Modelling of an Improved ITU-R 837-6 Rain Rate Prediction for Tropical and Equatorial Regions

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Abstract
The performance of radio communication system depends majorly on propagation medium which is badly affected by rain.This paper presents an enhanced rain rate model based on ITU-R 837-6 rain rate prediction. The improved model is derived from well behaved cumulative distribution function of over 100 rainfall rate samples from tropical and equatorial regions. The performance evaluation results show an improvement of -24.93% and 16.67% in term of bias and root mean square of the relative estimation error respectively. The model will be suited for prediction of accurate rain rate in tropical and equatorial regions.

Keywords
Rainfall database;Rain rate; TRMM; Satellite

I. Introduction
The most difficult task faced by link design engineers is on how to prevent signal outage in any communication link operating above 10 GHz. Most rain attenuation prediction models require 1-minute rainfall rate cumulative distribution function as one of the main parameters in the estimation of propagation impairment along the communication link [1-5]. However, rainfall rate measurements for short integration time are not typically available around the world most especially in the tropical and equatorial regions, where accurate rainfall measurements still remain a difficult task and most importantly in the remote areas [6-9]. The use of satellite radar for precipitation measurement are now employed. The advantage of large amount of radar data availability in a short period of time was utilized for adequate sampling of the spatial and temporal representation of the location.Therefore, a prediction model is required to predict the local cumulative distribution of 1-minute rainfall rate. The ITU-R P 837-6 rain rate prediction model is the globally accredited model for the prediction of 1-minute rainfall cumulative function [10]. However, the model is developed based on scattered rainfall data around the world. The temperate rainfall database is adequately represented while tropical and equatorial regions are sparingly presented. For instance, Malaysia was represented with only one location in Kuala Lumpur while Nigeria is not represented at all. Therefore, rainfall measurements for over 100 stations are employed in the derivation of this enhanced model, couple with satellite radar rainfall derived from TRMM products [11-14].

II. Enhanced ITU-R 837-6 Rain Rate Model
The modelling of the enhanced rain rate prediction was based on ten year rainfall data collected from Meteorological Departments of both Malaysia and Nigeria, and TRMM website for over 100 stations. The rainfall database was made up of 66 stations around Malaysia and 38 stations from Nigeria. The rainfall database of the two countries was combined because the two regions are located in the same latitudinal belts within the same tropical region. The rainfall distributions patterns around the region are closely related. From the reference rainfall database, anample number of 72 locations were selected for modelling purposes while the remaining 32 stations are devoted for testing. The conditions for selection were largely based on well behaved shape of the curve with respect to the analytical model so as to obtain reasonable parameters from the fittings and geographical distribution of stations.

In this enhanced model, the analytical function proposed in ITU-R 837-6was maintained. The expression is described as

$$P(R) = P_0 . e^{-aR\frac{1+bR}{1+cR}} \quad (1)$$

where

$$P_0 = P_{r6h} \cdot \left(1 - e^{-x\frac{M_S}{P_{r6h}}}\right) \quad (2)$$

$$b = \frac{M_c + M_s}{y.P_0} = \frac{M_T}{y.P_0} \quad (3)$$

$$c = z.b \quad (4)$$

The coefficients of P_0, a, b and c were derived from the linear regression fittings of cumulative distribution function of the rainfall rate of each location. The probabilities of rainy 6-h periods P_{r6h} were derived from 3-hourly TRMM 3B42 V7 with resolution 0.25 by 0.25. The parameters to be enhanced are as given in the equations (5) to (8). The unknown coefficients are derived from in-situ data and linear regression fitting parameters (a_{fit}, b_{fit}, c_{fit}, $p_{0\ fit}$)

$$x = \frac{P_{r6h}}{M_s} . ln\left(1 - \frac{p_{0\ fit}}{P_{r6h}}\right) \quad (5)$$

$$y = \frac{M_T}{b_{fit} \cdot p_{0\ fit}} \quad (6)$$

$$z = \frac{c_{fit}}{b_{fit}} \quad (7)$$

$$a = a_{fit} \quad (8)$$

The weighted averages of all the derived parameters are obtained by taking an arithmetic average for the coefficient 'a' and a geometric average for coefficients 'x', 'y', and 'z'. The geometric average shows that the parameters are not independent of each other. The new coefficients obtained are shown in Table 1.

Table 1: ITU-R 837-6 and the New Optimized Coefficients

	ITU-R837-6	Proposed Coefficients for Tropical Region
a	1.09	0.395
x	0.0079	0.01033
y	21797	50192
z	26.02	14.429

III. The Prediction Results of the Proposed Model

The result of rain rate cumulative distribution function of the proposed model is compared with measured data and ITU-R model. Results of the proposed model are closer to measured rain rate than ITU-R predictions. Fig. 1 shows results for eight selected stations. The improved model gives a percentage error of 10% for time percentage from 1% to 0.001 for the selected stations in Malaysia. Higher percentage error is recorded in some of the stations representing Nigeria. This is evidenced in the cumulative distribution function of rainfall rate shown for Uyo and Abakaliki stations. The proposed model produced a slightly higher rain rate values as compared with the measured one. The percentage error recorded is slightly above 12%. In all the stations considered for testing, ITU-R 837-6 underestimates rain rate prediction in the area except for stations at Uyo and Abakaliki where rain rate is overestimated at higher time percentage from 1% to 0.1%.

The reason for the closeness of the proposed model to measured rain rate from Malaysia may be attributed to the larger number of station database employed for model derivation compared to Nigeria and difference in rainfall distribution pattern observed due to topographic differences in the upper northern stations of Nigeria. Some of the results that are close to the proposed prediction are the ones that have similar distribution pattern with Malaysia within the same ITU-R zone P (Rainfall classification). The Northern parts of Nigeria are classified under zone N semi-arid region while Southern part are under zone P tropical wet region[15-16]. Therefore, the proposed model is most suitable for tropical wet and equatorial regions.

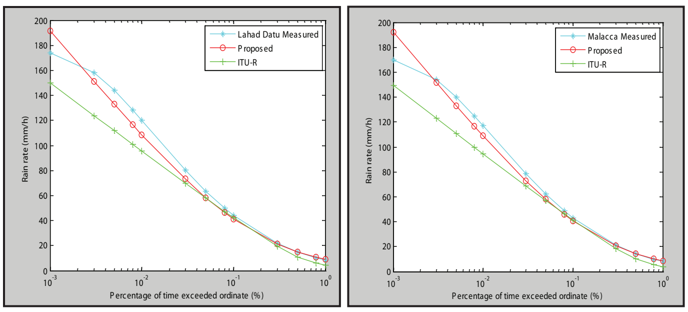
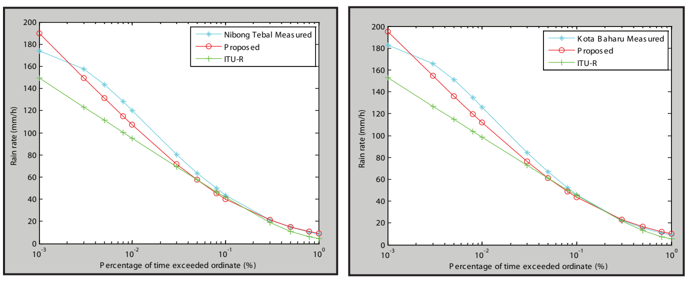


Fig. 1: Comparison of Proposed Model With Measured and ITU-R Model for Some Selected Stations (Cont.)



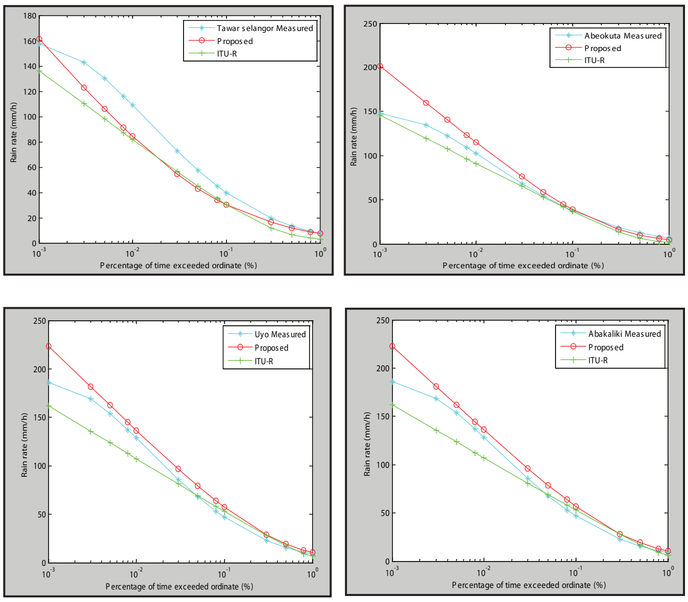


Fig. 2: Comparison of Proposed Model with Measured and ITU-R Model for Some Selected Stations

IV. Performance Evaluation of the New Optimized Parameters over ITU-R 837-6

The performance evaluation of the new constant coefficients derived from tropical region database over ITU-R 837-6 is evaluated based on 3 tests (Testing with all database, modelling database and testing database). The evaluation of the new model performance is tested using the following evaluation expressions

$$\varepsilon = \frac{R_{est}(p) - R_{meas}(p)}{R_{meas}(p)} \times 100\ \% \quad (9)$$

$$E = \frac{\sum_{i=1}^{N}\sum_{j=1}^{n} \alpha_i \times \varepsilon}{\sum_{i=1}^{N} n_i \times \alpha_i} \quad (10)$$

$$RMS = \frac{\sum_{i=1}^{N}\sum_{j=1}^{n} \alpha_i \times \varepsilon^2}{\sum_{i=1}^{N} n_i \times \alpha_i} \quad (11)$$

$$\sigma = \sqrt{RMS^2 - E^2} \quad (12)$$

As a result of differences in the number of years of observation of the data employed, a weighting factor as recommended by ITU-R is applied in order to account for the statistical stability of the experimental distribution. The weighting function is described as

$$\alpha_i = \frac{\sqrt{N}}{\sigma} \quad (13)$$

with being the standard deviation of the year-to-year variability of rainfall and N is the number of years of measurements.The evaluation of the new model performance is tested using the following evaluation expressions:

$$\varepsilon = \frac{R_{est}(p) - R_{meas}(p)}{R_{meas}(p)} .100\ \% \quad (14)$$

$$E = \frac{\sum_{i=1}^{N}\sum_{j=1}^{n} \alpha_i \times \varepsilon}{\sum_{i=1}^{N} n_i \times \alpha_i} \quad (15)$$

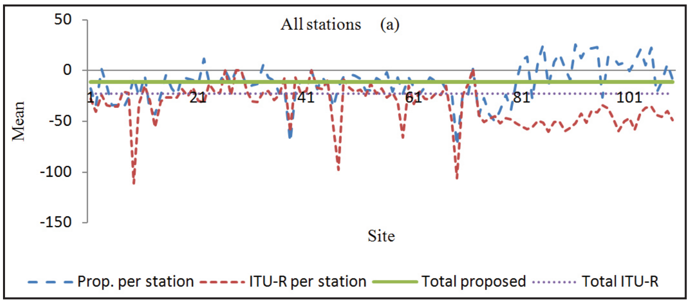
$$RMS = \frac{\sum_{i=1}^{N}\sum_{j=1}^{n}\alpha_i \times \varepsilon^2}{\sum_{i=1}^{N} n_i \times \alpha_i} \quad (16)$$

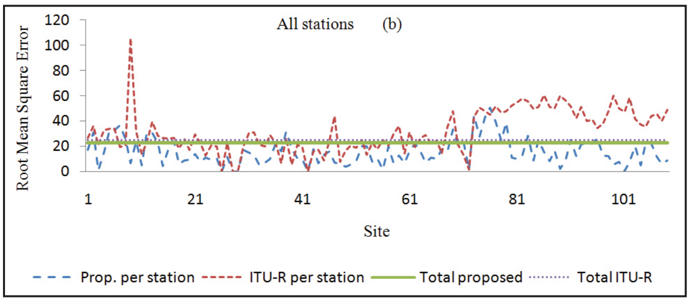
$$\sigma = \sqrt{RMS^2 - E^2} \quad (17)$$

The results of the performance evaluation of the proposed model for the three categories of testing are as shown in Table 2. The weighted average error, root mean squares (RMS) and standard deviation (STD) are depicted in Figure 2a-c, 3a-c and 4a-c for all databases, testing database and modelling database respectively. The obtained results revealed that there is an improvement of 22.84 % (for the whole database), 27.75% (for testing database) and 24.3 % (for modelling database) on the RMS of the estimated error over ITU-R 837-6 rain rate prediction model. Based on these results, the new enhanced ITU-R model is expected to perform better in tropical regions.

Table 2: Performance Evaluation Results

Test result for all the sites in the database			
	Mean Error (%)	RMS (%)	STD (%)
ITU-R 837-6	-36.359	39.508	15.458
Proposed Model for tropical	-11.425	22.842	19.779
Test result for the testing sites in the database			
ITU-R 837-6	-37.071	38.561	10.618
Proposed Model for tropical	-22.303	27.751	16.513
Test result for the modelling sites in the database			
ITU-R 837-6	-37.013	40.013	15.201
Proposed Model for tropical	-12.553	24.309	20.817





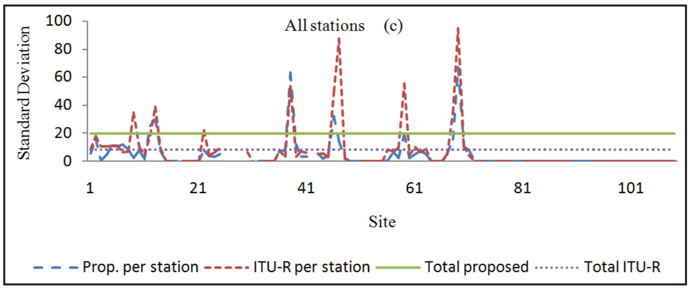


Fig. 2: Performance Evaluation Results for all sites (a) Mean (b) RMS (c) STD

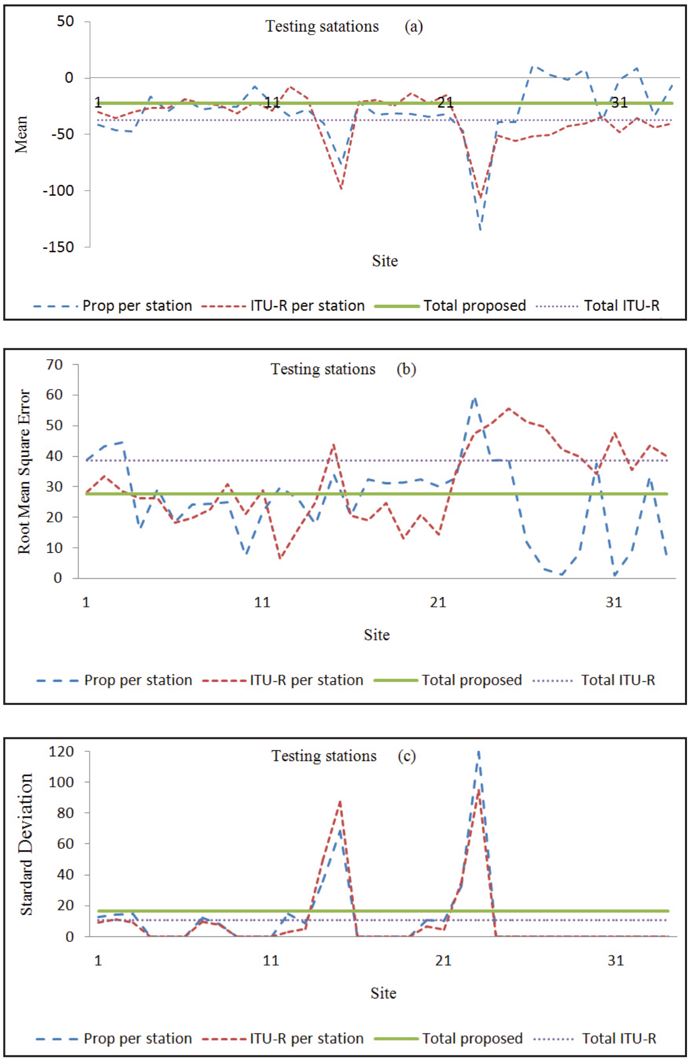
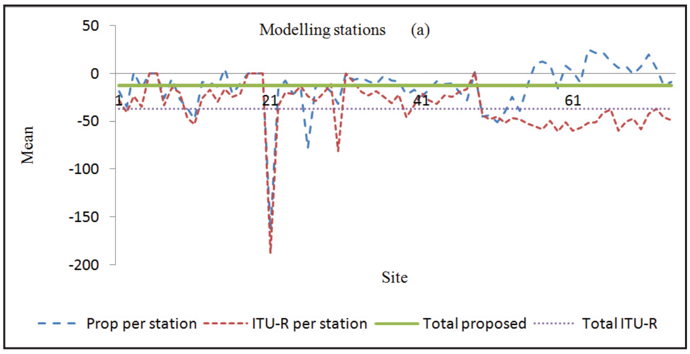


Fig. 3: Performance Evaluation Results for Testing Sites (a) Mean (b) RMS (c) STD



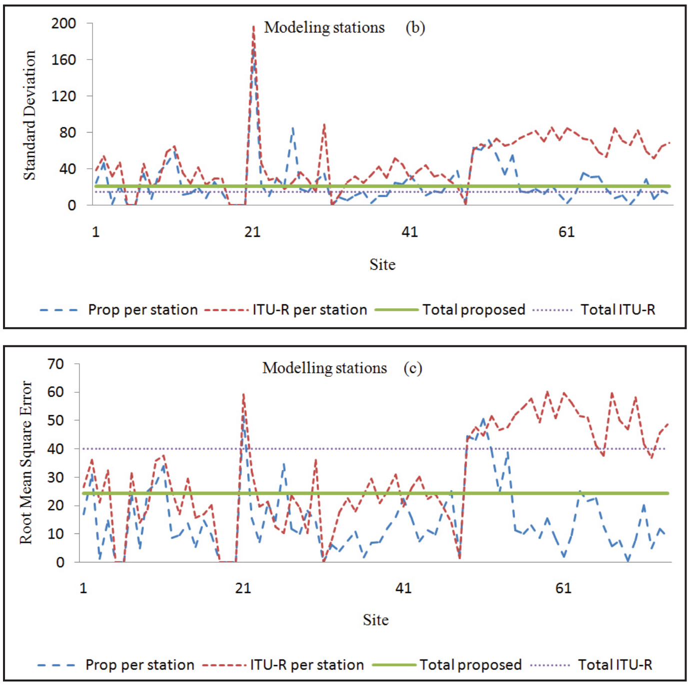


Fig. 4: Performance Evaluation Results for Modelling Sites (a) Mean (b) RMS (c) STD

V. Conclusion

In this paper, an enhanced rain rate prediction model is presented. The new improved model followed the analytical function proposed in ITU-R 837-6. Well sampled rain rate cumulative distribution functions of over 100 stations from tropical regions were used. The results produced a new set of coefficients that are well fitted to rainfall distribution pattern in tropical regions. The results of the performance evaluation of the new improved rain rate prediction model over ITU-R 837-6 rain rate model, revealed that there was an improvement of 22.84 % (for the whole database), 27.75% (for testing database) and 24.3 % (for modelling database) on the RMS of the estimated error.

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