Assessment of Statistical and Empirical Conversion Methods of Integration Time for Rainfall Rate in Malaysia

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Abstract This paper presents some preliminary observations of assessments regarding the precipitation intensity conversion methods from 60- to 1-min integration time. There are two conversion methods were identified and used for this findings; Rice-Holmberg and Khairolanuar et al. conversion methods. Different type of precipitation were analyzed and implemented in analytical method of Rice-Holmberg and characteristics of rainfall rate distributions were evaluated from the empirical method of Khairolanuar et al. Rainfall intensity data were acquired from Malaysia Meteorological Department (MMD). The rainfall rate data consist of twelve consecutive months from January to December 2009. The evaluations for the acquired data were carried out to produce annual rainfall rate cumulative distribution and as well as its cumulative distribution at 1-min integration time utilizing the aforementioned conversion methods. The comparisons of the performance of these two methods were also examined. Based on the evaluation, it can be observed that Rice-Holmberg and Khairolanuar et al. produced percentage errors around 19 % as compared to ITU-R P.837 at 0.01 % of time exceedance.

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1 Introduction

Distribution of precipitation intensity is inhomogeneous in space and time. Rainfall rate or rainfall intensity is defined as "a measure of the intensity of rainfall expressed by the increase in the height of water reaching the ground per unit time" [1]. It is universally conveyed in millimeter per hour and denoted as mm/hr. There are several equipments being used to obtain rainfall intensity measurements and depend on their locations. Some studies had been steered to compare the evaluation of rainfall rates logged using different type of precipitation measuring devices. Previous studies had indicated that different types of these equipments that are co-located at the location of interest would produce different rainfall rates [2].

It is well known that radio wave propagation of satellite links encounters severe attenuation at 10 GHz and above in rainy condition. It becomes a major concern for communication system engineers especially for locations in tropical region. Rain attenuation occurs due to the absorption and scattering of energy by raindrops that degrade the reliability and performance of the communication link. Prediction of rain attenuation for estimation of unavailable time percentage of the communication link above 10 GHz requires precise information and characteristics about rain rate distribution at the location of interest. The accurate knowledge of rainfall rate statistics is used as input for attenuation prediction method that evaluates the statistical behavior of the attenuation caused by rain.

Therefore, the International Telecommunication Union (ITU) recommends a standard that uses rain rate cumulative distribution functions CDFs with 1-min integration time for derivation of attenuation CDFs. The 1-min integration time was selected as a compromise between experimental accuracy and the amount of available rainfall data. Furthermore, it has been confirmed in literature that 1-min integration time interval promises a good level of precision in regenerating the time inconsistency of attenuation [3, 4]. However, 1-min integration time is not the standard time interval that is utilized in meteorological applications because of no significance of rapid changes of precipitation intensity. They most preferable in average quantities i.e. hourly, daily, monthly, or yearly accumulated rain. Thus, most of the data acquired from meteorological departments have longer integration time.

The non-availability of such integration time of rainfall rate data had motivated researchers to develop procedures that focusing on achieving CDFs of rainfall rate with 1-min time resolution from CDFs of rainfall rate of longer integration time or from the information of general local meteorological conditions. There are various prediction methods proposed by researchers and can be classified into three different sets, namely meteorology, analytical, and empirical based methods.

Meteorology based methods utilizes general climatic information as input (i.e. average monthly or yearly rainfall rate, number of rainy days per year, peak annual rain rate, etc.) such as proposed by Dutton et al. [5], ITU-R [6], Rice and Holmberg [7], and Crane [8] methods. On the other hand, analytical methods assumed that by changing the integration time resolution would not affect the analytical form of

CDFs of rainfall intensity. Different integration time has different CDFs due to the different parameters of CDFs equation. These methods give the prediction behavior of the parameters of the distribution change according to the integration time as proposed by Moupfouma and Martin [9], Karasawa and Matsudo [10]. Finally, empirical methods that are most widely proposed by researchers around the world. These methods provide conversion factors between the known CDF and the one to be estimated as a function of probability level. This type of method were utilized in the proposed methods by Segal and Allnutt [11], Chebil and Rahman [12], Burgueno et al. [13], Joo et al. [14], Watson et al. [15], Ismail et al. [16] etc. Comparison analyses using empirical conversion methods of integration time can be found in [17].

2 Conversion Methods from 60- to 1-Minute Integration Time

In 1973, Rice and Holmberg developed a global surface rain rate model from extensive long-term rain rate statistics from over 150 locations throughout the world [7]. Rice-Holmberg model is also known as R-H model provides a statistical rainfall rate distribution by assuming that the rain structure can be categorized into two types, or modes. These modes or types are "thunderstorm rain" and "all other rain". Each mode is determined by exponential functions and the sum of these two modes yields the total rainfall rate distribution. The percentage of an average year for which the rain rate exceeds R mm/hr at a medium location is as follows [7]:

$$P(R) = M\left\{0.03\beta e^{-0.03R} + 0.2(1-\beta)\left[e^{-0.258R} + 1.86e^{-1.63R}\right]\right\}. \tag{1}$$

where M is the average annual rainfall accumulation (mm), M_1 is annual accumulation of thunderstorm rain (mm), $\beta = M_1/M$ thunderstorm ratio, and R is clock minute rate (mm/hr).

The model provides global maps for β, M_1, and M. However, directly measured data can be used when available. Besides, R-H model has shown to produce very good agreement with directly measured long-term rain rate data for locations in the United States.

In 1994, a recommendation ITU-R P.837 had been proposed as a reference on evaluation of the characteristics of precipitation for propagation modeling. It suggests a global map with different climatic zones to represent general characteristics of the rainfall rate at the location of interest. Further development and improvement had been performed in order to produce a reliable conversion method for ITU-R. In 2009, a new-revised method proposed by Capsoni and Luini that exploits EXCELL Rainfall Statistics Conversion (EXCELL RSC) model [18]. It has the capability of facilitating users to generate statistics known as $P(R)$ of the local rainfall intensity, R (mm/hr) at 1-min integration time [18]. Their proposed method provides options for users to input either from local measurements statistic of rainfall intensity at integration times up to 60 min or from the global digital maps of rainfall parameters derived from numerical weather prediction data. The statistics of compilation data using locally measured rainfall intensity and integrated conversion model are predicted to provide the best approximation.

New empirical conversion method proposed by Khairolanuar et al. [19]. This empirical conversion method utilizes polynomial relationship using rainfall intensity data acquired in Malaysia [19]. Optical rain gauge was used for data collection for the duration of almost two years period. The estimation of 1-minute integration time of rainfall intensity statistics is summarized as follows [19]:

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

where $R_\tau(P)$ is the input of rainfall intensity data for τ integration time and a, b, c, d, and e are the empirical constants [19].

3 System Set-up for Data Collection and Measurements

The ground truth measurement data were collected from the Malaysia Meteorological Department (MMD) rain gauge station located at station Kuala Lumpur International Airport (KLIA) with 2° 44′N and 101° 42′E, about 5 km from the airport and 16.3 m above mean sea level [20]. The location of this study was selected at KLIA so that further analyses concerning the weather surroundings airport can be carried out in the future works.

The rain gauge used by MMD to collect the measured rainfall values consists of standard tipping bucket. The tipping bucket rain gauge follows the standard by World Meteorological Organization (WMO). This tipping bucket collects rainfall rate data every 60 min. The integration time for the collected data for the collected data is 60 min [20].

The tipping bucket comprises of two components; funnel-shaped at the top supported by a cylindrical-shaped at the bottom. This funnel has a water filter at the end of the funnel opening. The water drops of rainfall land in the funnel of the tipping bucket rain gauge. Water flowing into the funnel will be screened and will be collected by two metal water collectors (tipping buckets). The raindrops is poured into the cylinder when one of the collectors receives the raindrops of amount 0.2 mm and the next rain will then fall to the other metal collectors. This process is repeated and this repetition process is connected to a computing system (counter) that will count the number of times the rain that falls into the water collector metal. The amount of rainfall rate is calculated based on multiplication of the number of times the precipitation that falls on the metal rain collector with 0.2 mm of rain droplets. Maximum rainfall amount that can be obtained is 200 mm/h. Table 1 summarized the specifications of the tipping bucket rain gauge operated by MMD and Fig. 1 shows the tipping bucket that is located at KLIA [20].

Table 1 Specifications of tipping bucket rain gauge

	Specifications
Location (Latitude, Longitude)	KLIA, Sepang (2° 44′N and 101° 42′E)
Distance from KLIA	±5 km
Receiving collector	203 mm ± 0.2 mm
Accuracy	±1 % to 200 mm/h
Bucket capacity	0.2 mm
Dimensions	300 mm height, 230 mm body diameter, 280 mm base diameter
Physical	5.5 kg net weight

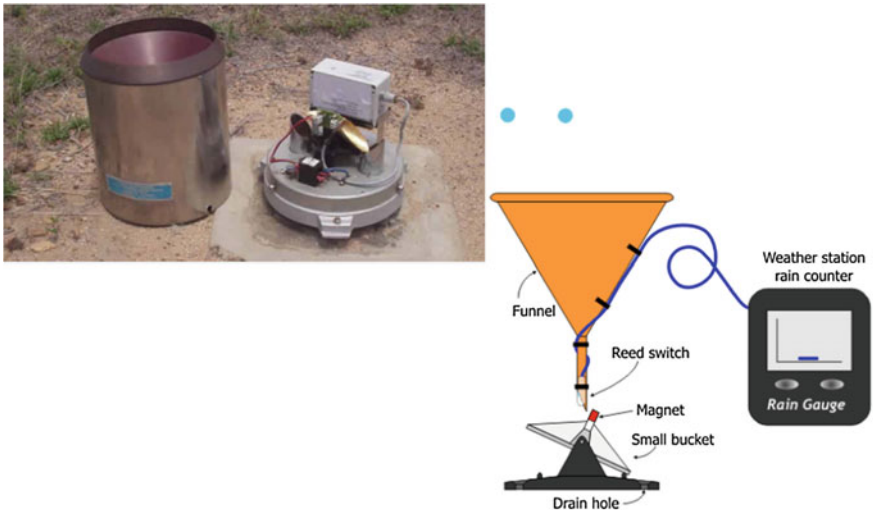

Fig. 1 MMD tipping bucket at KLIA

Figure 2 shows the overall system setup for the study that includes Terminal Doppler Weather Radar that is located at Bukit Tampoi. However, this paper presents only the study of the measured ground truth rainfall rate at the rain gauge station KLIA not inclusive radar data. In addition, radar data consists the information of rainfall rate that will be used for further analysis together with the rain gauge measurement data to find the correction of radar reflectivity to rainfall rate relationships.

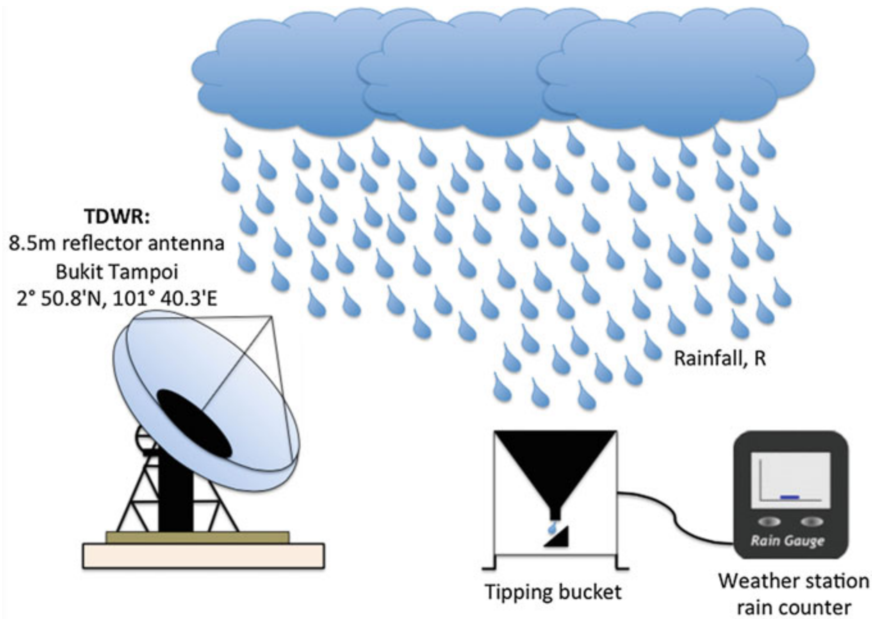

Fig. 2 Overall system set-up for data collection and measurements

4 Results and Discussions

The sampling time for the rainfall data acquired at KLIA is 60-min. The data were measured in real-time quantities for rainfall rate and precipitation accumulation. The measurements of this data were taken from January to December 2009 for period of one year. The highest precipitation intensity value recorded within one-year duration is 71.83 mm/h that occurred in March 2009.

The acquired rainfall data were analyzed in order to obtain its annual cumulative distribution function (CDF). The annual CDF of rainfall rate at KLIA is obtained from the accumulation of monthly CDFs. Figure 3 shows the annual CDF of rainfall data at KLIA for 2009. The figure illustrates that KLIA had experienced rainfall intensity of approximately 54.4 mm/h at 0.01 % time exceedance that is equivalent to 9 h of the year.

The acquired data were then further analyzed by characterizing the rainfall intensity types into stratiform and convective. These two different types of rainfall rate are important in order to implement the Rice-Holmberg's conversion method. The R-H method utilizes the use of two types of rain modes, M_1(mm) and M_2(mm) that represents the thunderstorm rain and all other rain respectively. Total of these two modes gives the average annual rainfall accumulation, M(mm). The ratio of thunderstorm rain to the average annual rainfall accumulation gives the thunderstorm ratio, β. From the collected data, it was found that the average annual rainfall

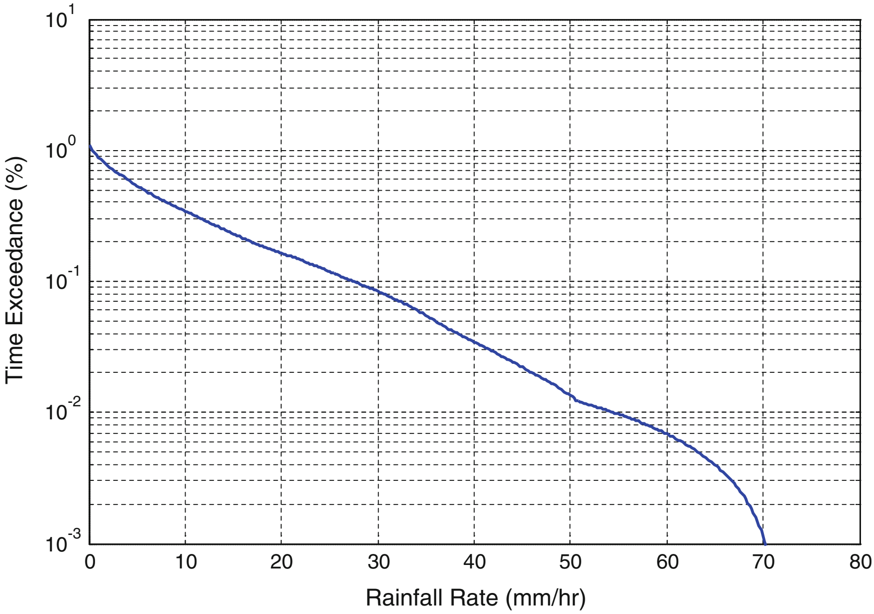

Fig. 3 Annual CDF of rainfall rate at KLIA

M is 2115.6 mm, thunderstorm rain M_1 is 261.4 mm, and thunderstorm ratio β is 0.123583. Then Eq. 1 was used to convert from 60-min integration time to 1-min equivalent integration time of the collected data. Khairolanuar et al. method as described in [19] was used to obtain the equivalent 1-min integration time by using Eq. 2.

Figure 4 depicts the comparison of R-H and Khairolanuar et al. for the collected rainfall data at KLIA. From the figure, it can be deduced that rain intensity value at 0.01 % time exceedance generated by R-H conversion method is 73.0 mm/h and Khairolanuar et al. conversion method is 74.14 mm/h. Table 2 shows summary of rainfall intensity values at 0.01 % time exceedance for the aforementioned converted statistics. The values of rainfall precipitation were chosen at 0.01 % time of exceedance, $R_{0.01}$ because of its reliability for rainfall attenuation prediction as had been used widely in the literature.

Further investigation of the assessments of each method applicability were carried out by determining the root mean square error (RMSE) and the percentage error of rainfall intensity value at 0.01 % of time exceedance. The relevant RMSE for these preliminary findings is defined as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(ECD_i - ITUD_i\right)^2}. \quad (3)$$

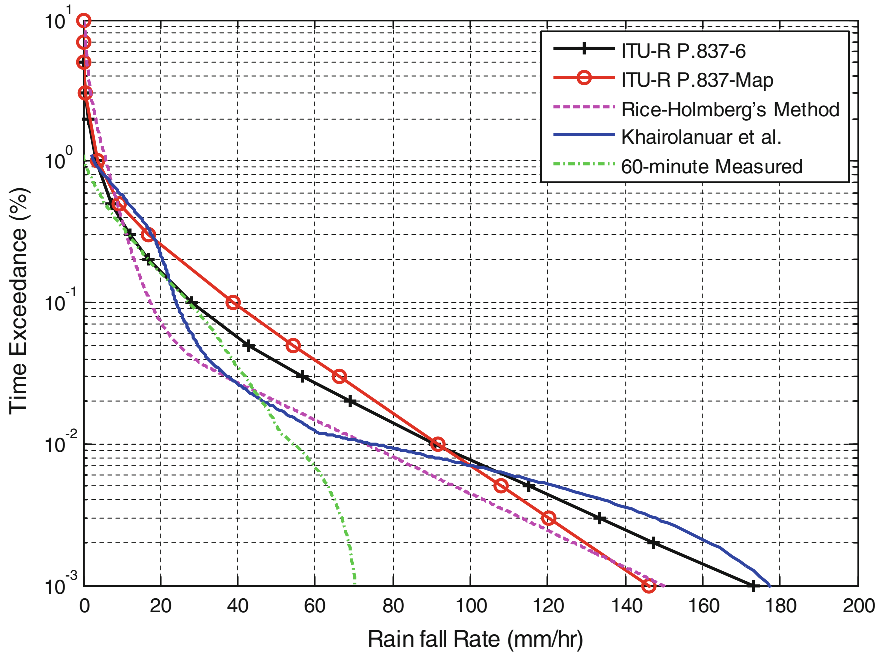

Fig. 4 Comparison of Rice-Holmberg, ITU-R, and Khairolanuar et al. conversion for rainfall rate at KLIA

Table 2 Rainfall intensity values at 0.01 % time exceedance ($R_{0.01}$)

	Rice-Holmberg	ITU-R P.837-Map	ITU-R P.837-6	Khairolanuar et al.
$R_{0.01}$ (mm/h)	73.0	91.75	90.77	74.14

where *n* is the number of data, ECD is the empirical conversion data and ITUD is the ITU-R data.

Table 3 summarizes the RMSE and percentage difference values at 0.01 % of time exceedance for Rice-Holmberg, ITU-R P.837-6, and Khairolanuar et al. conversion methods of rainfall intensity as compared to ITU-R P.837-Map rainfall intensity of 91.75 mm/h. The table shows that ITU-R P.837-6 physical has the lowest RMSE and percentage difference with 10.958 and 1.068 % respectively. According to the table, it also exhibits that Rice-Holmberg and Khairolanuar et al. yield RMSE of 19.451 and 18.388 % respectively and their percentage difference of 20.341 and 19.193 % respectively.

Table 4 demonstrates the RMSE and percentage difference of the above conversion methods as compared with ITU-R P.837 physical rainfall rate of 90.77 mm/h at 0.01 % of time exceedance. From the table, it can be deduced that

Table 3 Root mean square error and percentage error at 0.01 % time exceedance as compared with ITU-R P.837 rain map

	Rice-Holmberg	ITU-R P.837-6	Khairolanuar et al.
RMSE (%)	19.451	10.958	18.388
Percentage difference (%)	20.341	1.068	19.193

Table 4 Root mean square error and percentage error at 0.01 % time exceedance as compared with ITU-R P.837-6 conversion method

	Rice-Holmberg	ITU-R P.837 Map	Khairolanuar et al.
RMSE (%)	13.657	10.958	12.283
Percentage difference (%)	19.243	1.080	18.321

ITU-R P.837 rain map gives the lowest RMSE and percentage difference values with 10.958 and 1.080 % respectively. The table also reveals that RMSE and percentage difference produced by Rice-Holmberg and Khairolanuar et al.'s had slight difference with values of 13.657, 19.243, and 12.283 %, 18.321 % respectively.

5 Conclusion and Future Works

The scope of this paper is to study the comparison of conversion methods from 60 to 1-min integration time of rainfall rate. The comparison was carried out by selecting ITU-R P.837 proposed equivalent 1-min values at 0.01 % of time exceedance as a benchmark because of its applicability to the local climates. It can be concluded that RMSE and percentage difference values for Rice-Holmberg and Khairolanuar et al. result in around 19 % as compared to ITU-R P.837 at 0.01 % time exceedance are. The comparison of different conversion methods is useful in the analysis of rain attenuation prediction methods due to the fact of the significance of having 1-min integration time in such study. The results presented in this paper are obtained from calculations of rainfall data collected at one location for the duration of one year. More analyses need to be carried out using rainfall intensity data from different locations in Malaysia. Therefore, current evaluations are carried out using rainfall data at different locations with different year and the findings will be disclosed in future works and analyses.

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