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Propagation Loss Characterisation In A Gliricidia Sepium Arboretum (Botanical Garden) Using Extended Stanford University Interim Model

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***Abstract*—In this paper, propagation loss characterization in a Gliricidia Sepium arboretum (botanical garden) using Extended Stanford University Interim (EXSUI) model is presented. The study was for GSM signal in the 1800 MHz frequency band. The EXSUI model has three different versions based on the three different terrains that are supported in the model. The Root Mean Square Error (RMSE) method was used to tune each of the three terrain EXSUI models. The results show that the un-tuned EXSUI model for terrain A has the least RMSE value of 16.6 dB while the terrain C model has the worst RMSE value of 20.04. The results also show that the terrain A model has about 17.14 % reduction in the RMSE when compared with that of the terrain C model. Similarly, the results show that the tuned EXSUI model for terrain A has the least RMSE value of 2.99 dB while the terrain C model has the highest RMSE value of 3.08 dB. In all, the results showed that the tuned EXSUI model for terrain A is the best model for characterising the propagation loss in the study area, which is a Gliricidia Sepium Arboretum (Botanical Garden).**

Keywords— Propagation loss, Gliricidia Sepium arboretum, Extended Stanford University Interim (EXSUI) model, model tuning

1. Introduction

Without doubt, wireless network technologies have dominated the wired and fibre optic network technologies [1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18]. However, experts in the networking industry have continued to develop algorithms, strategies, protocol and mechanisms to make the wireless communication to be more robust in the face of many challenges [19,20, 21,22, 23,24, 25,6, 27,28, 29,30, 31,32, 33,34, 35,36, 37,38, 39]. Notably, propagation loss is one of the major concerns in wireless network communication system [40,41,42,43,44,45,46,47,48,49]. Apart from propagation loss, issues like diffraction loss, rain fading, interference and multipath fading are among the other concerns that wireless network designers have to address [50,51,52, 53,54,55, 56,57, 58,59, 60,61, 62,63, 64,65, 66,67, 68,69, 70, 71, 72]. These issues do affect the attainable communication range, the required transmitter power and other communication link parameters [73,74,75]. Importantly, in order to account for propagation loss in a wireless communication system, the designers use propagation loss models to predict the expected propagation loss over a given coverage area [76,77,78]. Some of the commonly used propagation loss models are the Hata Okumara model, Hata model, ECC 33 model, COST- 231 model, LEE model, Walfish and Bertoni model, as well as the Stanford University Interim model and the Extended Stanford University Interim model.

Specifically, in this paper, the Extended Stanford University Interim model is used to characterise the propagation loss that is expected for wireless signal propagating in a Gliricidia Sepium botanical garden [79,80,81]. The study is based on the empirical field measurement of the signal strength within the case study botanical garden. The measured signal strength is used to determine the propagation loss which then used to tune the Extended Stanford University Interim model parameters to provide more accurate prediction of the propagation loss in the botanical garden. Essentially, the study is meant to optimize the Extended Stanford University Interim model for the prediction of the propagation loss within the case study Gliricidia Sepium Arboretum (botanical garden).

2.0 Methodology

2.1 The Extended Stanford University Interim (EXSUI) Model

Propagation loss based on Extended Stanford University Interim (EXSUI) model (denoted in this paper as $P_{EXSUI}(dB)$) is expressed analytically as follows;

$$P_{EXSUI}(dB) = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi d}{\lambda}\right)\right) & for\ d < \delta_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\delta_o}\right)\right) + X_f + X_h & for\ d > \delta_o \end{cases} \quad (1)$$

Where

$$A = 20\left(\log_{10}\left(\frac{4\pi d_0}{\lambda}\right)\right) \quad (2)$$

$$X_f = 6\left(\log_{10}\left(\frac{f}{2000}\right)\right) \quad (3)$$

$$X_h = \begin{cases} -10.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type A and B} \\ -20.8\left(\log_{10}\left(\frac{h_m}{2000}\right)\right) & \text{for terrain type C} \end{cases} \quad (4)$$

Where d is the signal propagation path length in km, the signal frequency (f) is in MHz d_0 is set at 100m, while δ_o denote the modified reference distance which is defined as;

$$\delta_o = d_0\left(10^{-\left(\frac{X_h - X_f}{10(\gamma)}\right)}\right) \quad (5)$$

Again, X_h and X_f represent the correction factor for the receiver antenna and the frequency correction factor respectively. The path loss exponent is denoted as γ, while the correction factor for shadowing is denoted as S where $8.2 \le S \le 10.6$ dB . The height of base station antenna expressed in meters, h_b has acceptable range of values as $10\ m \le h_b \le 80\ m$.

$$\gamma = a + b(h_b) + \frac{c}{h_b} \quad (6)$$

Typical values of γ for different kinds of areas are given as;

$$\left.\begin{matrix} \gamma = 2\ for\ free\ space \\ 3 \le \gamma \le 5 \text{ for urban area} \\ \gamma > \text{for indoor} \end{matrix}\right\} \quad (7)$$

The EXSUI model is defined for different terrain categories with the values of the terrain constant parameters a, b and c given as shown in Table 1.

Table 1: The values of the EXSUI model terrain constant parameters a, b and c

Model Parameter	Terrain A	Terrain B	Terrain C
a	4.6	4.0	3.6
b(m^{-1})	0.0075	0.0065	0.005
c(m)	12.6	17.1	20

2.1 The Root Mean Square Error (RMSE) Method for Tuning The Extended Stanford University Interim (EXSUI) Model

In this paper, the Root Mean Square Error (RMSE) method is used to tune the EXSUI model based on the algorithm given as follows;

Step 1: Compute the sum of errors (SoE) as follows

$$SoE = \sum_{i=1}^{i=n}\left(PL_{meas(i)} - PL_{EXSUI(i)}\right) \quad (8)$$

Where $P_{m(i)}$ represents the pathloss that was empirically measured while $P_{EXSUI(i)}$ represents the pathloss that was predicted using the ESUI model and n is the maximum number of data items captured during the empirical measurement.

Step 2: Compute the Root Mean Square Error (RMSE) as follows;

$$\text{RMSE} = \sqrt[2]{\left\{\frac{1}{n}\left[\sum_{i=1}^{i=n}\left|P_{meas(i)} - P_{EXSUI(i)}\right|^2\right]\right\}} \quad (9)$$

Step 3: Compute the tuned EXSUI model propagation loss prediction ($P_{TEXSUI}(dB)$)

Step 3.1 : 3.1 For i= 1 to n Step 1

Step 3.2 : If $SoE < 0$ Then

$$P_{TEXSUI}(dB) = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi d}{\lambda}\right)\right) - RMSE & for\ d < \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\delta_o}\right)\right) - X_f + X_h \pm RMSE & fo \end{cases}$$

Else

$$P_{TEXSUI}(dB) = \begin{cases} 20\left(\log_{10}\left(\frac{4\pi d}{\lambda}\right)\right) + RMSE & for\ d < \delta_o \\ A + 10\gamma\left(\log_{10}\left(\frac{d}{\delta_o}\right)\right) + X_f + X_h + RMSE & for\ d > \delta_o \end{cases}$$

Endif

Step 3.3: Output $P_{TEXSUI}(dB)$

Step 3.4: Next i

The measured pathloss dataset used for the study is presented in Table 1 and Figure 1. The data was for GSM signal in the 1800 MHz frequency band. The picture of the Gliricidia Sepium Arboretum (Botanical Garden) as presented in [46] is shown in Figure 2.

Table 1 The field measured path loss (dB) within the Gliricidia Sepium Arboretum (Botanical Garden)

S/N	d (km)	Field Measured Path Loss (dB) within the Gliricidia Sepium Arboretum (Botanical Garden)	S/N	d (km)	Field Measured Path Loss (dB) within the Gliricidia Sepium Arboretum (Botanical Garden)	S/N	d (km)	Field Measured Path Loss (dB) within the Gliricidia Sepium Arboretum (Botanical Garden)
1	0.5	110.3	10	0.5369	116.3	19	0.566	119.3
2	0.5033	108.3	11	0.5424	111.3	20	0.5666	118.3

3	0.5097	111.3	12	0.5546	117.3	21	0.5685	116.3
4	0.512	110.3	13	0.5557	112.3	22	0.5707	120.3
5	0.5139	109.3	14	0.5611	117.3	23	0.5709	117.3
6	0.5191	114.3	15	0.5638	114.3	24	0.5712	119.3
7	0.5208	113.3	16	0.5683	114.3	25	0.5718	115.3
8	0.5263	117.3	17	0.565	114.3	26	0.5771	120.3
9	0.5319	111.3	18	0.5653	114.3	27	0.5773	122.3

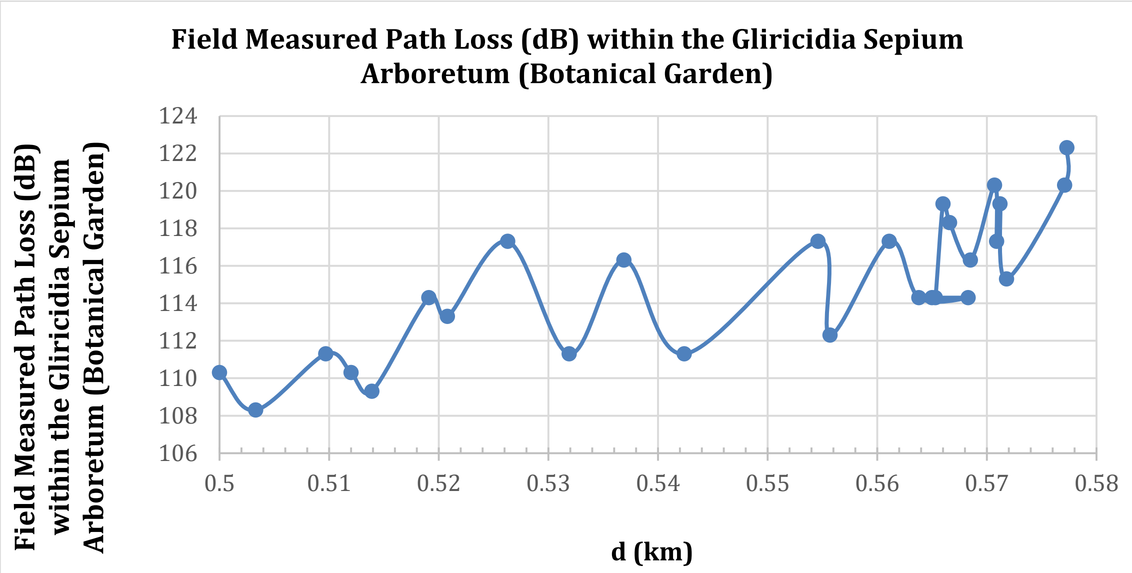

Figure 1 The field measured path loss (dB) within the Gliricidia Sepium Arboretum (Botanical Garden)

Figure 2 The image of the Gliricidia Sepium Arboretum (Botanical Garden) as presented in [20]

3. Results and Discussion

The path length contained in the dataset of Table 1 are used to predict the propagation loss using each of the three different terrain versions of the EXSUI model and the predicted values are compared with the measured value, as shown in Table 2, Figure 3 and Figure 4.

Comparison of the prediction performance of the three un-tuned EXSUI models is presented in Table 3 and Figure 5.

The results show that the un-tuned EXSUI model for terrain A has the least RMSE value of 16.6 dB while the terrain C model has the worst RMSE value of 20.04. The results in Table 3 show that the terrain A model has about 17.14 % reduction in the RMSE when compared with that of the terrain C model.

Table 2 The predicted propagation loss using the un-tuned EXSUI for Terrain A, Terrain B and Terrain C

d (km)	Field Measured Path Loss (dB) within the Gliricidia Sepium Arboretum (Botanical Garden)	Predicted Propagation Loss Using Un-tuned EXSUI for Terrain A	Predicted Propagation Loss Using Un-tuned EXSUI for Terrain B	Predicted Propagation Loss Using Un-tuned EXSUI for Terrain C
0.5	110.3	96.9	94.8	93.7
0.5033	108.3	97.0	95.0	93.8
0.5097	111.3	97.3	95.2	94.0
0.512	110.3	97.4	95.3	94.1
0.5139	109.3	97.5	95.3	94.2
0.5191	114.3	97.7	95.5	94.3
0.5208	113.3	97.7	95.6	94.4
0.5263	117.3	97.9	95.8	94.6
0.5319	111.3	98.1	96.0	94.8
0.5369	116.3	98.3	96.1	94.9
0.5424	111.3	98.5	96.3	95.1
0.5546	117.3	99.0	96.7	95.5
0.5557	112.3	99.0	96.7	95.5
0.5611	117.3	99.2	96.9	95.7
0.5638	114.3	99.3	97.0	95.7
0.5683	114.3	99.5	97.0	95.8
0.565	114.3	99.4	97.1	95.8
0.5653	114.3	99.4	97.1	95.8
0.566	119.3	99.4	97.1	95.8
0.5666	118.3	99.4	97.2	95.9
0.5685	116.3	99.5	97.2	95.9
0.5707	120.3	99.6	97.2	96.0
0.5709	117.3	99.6	97.2	96.0
0.5712	119.3	99.6	97.2	96.0
0.5718	115.3	99.6	97.3	96.0
0.5771	120.3	99.8	97.4	96.1
0.5773	122.3	99.8	97.4	96.1

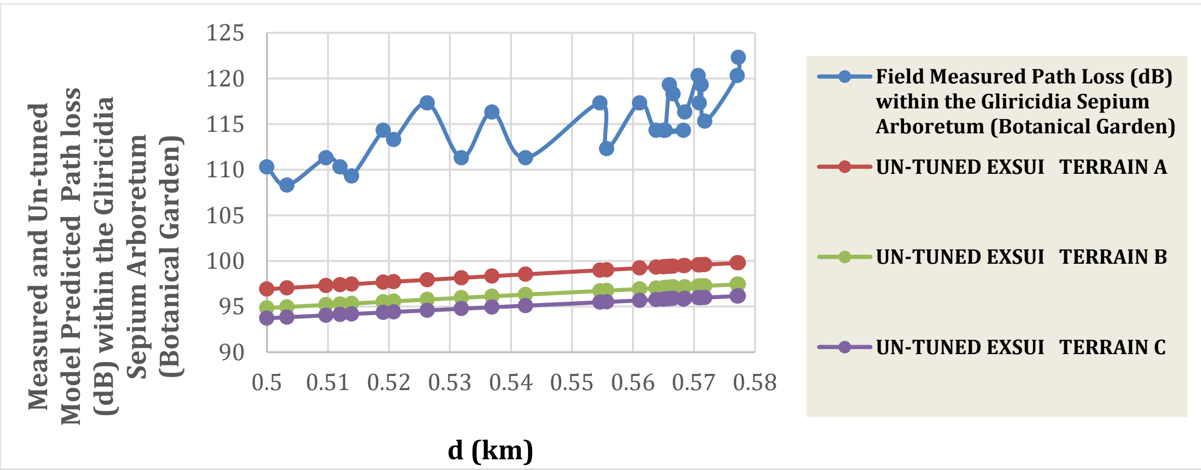

Figure 4 The scatter plot for the predicted propagation loss using the un-tuned EXSUI for Terrain A, Terrain B and Terrain C

Table 3 Comparison of the un-tuned EXSUI models prediction performance

	RMSE	Normalized with respect to worst case prediction model (%)
UN-TUNED EXSUI TERRAIN A	16.60	-17.14
UN-TUNED EXSUI TERRAIN B	18.82	-6.07
UN-TUNED EXSUI TERRAIN C	20.04	0.00

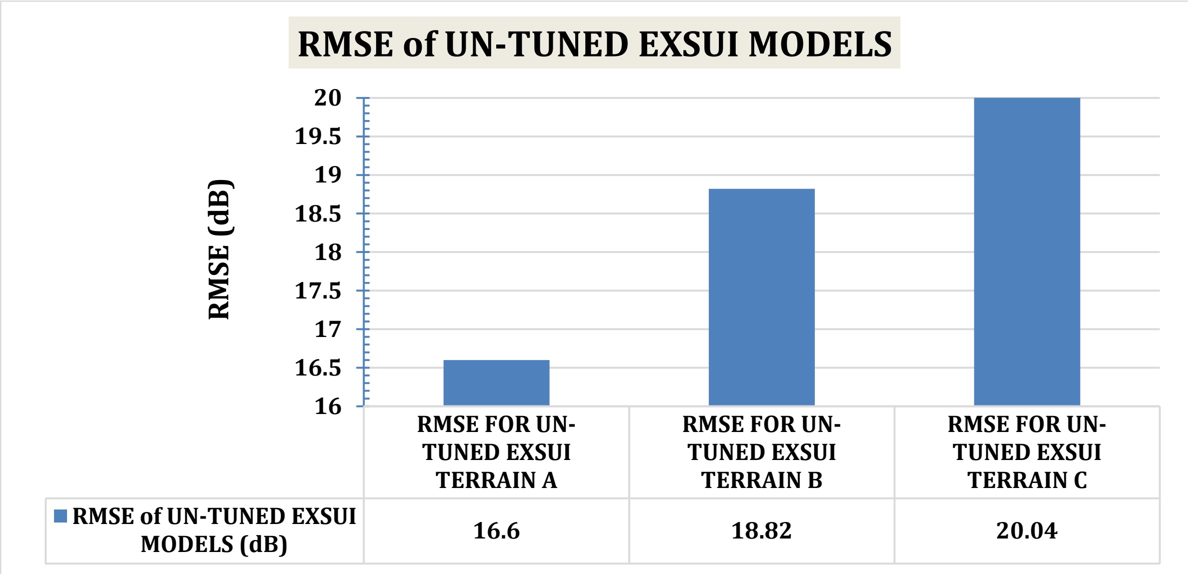

Figure 5 Comparison of the prediction performance (RMSE) of the three un-tuned EXSUI models

Each of the tuned EXSUI model for the three different terrain versions is used to predict the propagation loss compared with the measured value, as shown in Table 4, Figure 6 and Figure 7.
Comparison of the prediction performance of the three tuned EXSUI models is presented in Table 5 and Figure 7. The results show that the tuned EXSUI model for terrain A has the least RMSE value of 2.99 dB while the terrain C model has the highest RMSE value of 3.08 dB. The results in Table 5 show that the terrain A model has about 2.784 % reduction in the RMSE when compared with that of the terrain C model. In all, the results showed that the tuned EXSUI model for terrain A is the best model for characterising the propagation loss in the study area, which is a Gliricidia Sepium Arboretum (Botanical Garden).

Table 4 The predicted propagation loss using the tuned EXSUI for Terrain A, Terrain B and Terrain C

d (km)	Field Measured Path Loss (dB) within the Gliricidia Sepium Arboretum (Botanical Garden)	Predicted Propagation Loss Using Tuned EXSUI for Terrain A	Predicted Propagation Loss Using Tuned EXSUI for Terrain B	Predicted Propagation Loss Using Tuned EXSUI for Terrain C
0.5	110.3	113.5	113.7	113.7
0.5033	108.3	113.6	113.8	113.9
0.5097	111.3	113.9	114.0	114.1
0.512	110.3	114.0	114.1	114.2
0.5139	109.3	114.1	114.2	114.2
0.5191	114.3	114.3	114.3	114.4
0.5208	113.3	114.3	114.4	114.4
0.5263	117.3	114.5	114.6	114.6
0.5319	111.3	114.7	114.8	114.8
0.5369	116.3	114.9	114.9	115.0
0.5424	111.3	115.1	115.1	115.1
0.5546	117.3	115.6	115.5	115.5
0.5557	112.3	115.6	115.6	115.5

0.5611	117.3	115.8	115.7	115.7
0.5638	114.3	115.9	115.8	115.8
0.5683	114.3	116.1	115.9	115.8
0.565	114.3	116.0	115.9	115.8
0.5653	114.3	116.0	115.9	115.8
0.566	119.3	116.0	115.9	115.9
0.5666	118.3	116.0	116.0	115.9
0.5685	116.3	116.1	116.0	115.9
0.5707	120.3	116.2	116.0	116.0
0.5709	117.3	116.2	116.1	116.0
0.5712	119.3	116.2	116.1	116.0
0.5718	115.3	116.2	116.1	116.0
0.5771	120.3	116.4	116.2	116.2
0.5773	122.3	116.4	116.3	116.2

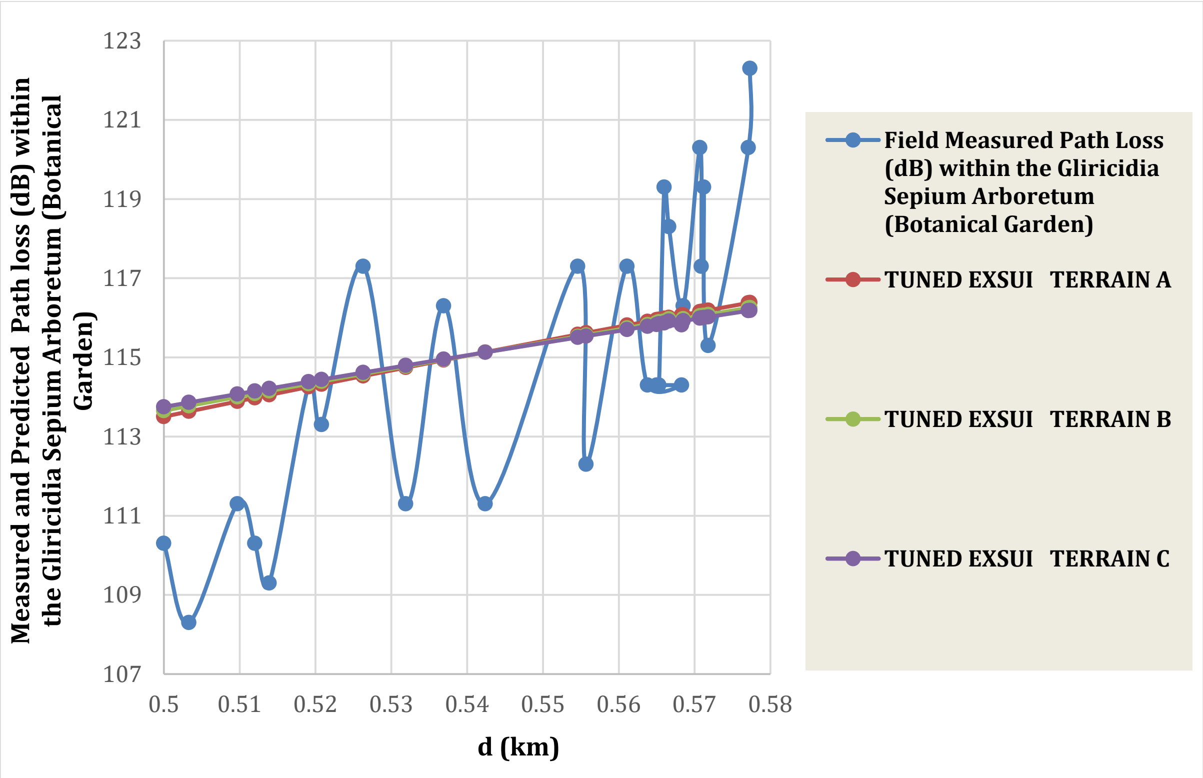

Figure 6 The scatter plot for the predicted propagation loss using the tuned EXSUI for Terrain A, Terrain B and Terrain C

Table 5 Comparison of the tuned EXSUI models prediction performance

	RMSE	Normalized with respect to worst case prediction model (%)
TUNNED EXSUI TERRAIN A	2.99	-2.78
TUNNED EXSUI TERRAIN B	3.04	-1.12
TUNNED EXSUI TERRAIN C	3.08	0.00

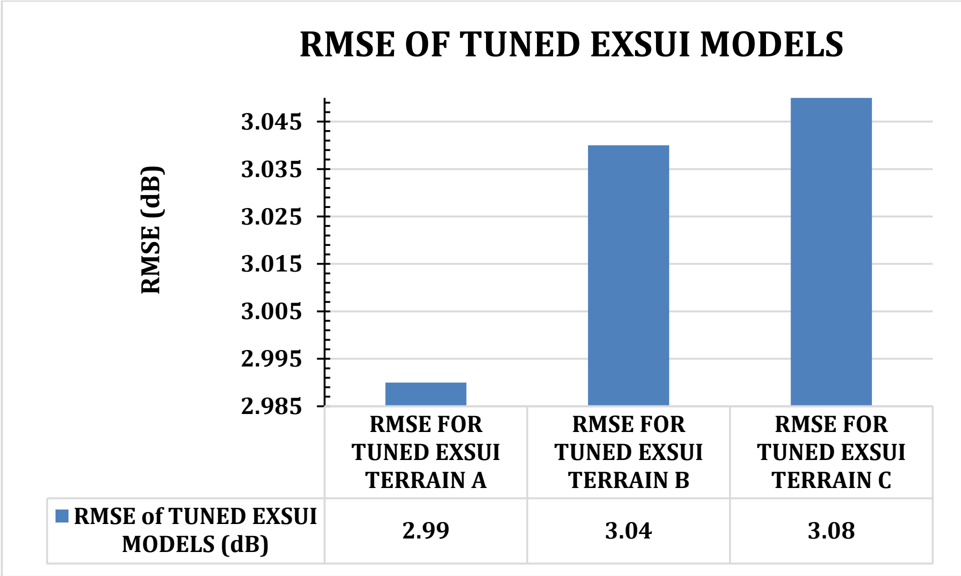

Figure 7 Comparison of the prediction performance (RMSE) of the three tuned EXSUI models

4. Conclusion

The Extended Stanford University Interim (EXSUI) model is used for the characterisation of the propagation loss in a botanical garden (Arboretum) for Gliricidia Sepium. The EXSUI model has three different versions based on the three different terrains that are supported in the EXSUI model. Each of the three terrains version of the EXSUI model was used to predict the propagation loss within the Gliricidia Sepium botanical garden and the prediction performance of the three models are compared with respect to the Root Means Square Error (RMSE) achieved.

In addition, each of the three terrains version of the EXSUI model was tuned and then used to predict the propagation loss within the Gliricidia Sepium botanical garden and the prediction performance of the three tuned EXSUI models are compared with respect to the RMSE achieved. In all, the tuned EXSUI model for terrain A had RMSE value and is therefore considered the best model for characterising the propagation loss within the Gliricidia Sepium Arboretum (botanical garden).

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