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Preliminary Study on Conversion Model Methods for Hydro-Estimator Rain Rate Integration Time in Malaysia

Hafiz Basarudin[1], Noor Hidayah Mohd Yunus[2]*, Nur Auni Izzati Aminudin[2], Ling Lloyd[1], Chung Boon Kuan[1], Aizat Faiz Ramli[2], Jahariah Sampe[3], Gan Hong Seng[4]

[1] *Lee Kong Chian Faculty of Engineering and Science,*
Universiti Tunku Abdul Rahman, Bandar Sungai Long Cheras, Kajang, 43000, MALAYSIA
[2] *Communication-Electronics Technology Section*
British Malaysian Institute, Universiti Kuala Lumpur, Gombak, 53100, MALAYSIA
[3] *Institute of Microengineering and Nanoelectronics*
Universiti Kebangsaan Malaysia, Bangi 43600, MALAYSIA
[4] *School of AI and Advanced Computing*
Xi'an Jiaotong-Liverpool University, CHINA

*Corresponding Author: noorhidayahm@unikl.edu.my
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Abstract

This research investigates the propagation of radio signals, specifically above 10 GHz, where rain-induced signal degradation due to the influence of hydrometeors, particularly rainfall, leads to a phenomenon referred to as rain fade. Current models from International Telecommunication Union or (ITU) have become guides for rain fade prediction, thereby enabling the allocation of appropriate fade margins in the strategic planning of radio networks. However, the existing models have limitations and exhibit a notably confined scope. This research explores alternative approaches using meteorological data, particularly rain radar data, to gain detailed insights into rainfall patterns. The key focus is to harmonize rain rate data into a 1-minute temporal framework suitable for radio network planning. Four methodologies under scrutiny encompass Burgeuno, Joo, Segal, and ITU-R 837 models are examined, as these models have been used in recent research for rain rate integration time conversion. Rigorous testing is conducted using 2020 Hydro-estimator data with 60 minutes integration time over Peninsular Malaysia, Sabah, and Sarawak. From the results, ITU-837 and Segal models produce 1-minute integrated rain rate results that are the closest to the actual rain gauge data compared to other models. By conducting this exploratory analysis, the paper aspires to broaden the comprehension of rain fade dynamics and contribute to the refinement of radio network design in Malaysia.

1. Introduction

In modern wireless communication, radio frequencies above 10 GHz have emerged as a prominent strategy to accommodate the escalating demand for high-speed data transmission and enhanced network capacity. However, this advancement is accompanied by an inherent susceptibility to atmospheric phenomena, particularly the interaction of radio signals with hydrometeors, especially rain. The consequent degradation in signal quality, referred to as rain fade, poses a significant challenge to the seamless operation of wireless communication systems

[1, 2]. Fig. 1 shows the specific attenuation from 0 to 100 GHz radio link due to rain fade. From the graph, it shows that higher frequency results in more attenuation or loss. In addition, higher rainfall rates also produce more attenuation.

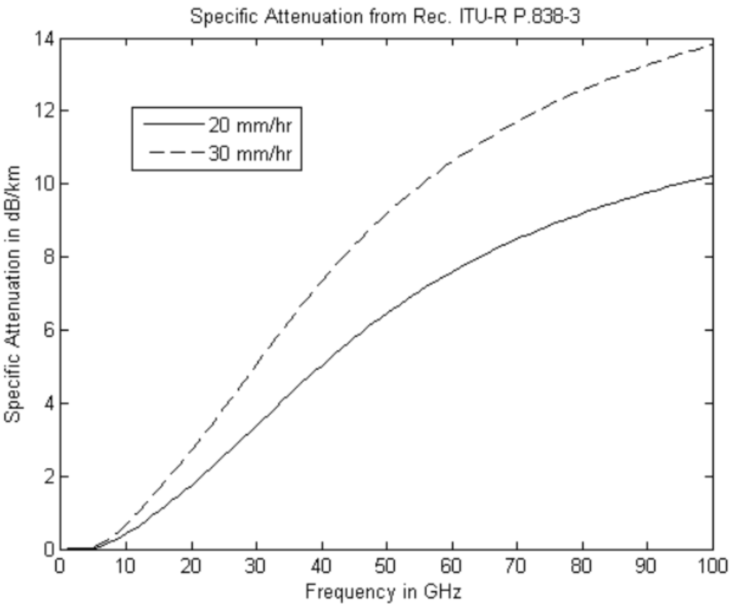

Fig. 1 *Specific attenuation for various frequencies of radio link due to rain fade [3]*

Radio engineers and communication network planners have traditionally relied on established models and recommendations from the International Telecommunication Union (ITU) to predict and mitigate the effects of rain fade [4]. These models, while serving as valuable tools, often exhibit limitations in capturing the intricate dynamics of rain-induced signal attenuation. Consequently, the efficacy of fade margin allocation and overall network performance optimization could be compromised [5].

As an alternative approach, meteorological data, particularly rain radar observations, offers a promising avenue for understanding the spatiotemporal distribution of rainfall, thereby augmenting the precision of rain fade prediction [6]. However, an essential consideration in this context is the integration time or temporal sampling interval applied to rainfall rate data derived from rain radar measurements. The significance of this temporal parameter lies in its impact on the accuracy and relevance of meteorological data for radio network planning [7].

The research paper in [8] addresses this critical gap by investigating various methods for converting rainfall rate integration times into a unified 1-minute temporal framework. This time scale is particularly pertinent to radio network planning and optimization endeavors, enabling engineers to make informed decisions about fade margin allocation and network design. This study evaluates and compares the effectiveness of well-established conversion methodologies, including the model method by Burgeuno, Joo, Segal, and ITU-R 837 [9-12], which have been utilized by researchers recently including Pérez-García, N. et. al. [13], Shrestha, S., and Choi, D. Y. [14, 15], and Samad, M. A. [16]. These models were developed based on data collected from rain radars, gauges, and other meteorological instruments at various locations.

To validate the proposed methodologies, empirical tests are conducted using Hydro-estimator rainfall data collected in the year 2020 across different regions of Malaysia, encompassing Peninsular Malaysia, Sabah, and Sarawak. The research endeavors not only to contribute to the advancement of rain fade prediction and network optimization strategies but also to expand the existing knowledge base on the unique rain attenuation characteristics observed within the Malaysian context. Research results from rain rate integration times could be used in tandem with measuring rain rate using microwave link measurements such as in [9-11].

2. Hydro-estimator: A Precipitation Estimation Tool

The Hydro-estimator represents a significant advancement in the field of meteorology, providing a valuable tool for the estimation of precipitation patterns and intensities. Rooted in the fusion of diverse remote sensing data sources, including satellite and ground-based radar observations, the Hydro-estimator offers a composite product that enables accurate and comprehensive insights into rainfall distribution and variability [17].

The Hydro-estimator methodology revolves around the concept of linearly perturbing climatological data to derive real-time precipitation estimates. By employing calibrated climatology as the baseline, the system considers factors such as spatial and temporal patterns, elevation, and historical precipitation data. This foundational information is then combined with the latest remote sensing inputs, including satellite infrared data and radar observations, to generate timely and reliable precipitation estimates [17, 18], similar to EUMETSAT data in [19].

One of the remarkable attributes of the Hydro-estimator lies in its ability to provide high-resolution data, capturing the spatiotemporal dynamics of rainfall at a granularity that is vital for various applications, including hydrological modeling, flood forecasting, and, importantly, telecommunications engineering, as in the case of this study. The data granularity and accuracy offered by the Hydro-estimator make it an ideal candidate for investigating the temporal integration times of rainfall rate, which are crucial in predicting rain fade in radio communication systems operating above 10 GHz. Similar research using Hydro-estimator is being studied for climate change effects on rain rate in [20-22].

In the context of this research paper, the Hydro-estimator dataset from the year 2020 serves as a foundation for exploring different methodologies to convert diverse rainfall rate integration times into a standardized 1-minute temporal framework. The inclusion of Hydro-estimator data facilitates an empirical assessment of the conversion methodologies' performance, considering real-world precipitation dynamics observed over Peninsular Malaysia, Sabah, and Sarawak regions.

As the Hydro-estimator continues to play a pivotal role in enhancing our understanding of precipitation patterns and their implications across various disciplines, its integration within the context of radio communication engineering exemplifies the interdisciplinary nature of contemporary scientific research [23-27]. By harnessing the power of the Hydro-estimator dataset, this study strives to contribute to both the refinement of rain fade prediction models and the optimization of radio network planning strategies. Fig. 2 shows an example of Hydro-estimator product with a rain rate in mm/hr at a global scale.

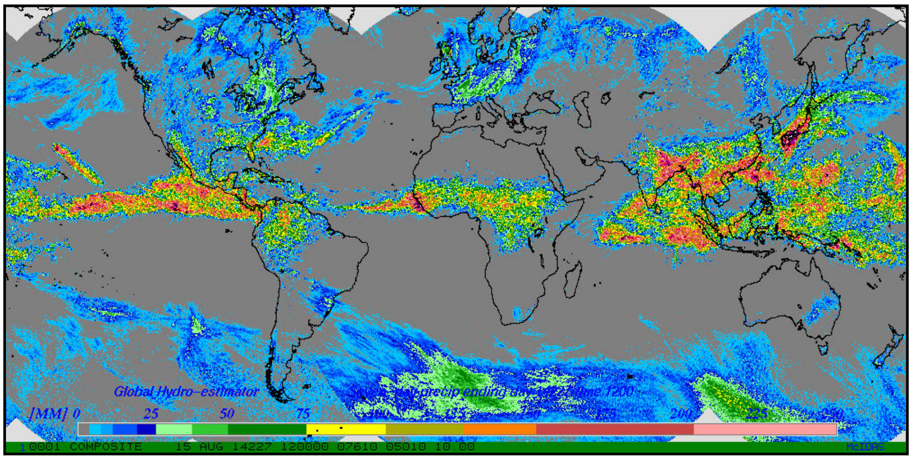

Fig. 2 *Hydro-estimator product at global scale with rain data in mm/hr (taken from https://www.tiempo.com/ram/94572/estimacion-precipitacion-hydro-estimator/)*

3. Methodology

In this section, the process of data collection and preparation of the Hydro-estimator, different conversion methods including Segal, Burgeuno, ITU, and Joo models for rain rate integration times and verification besides a discussion of the results are explained in detail.

3.1 Data Collection and Preparation

Data Collection and Preparation: Rainfall rate data used in this research were acquired from the Hydro-estimator dataset, which offers comprehensive spatiotemporal coverage of rainfall intensity over Peninsular Malaysia, Sabah, and Sarawak regions for the year 2020. The Hydro-estimator data, being a composite product of various remote sensing observations including satellite and ground-based radar data, provides an accurate representation of rainfall rates [17]. The raw data of Hydro-estimator is available at 60 minutes sampling time for a global scale.

3.2 Conversion Methodologies

Each methodology was applied to the collected rainfall rate data to generate the corresponding 1-minute temporal framework, facilitating direct comparison of the outcomes. Four distinct methodologies for converting rainfall rate integration times were selected for analysis: the method by Burgeuno, Joo, Segal and ITU-R 837 models. These methodologies were chosen due to their widespread usage and established theoretical underpinnings in rain attenuation studies [9-12].

3.2.1 Burgeuno Model

This method involves the digital conversion of the BB1 model of the raindrop size distribution to facilitate the transformation of rainfall rate values across different temporal scales [9]. This approach was applied to the collected data, allowing the computation of equivalent 1-minute rainfall rates.

$$R_1(p) = a[R_\tau\,(p)]^{\,b} \text{ mm/hr} \tag{1}$$

Equation (1) demonstrates the method where, R_1 which is the rain rate at 1-minute integration time can be obtained by identifying rain rate $R\tau$ at τ integration time, a and b which are regression coefficients. These coefficients depend on the frequency and orientation of a link. Both R_1 and $R\tau$ are exceeded with equal probability, p%. ITU-R P.837 in [12] employes an equation Burgueno et al. method other than with altered regression coefficients. Md Abdus Samad et. al in 2021 [16] utilizes Burgeuno model for rain fade models for Earth–Space telecommunication links. Similarly in 2017, Shrestha and Choi [15] utilized the model for conversion of different rain rate integration times in South Korea.

3.2.2 Joo Model

This method entails the conversion of rain rate statistics in both spatial and temporal domains, enabling the transition from diverse integration intervals to a standardized 1-minute temporal scale [15]. This methodology was employed to ascertain the conversion factors required for the transformation. The equation for Joo model is shown in Equation (2):

$$P_1 = aP_\tau 10^{\,b[exp(-\tau/24.28)]} \tag{2}$$

From equation (2), the exceedance probability for rain rate at 1-minute integration time or P_1 can be obtained by identifying a and b regression coefficients, $P\tau$ as the probability of the exceedance time for τ minute integration time. In 2016, Shresta and Choi [15] utilized Joo method for a rain integration time study in South Korea.

3.2.3 Segal Model

This method focuses on the propagation effects of microwave links at low elevation angles and provides insights into the variation of attenuation with integration time. By employing this method, the rainfall rate data were converted to the desired 1-minute scale for further analysis. The conversion method of Segal are shown in Equation (3) and Equation (4):

$$\rho_\tau = R_1(P)/R_\tau(P) \tag{3}$$

Conversion factor $\rho\tau$ (P) as a power law:

$$\rho_\tau(P) = aP^b \tag{4}$$

From equation (3) and (4), conversion factor $\rho\tau$ (P) can be obtained by power law or identifying rainfall rates at 1-minute $R_1(P)$ and and τ minutes integration time $R\tau$ (P), both with probability of occurrence P. The a and b are regression coefficients which just like in the previous models, depends on frequency and orientation of a link. Md Abdus Samad et. al in 2021 [16] utilized Segal model for rain fade models for Earth–Space telecommunication links. Similarly, Shrestha and Choi [15] utilized the model for rain rate integration times in South Korea in 2017.

3.2.4 ITU-R 837 Model

The ITU-R 837 model characterizes precipitation for propagation modelling and is widely utilized for rain fade prediction [12]. The model is similar to Equation (1) nonetheless with different coefficient values and was used to convert the collected rainfall rate data into the specified 1-minute temporal framework suitable for radio network planning. In 2023, Garcia et. al. [13] utilized the ITU-R 837 rain integration time model for Venezuela.

Table 1 shows the different coefficient values of *a* and *b* for all the conversion methods. The coefficient values depend on the required integration time. Most conversion methods are used to convert 5, 30, and 60 minutes to 1-minute rain rate distribution because most meteorological datasets from rain gauges, rain radars, and weather satellites are available in those integration times [22]. The use of coefficient values from the table is direct and straightforward. For instance, to convert 60 minutes to 1-minute of rain rate using Segal model, the coefficient values for *a* and *b* are 1.5390 and -0.0635, respectively. The regression coefficient values were discovered from the research based on historical rain rate distribution data from rain gauge and rain radar measurements. Burgeno's values were discovered from rain gauge measurements in Spain while Joo's values in South Korea. ITU-R P.837 values were based on various measurements globally.

Table 1 *Comparison of meteorological measurement methods*

Integration Time (min)	**Segal**		**Burgueno et al.**		**Joo et al.**		**ITU-R P.837-5**	
	a	***b***	***a***	***b***	***a***	***b***	***a***	***b***
5	1.0540	– 0.0289	1.3630	0.8814	0.2740	0.6530	0.906	1.055
30	1.3360	– 0.0307	3.1492	0.7551	0.8392	0.7784	0.561	1.297
60	1.5390	– 0.0635	6.4372	0.6170	10.2600	-8.5040	0.497	1.440

3.3 Comparative Analysis, Results, and Discussion

The converted rainfall rate data using each of the four methodologies were analysed and compared to evaluate their effectiveness in achieving a harmonized 1-minute temporal scale. The outcomes of the conversion methodologies were systematically presented and discussed in terms of their performance in achieving consistent 1-minute temporal data. The comparative analysis shed light on the strengths and limitations of each methodology in the context of rain attenuation prediction and radio network planning. Fig. 3 shows the original 60 minutes of Hydro-estimator data collected for the year 2020 over Peninsular, Sabah, and Sarawak regions in Malaysia. The average rain rate distribution for Peninsular Malaysia, Sabah, and Sarawak, is approximately 90 to 100 mm/hr at 0.01% exceedance probability which is similar according to ITU-R 837.

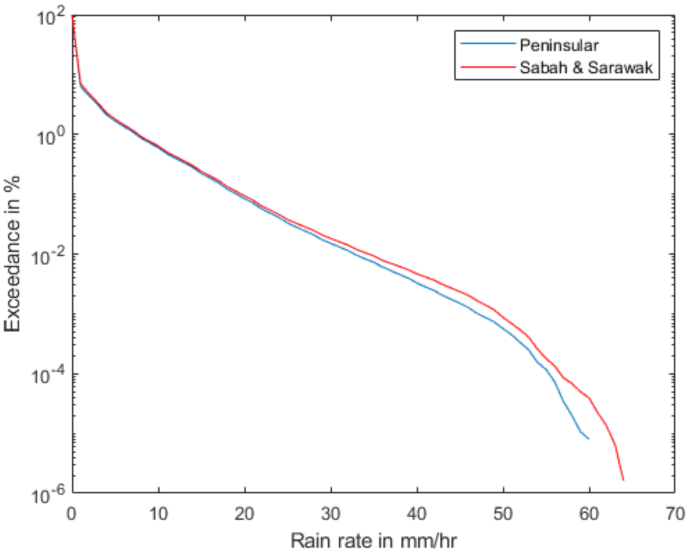

Fig. 3 *60 minutes rain rate distribution from hydro-estimator over peninsular, Sabah and Sarawak regions*

The results are compared to a rain gauge's rain rate distribution collected at Petaling Jaya, Peninsular Malaysia in the same year of 2020 and standard ITU-R 837 rain rate distribution model for Malaysia. Fig. 4 shows the rain rate distribution from the rain gauge and ITU-R 837 model. The result in Fig. 4 demonstrates that the rain gauge is consistent with the ITU-R 837 model for most of the exceedance probability percentages, from 100% to 0.01% and both can be used for verification purposes.

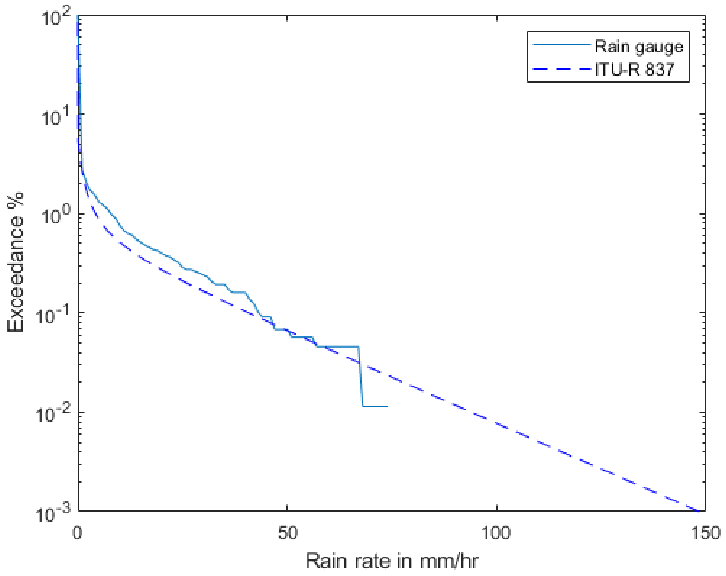

Fig. 4 *Rain rate distribution from rain gauge and ITU-R 837 for Malaysia*

Fig. 5 and Fig. 6 show the comparison results of rain rate distribution for the conversion methods of Burgeuno, Segal, Joo, and ITU-R 837 models, over Peninsular, Sabah, and Sarawak regions in Malaysia. All the different rain rate integration time conversion models were applied to Hydro-estimator year 2020 data to convert from 60 minutes to 1-minute integration time, as required by ITU and other calculations to measure signal's performance due to rain fade. From the results, all the models increased the rain rate distribution after the conversion to 1-minute, when compared to the original 60 minutes Hydro-estimator. This is expected, since shorter rain rate integration times capture more intense rain rate events as some events only last from few minutes to tens of minutes.

From the comparison results, the Segal and ITU-R 837 methods produce an average value of 65 to 75 mm/hr at 0.01 % exceedance probability. Both methods show more consistent and plausible results with rain gauge and ITU-R 837 rain rate distribution models than Burgueno and Joo methods. This is most likely due to the models from Joo and Burgueno which are developed mainly for more temperate weather. Joo model was developed based on the rain data collected over Korea whereas Burgueno was developed based in Spain. Malaysia is a tropical climate region with more intense rain events.

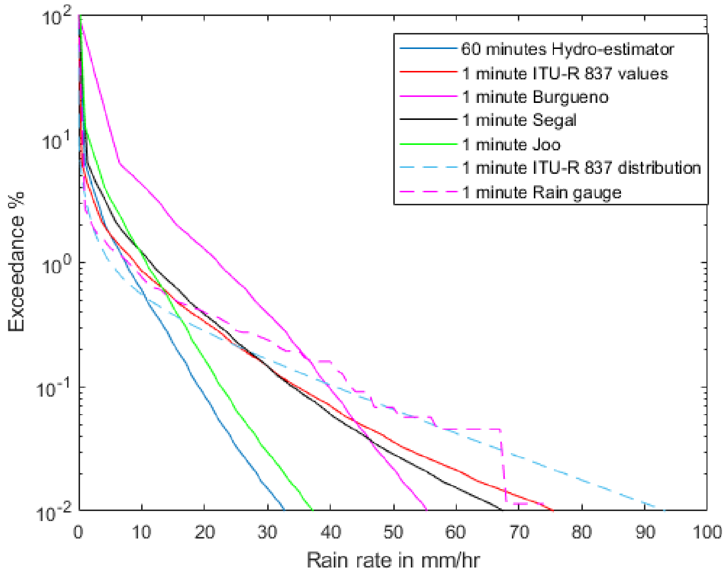

Fig. 5 *Rain rate distribution comparison results for Peninsular Malaysia*

The rain rate integration time model from ITU-R 837 shows a slightly more promising result when compared to rain gauge than the Segal method. For Peninsular Malaysia region comparison at 0.01% exceedance probability, the ITU-R 837 model is approximately 75 mm/hr while the rain gauge is around 72 mm/hr, slightly better than Segal method. Radio engineers typically rely on the rain rate in mm/hr at 0.01% exceedance probability when designing high-frequency radio links to ensure 99.99% signal availability in a year as recommended by ITU.

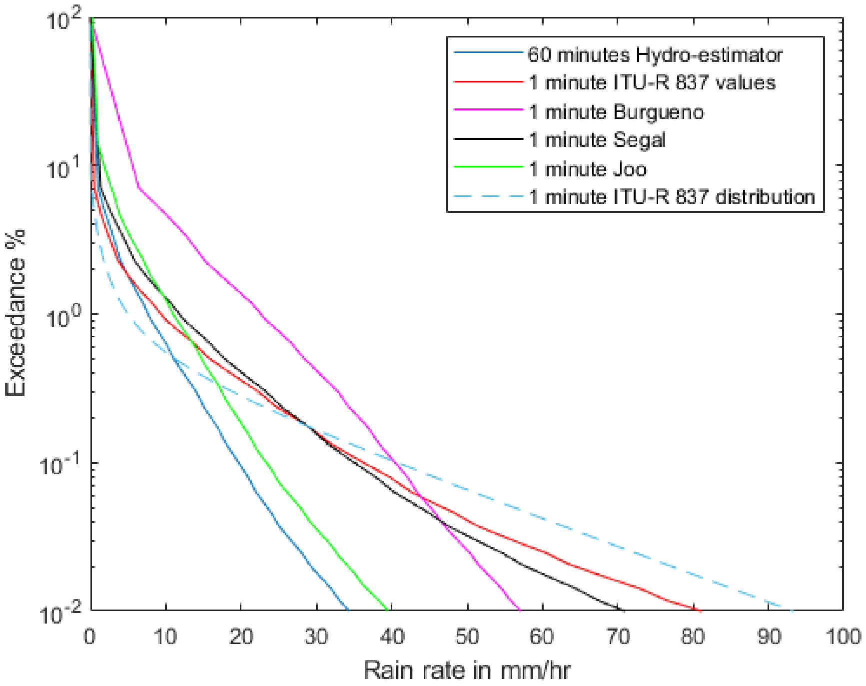

Fig. 6 *Rain rate distribution comparison results for Sabah and Sarawak, Malaysia*

4. Conclusion

Within the realm of radio engineering, a reliance on designated models and recommendations by ITU become customary for the prediction of rain fade. The scrutiny encompasses Burgeuno, Joo, Segal, and ITU-R 837 models, each presenting a unique perspective on the challenge at hand. These model methods were also recently cited and utilized by other researchers for rain rate integration time conversion. From the comparison results, ITU-R 837 and Segal conversion methods for different rain rate integration times offer the best results. The methods can be used for future research to reliably convert Hydro-estimator data from 60 minutes to 1-minute integration time, based on the 2020 Hydro-estimator data. Further improvements can be made to this research by collecting and analyzing more years of rain rate data from Hydro-estimator. Rain events tend to vary wildly from year to year, 10 years' worth of rain data would offer more stability to the rain rate distribution. In addition, other recent conversion models for different rain rate integration times would be explored as well.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Hafiz Basarudin, Noor Hidayah Mohd Yunus, Nur Auni Izzati Aminudin;* ***data collection:*** *Nur Auni Izzati Aminudin, Ling Lloyd, Chung Boon Kuan, Aizat Faiz Ramli, Jahariah Sampe, Gan Hong Seng;* ***analysis and interpretation of results:*** *Hafiz Basarudin, Noor Hidayah Mohd Yunus, Aizat Faiz Ramli;* ***draft manuscript preparation:*** *All authors. All authors reviewed the results and approved the final version of the manuscript.*

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