Assessment of Conversion Methods to Acquire 1-Minute Integration Time Rain Intensity Statistic

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Abstract This paper presents some preliminary findings of assessments carried out pertaining to the applicability of rain intensity conversion methods. Five conversion methods were identified in this study namely the ITU-R, Segal, Burgeuno, Chebil-Rahman and Khairolanuar et al. 1 year of rain intensity data were acquired from the Malaysian Meteorological Department (MMD) and utilized in the investigation. The research methodology involves productions of annual rain intensity cumulative distributions at 1-minute integration time using mentioned conversion methods. Predicted values established by ITU-R are used as benchmark. The values are then compared with values acquired using other conversion methods; in order to validate the applicability and effectiveness of each method. Based on the evaluation, it can be observed that the Khairolanuar *et al.* method seems to be a befitting conversion method and capable of generating values with smallest percentage difference.

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1 Introduction

In the design of Earth-to-space communication links, rain attenuation information has to be identified. This is due to the fact that rain can severely attenuate links with operating frequencies above 10 GHz. Raindrops absorb and scatter energy from the incident radio wave, resulting in rain attenuation which can degrade the reliability and performance of the communications link. In order to devise the services efficiently, it is important to accurately estimate the to-be-encountered impairments of the given link. Researchers have put extensive efforts in measuring and modeling the rain attenuation along the desired propagation path. Predictions are engaged in order to assess whether an acceptable service can be delivered at the involved receiver's area. Among established prediction models are the ones recommended by the radio communications sector of the International Telecommunication Union (ITU-R) [1], the Dissanayake, Allnut and Haidara (DAH) rain induced attenuation model [2] and the Crane models [3, 4]. One of the advantages of the prediction models is the ability to exploit the information to be used in other area. Most of the established prediction methods employ rain intensity information at 0.01 % time exceedance of the annual statistics ($R_{0.01}$) at 1-minute integration time. Several tools such as impact disdrometer and rain gauges are the common tools used in collecting the data. However, this information is not readily available as most of the data are collected in longer integration time especially data obtained from meteorological department. Several methods [5–10] have been proposed by researchers to convert statistics acquired at longer integration time into statistics at 1-minute integration of time. Unfortunately, the validity of these conversion methods are questioned by researchers particularly in the heavy rainfall regime of tropical countries as most methods depend almost entirely on measurements in temperate climate countries [7]. Malaysia is located in a tropical region where the rainfall intensity is significantly higher compared to the other parts of the world. High rainfall intensity has caused severe degradation in the reliability and performance Earth-to-space communication link in Malaysia. It is important to accurately predict the fading outage due to rain in Malaysia as it will help system designer to realistically determine link availability, establish the link margin and provide means to combat rain effects. This paper outlines the production of annual cumulative distributions of rainfall intensity using Segal, Burgueno, Chebil-Rahman, Khairolanuar et al. and ITU-R conversion methods. The results are then correlated with each other to find the likelihood. The synopsis of the employed conversion methods to convert statistics acquired at longer integration time into statistics at 1-minute integration of time is outlined in the next section.

2 Excerpts of Rainfall Intensity Conversion Methods

In 1986, Segal proposed an empirical conversion method using rainfall intensity data from 47 stations in Canada. Approximately 10 years of data were used in developing the technique. The 1-minute integration time of rainfall intensity statistics, $R_1(P)$ can be obtained by using the following relationship:

$$R_1(P) = aP^b R_\tau(P). \tag{1}$$

where a and b are empirical constant, $R_\tau(P)$ is the input rainfall intensity data for τ integration of time and P is time exceedance value for the exact rainfall intensity input value.

In 1988, another empirical conversion method was proposed by Burgueno using rainfall intensity data for period of 49 years. The 1-minute integration time of rainfall intensity statistics, $R_1(P)$ can be obtained by using the suggested expression (2):

$$R_1(P) = aR_\tau(P)^b. \tag{2}$$

where a and b are empirical constant and $R_\tau(P)$ is the input rainfall intensity data for τ integration of time.

In 1999, Chebil-Rahman proposed another conversion method based on the 1 min and hourly rainfall data. The 1 min data were collected at 3 sites for almost 3 years and hourly data were obtained from Malaysian Meteorological Services (MMS), former name of MMD, involving 35 sites at various locations around Malaysia. The 1-minute integration time of rainfall intensity statistics, $R_1(P)$ can be obtained by using the proposed relationship (3):

$$R_1(P) = (aP^b + c\exp(dp))R_\tau(P). \tag{3}$$

where a, b, c and d are empirical constant, $R_\tau(P)$ is the input rainfall intensity data for τ integration of time and P is time exceedance value for the exact rainfall intensity input value.

In 2012, the ITU-R has proposed a new recommendation that claims capable of enabling users to generate statistics known as P(R) of the local rainfall intensity, R (mm/h) at 1-minute integration time. The recommendation allow users to choose inputs either from global digital maps of rainfall parameters derived from numerical weather prediction data or local measurements statistic of rainfall intensity at integration times up to 60 min. The statistics compiled using locally measured rainfall intensity combined with an integrated conversion model are of great interest as it is anticipated that they can offer the best approximation as outlined in [8]. Figure 1 shows the full workflow of the proposed conversion method.

In 2014, Khairolanuar et al. proposed another empirical conversion utilizing polynomial relationship exploiting rainfall intensity data acquired in Malaysia.

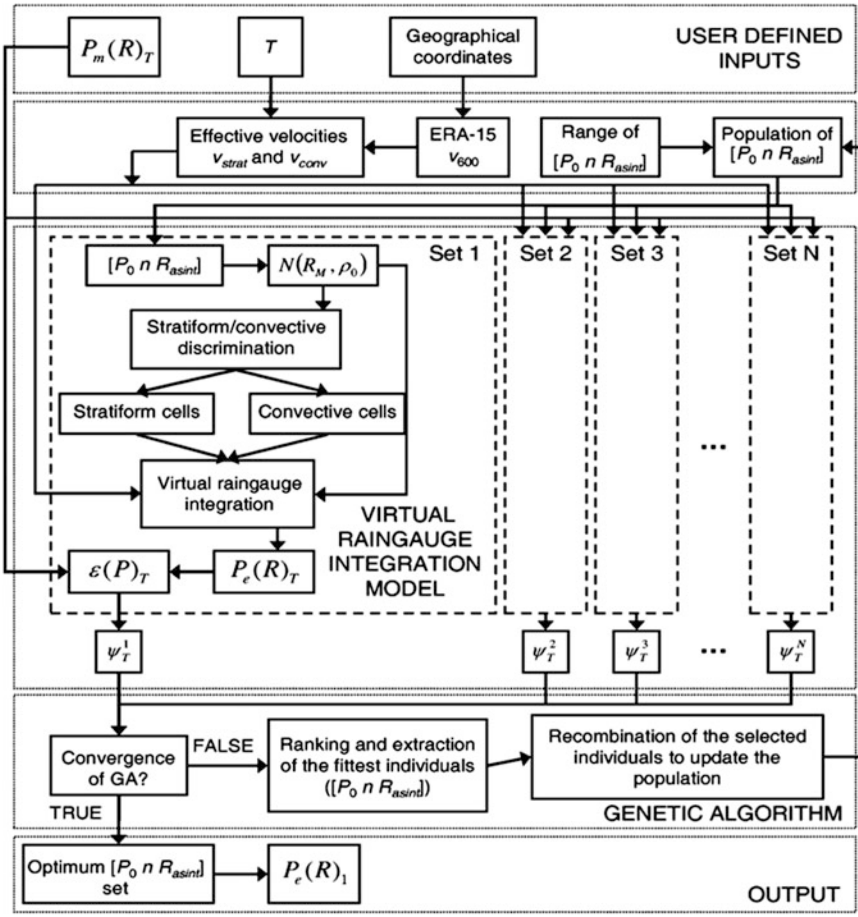

Fig. 1 ITU-R conversion method workflow [8]

The duration of collected data is for almost 2 years period. The data were acquired using optical rain gauge. The 1-minute integration time of rainfall intensity statistics, $R_1(P)$ can be obtained by using the presented formulation (4):

$$R_1(P) = aR_\tau(P)^4 + bR_\tau(P)^3 + cR_\tau(P)^2 + dR_\tau(P) + e. \tag{4}$$

where a, b, c, d and e are empirical constant, $R_\tau(P)$ is the input rainfall intensity data for τ integration of time.

Table 1 lists the empirical constant values for Segal's, Burgueno's and Khairolanuar et al. methods.

Table 1 Empirical constant values for 60 min

Empirical constant	Segal	Burgueno	Chebil- Rahman	Khairolanuar et al.
a	1.759	0.92	0.772	0
b	−0.054	1.24	−0.041	1.2659E-3
c	–	–	1.141	−0.084193
d	–	–	−2.570	2.1584
e	–	–	–	2.0883

3 Data Collection and Measurement

Figure 2 shows the tipping bucket used. The measurement system is located at 2° 44′ N latitude and 101° 42′ E, within the vicinity of Kuala Lumpur International Airport (KLIA) Sepang. The acquired data are for a period of 1 year from 1st January 2009 until 31st December 2009. The rain intensity data were collected every 60 min using standard tipping bucket type rain gauge. Table 2 lists the specification of the rain gauge.

Annual cumulative distribution was generated from the collected rain intensity data. Figure 3 shows the plotted statistic. From the collected data, the highest rainfall intensity recorded is at 71.83 mm/h.

Fig. 2 MMD standard tipping bucket

Table 2 Tipping bucket specifications

	Specifications
(Lat, Lon)	(2° 44’ N, 101° 42’ E)
Receiving collector	203 ± 0.2 mm
Accuracy	±1 % to 200 mm/h
Bucket capacity	0.2 mm
Dimension	Height: 300 mm
	Body diameter: 230 mm
	Base diameter: 280 mm
Net weight	5.5 kg

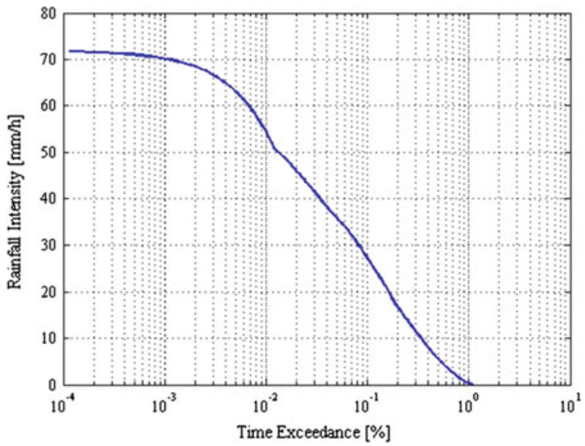

Fig. 3 Annual statistic of rain intensity at 60-minute integration time

4 Results and Analyses

The plotted 60 min rain intensity statistic was converted to 1 min rain intensity statistic using 5 conversion methods, namely Segal's, Burgueno's, ITU-R's, Chebil-Rahman and Khairolanuar et al's methods. Figure 4 shows the converted 1 min rain intensity statistic using the mentioned conversion methods including the propose value from ITU-R Rain Maps [12]. From the result, it can be observed that the highest rain intensity value at 0.01 % time exceedance is generated by Burgueno's conversion method with 130.6 mm/h follow by Segal's method with 122.7 mm/h, Chebil-Rahman's method with 111.2 mm/h, ITU-R Rain Map's with 91.75 mm/h, ITU-R physical's method with 90.77 mm/h and last but not least Khairolanuar *et al*'s method with 74.14 mm/h. Table 3 shows summary of rainfall intensity values at 0.01 % time exceedance for all converted statistics.

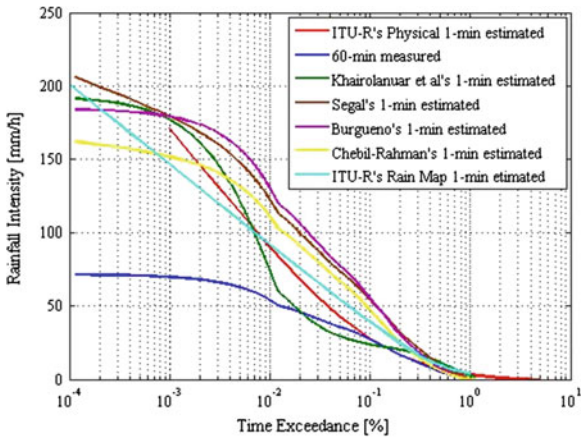

Fig. 4 Converted 1 min statistics

Table 3 Rain intensity values at 0.01 % time exceedance ($R_{0.01}$)

ITU-R physical (mm/h)	ITU-R rain map (mm/h)	Segal (mm/h)	Burgueno (mm/h)	Khairolanuar et al. (mm/h)	Chebil-Rahman (mm/h)
90.77	91.75	122.7	130.6	74.14	111.2

The plotted models were then compared with the ITU-R rain intensity conversion method. The ITU-R rain intensity conversion method was chosen as subject of reference due to its applicability to the local climate [11]. The assessments of each method applicability were further investigated by determination of the root mean square error (RMSE) and percentage error of rain intensity value at 0.01 % time exceedance. The relevant RMSE in this study can be defined as follow:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(ECD_i - ITUD_i)^2}. \quad (5)$$

where n is the number of data, ECD is the empirical conversion data and ITUD is the ITU data. Table 4 lists the RMSE and percentage difference for each conversion method as compared to ITU-R conversion method with value 90.77 mm/h. From the table, it can be noticed that ITU-R's rain maps method has the lowest percentage difference value with 1.080 % follow by Khairolanuar et al's method, 18.321 %, Chebil-Rahman's method, 22.507 %, Segal's, 35.177 % and lastly, Burgueno's method at 43.880 %.

Table 5 lists the RMSE and precentage error for each conversion method as compare with ITU-R rain map with value of 91.75 mm/h. From the table, it can be noticed that ITU-R's rain maps method has the lowest percentage difference value

Table 4 Root mean square error and percentage error at 0.01 % time exceedance as compare with ITU-R conversion method

	Segal	Burgueno	Khairolanuar et al.	Chebil-Rahman	ITU-R rain maps
RMSE (%)	23.972	28.425	12.283	16.015	10.958
Percentage difference (%)	35.177	43.880	18.321	22.507	1.080

Table 5 Root mean square error and percentage error at 0.01 % time exceedance as compared to ITU-R rain map

	Segal	Burgueno	Khairolanuar et al.	Chebil-Rahman	ITU-R physical
RMSE (%)	24.625	28.091	18.388	15.220	10.958
Percentage difference (%)	33.733	42.343	19.193	21.199	1.068

with 1.068 % follow by Khairolanuar et al. method, 19.193 %, Chebil-Rahman's method, 21.199 %, Segal's, 33.733 % and lastly, Burgueno's method at 42.343 %.

5 Conclusion

In this paper it can be concluded that based on comparison between the values of available conversion methods with the ITU-R conversion method and ITU-R rain map at 0.01 % time exceedance, the value of Khairolanuar et al's has the lowest percentage difference value of below 20 % follow by Chebil-Rahman's, Segal's and Burgueno's methods. Khairolanuar et al's and Chebil-Rahman's methods have reasonably low RMSE value of below 19 % as compared to the rest of conversion methods. It appears that low differences have been identified between converted values by ITU-R conversion method and ITU-R rain map proposed values. Evaluations are currently carried out using data collected at other locations and findings will be shared in future publication.

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References

1. Recommendation ITU-R P.618–11: Propagation data and prediction methods required for the design of earth-space telecommunication systems (2013)
2. Dissanayake, A., Allnut, J., Haidara, F.: A prediction model that combines rain attenuation and other propagation impairments along earth-satellite paths. IEEE Trans. Antennas Propag. **45**, 1546–1558 (1997)
3. Crane, R.K.: Prediction of attenuation by rain. IEEE Trans. Commun. **28**, 1717–1733 (1980)
4. Crane, R.K., Shieh, H.-C.: A two-component rain model for the prediction of site diversity performance. Radio Sci. **24**, 641–655 (1989)
5. Segal, B.: The influence of rain gauge integration time on measured rainfall-intensity distribution functions. J Atmos. Oceanic Technol. **3**, 662–671 (1986)
6. Burgueno, A., Puigcerver, M., Vilar, E.: Influence of rain gauge integration time on rain rate statistics used in microwave communications. Ann. Telecommun. **43**, 522–527 (1988)
7. Ismail, A.F., Hashim, W., Abdullah, K., Malek, N.A.: Empirical conversion of rainfall rate distribution for various integration times in Malaysia. In: 2011 IEEE International on RF and Microwave Conference (RFM), 270–273 (2011)
8. Capsoni, C., Luini, L.: A physically based method for the conversion of rainfall statistics from long to short integration time. IEEE Trans. Antennas Propag. **57**, 3692–3696 (2009)
9. Chebil, J., Rahman, T.A.: Rain rate statistical conversion for the prediction of rain attenuation in Malaysia. Electron. Lett. **35**, 1019–1021 (1999)

10. Khairolanuar, M.H., Ismail, A.F., Jusoh, A.Z., Sobli, N.H.M., Malek, N.F.A., Zabidi, S.A.: New empirical conversion technique for 1-minute integration time of precipitation intensity in Malaysia. Aust. J. Basic Appl. Sci. **8**, 290–295 (2014)
11. Khairolanuar, M.H., Ismail, A.F., Jusoh, A.Z., Khan, S., Alam, Z.: Assessment of ITU-R conversion method for 1-minute integration time of precipitation intensity in Malaysia. Wireless Technology and Applications (ISWTA), 2014 IEEE Symposium on. 141–145 (2014)
12. Recommendation ITU-R P.837–6: Characteristics of precipitation for propagation modelling (2012)