Comparison of Conversion Methods from 60- to 1-min Integration Time for Rainfall in Malaysia

Nuurul Hudaa Mohd Sobli, Ahmad Fadzil Ismail, Ani Liza Asnawi, Mimi Aminah Wan Nordin and Muhamad Haziq Khairolanuar

Abstract This paper presents some preliminary assessments of the precipitation rate conversion methods from 60-min to 1-min integration time. The conversion methods used in this study are Moupfouma and Khairolanuar et al., and ITU-R P.837. Rainfall rate data of twelve-months duration from January to December 2009 were acquired from Malaysia Meteorological Department (MMD) and exploited for the evaluation. The rainfall data were collected from MMD rain gauge station located at Kuala Lumpur International Airport (KLIA). The investigations comprise of producing annual rainfall rate cumulative distributions of the measured data. The equivalent 1-min annual rainfall rate cumulative distributions using conversion methods as mentioned above. Predicted values of annual 1-min cumulative distribution established by ITU-R P.837 are used as references. The equivalent 1-min equivalent cumulative distribution obtained from Moupfouma's and Khairolanuar et al.'s methods are then compared with that of ITU-R P.837 to validate the applicability and efficiency of each method. According to the results, it can be observed that Khairolanuar et al.'s method capable of generating equivalent 1-min rainfall values with smallest percentage difference as compared to ITU-R P.837 at 0.01 % of time exceedance.

N.H.M. Sobli (✉) · A.F. Ismail · A.L. Asnawi · M.A.W. Nordin · M.H. Khairolanuar
Department of Electrical and Computer Engineering, Kulliyyah of Engineering, International Islamic University Malaysia (IIUM), Jln. Gombak, 53000 Selangor, Malaysia
e-mail: hudaa@iium.edu.my

A.F. Ismail
e-mail: af_ismail@iium.edu.my

A.L. Asnawi
e-mail: aniliza@iium.edu.my

M.A.W. Nordin
e-mail: mimie@iium.edu.my

M.H. Khairolanuar
e-mail: haziq.khairolanuar@yahoo.com

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1 Introduction

Rainfall or precipitation is very complex and the phenomenon that occurs naturally. Many of its characteristics influence in various ways of different extents such as hydrology, meteorology, water cycle of the earth, remote sensing, radio communication and propagation, etc. Rainfall is generally measured by instrument that is called rain gauge. It provides the total height of water fallen during a given period of time, such as daily, hourly, or minutely [1]. Hence, 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’ [2]. The information of rainfall rate is considered important for climatologic or general meteorological purposes. However, the time resolution offered by the rain gauge is still insufficient enough when it comes to correlate rain with other fast changing phenomena, such as radar-measured rainfall rate or rain-induced attenuation for microwave telecommunication links.

The effect of attenuation due to rainfall is severe in the countries located in tropical and equatorial regions for microwave system operating at frequency 10 GHz and above because of the average annual cumulative rainfall intensity in tropical and equatorial region is high. Rain attenuation occurs due to the absorption and scattering of energy by raindrops that degrade the reliability and performance of the communication link. Therefore, precise information and characteristics of rainfall rate distribution at the location of interest is vital for prediction of rain attenuation and estimation of unavailable percentage of time at frequency 10 GHz and above in communication link. Accurate knowledge of rainfall rate statistics is used as input for attenuation prediction method that evaluates the attenuation’s statistical behavior that caused by rain.

International Telecommunication Union (ITU) recommends the use of rain rate cumulative distribution functions CDFs of 1-min integration time for derivation of attenuation CDFs in order to overcome the problem of different integration time interval [3]. 1-min integration time was selected as a compromise between experimental accuracy and the amount of available rainfall data. However, the standard time interval of 1-min integration time has not been utilized because of the significance of rapid change of precipitation intensity is not a major concern in meteorological applications. The most preferable rainfall rate is in average quantities such as hourly, daily, monthly, or yearly accumulated rain. This is the reason that most of the data acquired from meteorological departments have longer integration time. In addition, literatures also confirmed that lower integration time interval assures a good level of accuracy in regenerating the time variability of attenuation [4, 5].

For such purpose, researchers had came up with different proposed procedures that focusing on obtaining rainfall rate CDFs with 1-min integration time resolution from CDFs with longer integration time that was acquired from the general knowledge of local meteorological surroundings. Various conversion methods had been proposed in literature. These conversion methods can be generally classified into three categories. Firstly, meteorology based methods that utilize 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. [6], Rice and Holmberg [7], Crane [8], and ITU-R [9]. Secondly, analytical methods assumed that the analytical form of rainfall intensity CDFs would not be affected by changing the integration time. Different integration time has different CDFs because the parameters of CDFs equation are different. These methods give the prediction behavior of the distribution change's parameters according to the integration time as proposed by Moupfouma [10] and Karasawa [11]. Finally, empirical methods that are most widely proposed by researchers around the world. The empirical methods specify conversion factors to estimate new CDFs from the known CDFs as a function of probability level. This type of method were utilized in the methods proposed by [12–15]. Some of the empirical conversion methods had been studied and compared with ITU-R values using local measurement data in Malaysia [16].

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

In 1993, Moupfouma had derived a simple empirical model that offers a good description of the global cumulative rainfall intensity distribution above 2 mm/hr, for both high rainfall rates and low rainfall rates [10]. The method was derived using data from USA, Canada, Europe, and India. It is useful for radio system designers. The cumulative distribution of rainfall rate can be expressed as follows [10]:

$$P(R \geq r) = \left(\frac{R_{0.01}+1}{r+1}\right)^{b} \exp\left(u(R_{0.01}-r) - \log\left(10^{4}\right)\right). \tag{1}$$

where r(mm/hr) represents the rainfall rate exceeded for a fraction P of the time. Parameter b is approximated by the following analytical expression [10]:

$$b = \left(\frac{r - R_{0.01}}{R_{0.01}}\right) \log\left(1 + \frac{r}{R_{0.01}}\right). \tag{2}$$

The parameter u in Eq. 1 governs the slope of rainfall rate cumulative distributions and depends on the local climatic condition and geographical features. For tropical localities, it is expressed as follows [10]:

$$u = \frac{\log(10^{4})}{R_{0.01}} \exp\left[-\lambda\left(\frac{r}{R_{0.01}}\right)^{\gamma}\right]. \tag{3}$$

where λ and γ are positive constants. Based on the measured 1-min rainfall rate cumulative distribution at several locations in Malaysia, Singapore, and Indonesia, it was found that the best values for the parameters λ and γ are as follows [10]:

$$\lambda = 0.707 \quad \text{and} \quad \gamma = 0.06 \quad M < 3000. \tag{4}$$

where M(mm) is the mean annual rainfall.

In 1994, a recommendation ITU-R P.837 had been proposed by ITU-R as a reference on evaluation of the characteristics of precipitation for propagation modeling. This recommendation suggests a global map with different climatic zones to represent general characteristics of the rainfall rate at the location of interest. The latest version of this recommendation is ITU-R P.837-6.

In 2009, Capsoni and Luini proposed a new-revised method that exploits EXCELL Rainfall Statistics Conversion (EXCELL RSC) model [17]. The method enables users to generate statistics known as $P(R)$ of the local rainfall intensity, R (mm/hr) at 1-min integration time [17]. It also provides options that allow users to input either 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 integration time. The statistics of compilation data using locally measured rainfall intensity and integrated conversion model are predicted to provide the best approximation.

Khairolanuar et al. proposed a new empirical conversion method in 2014. The method was proposed by exploiting polynomial relationship for rainfall intensity data in Malaysia [18]. The data were acquired by using optical rain gauge for the duration of almost two years period. The estimation of 1-minute integration time of rainfall intensity statistics is summarized as follows [18]:

$$R_1(P) = aR_\tau(P)^4 + bR_\tau(P)^3 + cR_\tau(P)^2 + dR_\tau(P) + e. \tag{5}$$

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.

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 [19]. Airport was chosen as the location of interest for the analysis because further analysis regarding rainfall rate and radar estimated rainfall rate could be carried out in the future.

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 is 60 min [19].

Table 1 Specifications of MMD tipping bucket rain gauge at KLIA

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

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. As rain falls it lands 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/hr. 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 [19].

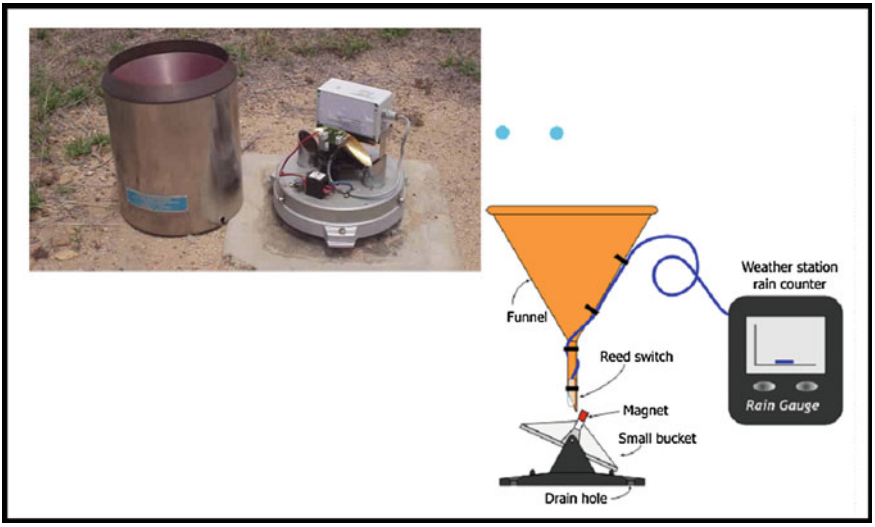

Fig. 1 Rain gauge tipping bucket at KLIA operated by MMD

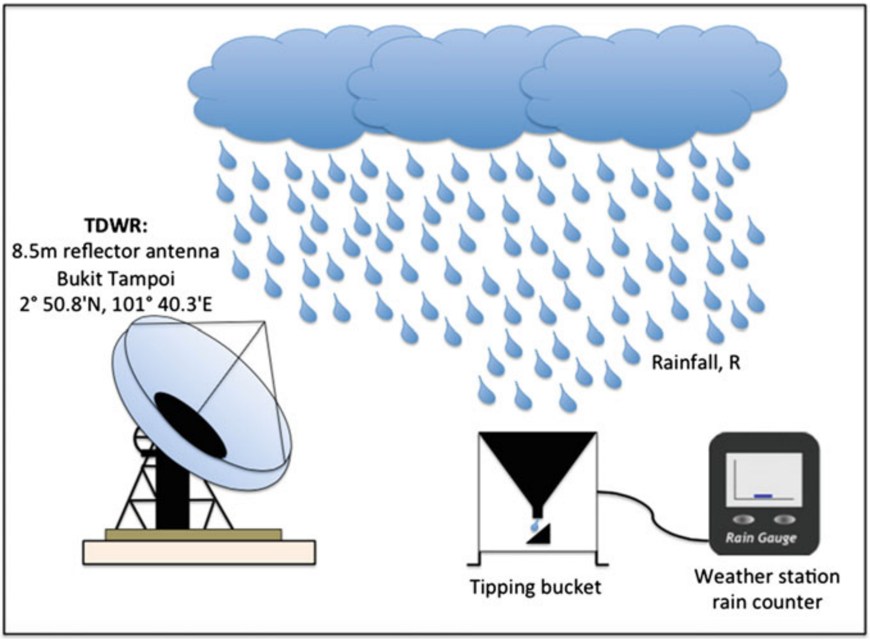

Fig. 2 Simplification of overall system set-up for the study

Figure 2 shows the simplification of overall system setup for the study including Terminal Doppler Weather Radar that is located at Bukit Tampoi. This paper presents only the study of the measured ground truth rainfall rate at the rain gauge station KLIA excluding radar data. However, the information of rainfall rate extracted from radar data will be used for further analysis together with the rain gauge measurement data to find the correction of radar reflectivity to rainfall rate relationships.

4 Results and Discussions

The rainfall intensity data were acquired from MMD rain gauge station located at KLIA. The acquired rainfall rate data were measured in real-time quantities for rainfall rate and precipitation accumulation. 60-min integration time is the standard resolution time employed by MMD for tipping bucket-acquired data at KLIA. The measurements of this data were taken for a period of one year that is from January to December 2009. The highest precipitation intensity value recorded within one-year duration is 71.83 mm/hr.

The acquired rainfall rate data were investigated to produce its annual cumulative distribution function (CDF). The annual CDF of rainfall rate at KLIA is

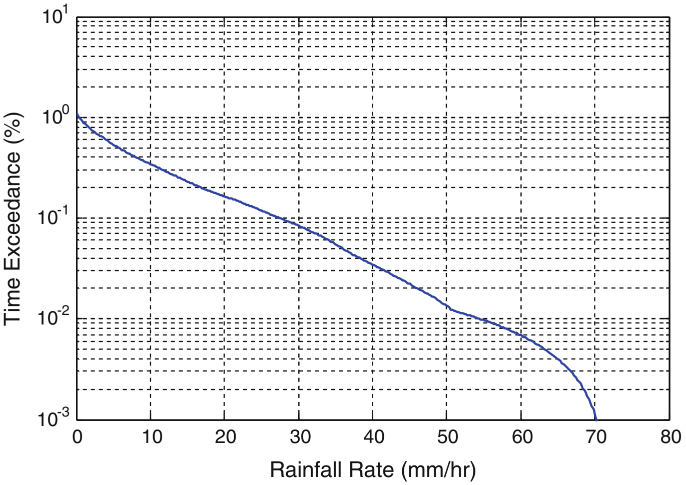

Fig. 3 Annual CDF of rainfall rate at KLIA in 2009

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/hr at 0.01 % time exceedance that is equivalent to 9 h of the year.

Further analyses were carried out by implementing the above conversion methods i.e. Moupfouma, ITU-R P.837, and Khairolanuar et al. The plotted 60-minute precipitation intensity statistics was converted to 1-minute precipitation intensity using eqn. [1] with substitution of the parameters by eqn. [2–4] for Moupfouma's and using eqn. [5] for Khairolanuar et al.'s methods respectively. The conversion method of ITU-R P.837-Map and ITU-R P.837-6 were used as the benchmark for comparison different conversion methods because of its appropriate to the local climate.

Figure 4 illustrates the comparison of the converted 1-minute rainfall intensity statistic using Moupfouma's, Khairolanuar et al. including the proposed values for ITU-R P.837-6, ITU-R P.837-Map for the collected rainfall data at KLIA. From the figure, it can be deduced that the highest rainfall rate value at 0.01 % time exceedance is generated by Moupfouma's conversion method with 119.6 mm/hr, and Khairolanuar et al.'s method produces 74.14 mm/hr. Meanwhile, ITU-R P.837 physical and ITU-R P.837 Rain Map yield 90.77 and 91.75 mm/hr respectively. Table 2 summarizes the rainfall rate values at 0.01 % time exceedance for all conversion methods statistics.

Moupfouma's and Khairolanuar et al.'s conversion methods were compared with the ITU-R P.837 rainfall intensity conversion method as this method has been chosen as subject of reference due to its applicability to the local climate. The values of rainfall rate were selected at 0.01 % of time exceedance, $R_{0.01}$ because of

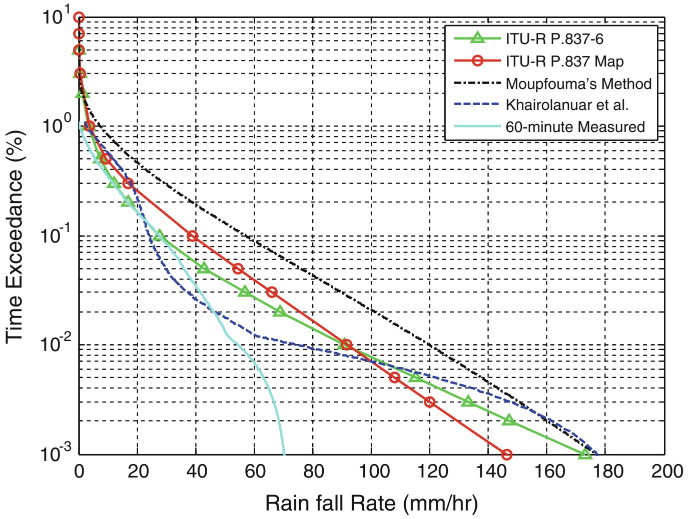

Fig. 4 Comparison of different conversion methods for rainfall rate at KLIA

Table 2 Precipitation rate values at 0.01% time exceedance ($R_{0.01}$) for rainfall rate in KLIA

	Moupfouma	ITU-R P.837 Map	ITU-R P.837-6	Khairolanuar et al.
$R_{0.01}$ (mm/hr)	119.6	91.75	90.77	74.14

its applicability and reliability for further rain attenuation prediction studies as described in literatures.

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

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(ECD_i - ITUD_i)^2}. \tag{6}$$

where n is the number of data, ECD is the empirical conversion data and ITUD is the respective ITU-R P.837 data under investigations.

Table 3 exhibits the comparison of RMSE and percentage difference values for each aforementioned conversion method rainfall intensity with ITU-R P.837 rain map rainfall intensity of 91.75 mm/hr at 0.01 % of time exceedance. The table shows that ITU-R P.837 physical has the lowest values of RMSE and percentage difference with 10.958 and 1.068 % respectively. However, Moupfouma's conversion method yields the highest RMSE and percentage errors with 68.765 and 75.594 % respectively. It is then followed by Khairolanuar et al.'s conversion method as compared to the ITU-R P.837 rain map with 18.388 and 19.193 % respectively.

Table 3 Comparison of RMSE and percentage error at 0.01% time exceedance with ITU-R P.837 rain map for rainfall rate in KLIA

	Moupfouma	ITU-R P.837-6	Khairolanuar et al.
RMSE (%)	68.765	10.958	18.388
Percentage difference (%)	75.594	1.068	19.193

Table 4 Comparison of RMSE and percentage error at 0.01% time exceedance with ITU-R P.837-6 conversion method for rainfall rate in KLIA

	Moupfouma	ITU-R P.837 Map	Khairolanuar et al.
RMSE (%)	45.863	10.958	12.283
Percentage difference (%)	67.664	1.080	18.321

Table 4 tabulates the RMSE and percentage difference of the discussed conversion methods as compared with ITU-R P.837 physical rainfall rate of 90.77 mm/hr at 0.01 % of time exceedance. From the table, it can be inferred that ITU-R P.837 rain map gives the lowest RMSE and percentage difference values with 10.958 and 1.080 % respectively. The table also demonstrates that the highest values of RMSE and percentage difference were produced by Moupfouma's conversion method, followed by Khairolanuar et al.'s conversion method with 45.863, 67.664 %, and 12.283, 18.321 % respectively.

5 Conclusion and Future Works

The scope of this paper is to study the comparison of different proposed conversion methods of 60- to 1-min integration time of precipitation intensity using measured rainfall rate at KLIA. 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 for that its applicability to the local climates. It can be concluded that Moupfouma's conversion method produced the highest RMSE and percentage difference values at 0.01 % time exceedance. The analysis in this paper can be useful for rain attenuation prediction methods study because of the significance of using 1-min integration time. The results obtained for this study were the analysis of rainfall data measured and collected at one location for the duration of one year. However, the evaluation of rainfall data at different locations will be discussed and disclosed in the future.

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