagation In The Tropics

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Abstract:
An important parameter in radio-wave propagation is the electric field strength and the covered distance, especially for television and radio. Fluctuation, interference, and not being able to receive clear signal has been major challenge in some part of Osun state, hence the need to carry out this research for proper planning of a wider listening audience.
This study investigates variations of electric field strength and power density of Redeemer's FM, a radio station transmitting on frequency 103.5 MHz. Digital field strength meter and a Global Positioning System were used to objectively measure the radio transmitter's received signal intensity and elevation angle over 19 specific distances from the base station to about 50 km.
The results showed that electric field strength decreases with increasing distances in some locations. High electric field strength recorded in a few of the locations which are relatively far from the base station is attributed to the terrain's ground constant, the earth's surface's reflection of the signal, the transmitter power, antenna height, and gain. These factors categorized the result of this study as primary, secondary, and fringe coverage areas.
The study provides information for better planning in increasing the coverage area with good reception in this region.
***Key Word**: Coverage area; Electric field strength; Field strength meter; Power density; Radio-Frequency.*

Date of Submission: 16-12-2023 Date of Acceptance: 26-12-2023

I. Introduction

The ability to transfer huge amounts of data over a long distance without impairment from noise and interference is a continuing issue for modern telecommunications. Modern digital telecommunication systems' basic parts must be able to transmit voice, data, radio, and television signals. Since the value of digital systems is significantly lower than the value of analog systems, this transmission is employed to achieve high reliability[1].

Magnetic and electric fields are components of radio waves where the electric field component, is expressed in terms of the change in potential over a specific distance, such as volts per meter[2]. This measurement is used to estimate the signal's coverage area by measuring the power of radio signals (electromagnetic waves) at certain locations. In the troposphere also known as the changing sphere, the electric field intensity of radio signals at Very High Frequency (VHF) and higher frequency bands typically varies due to variations in the ground constants and the refractive conditions of the air, which in turn depend on temperature variations and water vapor pressure. These differences are influenced by seasonal, yearly, and nocturnal tendencies[3].

Frequency modulation (FM) is a type of modulation that uses changes in a carrier wave's instantaneous frequency to express information, in contrast to amplitude modulation, which varies the carrier's amplitude while keeping its frequency constant. In analog processes, changes in an input signal's amplitude directly correspond to changes in the carrier frequency[4]. Frequency-shift keying is a method for representing discrete values as digital data by varying the carrier frequency[5], for high-fidelity broadcasts of music and speech, FM is typically employed at VHF radio frequencies. The digitized signal frequently goes via a source encoder, which uses several techniques to reduce the amount of binary information[6]. The digital signal is handled in a channel encoder after source encoding, adding redundant data that enables faults to be found and fixed. The encoded signal is built suitable for transmission by modulation onto a carrier wave and should be made part of a significant signal during a process referred to as multiplexing. The multiplexed signal is sent into a multiple-access channel. After transmission, the above procedure is reversed at the receiving end, extracting the information[7]. The multiplexing technique is used to combine the encoded signal with other modulated signals to make it appropriate for transmission[8]. Following transmission, the aforementioned process is carried out in reverse at the receiving end to extract the data[7].

Electrical signal measurement has recently been more widely available due to electronic technologies, with several benefits that are undeniable by using the proper measuring tools to determine the values of the electrical quantities[9]. These tools support human sense-making, perception, calculation, and evaluation abilities. The transducer, which serves as one of the fundamental components of various measurement devices, is responsible for converting physical variables into electrical variables[10].

A field strength meter in telecommunications is a tool for measuring the electric field that a transmitter emits. This process provides signal strength values and allows for the comparison and estimation of the efficiency of a transmitter and its expected range[11]. Today the field strength meter is the most common electronic equipment used. These devices will provide an easier way of aligning FM transmitters and improving FM radio stations' performance[12]. The reception of a good signal from a given broadcasting station by the Fast Serial Interface (FSI) at any given point depends on the Distance between the point of the reception and transmission of the signal and the resultant attenuation which the signal undergoes as it travels between the two points, antenna directivity, and carrier wave percentage modulation, fading as produced by a direct and indirect signal, strength of interference at the receiving end, the quality of the receiver system and its ability to filter out local noise or interference, adjacent channels interference, and convert the received radio frequency (RF) signal into an electrical signal without appreciable distortion[7].

A physical field called an electric field surround electrically charged particles and acts to either attract or repel other charged particles inside the field. Both electric charges and magnetic fields can produce electric fields[13]. The force an electric field will exert on a unit of positive charge at a specific location in space is measured as the electric field strength, which is also known as the electric field intensity. A radiating source produces electromagnetic radiation, which is known as radio emission[14]. The wave-front of a radio wave, which is at a right angle to the direction of propagation and power flow, is the plane that contains the electric and magnetic vectors (E and H) [15]. The frequency or wavelength of an electromagnetic field (EMF) is one of its key characteristics.

Electromagnetic Fields (EMFs) are the most common type of electromagnetic radiation that radio base stations emit into space. It has components of the magnetic and electric fields that move perpendicularly to one another. Since these signals are periodic, the third axis, which is perpendicular to them, is where the waves will travel. A series of equations known as Maxwell's equations describe how the electric and magnetic field parts of EMF interact with one another and with matter[16].

$$\Delta . E = \frac{\rho}{\varepsilon_0} \tag{1}$$

$$\Delta . B = 0 \tag{2}$$

$$E = -\frac{\partial B}{\partial t} \tag{3}$$

$$\Delta \times B = \mu_0 J + \mu_0 \varepsilon_0 \frac{\partial E}{\partial t} \tag{4}$$

where ρ is the charge density, which depends on position and time, μ_0 is the permeability of free space, ε_0 is the permittivity of free space, and J is the current density vector, also a function of position and time. By substituting the permittivity and permeability of free space with the permittivity and permeability of the linear material, Maxwell's equations changes in the linear material are given by[13].

$$B_0 = \frac{K}{\omega} E_0 = \frac{1}{C} E_0 \tag{5}$$

where ω is the angular frequency of the wave, k is the propagation constant, c is the speed of light in space and E_0 is the electric field intensity (strength). In general, the electric field intensity variation in space and time for a sinusoidal wave is given by equation (6) and the magnetic field by equation (7).

$$E(r,t) = \overline{E_0} e^{i(kr-\omega t)} . \hat{n} - \frac{k_3 e}{T} \tag{6}$$

$$\bar{B}(r,t) = \frac{1}{c} \overline{E_0} e^{i(kr-\omega t)} . \left(\hat{k} \times \hat{n}\right) \tag{7}$$

where $\hat{k}$ is the propagation vector, $\hat{n}$ is a unit vector in the wave's propagation direction- the polarization vector, and r is the space coordinate. The relationship of the electric field intensity to the magnetic field intensity is defined as equation 8 where, Z_0 is the characteristic impedance of the wave in free space ($Z_0 = 377\Omega$).

$$\frac{|E|}{|H|} = \frac{E_x}{H_y} = \sqrt{\frac{\mu_0}{\varepsilon_0}} = Z_0 \tag{8}$$

Power density is the amount of radiation per unit area. It is inversely proportional to the square of the distance from the source and directly proportional to the transmitted power. In open space, all radiation is subject to the inverse square law [17]. The power density of the wave that is transmitted at a new location is reduced to one-quarter of its prior value when the distance from a transmitter is doubled [3].

A study on the level of electromagnetic field (EMF) strength to which patients and staff in a magnetic resonance imaging (MRI) room were exposed was conducted by Mutul [18]. The measured values were compared to the International Commission on Non-Ionizing Radiation Protection's established boundaries (ICNIRP). A maximum level of 0.1729 A/m was recorded in the MRI room which is over the ICNIRP guidelines for EMF measurements.

Akinbolati et al. [10] investigated the received signal intensity and the propagation patterns for UHF channel 23, the broadcast signal at different altitudes in Ondo State, Nigeria (2016). The signal strength was statistically evaluated along many routes throughout the state using a digital field strength meter. These and many other works have been done by other researchers such as [19-24].

The inability of Redeemer's 103.5 FM transmissions to reach some areas within Ede environ as well as Osun state has been a source of concern despite the station's informative, educative, and good programs. This study aims to analyse the electric field strength of the Redeemer's 103.5 FM and categorises it as primary, secondary, and fringe coverage areas. It also measured the radiated power which has been a source of health hazard through research, to know the degree of its impact on people in and around the station.

II. Material And Methods

Figure 1 shows the 3-Axis RF Field Strength Meter (TM-195) equipment used for this study and Figure 2 shows the transmitter room of Redeemer's 103.5 F. M. The field strength meter is readily available in the laboratory of the Department of Physical Sciences, Redeemers University. The meter is used to identify electromagnetic pollution produced artificially and is calibrated between 50 MHz and 3.5 GHz. The meter converts the measurement values to the appropriate power density units ($\mu W/m^2$, mW/m^2 or $\mu W/cm^2$) and magnetic field strength units (μA/m or mA/m).

Figure 1: A 3-Axis R.F. Field strength meter

Figure 2: Transmitter room of Redeemer's F.M

Measurement of the Electric field strength (Ex, Ey, Ez) mV/m and Power density (Px, Py, Pz) $\mu W/m^2$ of Redeemer's 103.5 F.M transmitter were carried out in nineteen (19) different locations in Osun state with the aid of the 3-Axis R.F. Feld strength meter. The x, y, and z indicate the direction towards the east, west, and north, respectively, of the locations at which measurements were taken at a time. [25]categorized signal levels of terrestrial communication to primary, secondary, and fringe coverage areas.

Between the hours of 8 a.m. and 6 p.m., the measurement was done using a vehicle, and the distance between the two locations of measurement varied between 2 km and 5 km in order to prevent measuring the electric field intensity of space waves. Table 1 shows the parameters of the Redeemer's 103.5 F.M transmitting station in Ede, Osun state, while Table 2 shows the selected nineteen (19) locations with their coordinates and distances from the base station.

Table 1: Parameters of Redeemer's F.M Transmitting Station

Frequency	103.5 MHz
Transmitting power	EM250 Watts
Broadcast Tower	120 ft Three Broadcast tower
Location	Redeemer's University, Ede
Geographical coordinates	7°40'54.2"N 4°27'25.1"E
Accessories	Lightning Rod/cooper tape, spark arrestors galvanized base grounding kits, photocell switching arrangements, aviation obstruction lathing kit, surge/lightning protection for F.M.

Table 2: Study Locations with their Coordinates and Distances

S/N	Location	Distance (km)	Elevation (m)	Coordinates
1	Base station	0	269	7.2^0 N, 4.1^0 E
2	Adolak	1.2	284	7.2^0 N, $4.0\ ^0$ E
3	Oloki	2.7	284	7.9^0 N, 4.0^0 E
4	Oke-iresi	3.4	269	7.8^0 N, 4.6^0 E
5	Cottage	4.4	269	7.2^0 N, 4.3^0 E
6	Agip	5.9	311	7.3^0 N, 4.5^0 E
7	Aisu	6.7	287	7.5^0 N, 4.8^0 E
8	Sekona	7.4	295	7.2^0 N, 4.3^0 E
9	Timi palace	7.7	269	7.0^0 N, 4.1^0 E
10	Fed Poly	8.6	284	7.4^0 N, 4.9^0 E
11	Oke -gada	8.8	284	7.8^0 N, 4.6^0 E
12	Abeere	11.0	300	7.2^0 N, 4.9^0 E
13	Ile – oogi	12.0	232	7.4^0 N, 4.0^0 E
14	Owode-ede	12.0	237	7.0^0 N, 4.1^0 E
15	Olaiya Junction	16.0	320	7.4^0 N, 4.6^0 E
16	Ode omu	17.0	228	7.4^0 N, 4.0^0 E
17	Ara	23.0	221	7.5^0 N, 4.4^0 E
18	Ikirun	42.0	393	7.2^0 N, 4.1^0 E
19	Inisa	50.0	371	7.1^0 N, 4.6^0 E

III. Result

The measurement recorded by the field strength meter for the Electric field strength and power densities at the nineteen selected locations within Osun state were analyzed and the results are shown from Figure 3 to Figure 8. The Figures show locations with very strong primary coverage, secondary, and fringe coverage areas.

Figure 3 shows that the electric field strength has the highest value of 896.2 (mV/m) at the base station in the west direction (Ey). The signal was also observed to be high in all directions in the base station. At Akoda/Adolak, which is about 1 km from the radio station, the value of field strength decreased to 534 mV/m. However, between Oloki and Oke-iresi, there was a slight increase observed in the value of the field strength. At cottage, the value of field strength increased to 440.8 mV/m. The field strength value decreased from 676.9 mV/m to 464.1 mV/m at Agip and Aisu, respectively. It steadily increased from Aisu to Federal Poly, where it finally dropped to 523.1 mV/m at Owode-Ede.

For Ez, the electric field strength at the primary coverage region is highest at 0 km 246.5 mV/m. This value decreases drastically to 355.8 mV/m at 1.2 km. From 1.2 km to 3.9 km, the electric field ranges between 355.8 mV/m and 542 mV/m. This value decreases sharply to its lowest point of 237.6 mV/m at 6.7 km and surges to 699.8 mV/m at 7.7 km. It rises slightly to 742.6 mV/m at 8.6 km and drops to 523.1 mV/m at 12 km.

For Ex, the electric field strength begins with a value of 623 mV/m at 0 km. Between 1.2 km and 4.4 km, the value of Ex reaches its peak of 654.6 mV/m at 5.9 km. This value decreases drastically at 6.7 km and surges upwards to about 608.5 mV/m at about 7.7 km. Ex electric field strength value remains relatively stable until about 12 km.

The locations listed above have distortion-free signal transmission, making them the primary coverage area. The sudden increase in the electric field at distances ranging from 5.9 km to 12 km in Ey, from 7.7 km to 8.6 km in Ez, and from 5.9 km, 7.7 km to 12 km along Ex could be due to other RF radiation influences from other sources/base station in the reference locations.

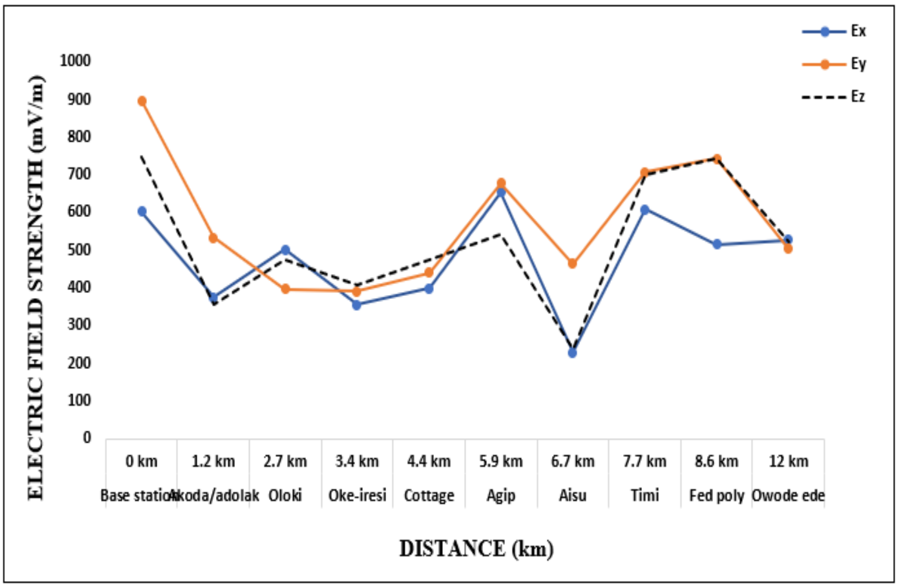

Figure 3: Electric Field strength against distance at primary coverage region

From Figure 4 it is seen that the highest power density value was recorded at 0 km at the base station, with the lowest value recorded at 6.7 km in Aisu. The highest value recorded from Pz at 0 km was 1496 $\mu W/m^2$ and the lowest value recorded from Px at 3.4 km was 104.73 $\mu W/m^2$ in Oke-iresi. The average peak value was recorded at 0 km (base station). The values began to decrease until 6.7 km from the base station, where the lowest average value is recorded, before surging back up at around 7.7 km and maintaining a relatively steady value up to 12 km.

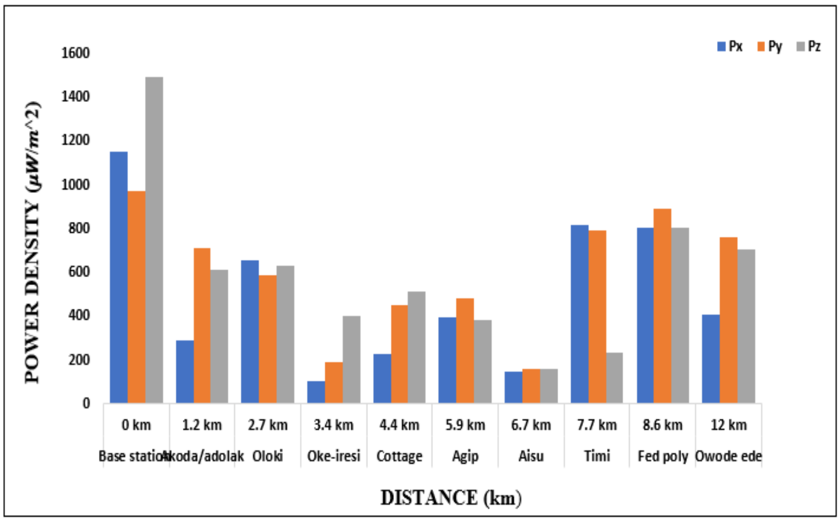

Figure 4: Power density against distance at primary coverage region

Figure 5 shows the secondary coverage region, ranging from Sekona to Ile-ogi. Ey at this region begins with an electric field strength of 433.5 at 7.4km from the base station. This value moves up to 720.5 mV/m at 8.8 km, where it experiences a minor and stable reduction in the signal level and then drops to about 269.3 mV/m at 12 km. Then the value steadily increases to 673.9 mV/m at 16 km.

For Ez, at 7.4 km, the electric field measurement value was 411.3 mV/m at Sekona. This value rose to the peak of its peak of 666.2 mV/m at 8.8 km in Oke Gada. The electric field strength dropped between 8.8 km to 12 km in Abere before finally rising to a very high value of 658.8 mV/m at 16 km in Olaiya Junction. For Ex, the value at 7.4 km from the base station begins at 415.9 mV/m. The value rises to 645.7 mV/m at 8.8 km, and then decreases slightly between 8.8 km and 12 km before finally increasing to 591.4 mV/m at 16 km.

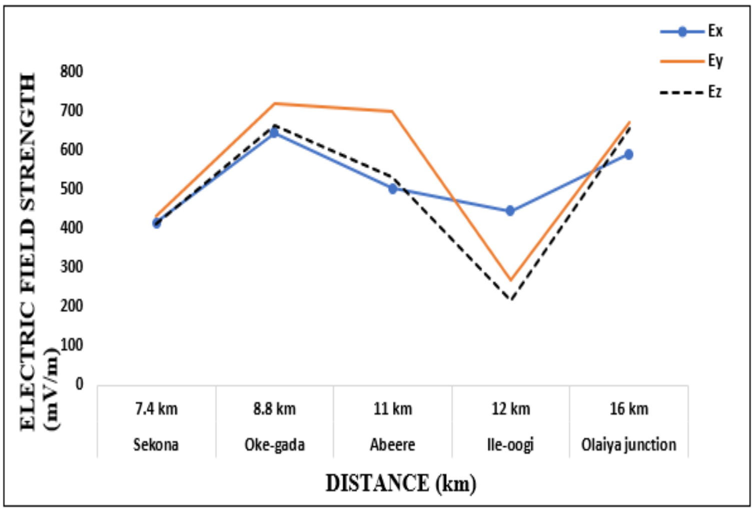

Figure 5: Electric Field strength against distance at secondary coverage region

Figure 6 shows the average value of power densities obtained from Py at about 8.8 km and the lowest value obtained from Pz at about 7.4 km. On the average, for Px, Py, and Pz, the lowest average is about 12 km, the highest at 8.8 km, and the second highest at 11 km. The fluctuations in the electric field strength and the power densities in this region as seen in figure 6 are attributed to the area's topography. A decrease in the signal strength is observed in sloppy locations. As we climbed up towards Olaiya junction, a very strong signal was received until about 12 km in Ile-oogi, where there was minor distortion in the signal strength. These locations were then categorized to be in the secondary coverage area.

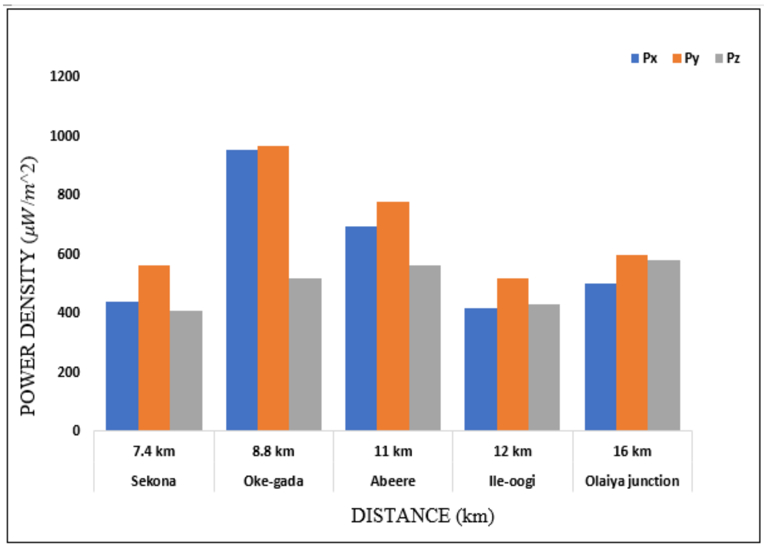

Figure 6: Power density against distance at secondary coverage region

Though it was observed that higher values of electric field strength were recorded at some far distances than closer locations to the transmitter due to higher elevation values as shown in Figure 3. Figure 7 shows the fringe coverage region from 17 km in Ode omu to 50 km in Inisa. Ey began with an electric field strength at a peak value of 500 mV/m in Ode Omu and steady declined to 207.9 mV/m at 42 km, which remains relatively constant up to 50 km.

For Ez, the value decreases from its peak of 325.8 mV/m at 17 km to its lowest value of 210.9 mV/m at 50 km. For direction, Ex, the value decreases steadily from its peak of 228 mV/m at 17 km to its lowest value of 185.5 mV/m at 50 km. The signal strength level in this area dropped drastically compared to other coverage areas. The signal level fluctuated almost every 5 minutes. Hence, it was categorized to be fringe. The elevation was high at Ode-Omu, Ikirun, and Inisa as shown in Table 2 so the signal strength was abysmally low. This is attributed to multipath fading, tall rise buildings obstructing the signal from reaching this area.

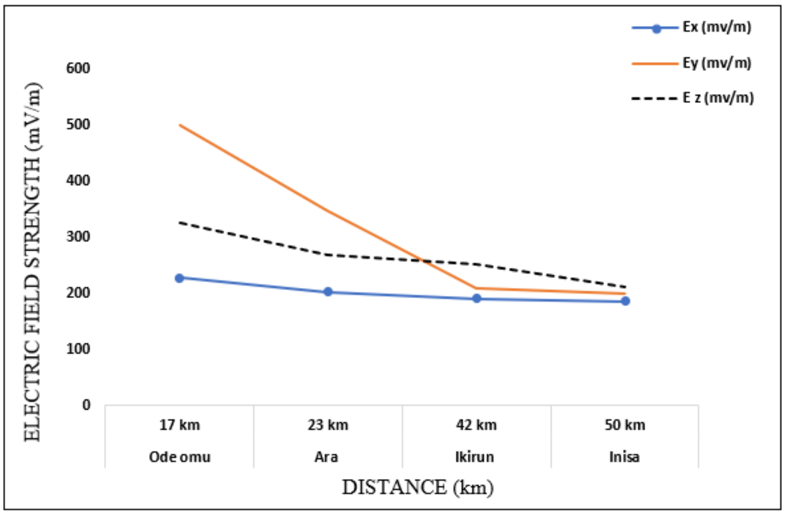

Figure 7: Electric Field strength against distance at fringe coverage region

Figure 8 shows the average peak of the power density recorded at 17 km, with Py at Ode-Omu giving the highest individual power density of 437.9 $\mu W/m^2$ at 17 km. On the average, the values dropped at 23 km but changed slightly over the 42 km and 50 km points.

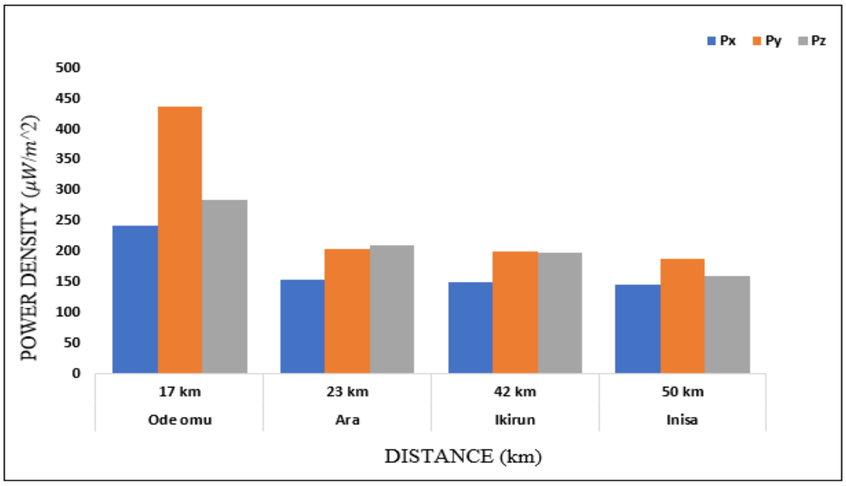

Figure 8: Power density against distance at fringe coverage region

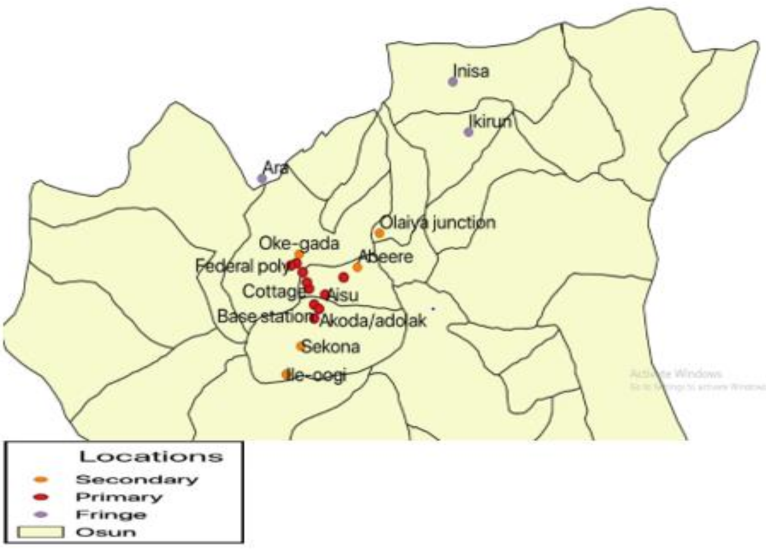

Figure 9: Geographical map of coverage areas

The distribution of the electric field strength was summarily put on the map of Osun state in Figure 9 to reflect the characteristics of signal reception in all the locations.

IV. Conclusion

The results from this study have identified the categories of the coverage areas as; primary coverage area having the best clear reception, secondary coverage area with clear audio but with little distortion, and fringe coverage area where the wave signal is significantly distorted. The values from the result of this research will definitely help in proper planning for wider coverage of good reception in this region

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