PERFORMANCE ASSESSMENT OF SOME RAIN MODELS FOR LAGOS AT 12 AND 23GHZ

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Abstract: The study of the effect of rainfall is very useful for construction of a modern satellite system. As a result of this, attenuation of rain predictive models had been used to calculate the impact of rainfall on satellite communication for different stations. In this study, performance assessment of attenuation due to rainfall was predicted for three locations of interest; namely, Ikeja, Oshodi and Marina in Lagos, Nigeria, using three popular prediction models viz. ITU-R, Synthetic Storm Technique (SST) and Dissanayake, Allnut and Haidara (DAH). Five (5) years monthly rainfall data were acquired from Nigerian Meteorological Agency (NIMET) for the selected three locations and then analysed at different percentages of time exceedances, ranging from 0.001% to 1%. Performances of the three under investigation were assessed and compared. Generally, DAH and ITU-R rain attenuation prediction models gave the closest predicted values to measurement attenuation values, both at 12 and 23GHz; and hence the recommended models for Lagos.

Keywords: Attenuation, ka-band, ku-band, meteorology, and prediction models, rain rate, satellite communication, slant-path.

Introduction

The Atmosphere has a key factor in the implementation of satellite-to-earth links especially at frequencies ranging above 10GHz (Allnutt and Goodyer, 1977; Alam et al., 2023). The effect of Raindrops scatter and absorb radio waves, leading to rain attenuation and reduction of the signal strength (Budalal et al., 2023). Rain fade or attenuation refers to the process of absorption of microwave radio frequency signal as a result of atmospheric rain, ice or snow which usually occur at frequencies above 10GHz. It is also known as the degradation of wave caused by electromagnetic interference of a storm front. The negative effect of rain varies directly with frequency and also with different locations (taking into consideration the coastal area and non-coastal area of Lagos). As a result of this, when planning both microwave terrestrial line-of-sight (LOS) and system links; there should be accurate prediction of rain attenuation on paths of propagation.

At the early stage, attenuation prediction process involved measurements extrapolation to other locations, elevation angles and frequencies; however, the complicated nature and regional changing of rain makes this approach highly not correct (Milani and Kidd, 2023). An empirical way of predicting rain attenuation calls for a 1 min-rain rate, but this is not available in tropical regions such as Nigeria. A method for converting the gotten rain rate values to the equivalent 1-minute rain rate cumulative distribution is necessary. The rain in Lagos is characterized by high rate of rainfall and increased presence of raindrops (Jolaosho et al., 2023). It is also affected by the rainfall types as other coastal and tropical areas in Nigeria.

Since one of the major problem or set back in transmission of radio signal at high frequency (above 10 GHz) is the effect of rain, a proper study of rain attenuation is needed to reduce this problem. Rain causes fading of the signal strength with variation in the degrees of impairment, and it depends on the raindrop size, intensity, rain rate and frequency of operation (Kelmendi et al., 2023). Thus, there effort must be put to accurately prove the amount of attenuation caused by rain in both satellite and terrestrial links. Although a lot of research have been made on this study in the past and present, thus, the result of this work will complement the existing.

This research assesses the performances of three existing rain attenuation prediction models (ITU-R, SST and DAH), with the aim of identifying the best at 12GHz (Ku-Band) and 23 GHz (Ka-Band) for earth to space links in three locations (Ikeja, Oshodi and Marina) in Lagos, Nigeria.

Several researches have been carried out on slant-path rain attenuation prediction models in order to mitigate the effect of rain attenuation. Some of these models are ITU-R P.816-10 model (International Telecommunication Union, 2021), Crane global model (Crane, 1977), Simple attenuation model (Stutzman and Yon, 1986), Garcia Lopez (García-López and Peiró, 1983), Karasawa (Karasawa and Maekawa, 1997), Synthetic Storm Technique (Matricciani, E., 1996), Svjatogor (Svjatogor, 1985), Bryant et. al (Bryant et al., 2001) and DAH (Dissanayake et al., 1997). However, Bryant model's seeming advantage is that it provides avenue for the threshold analysis in attenuation exceedance (Ramachandran, 2007). The ITU-R P.618 model is highly accepted around the world; hence usually serve as benchmark against the other developed models for reliability, especially for cases where measured data are not available (Action, 2002). In order to calculate the slant-path rain attenuation by the use of point rainfall rate, the procedure of step-by-step calculation of the ITU-R model can be obtained from Recommendation ITU-R. P.618 (International Telecommunication Union, 2012). SST is a useful tool to obtain rain attenuation series from rain rate series for any satellite radio link with elevation angle above 10°, at any frequency and at polarization from any site, as long as the spatial-temporal field isotropy holds (Yussuff, 2016). DAH was based on lognormal distribution of rain rate and rain attenuation, and it is similar to the ITU-R model because the rain input to the model is the rain intensity at 0.01% of the time. However, DAH is applicable to both terrestrial and slant paths within the frequency range 4–35GHz, and a percentage probability range of 0.001%–10% (Yussuff and Khamis, 2014).

Yussuff (2016) explored some selected rain attenuation prediction models for Lagos and their performance evaluation, and concluded that the other prediction models under consideration were out-matched by the ITU-R model. Omotosho et al. (2017) carried out research on three frequency bands: Ku (12/14GHz, Ka (20/30 GHz) and V (40/50 GHz) in Malaysia, and observed that the effect of heavy rainfall on satellite links in the eastern part is higher than in the western part of Malaysia. Kumar et al. (2010) investigated slant-path rain attenuation at various elevation angles in Singapore at 11GHz, 20GHz, 30GHz and 38 GHz. The slant-path rain attenuation pattern showed that rain attenuation is larger at great heights of elevation angles even at a shorter path length. They further concluded that, where the point rainfall rates increase, the reliability of slant-path rain attenuation on elevation angle models based on the cosec law are inconsistent for tropical countries.

Yussuff and Nor Hisham (2013) carried out research in which they proposed an Improved ITU-R rain attenuation prediction model for a location in Malaysia. The results showed that the proposed model at 12GHz was closer to the evaluated data than other models under investigation. Lastly, Darley et al. (2021) investigated the performances of some rain attenuation prediction models at some GSM network locations in Lagos, Nigeria, using remote sensing at Ku band on three different terrestrial microwave links. Findings revealed that ITU-R (ITU-R, 2017) either overestimated or underestimated the measurement at the three sites, namely, Tarzan Yard, Kofo Abayomi and GLO Shop.

Materials and Method

Four years annual rainfall data (2015 to 2019) measured at three stations (Ikeja, Marina and Oshodi) in Lagos, were collected from Nigerian NIMET. These data were used to derive one-minute integration time rain intensity data. These rainfall statistics were recorded with a tipping bucket rain gauge arrangement. Chebil and Rahman's proposed conversion model were used for the conversion of the hourly data to one-minute equivalent rainfall rate values (Chebil and Rahman, 1999). The steps are given below:

$$CF60 = 0.772p^{-0.041} + \exp(-2.570 * p) \quad (1)$$

$$CF60 = R_{1(p)} / R_{60(p)} \quad (2)$$

$$R_{1(p)} = CF60 * R_{60(p)} \quad (3)$$

The rain rate conversion factor $CF60$, which can be defined as the ratio of rain rates $R_{1(p)}$ at a given percentage of time (p) with an integration time of 1min and 60min, respectively. This model has a limitation of 0.001% ≤ p ≤ 1.0%; hence if $R_{60(p)}$is known, then $R_{1(p)}$ can be calculated. Shown in Table 1 is the $R_{1(p)}$ obtained after the conversion process for the three locations of interest.

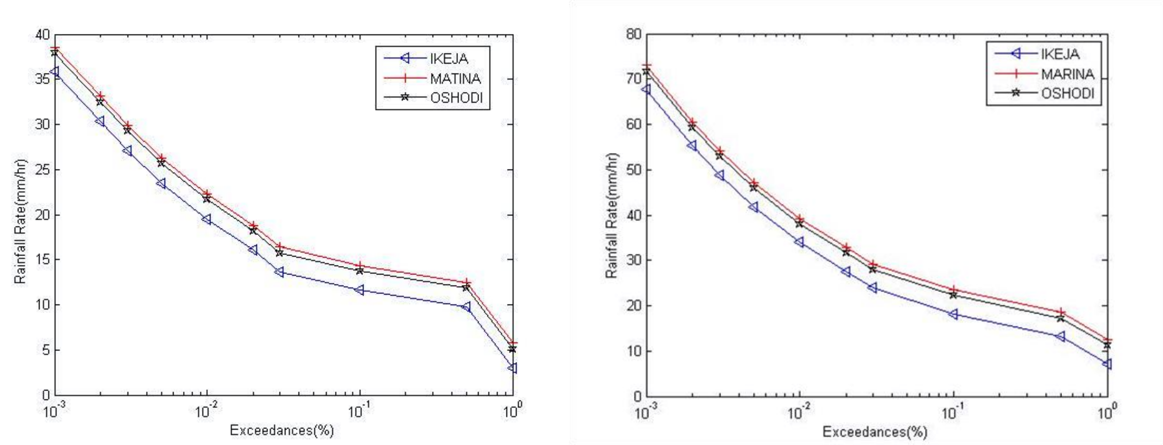
Table 1: One-minute rain rate for selected locations.

% time exceeded (p)	0.001	0.002	0.003	0.005	0.01	0.02	0.03	0.1	0.5	1
Ikeja (mm/hr)	141.19	139.12	137.86	136.16	133.46	129.92	127.15	112.99	72.56	56.1
Marina (mm/hr)	155.81	153.53	152.14	150.26	147.28	143.37	140.31	124.69	79.96	61.91
Oshodi (mm/hr)	147.55	145.39	144.07	142.29	139.47	135.77	132.87	118.08	75.72	58.62

Thereafter, the rain rate at different time percentage were plotted and analysed using MATLAB programming codes.

Results and Discussion

From Figures 1 (a) and (b), it can be observed that there is a significant difference in the rain rate exceedances at 12 and 23GHz for different percentages of time for the selected locations (Ikeja, Marina and Oshodi).

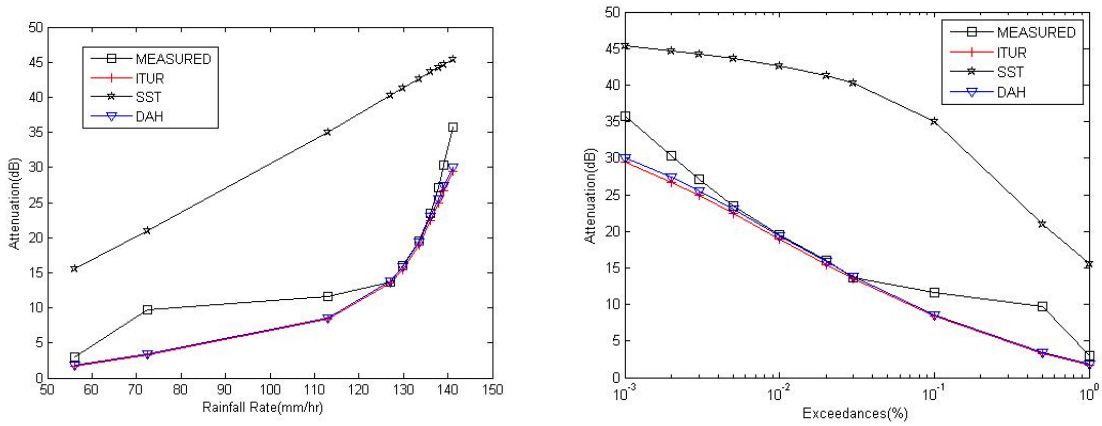


(a) (b)

Fig. 1 Comparison of measured attenuation values against rainfall rate for the three different locations at (a) 12 GHz (b) 23 GHz

Marina, being coastal location, has the highest rain rate of 147mm/hr and attenuation of 20dB and 39dB for 12GHz and 23GHz respectively at 0.01% when compared to Ikeja and Oshodi.

Figures 2 (a) and (b) shows the plots of attenuation exceeded for ITU-R, SST and DAH prediction models at 12GHz with varying rain rates and percentages of time exceeded, respectively.

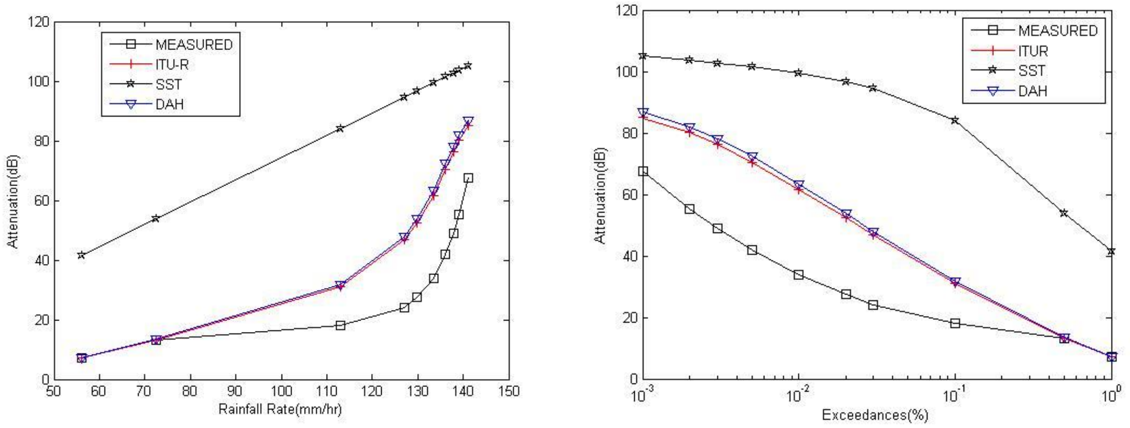


(a) (b)

Fig. 2 Comparison of attenuation values against (a) rainfall rate (b) percentage time for Ikeja at 12GHz.

It shows that the ITU-R and DAH model almost intercepted between 128mm/hr to about 135mm/hr rainfall rate and then continue to underestimate the measured attenuation values from 0.01% to 0.001% of time exceedances respectively, whereas SST model overestimated the measured attenuation. it can be seen that DAH model results in least error percentage of 16%, 1.0%, and 41% while it is 17.8%, 30%, 27% and 26%, 118%, 202% at 0.001%, 0.01%, and 0.1% of time exceeded, respectively for ITU and SST respectively (see Table 2 in the Appendix).

Shown in Figure 3 are the plots of attenuation values for the three prediction models at 23GHz with varying rain rates and percentages of time exceeded, respectively.

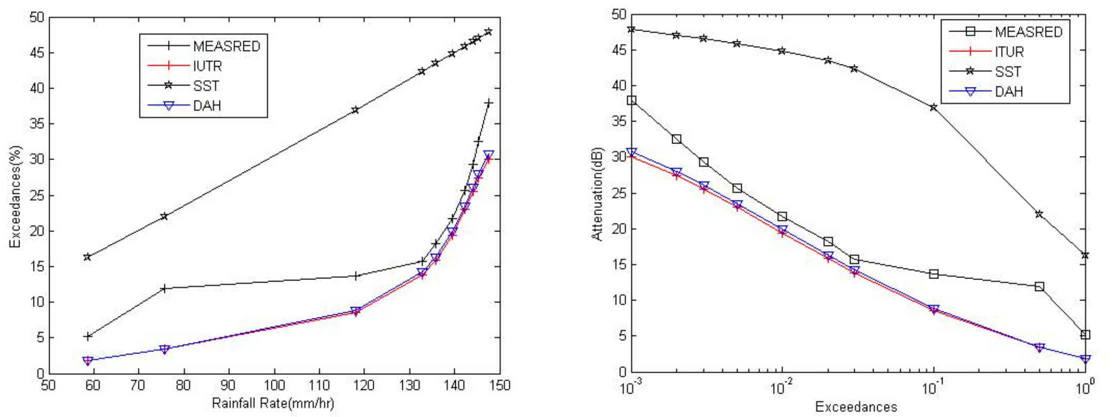


(a) (b)

Fig. 3 Comparison of attenuation values against (a) rainfall rate (b) percentage time for Ikeja at 23 GHz.

The ITU-R and DAH attenuation prediction models intercepted the measurement data between 0.1% and 1% exceedances and between 80mm/hr to about 90mm/hr rainfall rate. From Table 3 in the Appendix, it can also be seen that ITU-R P.530-17 results in least error percentage of 25%, 81.8%, and 70.3% while it is 28.6%, 86.7%, 75.4% and 55.5%, 192.8%, 363.8%; for DAH and SST model respectively, at 0.001%, 0.01%, and 0.1% of time exceeded, respectively.

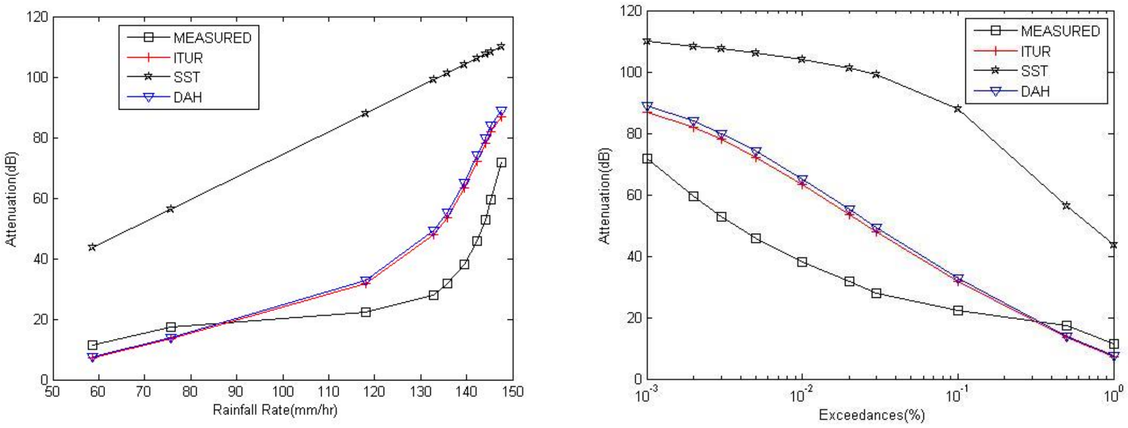
Figures 4 (a) and (b) are the plots of the attenuation values for the three selected prediction models for Oshodi at 12GHz. It shows that the DAH model gave the closest approximation to measured attenuation compared to the SST and ITU-R (see Table 4 in Appendix). It can be observed that DAH resulted in the error percentages of 19%, 8.0%, and 35.6%, while it is 20.7%, 10.4%, 37.3% and 26.1%, 106.8%, 168.6% for ITU-R and SST model respectively, at 0.001%, 0.01%, and 0.1% of time exceeded, respectively.



(a) (b)

Fig. 4 Comparison of attenuation values against (a) rainfall rate (b) percentage time for Oshodi at 12GHz

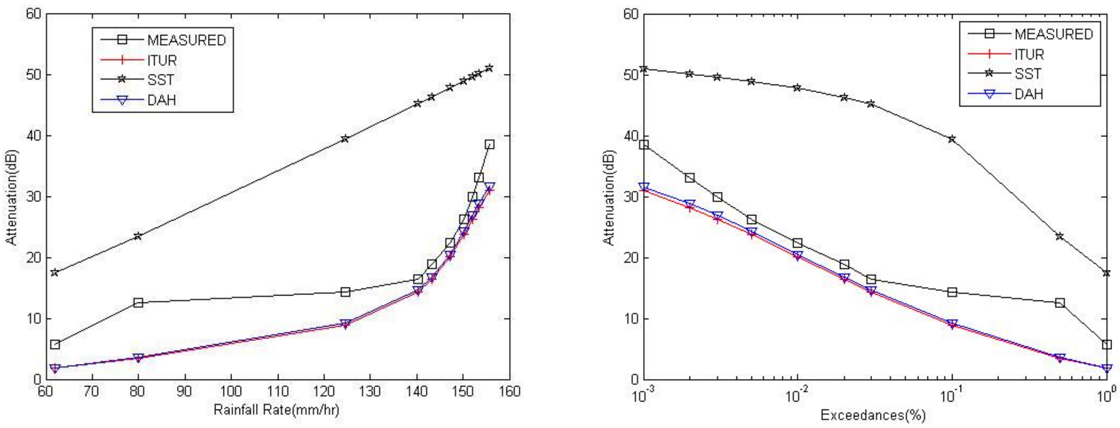
The plots of the attenuation exceedances for Oshodi at 23GHz are displayed in Figures 5 (a) and (b). ITU-R and DAH prediction models intercepted the measurement between 0.1% and 1% % of time exceeded (Figure 5 (b) and between 100mm/hr to about 110mm/hr rainfall rate (Figure 5 (a)).



(a) (b)

Fig. 5 Comparison of attenuation values against (a) rainfall rate (b) percentage time for Oshodi at 23GHz

The ITU-R gives the closest value to the measured attenuation compared to the DAH and the SST model with percentage errors of 20.9%, 66.2%, and 42.7% while it is 23.8%, 70.7%, 47% and 53.2%, 173.1%, 295.3% for DAH and SST model respectively, at 0.001%, 0.01%, and 0.1% of occurrence, respectively (as shown in Table 5 in the Appendix).

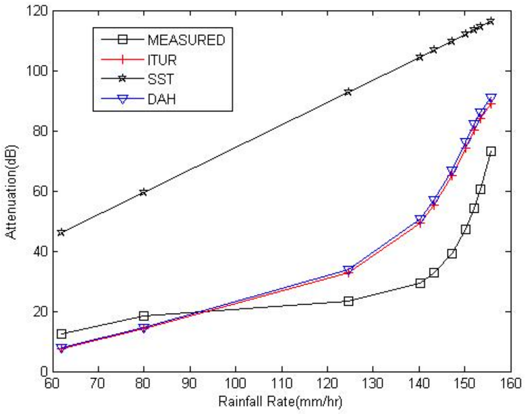


(a) (b)

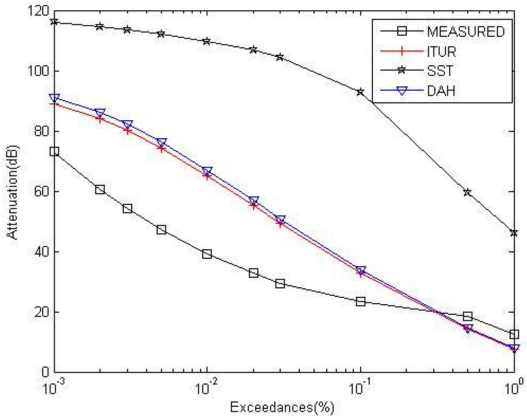
Fig. 6 Comparison of attenuation values against (a) rainfall rate (b) percentage time Marina at 12GHz

Figures 6 and 7 shows the plots of the attenuation exceedances for ITU-R, SST and DAH prediction models for Marina at 12 and 23GHz respectively. At 12GHz, DAH model gave the closest approximation to measurement value between 140mm/hr to 155mm/hr rainfall rate and from 0.1% to 0.01%, after which it continues to underestimate it (Figures 6 (a) and (b), respectively). Again, from Table 6 (see Appendix), it was clear that DAH presented the least percentage errors of 18.1%, 8.0% and 36.2% against 19.8%, 10%, 37.9% and 32.1%, 114.1%, 173.7%; for ITU-R and SST models, respectively, and at 0.001%, 0.01%, and 0.1% of times exceeded, respectively.

At 23GHz, the ITU-R model closely matched the measurement between 0.1% and 1% exceedances and at about 94mm/hr rainfall rate (Figures 7 (a) and (b), respectively). The ITU-R P.530-17 gives the closest value to the measured attenuation compared to the DAH and the SST model.



(a)



(b)

Fig. 7 Comparison of attenuation values against (a) rainfall rate (b) percentage time Marina at 23GHz

Finally, from Table 7 (see Appendix), ITU-R exhibited the least error percentage of 22%, 66% and 44%, while DAH and SST models presented 25%, 70.5%, 44% and 59%, 179.5%, 296.1%, respectively, at 0.001%, 0.01%, and 0.1% of times exceeded, respectively.

Conclusion

This paper presented the performance assessment of three popular rain attenuation prediction models for three different locations in Lagos, Nigeria, at 12 and 23GHz. It was observed that at different frequencies, different models gave the closest prediction model to the measured attenuation. The DAH model gave the closest prediction value to the measured rain attenuation for 12GHz between 0.001% to 0.1% of time exceedances and with percentage errors of 1.0%, 8.0% and 8.0% within Ikeja, Oshodi and Marina respectively at 0.01% of time exceeded.

However, at 23GHz, the ITU-R prediction model out-performed DAH and SST models, with percentage errors of 81.8%, 66.2%, 66% for for Ikeja, Oshodi and Marina respectively at 0.01% percentage of time.

Furthermore, Marina, the coastal location was found to experience higher rain attenuation compared to the non-coastal areas (Oshodi and Ikeja). This can be seen in the performances exhibited by the selected predicted models (ITU-R, DAH and SST) at both 12 and 23GHz, which shows a decrease in the attenuation values from Marina to Oshodi, and Oshodi to Ikeja.
Again, according to Recommendation ITU-R. P.311-15 (ITU-R, 2015), the prediction method that produces the smallest values of the statistical parameters is selected and thus recommended as the best prediction model. Hence, the ITU-R prediction model is the best of the three models under investigation.

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