ABUAD Journal of Engineering Research and Development (AJERD) ISSN: 2645-2685
Volume 2, Issue 1, 90-102

# Path Loss Modelling of UHF Radio Wave Propagation in Ado-Ekiti, Nigeria

Akinlolu Adediran PONNLE[1*], Olusola John OWOLABI[1]

[1]*Department of Electrical and Electronics Engineering, Federal University of Technology, P.M.B. 704, Akure, Ondo State, Nigeria*
ponnleakinlolu@yahoo.co.uk/speciall20@yahoo.com

*Corresponding Author:* ponnleakinlolu@yahoo.co.uk

*Date Submitted:* 16/01/2019
*Date Accepted:* 07/04/2019
*Date Published:* 24/04/2019

**Abstract:** *In order to achieve optimal performance of a wireless communication system in any given environment, empirical path loss models are used to predict the received signal strength and power. We present an assessment of the quality of UHF signal reception and development of path loss model in the UHF range for the city of Ado-Ekiti in Nigeria, using the signal field strength of the broadcast signal of Ekiti State Television (EKTV). Measurements of received signal field strength within and around the city were carried out and analyzed, from which path loss models in the UHF range were developed for Ado-Ekiti using linear regression model – one being a general model, and the other is for the western region of Ado-Ekiti with irregular terrain. The result of the field strength measurements from EKTV in comparison with ITU recommendation for analogue terrestrial television service in band V shows that the quality of reception within Ado-Ekiti metropolis is good. Also, path loss prediction for Ado-Ekiti using three conventional empirical models in literature: Okumura-Hata model, COST-Hata model, and Egli model were performed, and the results obtained were compared with results from the developed models. Comparison shows that COST-Hata model has the highest standard deviation value of 24.11 from the general model while Okumura-Hata and Egli model has lower values of 22.76 and 22.30 respectively. For the model of the western region with irregular terrain, COST-Hata model also has the highest standard deviation value of 26.61 while Okumura-Hata and Egli each has a value of 25.29 and 21.85 respectively.*

**Keywords:** *Radio wave propagation, signal field strength, path loss model, measurements, standard deviation.*

## 1. INTRODUCTION

During radiowave propagation, interaction between the waves and the environment attenuates the signal strength. This interaction causes path loss and finally limits coverage area. Path loss prediction is a crucial element in the first step of network planning [1]. One of the well-known complex environments is where there are physical structures. The appearance of buildings and topography of cities in the path of the communication link has significant effects on the quality of the received signal [2].

Propagation environments are dynamic. Radiowave propagation in a practical environment has various characteristics which are represented by models for engineers to predict the behavior of propagation in order to enhance the quality of service. Empirical, deterministic, and semi-deterministic models are being used to predict the performance of wireless networks during planning and design phase. According to Ranvier in [3], "empirical models based on measurement data, are simple (with few parameters), use statistical properties, and are not very accurate. Deterministic models are site-specific, require enormous number of geometrical information about the site, require very important computational effort, and are accurate. Semi-deterministic models are based on empirical and deterministic models respectively". Despite their limitations, these models allow a glimpse of signal behaviours as well as providing assistance to quality and design networks. Wireless models include: the Okumura model, the Okumura-Hata model, COST 231-Hata model, Egli model, SUI model, COST-231-Walfisch-Ikegami model, Walfisch-Bertoni model etc. [4]. Each of these models is site specific, and some of these models have been in existence for a long time. For example, models such as Okumura and Okumura-Hata were formulated over 50 years ago from a city in Japan which has tall buildings and other characteristics of an urban environment. Today, the city has changed with more tall buildings, more trees; changes in climatic conditions and increase in population. All these factors affect the models' reliability and applicability to a given environment. Hence need to come up with new models which considered the models' shortcomings [5]. Therefore in applying the models for analysis, they must be used for the right sites for which they were designed. There is a need for an experimental determination of the propagation characteristics of an environment, in order to develop a radiowave propagation model that can best fit the environment for optimum design and better network planning.

Some research works have been carried out on modeling of radio wave propagation of some areas and cities in the south western part of Nigeria. Famoriji and Olasoji in [1] worked on Ultra High Frequency (UHF) propagation mechanisms and empirical models for hilly areas by carrying out measurements of received signal field strength in Idanre town of Ondo State, Nigeria. A modified Cost 231-Hata model was developed and implemented with Matlab graphical user interface for simulation. Isabona and Konyeha in [6] worked on urban area path loss propagation prediction and optimization using Hata model at 800 MHz in which an optimized path loss model was developed based on the measurements collected in the Code Division Multiple Access (CDMA) network focusing on the city of Benin in Edo State, Nigeria.

Shoewu and Edeko in [7] analyzed radio wave propagation in Lagos and its environs based on signal measurements carried out at Imota village in Epe town and Lekki area of Lagos State, Nigeria. The path loss values were estimated and compared with existing model. Famoriji and Olasoji in [8] carried out modeling of UHF radiowave propagation for Akure metropolis in Ondo State, Nigeria. Similar work was also carried out for Akure by Akingbade and Olorunnibi in [9]. Ayekomilogbon *et al.* in [10] carried out evaluation and modeling of UHF radiowave propagation in a forested environment of Idanre-Apomu axis of Ondo State, Nigeria in which path loss estimation based on measurement of received UHF signal strength for two seasons was validated against theoretical estimations.

All the research works stated above provide measurement-based path loss models for various local environments within south western Nigeria in which Ado-Ekiti is located. Adeniji *et al.* in [11] performed analysis of propagation models for GSM base stations (BTS) transmitting antenna in Ado-Ekiti, Nigeria. They theoretically analyzed and compared two models: Okumura and Okumura-Hata on the basis of variation in antenna height and operational frequency between 900 MHz and 1800. The result obtained showed that Okumura-Hata model has a better signal strength delivery with a less reduced path loss variation compared to Okumura model. According to them, there are very little changes to the path loss in varying the transmitting antenna height or the operational frequency for the Okumura-Hata model. The work in [11] was theoretical and for GSM frequencies, but there is need to provide a measurement-based model in the UHF range for a better prediction for Ado-Ekiti which is the basis of the work in this paper.

Ado-Ekiti in Nigeria can generally be described as an urban city with irregular terrain. This type of terrain causes diffraction, scattering, multipath fading, and reflection of radio waves propagating within the city. These degrade the signal and consequently affect the quality of reception in the metropolis. Although as stated earlier, conventional empirical models for urban areas can be used to predict the behavior of radio wave propagation in this area but there has never been a site specific measurement based prediction model in the UHF band for Ado-Ekiti metropolis. The available conventional models were developed from foreign cities which are different from the nature of cities in Nigeria, therefore the need for this work.

Therefore, in this paper, we present the assessment and development of UHF radio wave propagation model(s) for Ado-Ekiti in Nigeria. The specific objectives are to determine the quality of reception of broadcast UHF radio wave signal in Ado-Ekiti; develop UHF path loss model(s) for Ado-Ekiti; and validate the developed model by comparison with some other conventional empirical models in literature. Since [11] reported that Okumura-Hata model performed better than Okumura model at 900 – 1800 MHz range, therefore, Okumura-Hata model, COST-Hata model, and Egli model were compared with the developed model.

## 2. RADIOWAVE PROPAGATION MODELS

The radio channel comprises of the transmitting antenna, the propagation medium, and the receiving antenna. Radio transmission takes place from a transmitter to a receiver through propagation paths. These are referred to as propagation mechanism arising out of different interactions with the interfering objects along the path as explained by Fleury and Leuthold in [12]. Experimental investigations are closer to reality, but theoretical investigations consider only simplified model of the reality. The problem of designing the experiments, and the interpretation of the results, are the major drawbacks of experimental investigations. Software simulation has one main advantage over experimental investigations in that the environment and the geometry are easily described and modified [13].

Radio propagation models are empirical in nature, which means they are developed based on large collections of data collected for the specific scenario. Like all empirical models, radio propagation models do not point out the exact behaviour of a link, rather, they predict the most likely behavior the link may exhibit under the specified conditions. Different models have been developed to meet the needs of realizing the propagation behaviour in different conditions [14, 15].

In radio wave propagation, the free space path loss model shown in Eq. (1) acts as a lower bound for the estimation of path loss [15]

$$L_{free} = -27.56 + 20\log_{10}(f) + 20\log_{10}(d) \quad (1)$$

where *f* is the frequency in MHz, *d* is the distance between the isotropic transmitting and receiving antennas in meters, and $L_{free}$ is the free space path loss in dB.

When the radio wave propagates near the ground with a line of sight (LOS) condition, the path loss can be better described by the plane earth (PE) path loss model rather than the free space model [15]. The plane earth path loss model includes the effect of ground reflection and is given as

$$L_{PE} = 40\log_{10}(d) - 20\log_{10}(h_T) - 20\log_{10}(h_R) \quad (2)$$

where $L_{PE}$ is the plane earth path loss in dB, $d$ is the distance between the isotropic transmit and receive antenna in meters, $h_T$ and $h_R$ are transmit and receive antenna heights respectively, also in meters. In this model, there is an assumption that $d$ is much larger than the $h_T$ and $h_R$.

### 2.1 Okumura Model

Okumura model is one of the most widely and frequently used wireless macroscopic propagation models being applied to suburban and urban environments [16]. The model was designed for use in the frequency range 150 MHz up to 1920 MHz, and mostly in an urban propagation environment. The Okumura model is stated as:

$$PL = FPL + A(f,d) - G(h_{te}) - G(h_{re}) - G(Area) \quad (3)$$

where FPL is the free space path loss in dB, $c$ is the speed of light in m/s, $f$ is the frequency in Hz, $h_{te}$ is the effective height of the transmitting antenna in metres, $h_{re}$ is the effective height of the receiving antenna in metres, $d$ is the distance between the transmitting and the receiving antennas in metres, G(Area) is the correction factor gain in dB, and A($f$,$d$) is the median attenuation (in dB) which is a function of frequency and distance.

$$FPL = 20\log\left(\frac{4\pi df}{c}\right), \quad (3.1)$$

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) \text{ for } h_{te} \text{ between 30 m and 1000 m,} \quad (3.2)$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) \text{ for } h_{re} \text{ between 3 m and 10 m,} \quad (3.3)$$

$$G(h_{re}) = 10\log\left(\frac{h_{re}}{3}\right) \text{ for } h_{re} \text{ less than 3 m,} \quad (3.4)$$

G(Area) = 33dB for urban, 27dB for sub-urban and 13dB for medium urban.

### 2.2 Okumura-Hata Model for Urban Areas

The Okumura-Hata model is a further developed version of the Okumura model and is the most widely used radio frequency propagation model for predicting the behaviour of cellular transmissions in built up areas, point-to-point and broadcast transmissions; and it is based on extensive empirical measurements taken. According to [9], the model is stated as:

$$PL = 69.55 + 26.16\log f - 13.82\log h_T - a(h_R) + [44.9 - 6.55\log h_T]\log d \quad (4)$$

where PL is the path loss in dB, $h_T$ is the height of the transmitting antenna in meters, $h_R$ is the height of the receiving antenna in meters, $f$ is the frequency of transmission in MHz, $a(h_R)$ is the receiving antenna height correction factor and $d$ is the distance between the transmitting and the receiving antennas in kilometres.
For large city with the frequency of transmission, $f \geq 300$ MHz,

$$a(h_R) = 3.2[\log(11.75h_R)]^2 - 4.97 \quad (4.1)$$

For specifications, Okumura-Hata has the following range: Carrier frequency: 150 MHz $\leq f \leq$ 1500 MHz, Transmitting antenna height: 30 m $\leq h_T \leq$ 200 m, Receiving antenna height: 1 m $\leq h_R \leq$ 10 m, and distance between the transmitting and receiving antennas: 1 km $\leq d \leq$ 20 km.

### 2.3 The COST-231 Hata Model

The COST-231 Hata model was devised as an extension to the Okumura - Hata model usable in the frequency band 1500 MHz to 2000 MHz. It contains correction factors for urban, suburban and rural (flat) environments. The basic equation for path loss in decibels (dB) as described in [17] is:

$$PL = 46.3 + 33.9\log_{10}(f) - 13.82\log_{10}(h_T) - ah_m + (44.9 - 6.55\log_{10}(h_T))\log_{10} d + c_m \quad (5)$$

where $f$ is the frequency in MHz, $d$ is the distance between the transmitting and the receiving antennas in kilometres, and $h_T$ is the transmitting antenna height above ground level in meters. The parameter $ah_m$ is defined for different environments. For instance, for urban environments and $f \geq 300$ MHz:

$$ah_m = 3.20(\log_{10}(11.75h_R))^2 - 4.97 \quad (5.1)$$

for suburban or rural (flat) environments:

$$ah_m = (1.1\log_{10} f - 0.7)h_R - (1.56\log_{10} f - 0.8) \quad (5.2)$$

where $h_R$ is the receiving antenna height above ground level.
The correction factor $c_m$ is defined as 0 dB for suburban or open environments and 3 dB for urban environments or metropolitan centres.

 ISSN: 2645-2685

### 2.4 Egli Model

The Egli model is a terrain model for radio frequency propagation, derived from real-world data on UHF and VHF televisions in several large cities. It also predicts the total path loss for a point-to-point link, and typically used for outdoor line-of-sight transmission. The model is suitable for communication scenarios where the transmission has to go over an irregular terrain, but it does not take into account propagation through some vegetative obstruction, such as trees or shrubbery. The Egli model is mathematically expressed as in [18] as:

$$L = G_T G_R \left[\frac{h_T h_R}{d^2}\right]^2 \left[\frac{40}{f}\right]^2 \quad (6)$$

where $G_T$ is the gain of the transmitting station antenna, $G_R$ is the gain of the receiving antenna, $h_T$ is the height of the transmitting antenna in metres, $h_R$ is the height of the receiving antenna in metres, $d$ is the distance between the transmitting and the receiving antennas in metres, and $f$ is the frequency of transmission in MHz.

## 3. MATERIALS AND METHODS

The work was carried out in Ado-Ekiti of Ekiti State, in Nigeria using Ekiti State Television Station (EKTV) broadcast signal and transmitting antenna as the reference signal and base transmitter respectively. The work involved obtaining the transmitting parameters of the station such as radiating power, antenna height, antenna characteristics, polarization etc., as well as the topography of Ado-Ekiti region. The topography of the region was developed from the region's GIS data obtained from the Nigeria Meteorological Agency (NIMET) in Oshodi, Lagos. Series of signal strength measurements were carried out within and round the city of Ado-Ekiti using a signal field strength meter. The whole activity is represented by the block diagram in Figure 1.

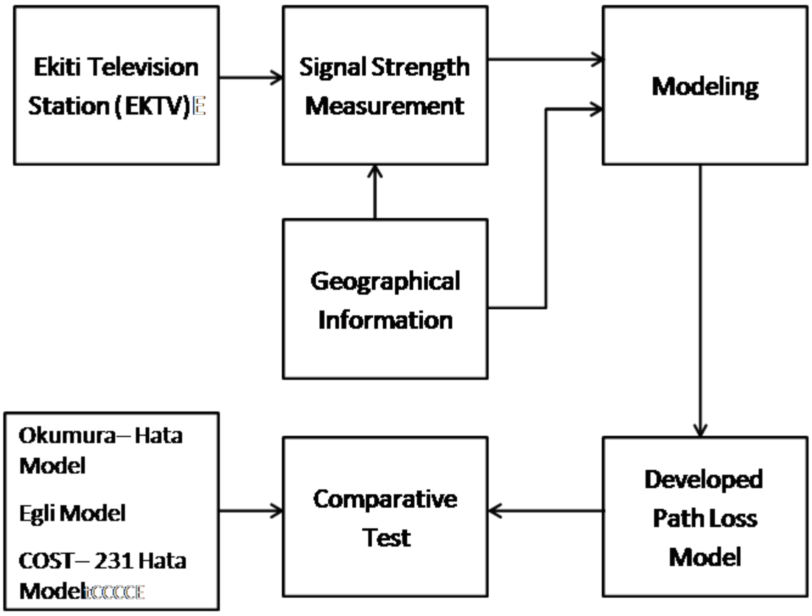


Figure 1: Methodology in block diagram.

### 3.1 Study Area (Ado Ekiti)

Ado Ekiti is a city in southwest Nigeria, which is also the capital of Ekiti State. It lies on the coordinates 7º 37' 16'' N and 5º 13' 17'' E. Ado Ekiti has two universities and one polytechnic – the Ekiti State University, the Afe-Babalola University, and the Federal Polytechnic, Ado-Ekiti. The city has two local television stations – Nigeria Television Authority, and Ekiti State Television (EKTV); and two radio stations – Ekiti Radio, and Progress FM, Ado-Ekiti. The city is the trade centre for a farming region where yams, cassava, grain and tobacco are grown. Map of Nigeria indicating the location of Ekiti State is shown in Figure 2.

### 3.2 Digital Terrain and Elevation Modeling of Ado-Ekiti

Arcview GIS software and Surfer 11 software were used to model the topography of Ado-Ekiti by the use of remote sensing data obtained from the Nigeria Meteorological Agency (NIMET) in Oshodi, Lagos.

 ISSN: 2645-2685

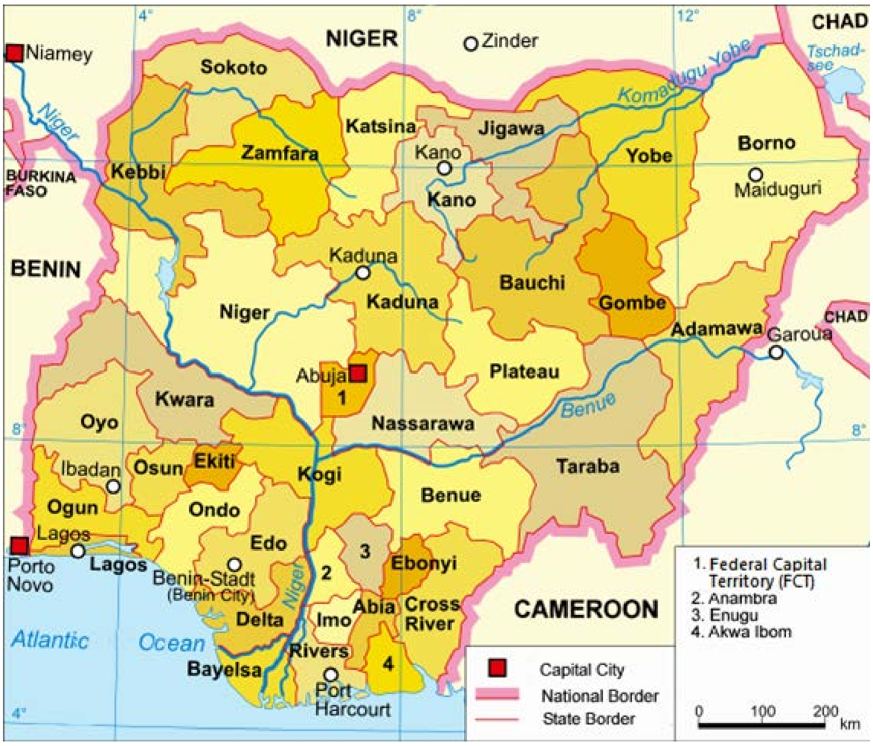


Figure 2: Map of Nigeria showing the States [19].

### 3.3 Characteristics of the Transmitting Antenna of EKTV

The measurements carried out were based on the signal radiated from the Ekiti State Television broadcasting station (EKTV) at Ilokun in Ado-Ekiti with the characteristics specified in Table 1.

Table 1: EKTV Transmitting Parameters

| Parameter | Value |
|---|---|
| Location | Ilokun, Ado-Ekiti. (07$^0$ 40’29’’N, 05$^0$14’48”E) |
| Frequency (vision) | 631.25 MHz |
| Frequency (sound) | 617.25 MHz |
| Polarization | Horizontal |
| Azimuth pattern | Peanut |
| Beam Tilt | 0.81$^0$ |
| Transmitted Power | 20 kW |
| Power gain | 2.0 (3 dB) |
| Height of location (a. s. l.) | 351 m |
| Height of transmitting antenna | 200 m |

### 3.4 Signal Strength Measurement and Materials

Series of signal field strength measurements were carried out round the city of Ado-Ekiti, using a signal field strength meter (model MS 1803) designed for monitoring and measuring TV broadcast signals (vision and audio), in the VHF/UHF Bands I, III, IV and V. The field strength meter is a handheld digital/analogue field strength meter, having a RF signal processing system and a micro-computer technology as core technology, and equipped with large screen graphic display. It has a frequency range of 46 MHz to 870 MHz and an input impedance of 75 ohms. It has a power button, numerical keys, LCD display, RF input and a charging port.

For the measurement, Ado-Ekiti was divided into five regions based on the topography: Iyin road region was designated as region A, Afe-Babalola University region was designated as region B, Ikere road region was designated as region C, Ilawe road region was designated as region D, and Afao road region was designated as region E. Iyin road region can be described as a relatively high land with a gentle slope. The region is largely made up of average height residential buildings and there are vegetations towards the remote part of the region. Afe-Babalola University region is a relatively low land with an average elevation of 350 m. The region has residential buildings, vegetations, river Ogbese tributaries and a university environment. Ikere road region is another relatively low-land region with an average elevation of 400 m. The region is mostly made up of residential buildings. Thre are some scattered uplands between the Afe-Babalola University region and Ikere road region. Ilawe road region is the region with the highest elevation of 450 m – 700 m. It has a good number of mountain-like structures scattered within the region and some of these structures are covered with vegetations. Part of this region is residential while the other part is of slightly thick vegetation. Afao road region is a flat relatively low-land area with an average elevation of 400 m. It is a developing area of Ado-Ekiti and it is largely residential.

Received signal field strength measurements were taken along straight routes of line of sight distance in each region at intervals of about 1 km though with some variations because of constraint of accessibility of some locations due to topography. An active receiving antenna (Century WA-5020TG-C) covering both VHF and UHF frequency bands was used for measurements. The receiving antenna has a gain of 28 ± 3dB, and an output impedance of 75Ω. The output of the antenna was coupled through a 75-ohm coaxial cable to the field strength meter. At each spot of measurement, the measurements were taken at a receiving height of 3 m above ground level for vision signal at a frequency of 631.25 MHz. Two sets of measurements were taken at each spot in succession. All the measurements were conducted between 3pm and 7pm each day during the raining season of the year.

Figure 3: Setting up equipment for measuring the received signal strength at one of the spots of measurement along the route in Region C.

### 3.5 Radiowave Propagation Modeling

The estimated path loss corresponding to the received signal field strength measured at different observation points were determined using Eqs. (7) to (12).

$$P_r = A_e S \tag{7}$$

$$A_e = \frac{G_r \lambda^2}{4\pi} \tag{8}$$

$$S = \frac{E^2}{Z_0} \tag{9}$$

where $$Z_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 120\pi \approx 377\Omega \tag{10}$$

$$P_r = \frac{G_r \lambda^2 E^2}{4\pi Z_0} \tag{11}$$

So $$PL = \frac{P_t G_t G_r}{P_r} \tag{12}$$

where $G_t$ and $G_r$ are the transmitting antenna gain and the receiving antenna gain respectively, λ is the wavelength, $P_t$ is the transmitted power, $P_r$ is the received power, $A_e$ is the antenna equivalent area (m$^2$), $S$ is the power density (W/m$^2$), $E$ is the electric field strength (V/m), $Z_0$ is the characteristic impedance of free space (Ω) and PL is the path loss.

The estimated path loss with corresponding line-of-sight distances for each region were analysed using ordinary least square (OLS) regression from which regression lines (or equations) were developed representing the path loss model equations for each of the regions. From the path loss model equations of all the regions, a general model equation that can be used to predict path loss of UHF band broadcast signal in Ado-Ekiti metropolis was developed.

Also, prediction of path loss in Ado-Ekiti by three conventional empirical models in literature: Okumura-Hata model, COST-Hata model, and Egli model was performed, and the results obtained were compared with the results from the developed model to determine which of the conventional model is closest to the developed model and most applicable to Ado-Ekiti metropolis. Although, the signal-frequency of measurement for this work does not fall within the frequency range of the COST-Hata model, its simplicity, extensive usage and availability of correction factors influenced the choice of this model for path loss prediction at the frequency of measurement.

## 4. RESULTS AND DISCUSSIONS

### 4.1 Ado-Ekiti Terrain

Terrain maps of Ado-Ekiti are shown in Figures 4 and 5. Figure 4 shows the digital terrain map with the location of EKTV indicated by the red star. Figure 5 shows the digital elevation map showing the route of measurements in each of the regions. The maps give the broad view of terrain features of Ado-Ekiti area. The elevation of the area ranges between 350 m and 700 m above sea level.

Based on the terrain maps of Figures 4 and 5, the western parts of Ado-Ekiti have the highest elevation, while the eastern parts are low land-terrain areas with gentle slope. Regions A and D lie in the high-land western part, regions E and B lie in the low-land eastern part and region C lies in-between.

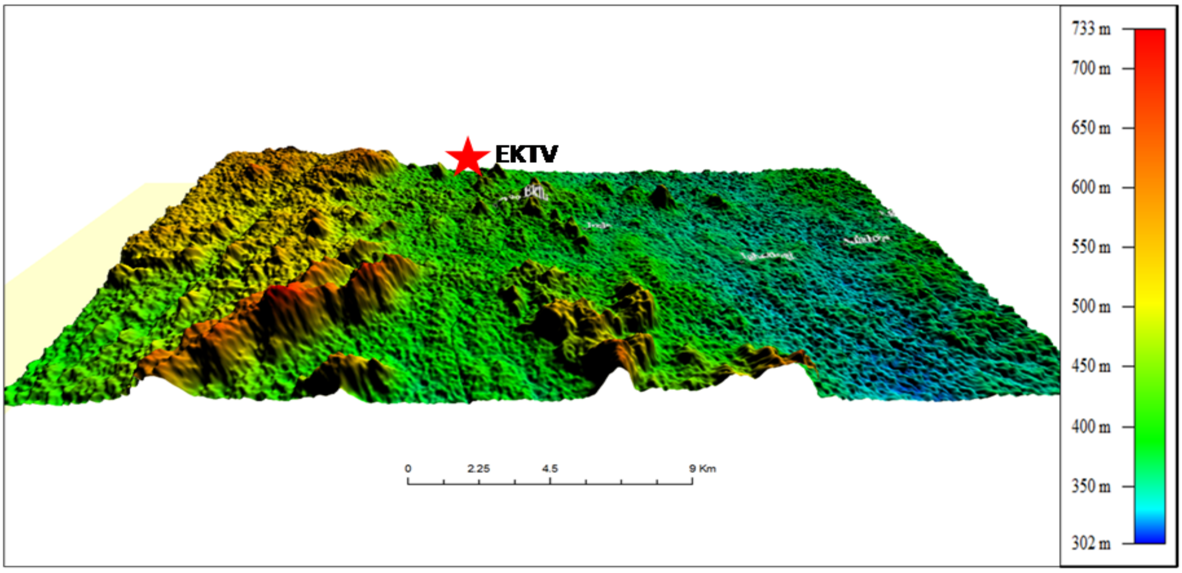


Figure4: Digital terrain map of Ado-Ekiti.

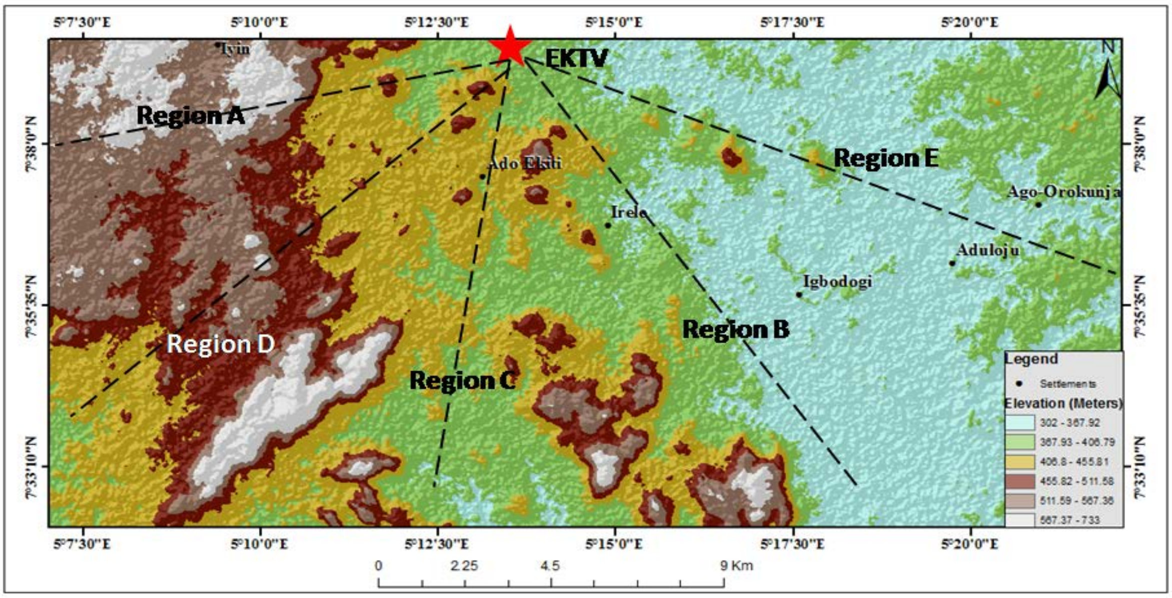


Figure5: Digital elevation map of Ado-Ekiti showing the routes of measurements in the regions.

### 4.2 Signal Strength Measurement

The received signal field strength measurements (in dBµV/m) which were taken along the five different routes (in each region) of Ado-Ekiti are presented in Figure6.

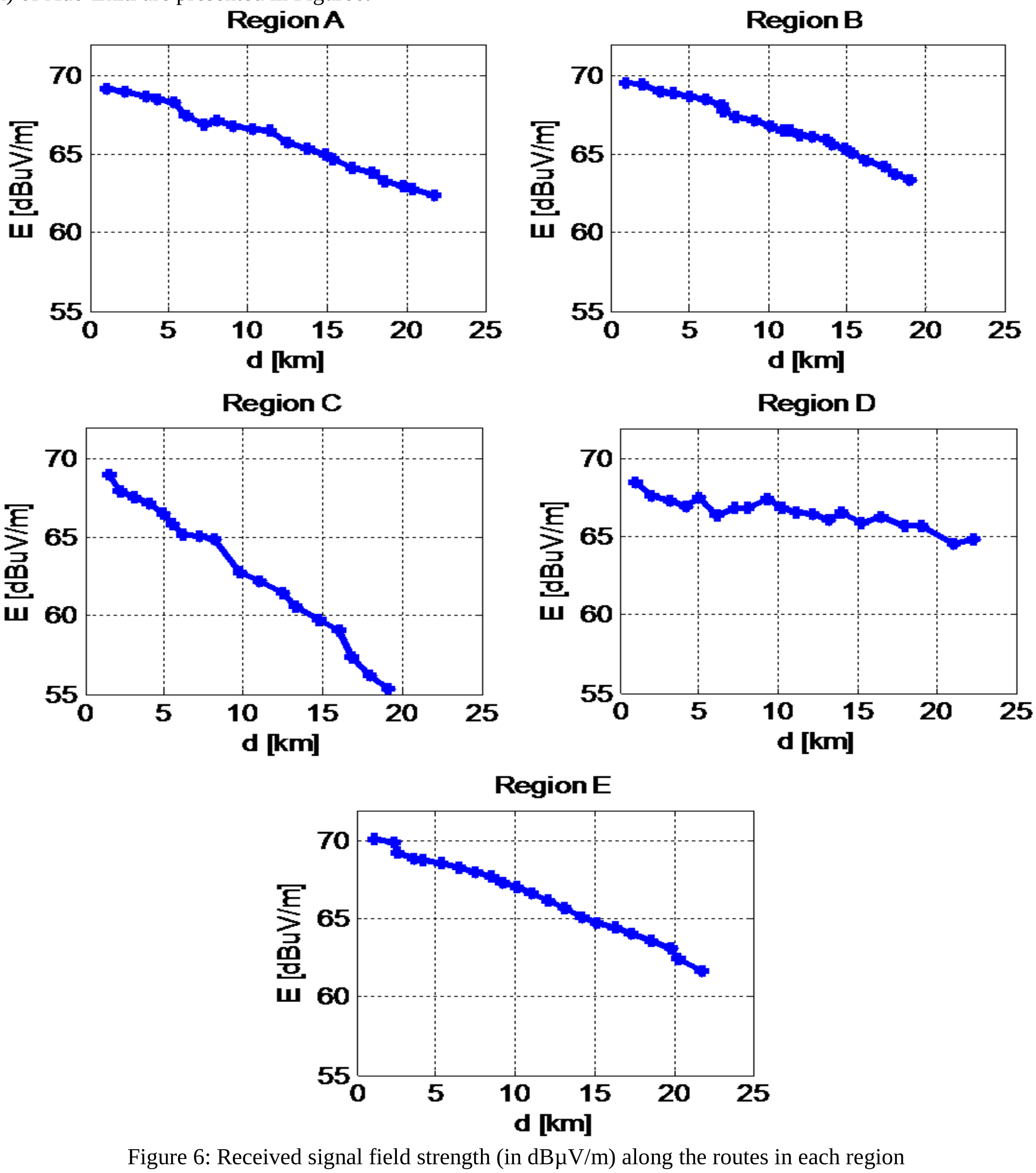


Figure 6: Received signal field strength (in dBµV/m) along the routes in each region

The received broadcast signal strength decreased as distance increased away from the transmitting antenna of EKTV station. This is due to signal attenuation that occurred along the transmission path with distance. Along the routes in regions A, B, C, and E, there is expected signal attenuation pattern (falling off rapidly but somewhat linearly) with distance. It can be observed that there is an exception to (or deviation from) this along the route in region D. Region D is in western part of Ado-Ekiti with higher elevation and irregular terrain as shown in figures 4 and 5. The received signal levels along the entire route in the region is relatively higher, and does not exhibit the rapid signal fall off with distance as observed for the other routes in the other regions. The higher elevation of the terrain in this region seemed to be an advantage. However, the signal levels showed a zig-zag pattern with distance which could be due to abrupt changes in elevation with distance.

Considering the signal field strength of all the routes, the maximum field strength measured is about 70.1 dBµV/m (in region E), and the minimum field strength measured is about 55.56 dBµV/m (in region C) at a receiving height of 3 m above ground level. With increase in receiving antenna height, there will be increase in the received signal field strength. ITU-R BT. 417-5 [20] recommended minimum field strength for an analogue terrestrial television service in band V at a receiving height of 10 m above ground level for urban area is 70 dBμV/m and for rural areas is 58 dBμV/m. Ado-Ekiti can be categorized as urban surrounded by rural areas. Therefore, comparing the minimum field strength from the measurements with ITU recommendation, it can be concluded that the quality of reception within Ado-Ekiti metropolis and its environs is good. Figure7 shows the field strength contour map overlaid on the terrain map of Ado-Ekiti and its environs.

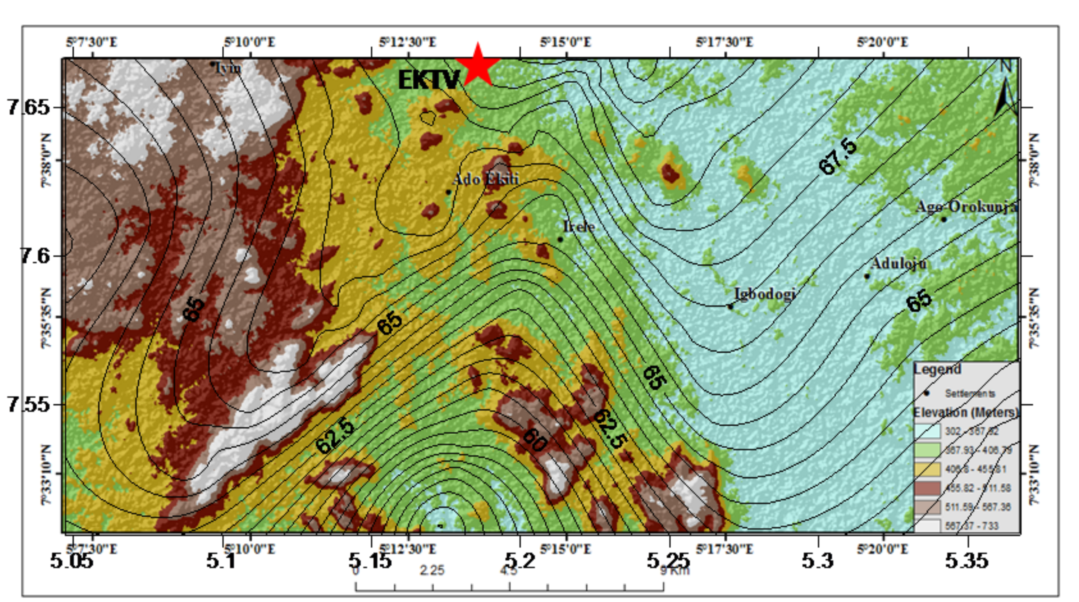


Figure7: Field strength contour map (dBμV/m) of Ado-Ekiti obtained from the measurements.

### 4.3 Estimated Path Loss

Figure 8 (a) – (e) shows the estimated path loss along each of the routes in each region corresponding to the signal strength measurements of Figure6. The path loss increases almost linearly with distance along each route in regions A, B, C, and E, but in a zig-zag fashion along the route in region D which could be as a result of irregular terrain or the topographic nature of the environment.

### 4.4 The Developed Model

Table 2 shows the ordinary least square regression analysis of the estimated path loss with corresponding line-of-sight distances along each route taken within Ado-Ekiti Metropolis. For each route, a regression line (or equation) was developed to represent its path loss model equation.

Table 2: Ordinary least square regression analysis for the regions.

| Regression Line Parameters | Region A | Region B | Region C | Region D | Region E |
|---|---|---|---|---|---|
| Correlation Coefficient | 0.99 | 0.99 | 0.99 | 0.91 | 0.99 |
| Coefficient of Determination | 0.99 | 0.99 | 0.99 | 0.83 | 0.99 |
| Coefficient of *x*-variable | 0.34 | 0.34 | 0.73 | 0.13 | 0.39 |
| Intercept (dB) | 111.46 | 111.04 | 111.21 | 113.29 | 110.65 |

In the table, the *x*-variable is the line-of-sight distance, while the coefficient of the *x*-variable is the slope of the regression line, which indicates the amount (in dB) by which the path loss increases with 1 km increase in distance between the transmitting and the receiving antennas. Considering the correlation coefficients and coefficients of determination; the coefficients of *x*-variable and the intercepts; it can be observed that the developed regression line (or equation) for each route in all the regions matches very well with their respective estimated path loss with distance.

However, for the route in region D, the analysis indicated that the correlation coefficient of the regression line is approximately 0.91, while the coefficient of determination is approximately 0.83. Also, the coefficient of *x*-variable is 0.13 while the intercept is 113.29 dB. Nevertheless, the developed regression line for the route in region D still matches to a good extent the estimated path loss with distance for the route, as 83% of the data points fall on the regression line.

 ISSN: 2645-2685

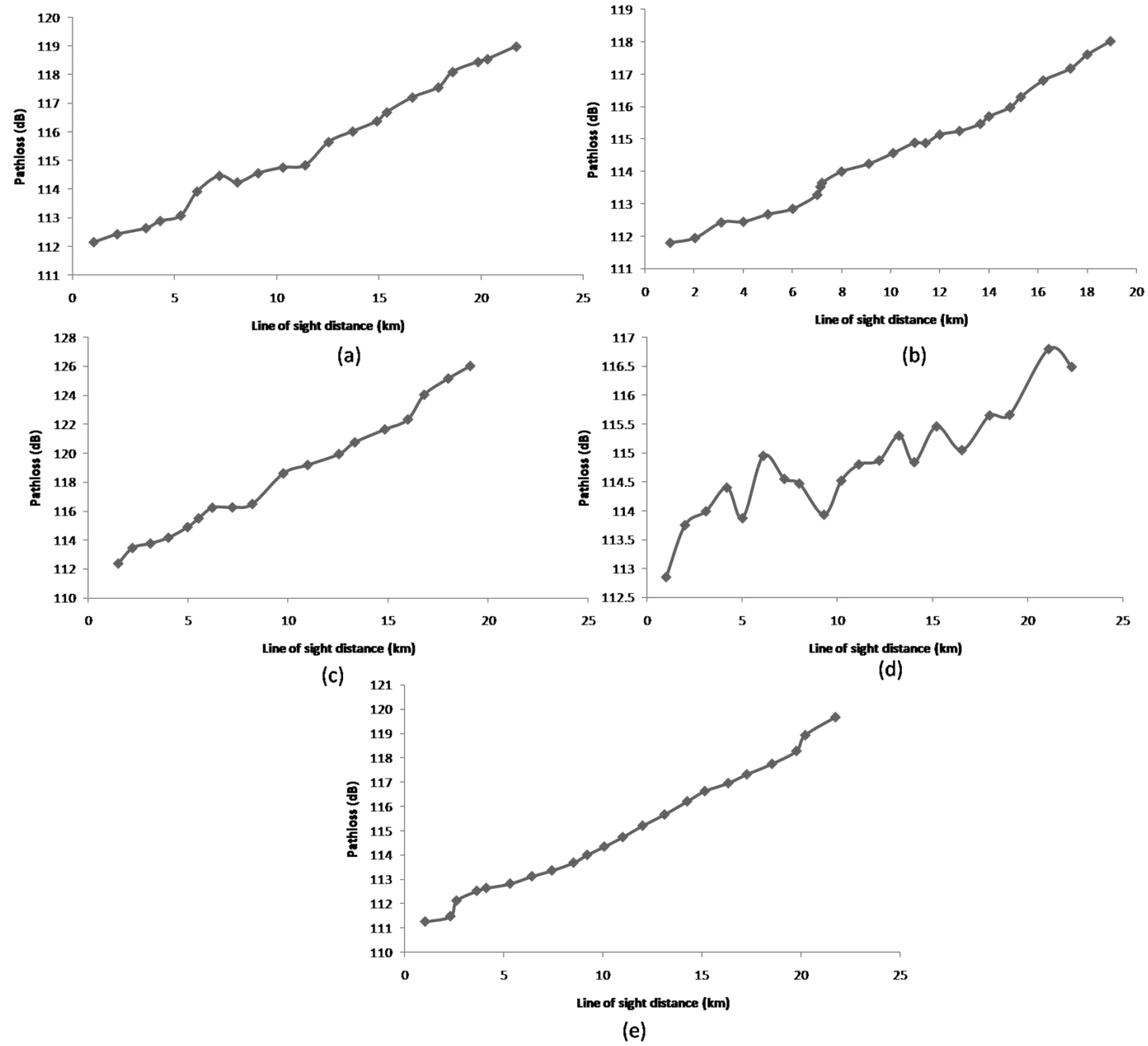


Figure8: Estimated path loss against distance along the routes in (a) Region A, (b) Region B, (c) Region C, (d) Region D, and (e) Region E.

The developed path loss model equation for each route is as expressed in Eqs. (13) to (17).

A: Iyin road region: $PL_A(dB) = 111.46 + 0.34d_{LOS(km)}$ (13)

B: Afe-Babalola University region: $PL_B(dB) = 111.04 + 0.34d_{LOS(km)}$ (14)

C: Ikere road region: $PL_C(dB) = 111.21 + 0.73d_{LOS(km)}$ (15)

D: Ilawe road region: $PL_D(dB) = 113.29 + 0.13d_{LOS(km)}$ (16)

E: Afao road region: $PL_E(dB) = 110.65 + 0.39d_{LOS(km)}$ (17)

Equations (13) to (17) represent the path loss model equations for the five regions in Ado-Ekiti metropolis that were considered in this work. Obtaining the average of the coefficients of the *x*-variable, and the intercepts in the path loss model equations of the regions excluding the route in region D, a general path loss model can be proposed for Ado-Ekiti as:

$$PL_{ADO-EKITI}(dB) = 111.09 + 0.45d_{LOS(km)} \quad (18)$$

where $d_{LOS(km)}$ is the line-of-sight distance in kilometre (1 km $\le d \le$ 25 km). Equation (18) can therefore be used to predict path loss of UHF band broadcast signal in Ado-Ekiti metropolis, while Eq. (16) can be used to predict the path loss for the western part of Ado-Ekiti.

### 4.5 Comparison of the Developed Models with other Conventional Empirical Models

Figure 9 shows the comparison of three conventional empirical models: Okumura-Hata, COST-Hata and Egli, with the developed general model and the developed Region D model. The path loss of the developed general model is equal to that of the developed Region D model at about a distance of 7 km from the transmitting antenna. Okumura-Hata and COST-Hata models have values above that of the developed models (over predict) except at distances close to the transmitting antenna. Egli model has values lower than that of the developed models (under predict) though the difference becomes smaller with distance. At about a distance of 32 km from the transmitting station, the path loss of the Egli model meets that of the developed Region D model (not shown in Figure 9).

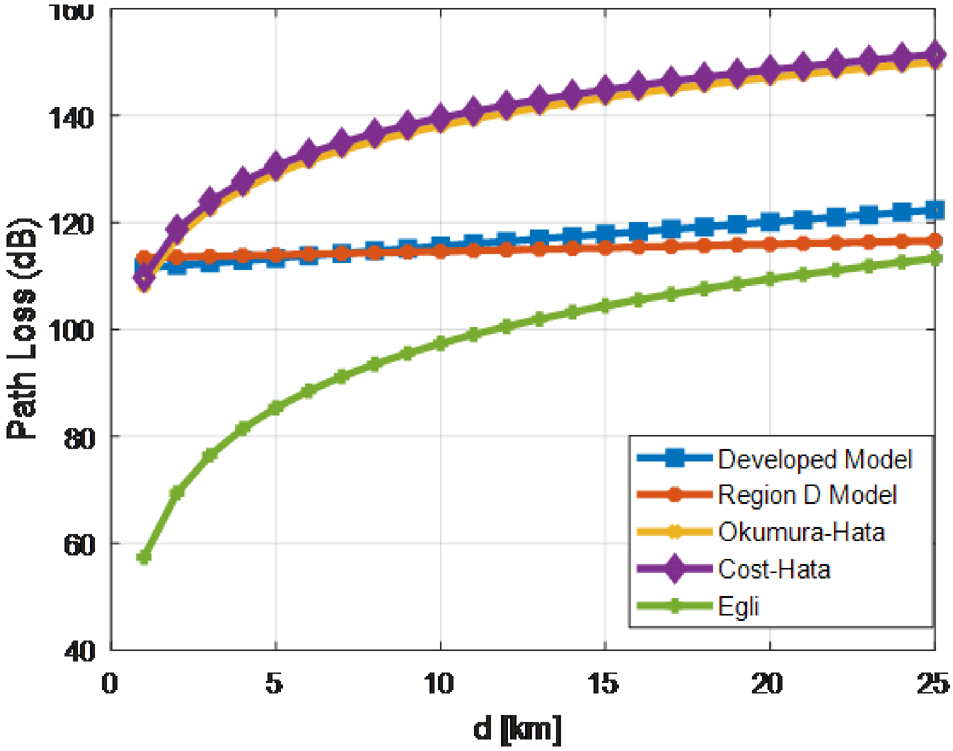


Figure9: Comparison of other conventional empirical models with the developed models.

Path loss for each model was calculated within transmitter-receiver distance of 1 km $\leq d \leq$ 25 km, and its standard deviation (SD) from the developed general model, and the developed model for region D (western part of Ado-Ekiti) were determined.

The standard deviation was determined using Eq. 19.

$$SD = \sqrt{\frac{\sum (x-y)^2}{N}} \tag{19}$$

where $x$ is the estimated path loss from empirical model, $y$ is the estimated path loss from the developed model and $N$ is the number of samples.

The standard deviations of the three conventional models from the developed models are shown in Table 3.

Table 3:Standard deviations of other Empirical Models from the Developed Models

| Model | Okumura-Hata | COST-Hata | Egli |
|---|---|---|---|
| SD from the developed general model | 22.76 | 24.11 | 22.30 |
| SD from the developed Region D model | 25.29 | 26.61 | 21.85 |

For the developed general model, Okumura-Hata model and COST-Hata model has a value of 22.76 and 24.11 respectively, while the value for Egli model is 22.30. Also for the developed Region D model, Okumura-Hata and COST-Hata has a value of 25.29 and 26.61 respectively, while Egli model shows a value of 21.85. These are in agreement with the plots in Figure 9.

## 5. CONCLUSIONS

We have developed UHF radiowave propagation models applicable to Ado-Ekiti metropolis for path loss prediction within and around the city from measurements of received broadcast signal of Ekiti State Television Station (EKTV). The terrain of the city is both irregular and gentle. Results of signal strength measurements showed that the quality of reception and the strength of the EKTV signals within the city and its environs are good. The developed general path loss model matched very well the results from measurements. Western part of Ado-Ekiti has a remarkably different topography from others which necessitated a separate but similar model to be developed for the region.

Also, three conventional empirical propagation models: Okumura-Hata model, COST-Hata model, and Egli model were also applied in predicting the path loss for UHF signals in Ado-Ekiti. Their results were compared with the predictions made by the developed models. The result shows that COST-Hata model has the highest standard deviation from the developed models while Okumura-Hata and Egli models have lower standard deviation values.

It should be noted that in this work, the signal strength measurements were carried out during the raining season of the year; so, similar work could be carried out during the dry season, and a unified model could then be developed for the two seasons. It is recommended that measurement of received signal strength should be carried out from time to time in a developing urban or semi urban environment in order to always account for the effects of physical developments on the quality of wireless signals within the environment.

**ACKNOWLEDGMENT**

The authors appreciate Nigeria Meteorological Agency (NIMET), Oshodi, Lagos, and Ekiti State Television (EKTV) broadcasting station for making available their necessary and required data for this work.

**REFERENCES**

[1] Famoriji, J.O. and Olasoji, Y.O. (2013). Radio Frequency Propagation Mechanisms and Empirical Models for Hilly Areas, *International Journal of Electrical and Computer Engineering,* 3(3), 372-376.

[2] Meeks, M.L., Wu, K.I. and Rao, K.I. (2009). VHF Propagation over Hilly Forested Terrain, *IEEE Transactions on Antennas and Propagation,* AP-31(3), 483-489.

[3] Ranvier, S. (2004). Physical layer methods in wireless communication systems, Helsinki University of Technology, vol. S-72, p. 333.

[4] Saunders, R.S. (1999). *Antennas and Propagation for Wireless Communication Systems*, 1st Ed., John Wiley and Sons Inc., New York, USA, p.409.

[5] Deme, A., Danjuma, D., Buba, B., Mohammed, M. and Davou, C. (2013). Hata-Okumura Model Computer Analysis for Path Loss Determination at 900 MHz for Maiduguri, Nigeria. *Mathematical Theory and Modeling,* 3(3), 1-10. [online]Available: http://www.iiste.org/Journals/index.php/MTM/article/viewFile/4908/4986

[6] Isabona, J. and Konyeha, C.C. (2013). Urban Area Path Loss Propagation Prediction and Optimisation using Hata Model at 800 MHz, *IOSR Journal of Applied Physics*, 3(4), 8-10.

[7] Shoewu, O. and Edeko,F.O. (2011). Analysis of Radiowave Propagation in Lagos Environs, *American Journal of Scientific and Industrial Research*, 2(3), 438-455.

[8] Famoriji, J.O. and Olasoji, Y.O. (2013). UHF Radio Frequency Propagation Model for Akure Metropolis, *Research Journal of Engineering Sciences*, 2(5), 6-10.

[9] Akingbade, K.F. and Olorunnibi, E.D. (2013). Path Loss Prediction Model for UHF Radiowave Propagation in Akure Metropolis, *International Journal of Engineering*, 8(3), 30-37.

[10] Ayekomilogbon, O.T., Famoriji, J.O. and Olasoji, Y.O. (2013). Evaluation and Modeling of UHF Radiowave Propagation in a Forested Environment, *International Journal of Engineering and Innovative Technology*, 2(12), 101-106.

[11] Adeniji, K.A., Ikpeze, O.F., Ejidokun, T.O. and Alli, K.S. (2018). Analysis of Propagation Models for Base Station Antenna: A Case Study of Ado-Ekiti, Nigeria, *ABUAD Journal of Engineering Research and Development (AJERD)*, 1(1), 124-129.

[12] Fleury, B.H. and Leuthold, P.E. (1996). Radiowave Propagation in Mobile Communications: An Overview of European Research, *IEEE Communication Magazine*, 34(2), 70-81.

[13] Sarwar, F.J. (2008). Radiowave Propagation in Hilly Terrain, *IEEE Transactions on Vehicular Technology*, 46, 931-946.

[14] Garg,V. K. (2007). *Wireless Communications and Networking*, 1st Ed., Morgan Kaufmann Publishers, San Francisco, CA 94111.

[15] Parsons, J.D. (2000). *The Mobile Radio Propagation Channel*, 2nd Ed., John Wiley and Sons Ltd, Chichester, England.

[16] Hata, J. and Davidson, B. (1997). A report on technology independent methodology for the modeling, simulation and empirical verification of wireless communications system performance in noise and interference limited systems operating on frequencies between 30 and 1500 MHz, IEEE Vehicular Technology Propagation Committee, TIA TR8 Working Group.

[17] Abhayawardhana,V.S., Wassell, I.J., Crosby, D., Sellars, M.P. and Brown, M.G. (2005). Comparison of empirical propagation path loss models for fixed wireless access systems, *IEEE 61st Vehicular Technology Conference*, Spring, vol. 1, pp. 73-77.

[18] Odongo,S.E. (2008). Heuristic for Wireless Metropolitan Area Network Optimum Performance: Focus on Terrain, M. Sc. Dissertation, Data Communication and Software Engineering of Makarere University, Kenya.
[19] A clickable map of Nigeria showing all the 36 states and the FCT. https://en.wikipedia.org/wiki/Nigeria, Accessed 6thJune, 2016.
[20] ITU-R BT.417-5 (2002). Minimum field strengths for which protection may be sought in planning an analogue terrestrial television service, International Telecommunications Union.