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Adaptation of Electric Field Strength Models for Terrestrial Television Broadcast Application in Ekiti State, Nigeria

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Abstract: Electric field strength propagation models play vital roles in planning terrestrial television network coverage, the interference estimations and analyzing the network signal. This work adapted some existing empirical electric field strength models that are best suitable for Ekiti State in Nigeria, using ultra high frequency (UHF) signal. A television signal (Broadcasting Service of Ekiti State (BSES)) was used for this work. The propagation models considered are: free space, Hata, ITU-R and ERC Report 68 models. The BSES channel 41 station transmits at a frequency of 631.25 MHz for video signal. The signal levels of the transmitted signal were measured radially along four routes using a digital signal level meter and the corresponding distances were also measured using a global positioning system (GPS). Data processing and computations were carried out and the results show that the modifed free space model gives a better prediction for the electric field strength in Ekiti State with a correction factor of -25.48 and root mean square error of 6.21 dBμV/m.

Keywords: Coverage area, Empirical propagation model, Electric field strength, Signal level, UHF

Introduction

In a broadcasting system, propagation prediction models are pivotal in planning, designing and analyzing radio communication networks. It is important to point out that propagation models are environment specific and no particular model can be generalized for all environments. Therefore, each model can be useful for some specific environment and accuracy of any particular model depends on the fit between the parameters available for the area concerned and the parameters required by the model (Josip et al., 2010).

Electric field strength curves or propagation curves are essential parameters neccessary for the planning of VHF and UHF transmission especially for the determination of the coverage areas and the field strength signal levels desired (Kennedy & Bernand, 1992). This field strength is affected by a number of conditions such as time of day, atmospheric conditions, transmitter-receiver distance, transmitter power and others like, terrain effect, transmitting and receiving antenna heights, and the gain of the transmitting antenna (Bothias, 1987).

The present trend in broadcasting is to use widespread broadcast transmitter of VHF or UHF range of frequencies to serve areas not far away from the transmitter (Barclay, 1991). Propagation models can be divided into three main groups, namely: empirical, deterministic and semi-deterministic models (Abhayawardhana et al., 2005). The aim of this work is to adapt some existing empirical field strength models in UHF to suit the city of Ekiti State, Nigeria.

Field Strength Models

Field strength models are radio signal propagation models which present the electric field strength as a function of the signal distance from the point of transmission. There are various empirical field strength models for broadcasting services but attention will be given to free space model, Hata model, International Telecommunication Union Radio (ITU-R P.529-3) model and European Radio Communications Committee (ERC Report 68) model because they are widely accepted (Faruk et al., 2013 & Moses et al., 2015).

Free Space Model

Free-space propagation model is used to predict received signal strength when the path between the transmitter and receiver is a clear and unobstructed line-of-sight (Obiyemi et al., 2012). The ideal propagation radiates in all directions from transmitting source and propagating to an infinite distance with no degradation. Attenuation occurs due to spreading of power over greater areas (Nadir et al., 2008).

$$S = \frac{P_T}{4\pi d^2} \quad (1)$$

$$S = P_T - 20\text{logd} - 41 \quad (2)$$

where:
S = power flux density in decibels relative to 1W.m^{-2}
P_T = power in decibels (dB) relative to 1 kW
d = distance (km)
The equivalent field strength, E is given as:

$$E = \sqrt{S.120\pi} \quad (3)$$

$$= \frac{\sqrt{30P_T}}{d} \quad (4)$$

or $E(mV/m) = \frac{173\sqrt{P_T(KW)}}{d\ (km)}$ (5)

$$E = P_T - 20\text{logd} + 104.8 \text{ in } dB\mu V/m \quad (6)$$

Hata Model

The model is based on an empirical relation derived from Okumura's report on signal strength variability measurements (Okumura, 1968). The original Hata equation is given in terms of a path loss in dB.

$$E = 69.82 - 6.16logf + 13.82logh_b + a(h_m) - (44.9 - 6.66\log(h_b)) \times \log d \ (dB\mu V/m) \quad (7)$$

where:
E = Field strength at a distance from a 1 kW ERP transmitter in $dB\mu V/m$
f = Frequency of the transmission (MHz)
h_b = Height of the base station or transmitter (m)
h_m = Height of the mobile or receiver (m)
d = Distance between the receiver and transmitter (km)

ITU-R P.529-3 Model

The ITU-R determines the analytical expressions that are suitable for same frequency ranges and correspond approximately to some of its propagation curves. The equation is given by (ITU-R, 1999).

$$E = 69.82 - 6.16logf + 13.82logh_b + a(h_m) - (44.9 - 6.55\log(h_b)\,(\log d)^b) \quad (8)$$

where:
E = Field strength for 1 kW ERP

f = Frequency (MHz)
h_b = Base station antenna height in the range of 30-200 m.
h_m = Mobile station antenna height in the range 1-10 m.
d = Distance (km)

$$a(h_m) = (1.1 \log f - 0.7)h_m - (1.56 \log f - 0.8) \quad (9)$$

b = 1 for d ≤ 20 km (10)

$$b = 1 + \left(0.14 + 1.87 \times 10^{-14} f + 1.07 \times 10^{-3} \acute{h}_b\right)\left(\log \frac{d}{20}\right)^{0.8} \text{ for 20 km} < \text{d} < \text{100 km} \quad (11)$$

where:

$$\acute{h}_b = \frac{h_b}{\sqrt{1+7\times10^{-8}{h_b}^2}} \quad (12)$$

This model is suitable for use over the ranges:
Frequency range, 150-1500 MHz
Base station height, 30-200 m
Mobile height, 1-10 m
Distance range, 1-100 km

ERC Report 68 Model

In this model, the equation covers the same frequency range as the original Hata equation. This equation has only the distance term raised to the power b and the equation equates approximately to the original Hata equation for distances less than 20 km. The equation is given by (Spectrum planning report, 2001):

$$E = 69.75 - 6.16 log f + 13.82 log h_b + \alpha \times (44.9 - 6.55 \log h_b \times \log d) + a(h_m) + b(h_b) \quad (13)$$
where:

α = 1 if d ≤ 20 km (14)

$$\alpha = 1 + (0.14 + 1.87 \times 10^{-4} \times f + 1.07 \times 10^{-3} h_m) \times \left(\log \frac{d}{20}\right)^{0.8} \text{ if d} > 20 \text{ km} \quad (15)$$

$$a(h_m) = (1.1 \log f - 0.7) \times minimum(10, h_m) - (1.56 \log f - 0.8) + maximum\left(0, 20 \log \frac{h_m}{20}\right) \quad (16)$$

$$b(h_b) = minimum\left(0, 20 \log \frac{h_b}{30}\right) \quad (17)$$

This model is suitable for the ranges:

Frequency range 150 – 1500 MHz
Base station height 1 - 200 m
Mobile height 1 - 200 m
Distance range 1 - 100 km

Study Area

Ekiti State of Nigeria was chosen for this research (Figure 1). The State is located in the south western part of Nigeria between latitude 7°40'N and latitude 7.667°N and longitude 5°15'E and 5.250°E with the capital at Ado-Ekiti. The state is bounded in the north by Kwara State and Kogi State while Osun State occupies the west and Ondo State lies in the south and extends to the eastern part. Ekiti State has sixteen local government areas with an overall population of about 2,384,212 people that spread over an approximately 88.7 km^2. The region lies at about 250 m above the sea level.

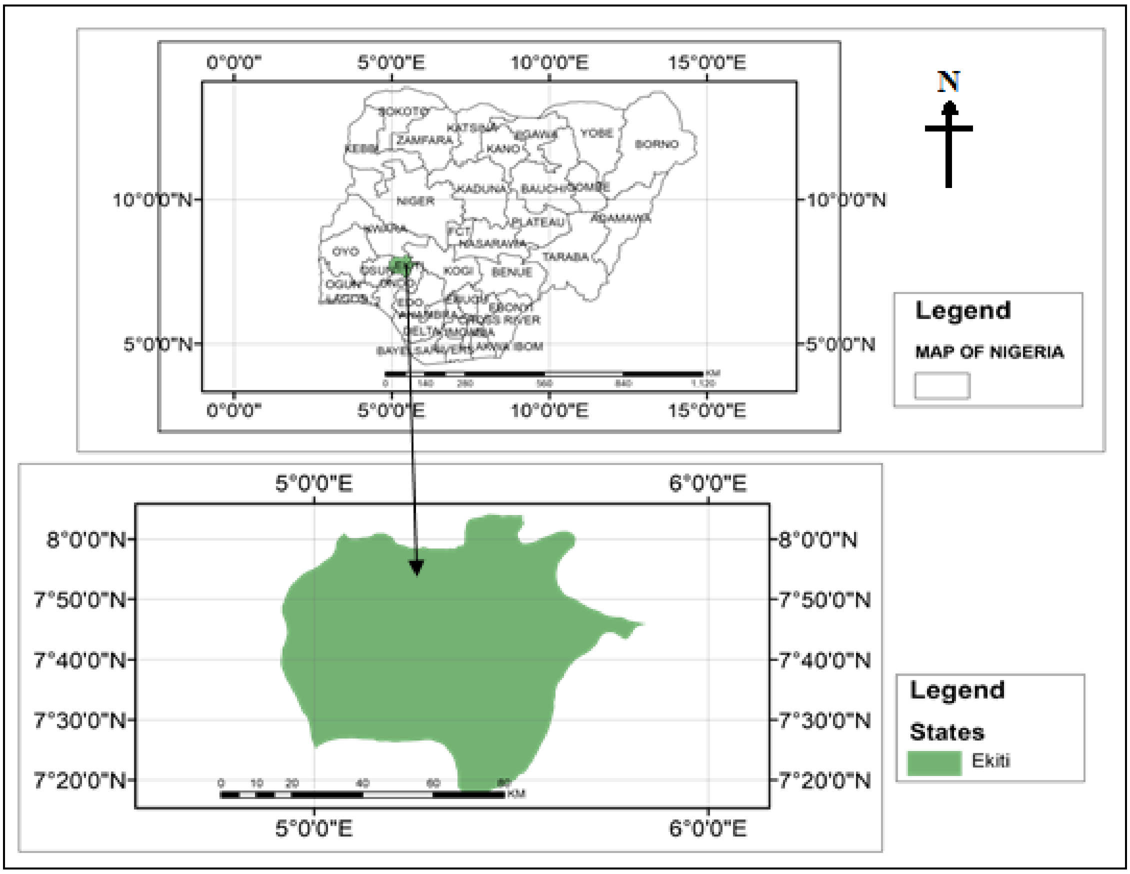

Figure 1. Map of Ekiti State in Nigeria

Data Collection and Analysis

This work was carryout in Ekiti State, Nigeria, using the UHF television station signal of Broadcasting Service of Ekiti State (BSES), channel 41. The television station transmits signal at frequency of 631.25 MHz for video signal and the output power of the transmitter was 7 kW while the transmitting antenna was mounted on a mast of 200 m high.

Figure 2. The route along which measurement were taken

The signal levels of the transmitted signal were measured radially along the four accessible routes using a digital signal level meter until the signal faded out and the corresponding distances were also measured using a global positioning system (GPS). Data processing and computation were carried out using Microsoft office excel application. From the measured signal levels, the field strength values in dBμV/m were calculated for a 1 kW Effective Radiated Power (ERP) transmitter to aid comparison with other models. The field strength for each route was obtained and the corresponding field strength as predicted by the free space, Hata, ITU-R.P529-3 and ERC Report 68 models were also evaluated.

For each model, the root mean square error (RMSE) was determined along the four routes (Figure 2) and the mean prediction error (MPE) was also determined and used as a correction factor to modify each model to get the least RMSE. As a result of different routes considered, there are a number of correction factors for each model for the city. So, to generalise each model for all routes in Ekiti State, the average value of the MPE of the four routes considered were estimated and used as the correction factor to generalise the field strength models.

Results and Discussion

Electric Field Strength Models

The comparison of the field strength models with the measured field strength for the four routes considered are shown in the Figures 3 to 6. The models have the same trend for all the routes considered. From the Figures, the free space model has the highest values of the prediction while the ERC Report 68 model has the lowest prediction values. The RMSE of the field strength models for each route are shown in Table 1. Hata model has the least average RMSE (11.71 dBμV/m) for all the routes

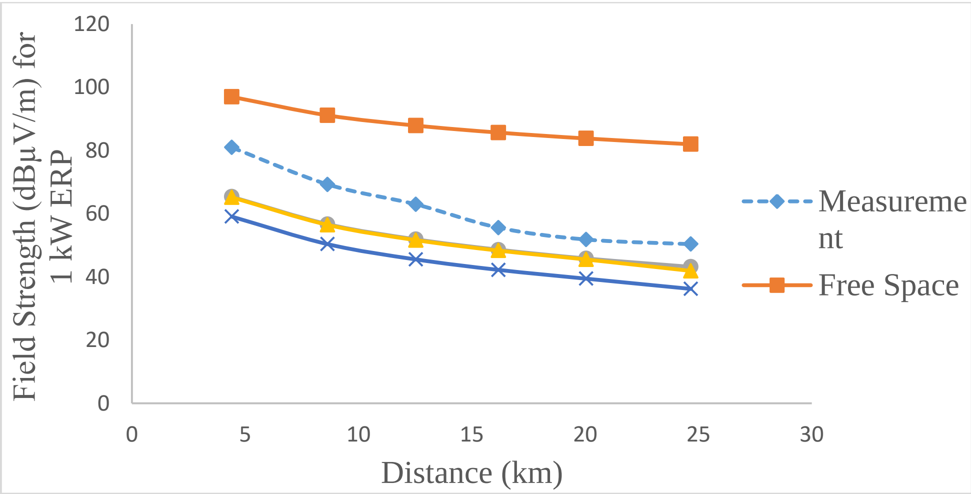

Figure 3. Field strength models for route A

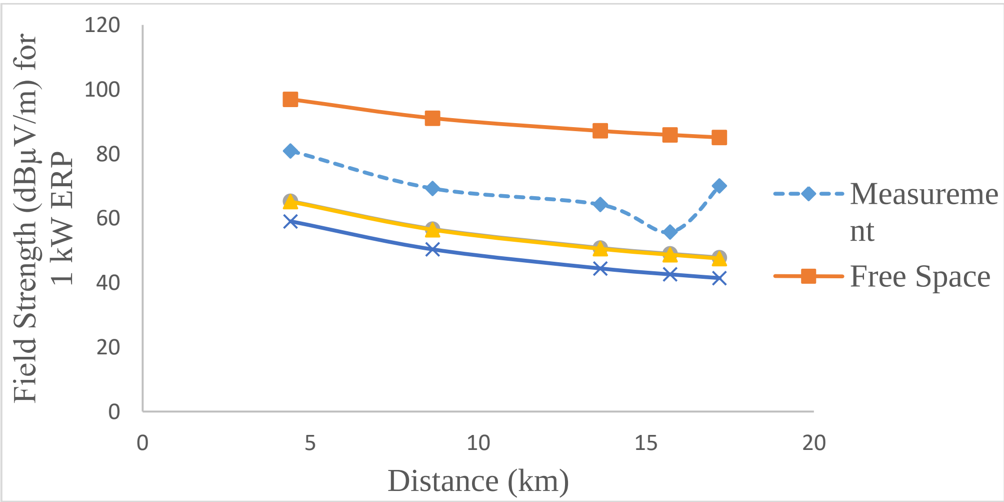

Figure 4. Field strength models for route B

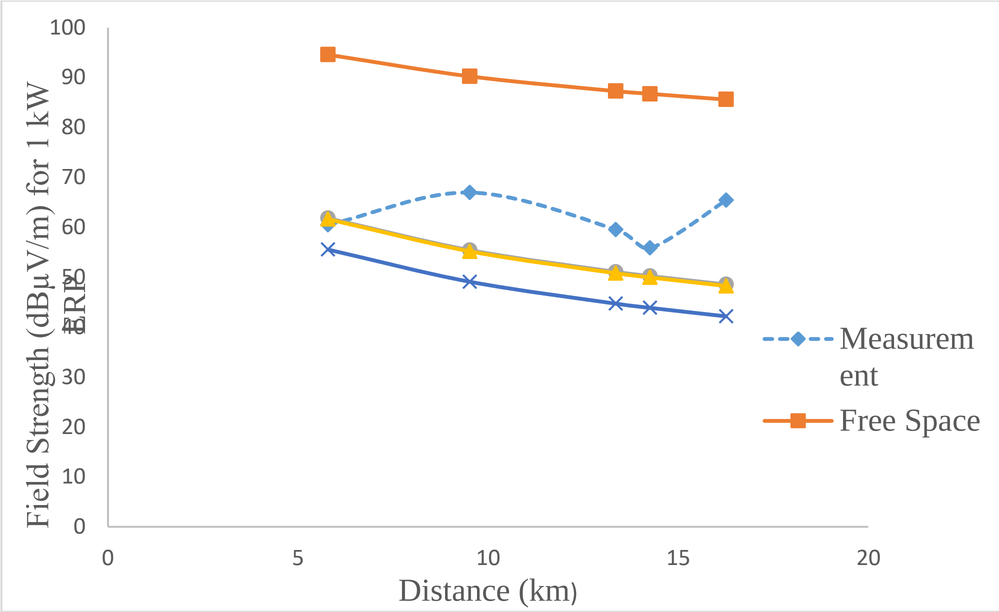

Figure 5. Field strength models for route C

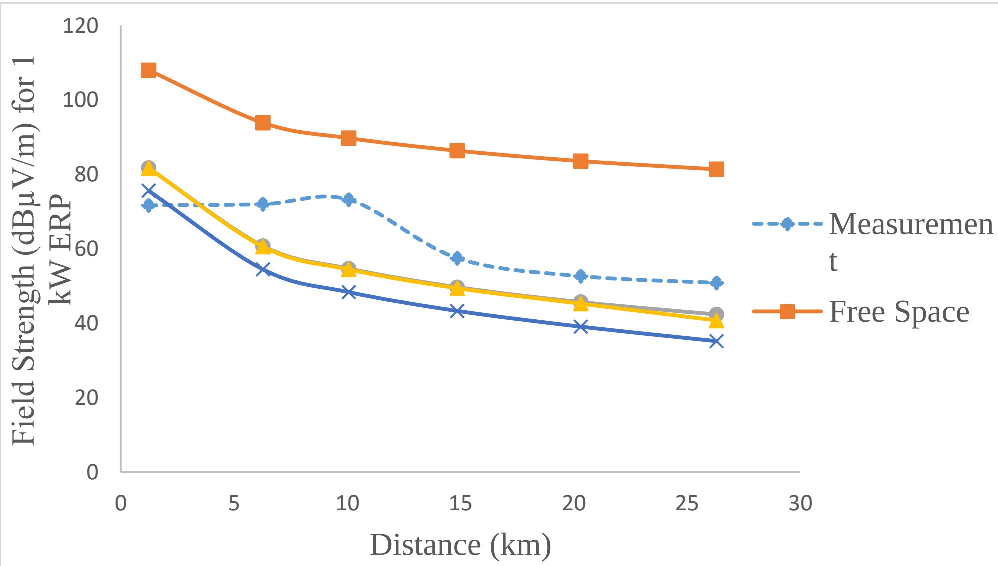

Figure 6. Field strength models for route D

Table 1. Root mean square error of the field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	26.70	10.47	11.24	16.67
B	21.87	14.98	15.02	20.83
C	27.60	10.22	10.45	15.80
D	28.24	11.18	11.57	16.17
Average	26.10	11.71	12.07	17.36

Modified Field Strength Models

Figure 7 to 10 show the modified field strength models for the routes. Table 2 shows the correction factors used for modified field strength models while Table 3 gives the RMSE of the modified field strength models for each route. The modified models show that the free space model has the lowest field strength prediction and all the models follow the same trend.

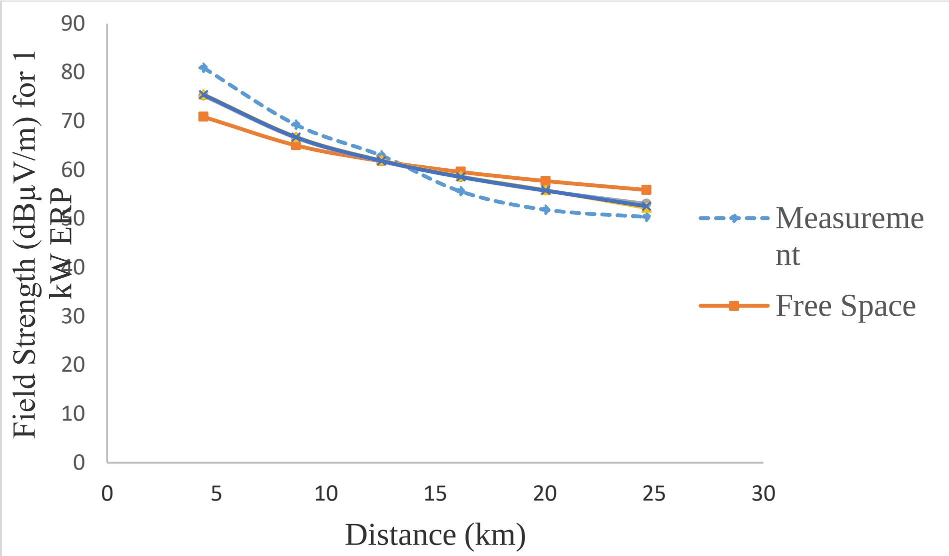

Figure 7. Modified field strength models for route A

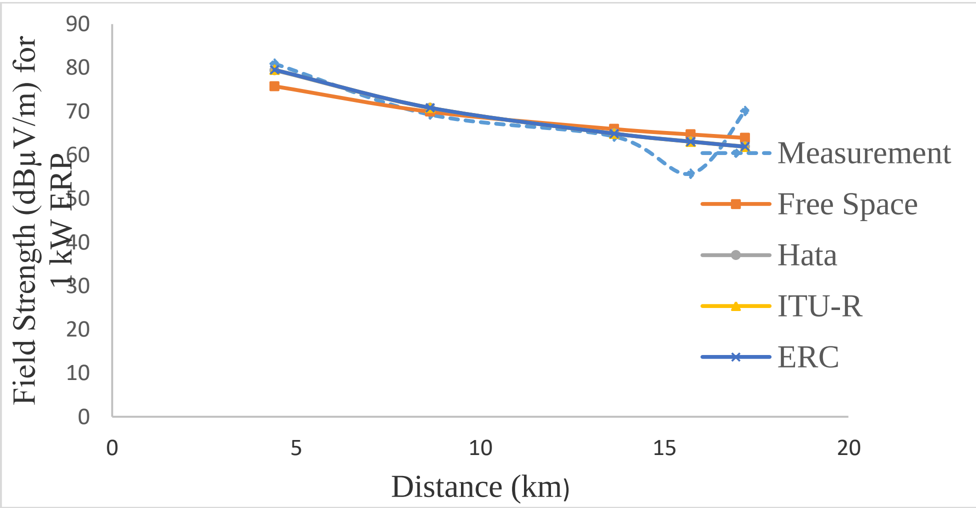

Figure 8. Modified field strength models for route B

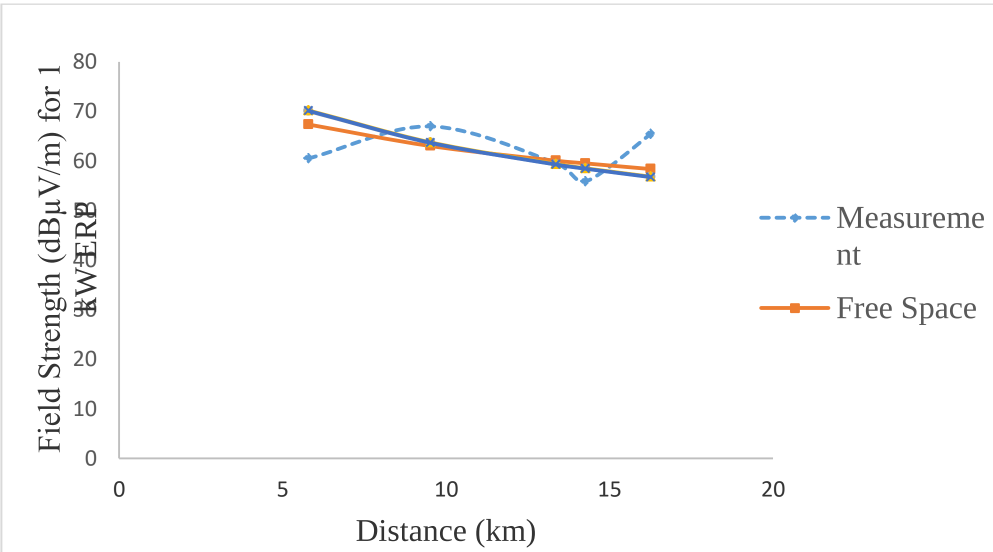

Figure 9. Modified field strength models for route C

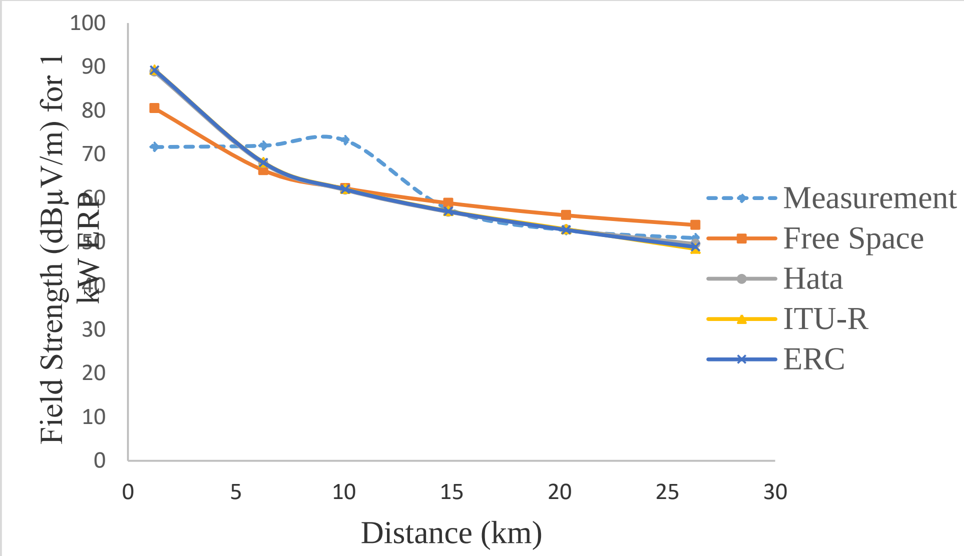

Figure 10. Modified field strength models for route D

Table 2. Correction factors used for the modified and the generalised field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	-26.06	9.89	10.32	16.33
B	-21.18	14.11	14.36	20.46
C	-27.22	8.24	8.57	14.58
D	-27.49	7.16	7.62	13.64
Average	-25.48	9.85	10.21	16.25

Table 3. Root mean square error of the modified field strength models

Route	Free Space (dBµV/m)	Hata (dBµV/m)	ITU-R (dBµV/m)	ERC (dBµV/m)
A	5.78	3.46	3.30	3.35
B	5.45	4.99	4.99	5.47
C	5.02	6.06	6.09	6.08
D	6.48	8.59	8.71	8.69
Average	5.68	5.77	5.77	5.89

Generalised Field Strength Models

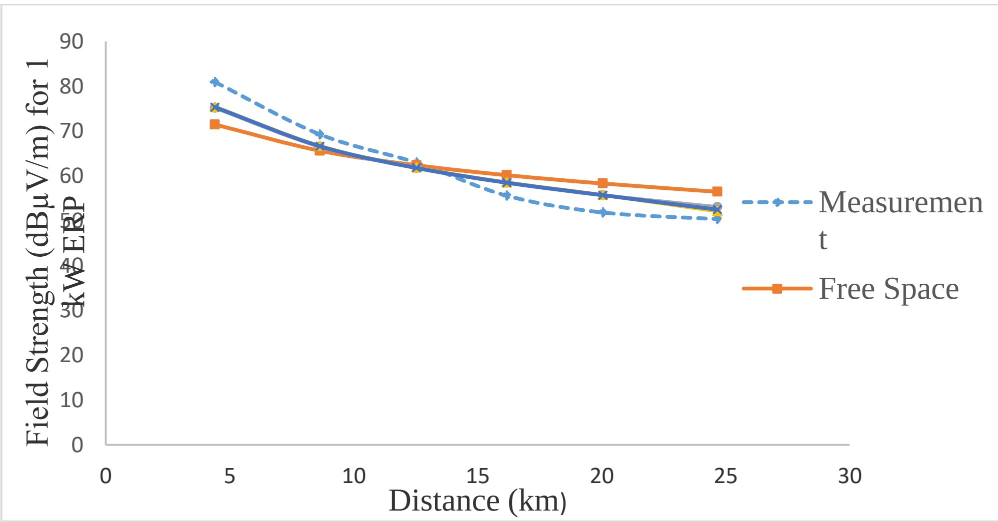

Figure 11. Generalised field strength models for route A

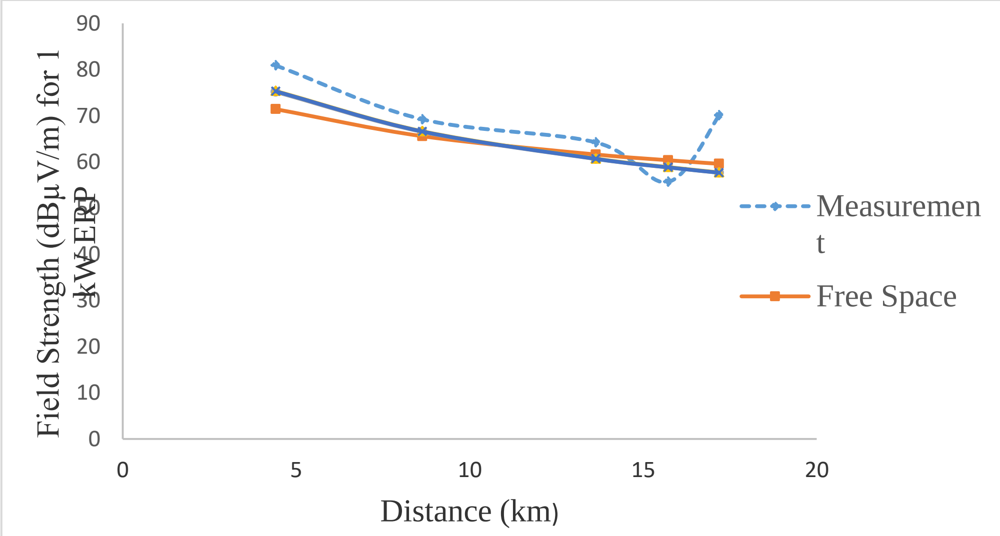

Figure 12. Generalised field strength models for route B

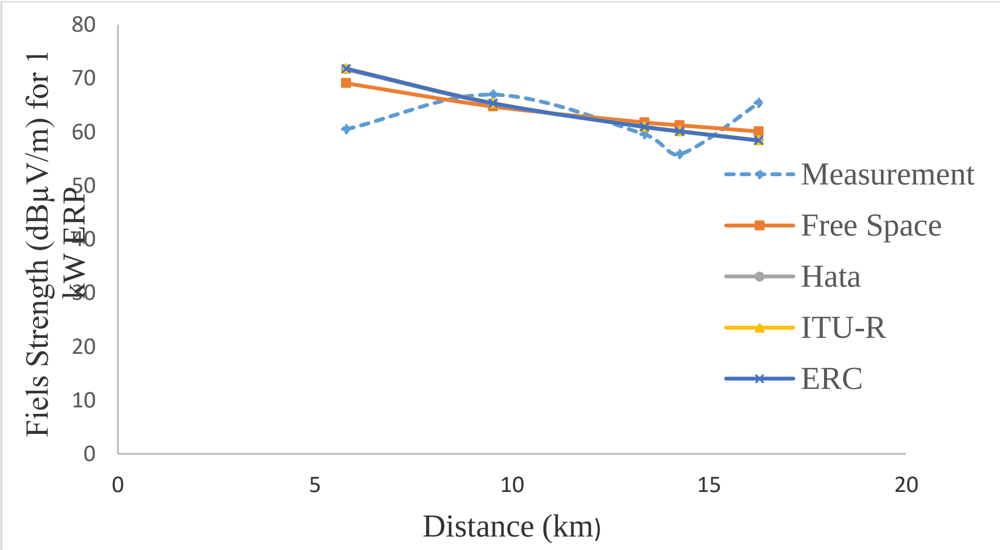

Figure 13. Generalised field strength models for route C

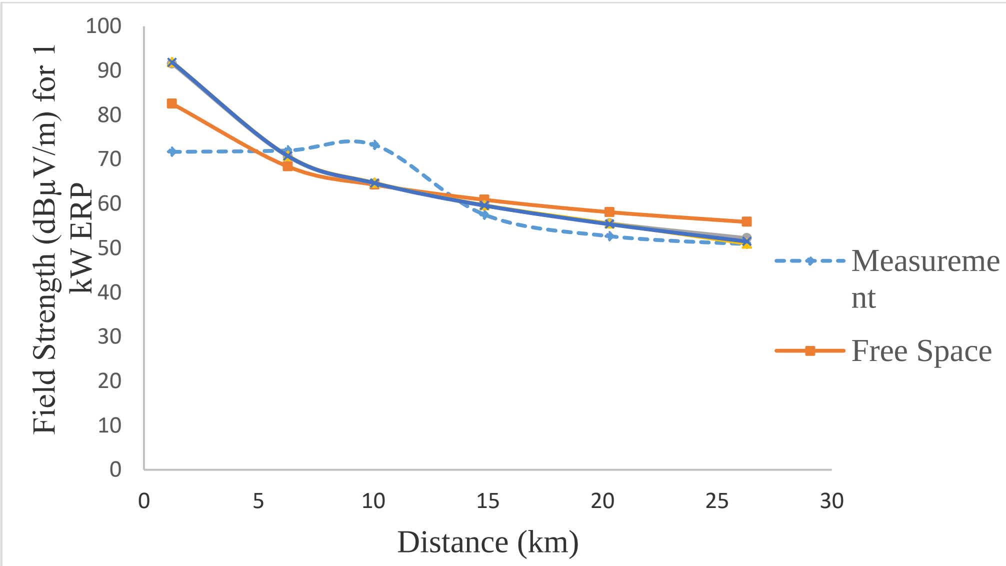

Figure 14. Generalised field strength models for route D

Table 4. Root mean square error of the generalised field strength models

Route	Free Space (dBμV/m)	Hata (dBμV/m)	ITU-R (dBμV/m)	ERC (dBμV/m)
A	5.81	3.47	3.30	3.35
B	6.95	6.59	6.52	6.55
C	5.31	6.27	6.32	6.31
D	6.78	9.03	9.08	9.07
Average	6.21	6.34	6.30	6.32

The generalised field strength models are shown in Figures 11 to 14. The free space has the lowest field strength prediction. The correction factors used to generalise the field strength models for Ekiti State are the average values of the mean prediction error of all the four routes. Table 4 shows the RMSE values of the generalised field strength models for each route and free space model has the least average RMSE of 6.21 dBμV/m for all the routes considered.

Conclusion

The generalised field strength models for Ekiti State, for terrestrial television broadcast application, were obtained by using the average of the mean prediction errors of the four routes as the correction factor for each model. The average values of the RMSE of the generalised field strength models for the four routes are taken as the RMSE values for Ekiti State. The correction factors used for all the field strength models are as follows: -25.48 for free space, 9.85 for Hata, 10.21 for ITU-R P.529-3 and 16.25 for ERC Report 68 models with average RMSE of 6.21dBμV/m, 6.34 dBμV/m, 6.30 dBμV/m and 6.32 dBμV/m respectively. Hence, the generalised free space field strength model gives a more accurate prediction for field strength in Ekiti State as compared to other models.

Recommendation

This work can be repeated for different seasons of the year to observe the variation of the signals with seasons

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors

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