IJST EXPLORE International Journal of Science and Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-7318

International Journal of Science and Technology Volume 2 No. 9, September, 2013

# Determination of Propagation Path Loss and Contour Map for Adaba FM Radio Station in Akure Nigeria

**Oyetunji S. A, Alowolodu O. D**
Federal University of Technology Akure, Nigeria

## ABSTRACT

FM signal propagation through the troposphere interacts with the terrain as obstacles and reflection planes. To understand the degree of interaction, signal strength measurements of the 88.9MHz frequency modulated Adaba Radio located at Akure Nigeria (Longitude 5.125431E, Latitude 7.324499N) was carried out in the area surrounding the station. The paper reviews the various models for predicting transmission loss and employed the long rice irregular terrain model for its versatility for the study. The losses along the paths were determined and this was compared with the path loss predicted by the irregular terrain model and this was highly correlated. The result offers useful data for developing the contour map of the propagation loss which was developed for the station. It was concluded that with the irregular terrain model predictions can be used for accurate spectrum management in Nigeria.

**Keywords**: *Signal Strength, Spectrum Management, Terrain and Transmission Loss.*

## 1. INTRODUCTION

FM signal propagation through the troposphere interacts with the terrain as obstacles and reflection planes [1]. Thus, the location of a Transmitter for radio communication in any locality depends on a number of considerations such as altitude, latitude, longitude and centrality to coverage area [2]. In addition, political considerations play dominant role since the liberalization of the broadcasting industry in Nigeria. This study investigates the correlation of signal strength predicted by [3] with field measurements at different locations. The study was carried out in a frequency modulated (FM) radio station located at Ilaramokin, Akure, Nigeria.

In free space, all electromagnetic waves obey the Inverse Square Law which states that electromagnetic waves strength is proportional to the inverse of the square of the distance from the source [4]. In addition to the Inverse Square Law, radio propagation on earth is also affected by a number of other factors determined by its path from point to point. These factors include the ground constant of conductivity and permittivity, vegetation, buildings, mountains, hills and of course the atmospheric conditions such as water vapour and other gases that constitute the air [4]. When a radio frequency current flows into a transmitting aerial, a radio wave at the same frequency is radiated in a number of directions as predicated by radiation patterns of the aerial. Various modes of propagation are usually employed, such as the surface or ground wave, the sky wave, the space wave, use of communication satellite and etc. However, these are frequency dependent as shown in figure 1 [4].

The justification for the study is to determine the coverage area of the station with the specific objective of determining compliance with the regulatory body- Nigerianl Broadcasting Cooperation (NBC). In addition, the study offers suggestion on how to improve the coverage where environmental factors affect the signal reception. The study provides platform for spectrum management in Nigeria. This becomes necessary with the recent Libralisation of Broadcasting industry in Nigeria [1]

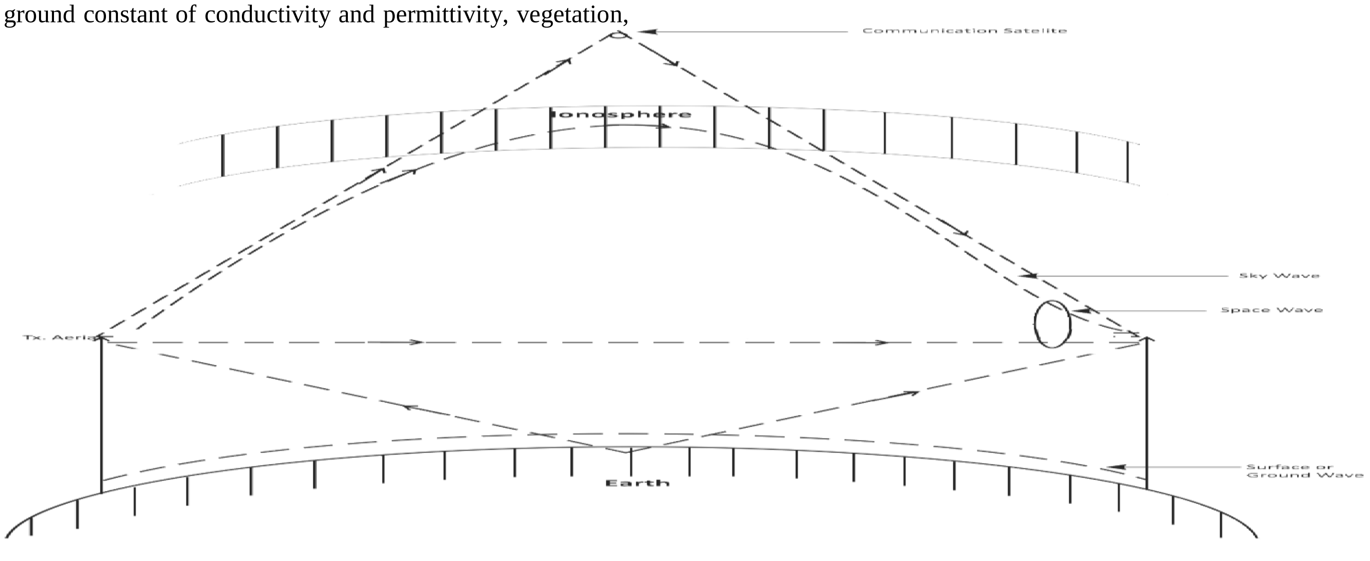


**Fig. 1: Modes of Wave Propagation**

**Table 1: Frequency Spectrum Table**

| Classification | Frequency Band (KHz) | Mode of Propagation |
|---|---|---|
| Very Low Frequency (VLF) | 3 – 30 KHz | Guided between the earth and the ionosphere |
| Low Frequency (LF) | 30 – 300 KHz | Guided between the earth and the ionosphere – Ground waves |
| Medium Frequency (MF) | 300 – 3,000 KHz | Ground waves during the day– E- layer Ionospheric reflections at night |
| High Frequency (HF) | 3 – 30 MHZ | E - layer Ionospheric reflection – F– layer Ionospheric reflections |
| Very High Frequency VHF) | 30 – 300 MHz | Line of sight – E-layer Ionospheric reflections |
| Ultra High Frequency (UHF) | 300 – 3,000 MHz | Ionospheric reflections |
| Super High Frequency (SHF) | 3 – 30 GHz | Ionospheric reflections |

## 2. MECHANISM OF RADIO WAVE PROPAGATION

Ground waves exist only for vertical polarization, produced by vertical antennas when the transmitting and receiving antennas are close to the surface of the earth. The transmitted radiation induces currents in the earth's surface being attenuated according to the energy absorbed by the conducting earth [5]. The ineffectiveness of horizontal electric field is due to the energy loss through the earth as the signal propagates. Ground wave propagation is common for frequencies of a few MHz. Sky wave propagation is mainly dependent on reflection from the ionosphere, a region above earth's surface of ratified air that is ionospheric by sunlight (primary ultraviolet radiation). The ionosphere is responsible for long distance communication in the high frequency band between 3 and 30MHz, but it is very dependent on time of day, season, longitude on the earth [5]. It makes possible, long-range communication using very low power transmitters.

The most important propagation mechanism for short-range communication on the VHF and UHF bands is that which occurs in an open field, where the received signal is a vector sum of a direct line-of-sight signal and as signal from the same source that is reflected off the earth [6]. This shows that there exist a relationship between signal strength and range in line-of-sight and open field topographies. The range of line-of-sight signals when there are no reflections from the earth or ionosphere is a function of the dispersion of the waves from the transmitter antenna. For this free-space case, the signal strength decreases in inverse proportion to the distance away from the transmitter antenna. But when the radiated power is known, the field is derived by[6]:

$$E = \frac{\sqrt{30 P_t G_t}}{d} \quad (1)$$

Where $P_t$ is the Transmitter power (Watts), $G_t$ is the Transmitter Antenna gain, d is the distance (Meters), E is the Volts/Meter

To find the received power ($P_r$) when the power into the transmitter is known equation 2 [7] is used.

$$\Pr = \frac{PtGtGr\lambda^2}{(4\lambda d)^2} \quad (2)$$

Where λ is the Wavelength, $G_r$ is the Receiver Antenna gains, $G_t$ is the Transmitter Antenna gain

d is the distance (Meters) and $P_t$ is the Transmitter power (Watts)

Through the above equations, the range is calculated on this basis at high (UHF) and microwave frequencies when high-gain antennas are used and located many wavelengths above the ground. The actual range of a VHF or UHF is affected by reflections from the ground and surrounding objects; the path lengths of the reflected signals differ from that of the line- of-sight signal so then the receiver sees a combined signal with components having different amplitudes and phases. It is very important to take into consideration the field strength versus distance for open field propagation. As the range increases, the signal strength followed an Inverse Square Law and by increasing the antenna heights, the distance is extended. The approximate distance is extended by [7]:

$$Dm = 12 \times h_1 \times h_2 / \lambda \quad (3)$$

Where: $h_1$ is the Transmitting Antenna heights, $h_2$ is the Receiving Antenna heights and λ is the Wavelength

The propagation of radio waves is influenced by a lot of factors which are frequency dependent. These include [8]:

(a) Curvature of the earth terrain

(b) The dielectric and resistivity constant of the earth and sea.

(c) Troposphere absorption

## 3. MODELS FOR PREDICTING RADIO PROPAGATION LOSS

Various models have been developed for predicting the propagation of radio signal in the atmosphere [8]. These models considered factors limiting the propagation of radio waves and are useful in the determination of the primary and secondary coverage areas for Broadcasting Stations [9]. FM radio stations and TV stations usually enjoy coverage beyond the radio horizon but the coverage beyond this radio horizon is said to be diffracted and the actual loss can also be determined. A station's coverage map is an essential ingredient in comparing the station's predicted signal strength with the actual measured values. Some of the prediction models are discussed below

### 3.1 Longley-Rice Model

In January 1, 1967, the American National Bureau of Standards published Technical Note 101, [3] - a two-volume propagation treatise. The concepts expressed in these documents were incorporated into a series of computer routines that is being referred to as the "Longley-Rice Model". The model uses terrain information to compute terrain roughness and radio horizons if the other environmental variables such as average climate conditions, soil conductivity etc. are supplied significant results for field strength calculations compared to field actual measurement can be achieved even at low frequencies like 30 – 40 MHz [3]. The Longley-Rice Model considers atmospheric absorption including atmospheric absorption by water vapour and oxygen, loss due to sky-noise temperature and attenuation caused by rain and clouds. It considers terrain roughness, ground reflections, knife-edge, loss due to isolated obstacles, diffraction, forward scatter and long-term power fading in its pre-defined signal level representations. The Longley-Rice Model is the most common and extensively used prediction method today. It is usually used for calculating coverage areas and interference for broadcasting stations. The model predicts long-term median transmission loss. The model was designed for frequencies between 20 MHz to 40 GHz and for path lengths between 1Km to 2,000 Km. The Longley-Rice Model requires the input of certain general parameters so as to set-up the programme for propagation calculations. These parameters include the following:

a) Frequency;

b) Effective Radiated Power;

c) Antenna Direction;

d) Heights;

e) Polarization;

f) Refractivity;

g) Permittivity;

h) Conductivity;

i) Variability

j) Climate

### 3.2. Okumura Propagation Model

The basic Okumura Model uses the height above average terrain to calculate path loss and it does not consider specific terrain obstacles, a set of equations have been provided for the computer use of Okumura Model Predictions [10]. The Okumura model for Urban Areas is a Radio Propagation Model that was built using the data collected in the city of Tokyo, Japan. Okumura model was built into three modes which are urban, suburban and open areas. The frequency range of Okumura Model is between 200MHz and 1,900MHz [7] and it is mathematically expressed as:

$$L = L_{FSL} + A_{MU} - H_{MG} - H_{BG} - \sum K_{correction} \quad (4)$$

Where:

L is the median path loss unit: Decibel (dB);

$L_{FSL}$ is the free space loss unit: Decibel (dB);

$A_{MU}$ is the Median attenuation unit: Decibel (dB);

$H_{MG}$ is the Mobile station antenna height gain factor;

$H_{BG}$ is the Base station antenna height gain factor; and

$K_{correction}$ is the Correction factor gain (such as type of environment, water surfaces, isolated obstacle etc.)

Okumura model does not provide a mean to measure the free space loss. However, any standard method for calculating the free space loss can be used.

### 3.3. International Telecommunications Union (ITU-RP 1546-1)

The ITU Model is widely used in Europe and Central America [11]. The model developed field strength predictions for terrestrial sources in the 30MHz to 3,000MHz frequency range. It used a set of propagation curves that are based on measurement data mainly relating mean climatic conditions in temperature climates. The model considers the transmitter height above average terrain, the receiver antenna height and incorporates a correction for terrain clearance angle when making field strength predictions.

### 3.4. Cost-231 Propagation Model

This model uses the (Height Above Average Terrain) HAAT along each radial to determine the attenuation based on the following [12:

**Path Loss (dB)**

$$46.3 + 33.9\log(f) - 13.82\log(H) + [44.9 - 6.55\log(H)]\log(d) + C \quad \textbf{(5)}$$

Where:

f = Frequency (MHz)

d= Distance between base station and receiver

H= HAAT in the direction of the receiver (m)

C= Environmental Correction factor (dB)

This model impalements the cost-231/HATA version of COST – 231 Propagation Model [13]. The HATA correction for receiver height and frequency is then applied for the attenuation.

### 3.3. TIREM Model

TIREM stands for Terrain Integrated Rough Earth Model [11]. This model with Tech Note 101 base but has been modified over the years to make up for believed inaccuracies in the Longley-Rice Model. These techniques considered factors/components such as free-space spreading, reflection, diffraction, surface-wave, tropospheric-scattering and atmospheric absorption to arrive at the path loss.

As opposed to Longley-Rice, TIREM has built-in routines for evaluating radio paths over sea water [11]. TIREM is used by the US Department of Defense. However, as a proprietary model, it is less attractive.

## 4. METHOD OF DATA COLLECTION

The methodology adopted includes the following:

a. segmentation of the coverage area into eight (8) different sectors for measurement of signal strength, longitude and latitude,

b. point-to-point measurements for determining the signal strength at different locations using a GPS Receiver and Digital Signal Strength Meter;

c. collection of relevant information about the station under consideration as presented in table 3;

d. development of coverage contour map for the station under consideration.

**Table 2: Station Parameters for Adaba FM Station.**

| Altitude (Msl) | Frequency | Longitude | Latitude | Transmitter output power | Antenna Height above ground level |
|---|---|---|---|---|---|
| 422.70 | 88.9 MHz | 5.125431 | 7.324499 | 25KW | 274.32m |

### 4.1 Method of Data Collection

The areas of locations marked out to be visited were Ondo town, Owo town, Ilesha and Ikere-Ekiti. These locations were chosen because of their geographical positions which represent the South-Western part; the North-Western part, the South-Eastern and Northern part of Akure. These locations provide an adequate estimation of Adaba radio signal strength on all sides. The equipments used in the acquisition of data are:

(a) A Digital Signal Level Meter (GILBERIT, GE - 5499)
(b) A GPS (Global Positioning System) Receiver (UBLOX ANTARIS 4)
(c) Laptop Computer
(d) Laptop Computer

The collected data includes the following:
GEOGRAPHICAL CORDINATES: comprises the Latitude, Longitude and Elevation of the points. This data was provided by the ANTARIS GPS Device.
SIGNAL STRENGTH: the strength of the Adaba FM radio station signal as indicated by the digital signal level meter device at the various points.
DISATANCE ITM: this is the distance, along the line-of-sight, between the transmitter and a point as provided by the ITM software.

## 5. DATA PRESENTATION AND ANALYSIS OF RESULTS

The coverage area of the station is expressed in Fig. 2.

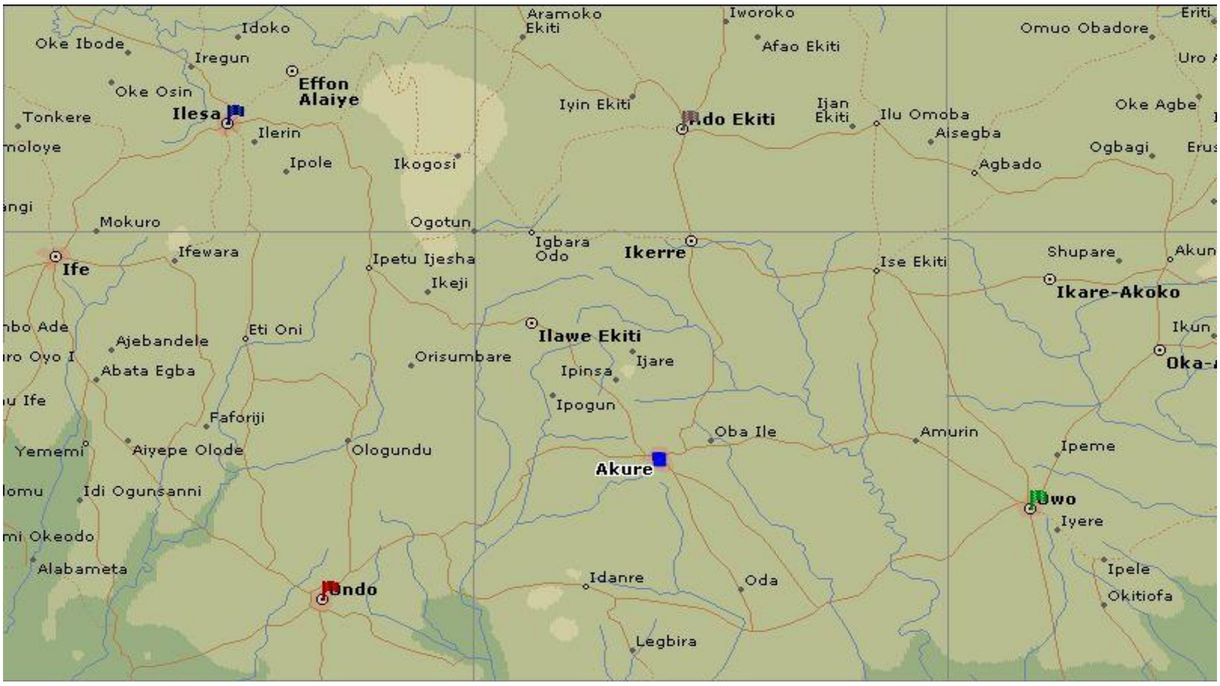


**Fig. 2: Geographical Map of Ondo showing the Various Locations.**

Three softwares were used in the analysis of the results and values obtained. They are the Surfer 8 software, Irregular terrain Model and Microsoft excel. ITM estimates radio propagation losses over irregular terrain. It is an improved version of the Longley-Rice Model which gives an algorithm developed for computer applications [15]. The output is a list of estimated transmission losses for specifies values of reliability and confidence levels. For this project work, the Point-to-Point prediction mode was used because the specific value of each location was known. The comparison of the measured and predicted is shown in Figure 4. The Longley-Rice model was estimated using the Irregular Terrain Model (ITM) package [13]. The ITM estimates the path loss between the transmitter and receiver using the GLOBE data [14] to compute the terrain along the path. Longley-Rice model parameters are chosen for different regions. The result is as shown in Table 3.

**Table 3: Estimated Basic Transmission Loss according to Longley-Rice Model.**

| Longitude ($^o$) | Latitude ($^o$) | Altitude (Msl) | MeasuredTransmission Loss (dB) | Longley-Rice Transmission Loss (dB) |
|---|---|---|---|---|
| 5.100667 | 7.347988 | 338.10 | 67 | 101.6 |
| 5.083903 | 7.381420 | 319.60 | 67.3 | 99.3 |
| 5.058876 | 7.397853 | 342.40 | 64.8 | 104.6 |
| 5.515388 | 7.237063 | 324.00 | 70.3 | 123.6 |
| 5.422646 | 7.272602 | 328.6 | 58.2 | 118.9 |

The contour map generated from the Latitude, Longitude and Signal strength values at the various locations is as shown Figure 3.

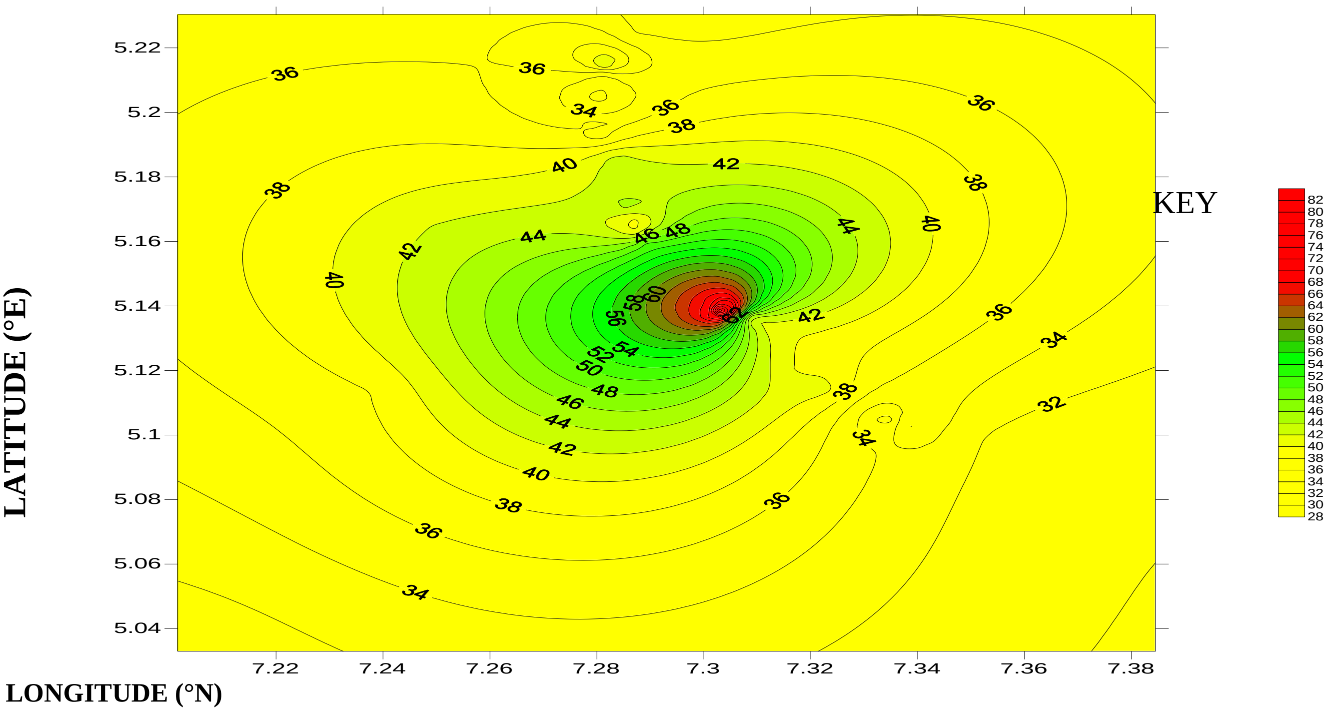


**Figure 3: The Contour Map of Ondo, Ilesha, Owo and Ado-Ekiti.**

The map in Figure 2 shows the distribution of the signal across Akure and its environs. The red colored regions shows the areas with very strong signal strength, the green areas are for locations with less strong signal strengths while the yellow region is for locations with the least signal strengths. The middle region is Akure where the radio station transmitter is located and from the contour map it is obvious that the signal strength is high at the middle region. The overlay of the geographical map and the contour map for the same coverage area having maximum value of (7.09456, 4.81809) to (7.606518, 5.498938) is shown in Figure. This value was used in order to get the exact locations of the coverage area and for proper overlay of both maps.

Fig. 4 is a plot of the comparison made on the measured and predicted Basic Transmission loss for a better analytical inference. The graph shows that the measured and predicted transmission loss is highly correlated. Based on the high correlation of the measured data with the predicted data, prediction was done for some other points. The data was then used to generate a contour map for the radio station. The contour is shown in Fig.3

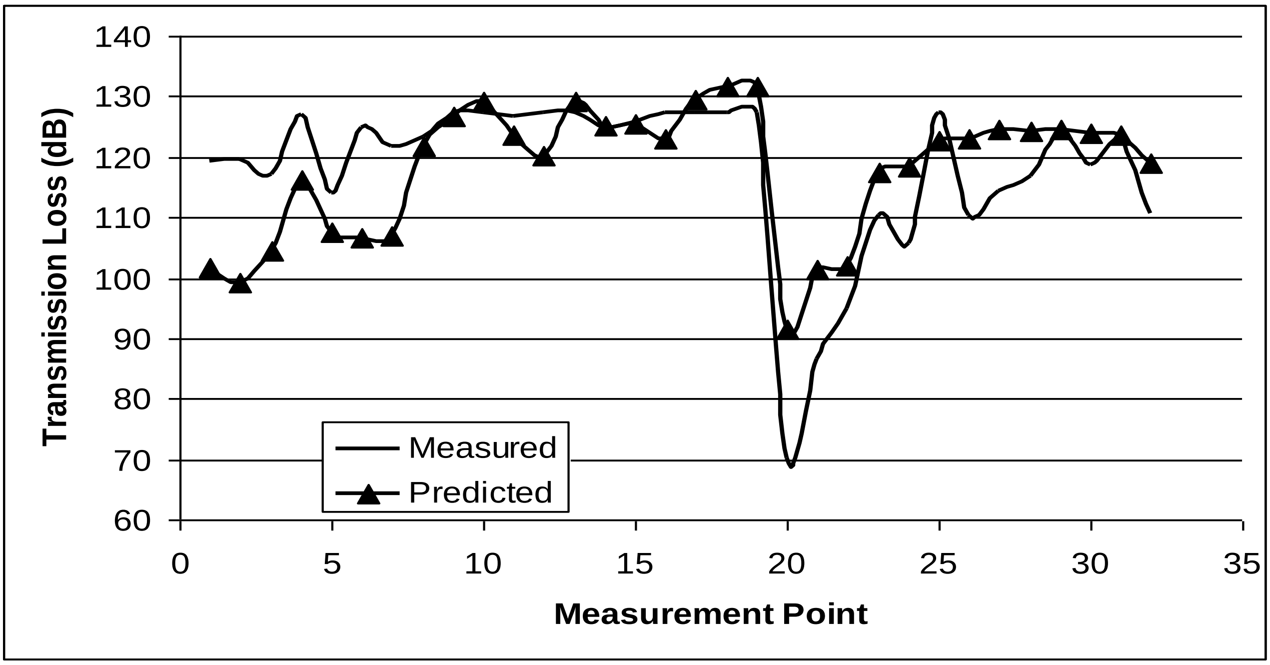


 

**Fig. 3 Comparison of the basic transmission losses**

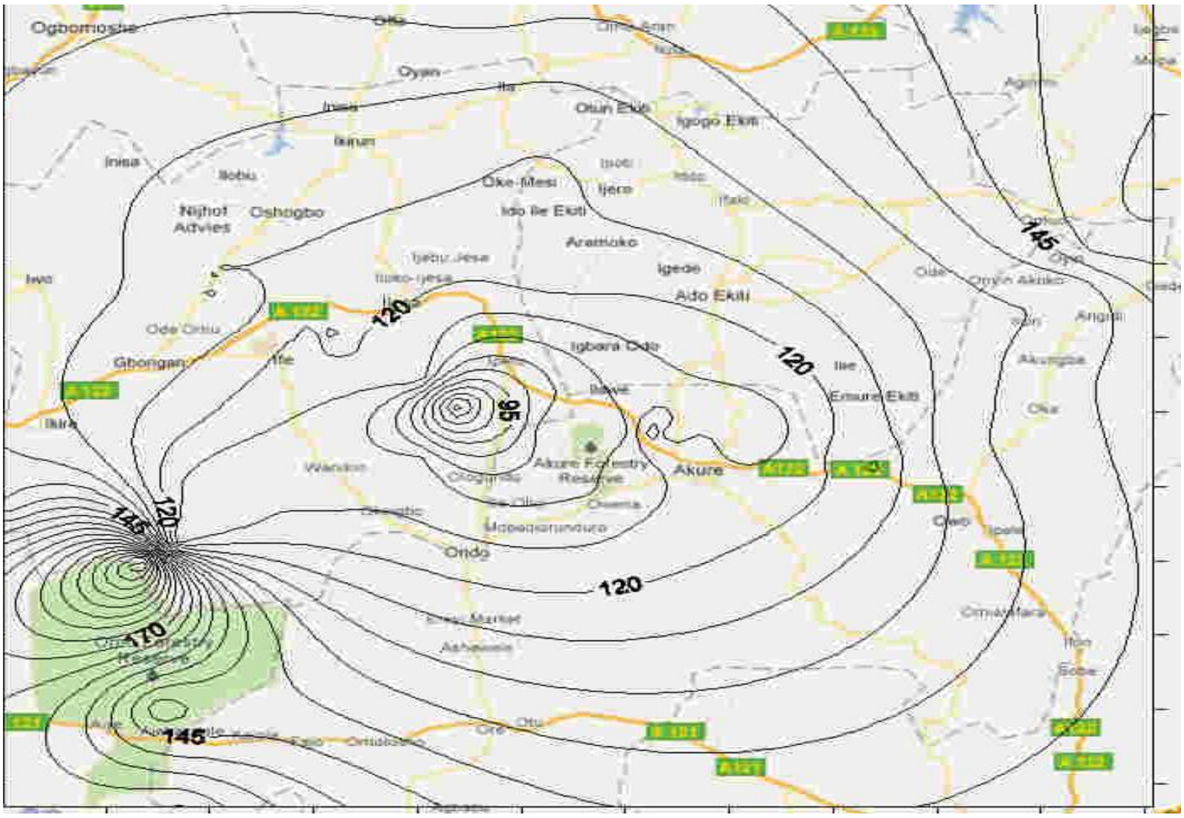


**Fig. 4: Map of Coverage area shown contour of transmission loss (dB)**

The overlay of the geographical map and the contour map for the same range of values or coverage area is shown in Fig. 4 .The geographical map was derived using the Longitude, Latitude and elevation of the land at the various locations while the contour map was gotten from the Latitude, Longitude and Signal strength of the Signals at the various locations. The contour map indicates the magnitude of the signal strength by the distance between consecutive lines or curves.

## 5. CONCLUSION

It was observed that the signal was strongest along the Ondo town axis. The route to Ilesha had the lowest signal strength observed while Owo had an average signal strength value. With the analysis of the readings obtained, the antennas should be repositioned to enhance the reception along Ilesha and keep the signal within the coverage area. This work establishes the accuracy of the Longley-Rice model in predicting FM radio propagation loss in South-West Nigeria. With liberalization of broadcast industry in Nigeria, the regulatory authority (Nigerian Broadcasting Commission) would benefit from this study in the areas of radio planning and spectrum management.

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