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Comparison of Different Empirical Conversion Methods from 60-minute to 1-minute Integration Time in Malaysia

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ABSTRACT

Background: This paper presents the comparison of the existing prediction models from 60-minute to 1-minute integration time of rainfall rate in Malaysia. The availability of rain gauge to measure point rainfall rate at lower than 10-minute integration time is very limited. Therefore, acquired rainfall rate statistics are derived from 10-minutes or longer. The conversion of longer integration time data to its equivalent 1-minute integration is important for accurate prediction of rainfall attenuation at a location. There are several previously proposed conversion methods from 60-minute to 1-minute and had been tested for measured rainfall rates in the tropical and high rainfall rate regions. **Objectives:** To analyze the behavior of the measured rainfall rate characteristics at KLIA. To compare previously proposed conversion methods including ITU-R P.837-6 using the measured rainfall rate data at KLIA. **Results:** The measured rainfall rate data for 12 months period at KLIA are used in this paper. The statistics of this data are generated including the month and annual cumulative distribution functions (CDF). Furthermore, CDFs of other previously proposed conversion methods from 60-minute to 1-minute integration time are compiled and compared. **Conclusion:** The comparison of different established conversion methods using measured rainfall rate data at KLIA shows that the Chebil-Rahman's method gives values close to ITU-R P.837-6 for Malaysia with lowest errors among other conversion methods.

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INTRODUCTION

It is common to know that severe attenuation due to rain for telecommunication system could occur at frequency 10GHz and above. Rain attenuation occurs when raindrops absorb and scatter energy from the incident radio wave and thus degrade the reliability and performance of the communication link. Researchers globally had gone through extensive studies to model and develop prediction methods of rain attenuation at the location of interest. The advantage of such prediction method is that it can be used in other area of interest but with different parameters depending on the climatology characteristics. In order to develop such models or methods, information and characteristics of the rainfall rate should be carefully acquired. High accuracy and high resolution of rainfall rate are among the important features in designing terrestrial and satellite microwave links.

The established prediction methods in literature employ rainfall intensity information at 0.01% time exceedance of the annual cumulative with 1-minute integration time. The information of rainfall intensity at 1-minute integration time is needed for the attenuation model because it is typically used for developing an adequate link margin on the slant path to a satellite (Singh *et al*., 2007). In addition, cumulative distribution of rainfall rate relies on the effective sampling time of the rain gauge due to the rapidly changing nature of rainfall at a given point. Furthermore, International Telecommunication Union (ITU) has implicitly indicated that a 1-minute integration time is the most suitable for attenuation prediction. However, 1-minute integration time of rainfall data is not available in most countries and they utilize longer integration time of rainfall data especially from meteorological department. In order to comply with the standard implied by ITU, various conversion methods to convert from longer integration time to 1-minute integration time of rainfall rate had been proposed in the literature. Unfortunately, the rainfall rate data from tropical countries were not sufficient enough to obtain

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the most accurate formula in the previously proposed conversion methods for tropical region. Most of the previously proposed conversion methods employ entirely on measurements in temperate countries (Ismail *et al*. 2011).

Conversion Methods From τ-Minute To 1-Minute Integration Time:

A) Segal's Method:

Segal proposed an empirical conversion method using 10 years of daily tipping bucket rain gauge data from 47 stations in Canada (Segal, 1986). These 47 stations were purposely chosen for which to have numerous climatological and physiographical systems. The proposed empirical conversion method expressed as follows:

$$R_1(P) = aP^b R_t(P) \tag{1}$$

$R_1(P)$ and $R_\tau(P)$ are the rainfall rate at 1-minute and τ-minute integration time respectively with equal probability of occurrence P, and parameters a and b are the regression coefficient derived from the computed rainfall data.

B) Burgueno et al.'s Method:

The conversion method proposed by Burgueno *et al*. used 49 years rainfall rate data from Barcelona, Spain (Burgueno *et al*, 1988). The proposed conversion method applied the principle of direct power-law fit as follows:

$$R_1(P) = aR_t^b(P) \tag{2}$$

$R_1(P)$ and $R_\tau(P)$ represent the rainfall rate with sampling time of 1-minute and τ-minute respectively with percentage of time exceedance P, and parameters a and b are the empirical constants.

C) Chebil-Rahman's Method:

Chebil-Rahman employed conversion process from 60-minute and 1-minute integration time of rainfall intensity data in Malaysia to establish the conversion method (Chebil and Rahman, 1999). The 1-minute rainfall data were obtained from 3 different tipping bucket stations over the period of 3 years and 60-minute rainfall data were acquired from Malaysia Meteorological Department (MMD) formerly known as Malaysia Meteorological Service (MMS) for 35 stations at various locations in Malaysia that cover a period of 12 years for each station. The proposed conversion formula is expressed as follows:

$$R_1(P) = (aP^b + c\exp^{(dP)})R_t(P) \tag{3}$$

$R_1(P)$ and $R_\tau(P)$ are the rainfall rate with integration time of 1-minute and τ-minute respectively with percentage of time exceedance P, and parameters a, b, c and d are the conversion variables.

D) Joo et al.'s Method:

Joo *et al*. utilized 2 years of rainfall intensity data in Korea with various integration times (1-, 10-, 20-, 30-, and 60-minute) to obtain a conversion method (Joo *et al*.'s, 2000). The proposed conversion method used the distribution of entire rainfall event to estimate rainfall rate data. Joo *et al*. expressed the conversion methods in terms of 1-minute probability of time exceedance as follows:

$$P_1 = aP_t 10^{[b\exp(-\frac{t}{24.28})]} \tag{4}$$

P_1 and P_τ are the probability of time exceedance at 1-minute and τ-minute integration time respectively. Parameter t is the sampling time interval (min) for the rain gauge, and parameter a and b are the regression coefficients.

E) Ismail et al.'s Method:

Ismail *et al*.'s proposed another empirical conversion method using 2 years optical rain gauge data at Bukit Jalil, Malaysia (Ismail *et al*., 2011). The acquired data provided sampling time of 10-second interval. The proposed conversion is expressed as follows:

$$P_1(R) = aP_t(R)^b \tag{5}$$

$P_1(R)$ and $P_\tau(R)$ are the percentage of time exceedance with equal rainfall rates for integration time of 1-minute and τ-minute respectively. Parameter a and β are the conversion variables.

E) ITU-R P.837:

ITU-R has proposed a new recommendation known as ITU-R P.837 that claims capable of enabling users to generate statistics known as *P(R)* of the local rainfall intensity, *R* (mm/hr) at 1-minute integration time (ITU-R P.837, 2012). The recommendation provides options that allow users to input 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 minutes. This recommendation exploits EXCELL Rainfall Statistics Conversion (EXCELL RSC) model as proposed by Capsoni and Luini (Capsoni and Luini, 2009). The statistics of compilation data using locally measured rainfall intensity and integrated conversion model are anticipated to provide the best approximation. Fig. 1 shows the full workflow of the proposed conversion method.

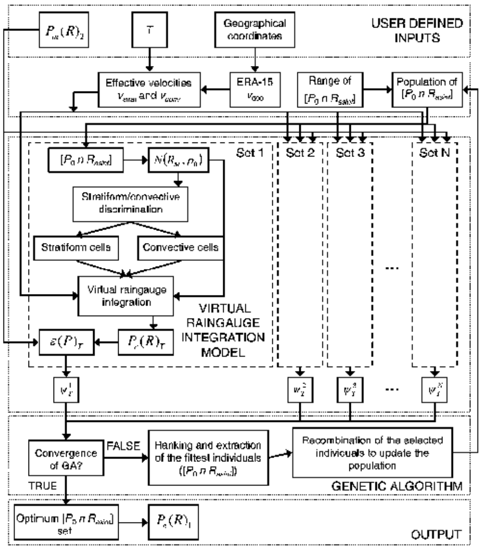

Fig. 1: Full workflow of EXCELL RSC model (Capsoni and Luini, 2009).

System Set-Up:

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 5km from the airport and 16.3m above mean sea level. 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 minutes. The integration time for the collected data for the collected data is 60 minutes.

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 0.2mm 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 0.2mm of rain droplets. Maximum rainfall amount that can be obtained is 200mm/hr. Table I summarized the specifications of the tipping bucket rain gauge operated by MMD and Fig.2 shows the tipping bucket that is located at KLIA. Fig. 3 shows the overall system setup for the study that includes terminal Doppler weather radar. However, this paper presents only the study of the measured ground truth rainfall rate at the rain gauge station KLIA not inclusive radar data. Radar data will be used for further analysis together with the rain gauge measurement data.

Table 1: Specifications Of Tipping Bucket Rain Gauge.

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

Fig. 3 also shows the location of the Terminal Doppler Weather Radar that is located at Bukit Tampoi. Radar data that consists the information of rainfall rate at KLIA are also required in order to compare with the rain gauge measurement data. However, this paper will only present the statistics and behavior of the rainfall at

KLIA. The radar data will be used in future works to find the correction of radar reflectivity to rainfall rate relationships.

Fig. 2: MMD tipping bucket at KLIA.

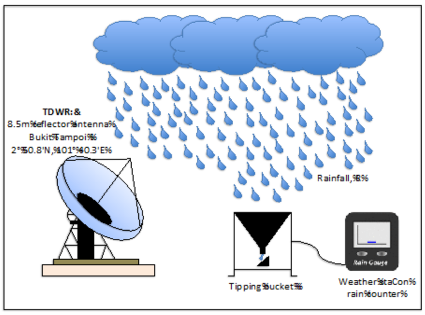

Fig. 3: Overall system setup.

Analysis Of Measured Rainfall Rate And Its Cumulative Distribution Functions:

The acquired rainfall data by tipping bucket rain gauge at KLIA utilizes sampling time of 60-minute and measures in real-time quatities for rainfall rate and rain accumulation. The measurements were taken over one year period from January to December 2009. The following paragraphs discuss the cumulative distribution functions of monthly, annually and different conversion methods from 60-minute to 1-minute respectively.

Fig. 4 shows the monthly cumulative distribution function of the acquired rainfall rate at KLIA. The plot for each month is presented with different colors to contrast each other. The figure also shows that there is no specific month that dominates the time percentage within twelve months period. However, it is clearly shown that the highest distribution of rainfall rate at 0.1% and 0.01% time exceedance occurs in March. The lowest rainfall rate distribution at 0.01% time exceedance occurs in August. Therefore, it can be concluded that March is subjected to severe rainfall intensity occurs for the time fraction lower than 0.1% time exceedance compared to other months.

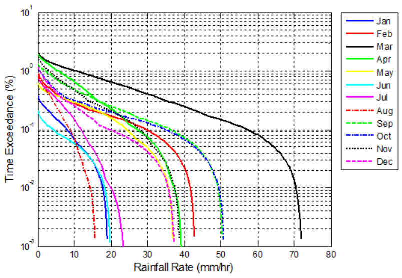

Fig. 4: Monthly cumulative distribution function of rainfall at KLIA, Malaysia.

Annual cumulative distribution function of rainfall rate at KLIA is obtained from the accumulation of monthly cumulative distribution functions. The twelve months cumulative distribution functions from January to December 2009 of the measured rainfall rate at KLIA had been presented in previous subsection. Fig. 5 depicts the annual cumulative distribution function of rainfall rate at KLIA for the year 2009. The figure shows that at 0.01% time exceedance equivalent to 9 hours of the year, KLIA had experienced rainfall rate of approximately 54.4mm/hr. As mentioned in previous section that the integration time for the collected data at KLIA is 60 minutes. Therefore, the value of 54.4mm/hr at 0.01% time exceedance shown in Fig. 6 is the value of rainfall rate for 60-minute integration time. However, the standard that had been imposed by ITU-R P.837-6 indicates that further analyses using rainfall rate data must exploit 1-minute integration time of rainfall rate. Furthermore, world rainfall maps approved by ITU-R also utilizes the 1-minute integration time of rainfall rate.

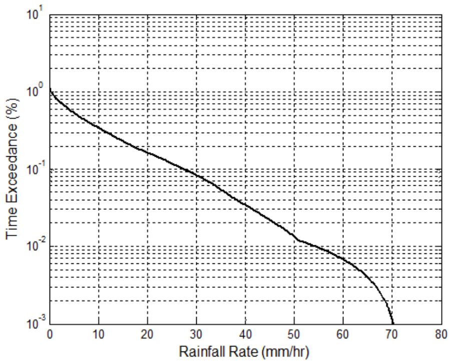

Fig. 5: Annual cumulative distribution function of rainfall at KLIA, Malaysia.

The annual rainfall distribution of 60-minute integration was converted into equivalent 1-minute integration time statistics using different conversion methods as mentioned in previous sections. Fig. 6 shows comparison of the cumulative distribution functions of KLIA rainfall data from different conversion methods proposed by previous researchers with ITU-R P.837-6. It is clearly shown that Burgueno's conversion method produced highest rainfall rate value of 130.6mm/hr at 0.01% time exceedance. Segal's and Chebil-Rahman's methods give rainfall rate values of 122.7mm/hr and 111.2mm/hr respectively. Table II summarizes rainfall rate values, $R_{0.01}$ at 0.01% time exceedance for all conversion methods.

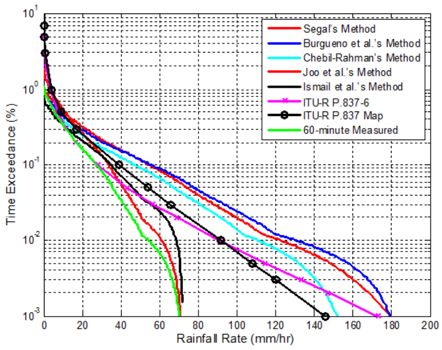

Fig. 6: Cumulative distribution function of different conversion methods for rainfall at KLIA, Malaysia.

Table 2: Rainfall Rate Values at 0.01% Time Exceedance ($R_{0.01}$).

Conversion Methods	ITU-R P.837-6	ITU-R P.837 Map	Segal's	Burgueno *et al.*'s	Chebil-Rahman's	Joo *et al.*'s	Ismail *et al.*'s
Rainfall Rate (mm/hr)	90.77	91.75	122.7	130.6	112.2	61.2	68.6

The comparison of each conversion method with that of ITU-R rainfall is further analyzed by calculation of root mean square error (RMSE) and percentage error of rainfall rate values at 0.01% time exceedance. The RMSE is expressed as follows:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(EC_i - ITU_i)^2} \qquad (6)$$

where n is the number of data, EC is the empirical conversion data and ITU is the ITU-R data.

Table III summarizes the RMSE values and percentage difference at 0.01% time exceedance as compared to ITU-R P.837-6 conversion method with value of 90.77mm/hr. The table shows that ITU-R P.837 rain map has the lowest RMSE and percentage of difference when compared to that of ITU-R P.837-6 rainfall rate estimation model with the values of 10.958 and 1.080 recpectively. Meanwhile, Chebil-Rahman's method produces RMSE with value of 16.015 and percentage difference with value of 22.507.

Table IV summarizes the RMSE values and percentage difference at 0.01% time exceedance as compared to ITU-R P.837 rain map value of 91.75mm/hr. The table shows that ITU-R P.837 rainfall rate estimation model has the lowest RMSE value of 10.958 and percentage of difference value of 1.068 as compared to that of ITU-R

P.837-6 rainfall rate estimation model. Chebil-Rahman's method produces RMSE and percentage difference of 15.220 and 21.199 respectively.

Table 3: RMSE and Percentage Difference at 0.01% Time Exceedance as Compared with ITU-R P.837-6.

Conversion Methods	ITU-R P.837 Map	Segal's	Burgueno *et al*.'s	Chebil-Rahman's	Joo *et al*.'s	Ismail *et al*.'s
RMSE	10.958	23.972	28.425	16.015	19.667	17.763
Percentage Difference (%)	1.080	35.177	43.880	22.507	24.352	30.795

Table 4: RMSE and Percentage Difference at 0.01% Time Exceedance as Compared with ITU-R P.837 Map.

Conversion Methods	ITU-R P.837-6	Segal's	Burgueno *et al*.'s	Chebil-Rahman's	Joo *et al*.'s	Ismail *et al*.'s
RMSE	10.958	24.625	28.091	15.220	18.445	16.593
Percentage Difference (%)	1.068	33.733	42.343	21.199	23.309	29.482

Conclusion And Future Works:

The scope of this paper is limited to the study of different conversion methods proposed by other researches for 60-minute to 1-minute integration time of rainfall rate. The comparison of different conversion methods used measured 12-months tipping bucket rainfall data at KLIA. This paper also includes the annual and cumulative distribution functions for the measured data. From the results obtained, it shows that the all the conversion methods proposed from other researchers produced large difference compared to that of ITU-R P.837.6. Furthermore, it can be concluded that the Chebil-Rahman's method produced the lowest RMSE and percentage difference at 0.01% time exceedance as compared to both ITU-R P.837-6 rainfall estimation model and ITU-R P.837 rain map.

However, this is only a preliminary result. Further analysis need to be carried out using different locations of rainfall data for several years. Next investigation will involve in converting the acquired 60-minute integration time to 1-minute rainfall rate data in order to obtain annual cumulative distribution of rainfall that complies with ITU-R P. 837-6. Comparison of new proposed conversion method with others' will also be presented in the future work and analyses.

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