Journal of Sustainability Science and Management
Volume 17 Number 6, June 2022: 52-65
eISSN: 2672-7226

SITE SPECIFIC RAINFALL TEMPORAL PATTERN (RTP) FOR SUSTAINABLE DEVELOPMENT OF KUCHING CITY, SARAWAK, MALAYSIA

BONG CHARLES HIN JOO[1]*, JOSEP ABIGAIL[1], RUJI EDNA MATTHEW[2] AND GABDA DARMESAH[3]

[1]Department of Civil Engineering, Universiti Malaysia Sarawak, 94300, Kota Samarahan, Sarawak, Malaysia. [2]Department of Irrigation and Drainage Sarawak, 93626, Kuching, Sarawak, Malaysia. [3]Faculty of Science and Natural Resources, Universiti Malaysia Sabah, 88400, Kota Kinabalu, Sabah, Malaysia.

**Corresponding author: bhjcharles@unimas.my*
Submitted final draft: 7 November 2021 *Accepted: 16 December 2021* http://doi.org/10.46754/jssm.2022.06.005

Abstract: An understanding of rainfall temporal patterns is important for flood estimation and planning for sustainable flood designs and management. However, current published rainfall temporal patterns in design manuals are mostly generalised for a region which covers large areas. This raises doubts regarding its accuracy, especially for sensitive urban areas which are prone to flash floods. In the current study, a site-specific rainfall temporal pattern has been developed for Kuching using the Average Variability Method. The data of 5 minutes interval from year 2010 to 2018 for Kuching Airport rainfall station was used in the current study. Both the normalized and non-normalised rainfall temporal patterns were developed for 10 minutes, 15 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes and 360 minutes. The developed rainfall temporal patterns were then compared with the recommendations from two other published design manuals. Results showed that most of the fractions in the published rainfall temporal patterns have more than 20% differences when compared with the current study. The developed rainfall temporal patterns from the current study can be adopted for flood design purposes in the city of Kuching in Sarawak. This fulfils Sustainable Development Goal 11 by reducing the adverse effects of flood in the city.

Keywords: Average variability method, hydrographic storm, rainfall temporal pattern, sustainable flood management, urban flood.

Abbreviations: Average Variability Method (AVM), Hydrological Procedure No. 1 (HP 1), Hydrological Procedure No. 26 (HP 26), Urban Stormwater Management Manual for Malaysia (MSMA), Rainfall Temporal Pattern (RTP).

Introduction

Estimation of design flood is required in engineering practice for the design of hydraulic and flood mitigation structures. To estimate flood levels for designs, a design rainfall is required. Most of the existing studies focus more on the effects of rainfall durations and intensity on flood and design flood while ignoring the importance of rainfall temporal patterns on floods and water levels (Mu *et al.,* 2021).

The rainfall temporal pattern (RTP) refers to rainfall intensity; hence reflecting on the process of occurrence, development and extinction of the event. Study by Yuan *et al.* (2019) has shown that the timing of rainfall peak has significant influence on the peak flow which may cause a flood. Hence, RTP is important to facilitate a more reasonable analysis and calculation of peak flow related to flood. Study by Mu *et al.* (2021) has classified four different RTPs for the city of Hue, Vietnam and summarised as R1 (peak near the beginning), R2 (peak near the end), R3 (peak exactly at the beginning, where the first bar of the hyetograph is at its maximum) and R4 (peak at the middle).

Mu *et al.* (2021) also showed that the pattern where the rainfall peak in the middle (R4) yielded the maximum water depth, while peak rainfall near the beginning (R1) resulted in larger inundation areas. In terms of climate change, Hettiarachchi *et al.* (2018) stated that research focusing on the impact on rainfall temporal pattern remains limited.

Findings from the study by Hettiarachchi *et al.* (2018) showed that the rainfall temporal pattern intensified when scaled based on estimated temperature increased due to climate change. Another study on the sensitivity of peak flow to the change of RTP due to climate change by Fadhel *et al.* (2018) found that at warmer temperatures the rainfall temporal patterns became less uniform; with more intensive peak rainfall during higher intensive times and weaker rainfall during less intensive times.

Design rainfall for rainfall temporal patterns is needed as inputs for hydrologic models to derive flood hydrographs (Hong *et al.,* 2018). The Urban Stormwater Management Manual for Malaysia, MSMA (DID, 2000; 2012) also suggested that rainfall temporal patterns should be used in the development of hydrographic storms for the purpose of sustainable urban stormwater management measure and design.

There are various methods available to develop RTP such as Average Variability Method (AVM) (Pilgrim *et al.,* 1969), Huff's Time Distribution (Huff, 1967), Triangular Hyetograph (Yen & Chow, 1980) and Soil Conservation Service Method (SCS, 1986). However, the AVM is the most used method in Malaysia to develop RTP (Bustami *et al.,* 2012; Che Ali *et al.,* 2015; Hong *et al.,* 2018). The AVM has been used to develop rainfall temporal patterns for Peninsular Malaysia in design manual such as HP No.1 (DID, 1982) and MSMA (DID, 2000; 2012).

In Malaysia, rainfall temporal patterns for Peninsular Malaysia are available in both editions of MSMA and MSMA2 (DID, 2000; 2012). However, for Sabah and Sarawak, the recommendation is merely to follow the non-normalized rainfall temporal pattern developed for East Coast of Peninsular Malaysia (DID, 2000) with the assumption that the climatic conditions are like Sabah and Sarawak. However, this may not be the case due to the precipitation for Sabah and Sarawak is more as compared to the East Coast of Peninsular Malaysia (Bustami *et al.,* 2012).

It was only recently that the rainfall temporal patterns for Sabah and Sarawak were updated and published in HP 26 (DID, 2018). In both MSMA2 and HP 26, the published normalized RTPs referred to regions and not to stations or sites. In MSMA2 (DID, 2012), the rainfall temporal patterns were divided to five regions (Samat *et al.*, 2015):

Region 1: Terengganu, Kelantan and Northern Pahang

Region 2: Johor, Negeri Sembilan, Melaka, Selangor and Pahang

Region 3: Perak, Kedah, Pulau Pinang and Perlis

Region 4: Mountainous area

Region 5: Urban area (Kuala Lumpur)

As for HP 26, Sabah and Sarawak were divided into nine regions. This provides a more generalised RTP which covers a large area for each region, which may raise doubt in terms of accuracy, especially for major urban areas which are prone to flash flood. Samat *et al.* (2015) proposed RTPs for Kuantan River Basin, which was a site-specific approach based on the data from five rainfall stations in the basin for design purposes since the overall differences of the RTP fractions developed from their study was more than 20% from the Region 2 RTP recommended by MSMA2 (DID, 2012). Work by Wang (2020) found that rainfall temporal patterns are not strongly related to the macro-climate but more likely to be affected by the local climate and topography which requires further studies on a smaller scale.

Study by Rahman *et al.* (2006) in Australia for the Gold Coast region indicated a minimum distance of 7 km showed insignificant correlation between rainfalls of two stations. A similar study by Faridah *et al.* (2011) for Klang Basin showed an effective range of influence was 6.27 km for two rainfall stations. From both these studies on range of influence for rainfall stations, it can be deduced that data from each rainfall stations used to develop RTPs is actually site specific rather than region specific which covers large areas. Furthermore, MSMA2 recommends deriving temporal patterns using local data if the data is available. Hence, from all these studies, there is indication that site specific RTP is a better representation for an area compared with the published RTP for a region.

Hence, the current study aims to develop a site specific RTP for Kuching, the capital of the state of Sarawak. Kuching has been subjected to rapid development in the recent decades and the occurrence of flash flood has become more common.

Among the most recent flash floods in Kuching reported by the Department of Irrigation and Drainage (DID) Sarawak website (did.sarawak.gov.my) was on January 12, 2021 with 179.5 mm rainfall recorded at Kuching Airport rainfall stations causing flood depths of 0.1 m – 0.8 m for the surrounding areas, the February 18, 2021 event with 231.0 mm of rainfall recorded at Kuching Airport station with flood depths of 0.1 m – 0.6 m for surrounding areas, the December 4, 2017 event with 65 mm rainfall recorded at Kuching Airport rainfall station causing flood depths of 0.1 m – 0.4 m, the December 18, 2017 event with 79.5 mm recorded rainfall at Kuching Airport rainfall station caused flood depths of 0.8 m – 1.0 m and the January 18, 2015 event with 289 mm rainfall recorded causing flood depths between 0.1 m and 0.5 m.

In the current study, the rainfall data for the most recent years (2010 – 2018) was obtained from the Department of Irrigation and Drainage, Sarawak to develop the RTPs for various durations using the AVM. The developed RTPs were then compared with the published RTPs from MSMA (DID, 2000) and HP 26 (DID, 2018). It is to be noted that the RTP published for East Coast of Peninsular Malaysia (DID, 2000) was non-normalised while for HP 26 (DID, 2018) was normalized. Results from the comparison can be used in the decision of the suitable RTP for the design of sustainable drainage systems and management in a sensitive area like Kuching. This fulfils Goal 11: Sustainable Cities and Communities of the Sustainable Development Goals (SDGs) set out by the United Nations which is aimed at reducing the adverse effects of natural disasters such as floods.

Materials and Methods

Sarawak state capital Kuching (Figure 1) is in the Sarawak River Basin to the south which has a catchment area of 2,456 km^2 and river length of 120 km (Bong & Richard, 2020). Sarawak River Basin experiences two monsoon seasons, the northeast monsoon (November – March) when the wet season is recorded and the southwest monsoon (June – September) which is when the dry season is recorded. The basin has a high annual total rainfall of about 3,830 mm (Abdillah *et al.,* 2013).

For the present study, the 5-minutes rainfall data from Kuching Airport rainfall station (Station ID: 1403001) for the year 2010 to 2018 was obtained from the Department of Irrigation and Drainage in Sarawak.

The Kuching Airport rainfall station was chosen due to the consistent and reliable data of the station (having less than 10% missing data for each year chosen for the study) and located within the city. From the 5-minutes rainfall data, the time interval for 5 minutes, 10 minutes, 15 minutes and 30 minutes (which is in increments of 5 minutes) can be obtained in order to develop the RTP for different storm durations as stated in Table 1 according to recommendations by MSMA (DID, 2000). MSMA2 (DID, 2012) also recommended seven standard durations for the RTP, namely 10 minutes, 15 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes and 360 minutes duration.

In HP 26 (DID, 2018), the RTPs was developed up to 72 hours (4,320 minutes), however for the purpose of this study, the comparison has been made up to 6 hours (360 minutes) only to standardize the comparison with the one recommended by MSMA (DID, 2000) which suggested standard durations up to 360 minutes. Furthermore, for HP 26 (DID, 2018), the durations suggested were 15 minutes, 30 minutes, 60 minutes, 180 minutes, 360 minutes, 720 minutes, 1,440 minutes, 2,880 minutes and 4,320 minutes (72 hours). Hence, no comparison was done for the durations of 10 minutes, 120 minutes, 720 minutes, 1,440 minutes, 2,880 minutes and 4,320 minutes. Also, for HP 26 (DID, 2018), there are more fractions for durations of 180 minutes and 360 minutes due to the interval for each fraction used were 15 minutes and 30 minutes, respectively.

However, for this study, the interval of durations for 180 minutes and 360 minutes are 30 minutes and 60 minutes, respectively. Hence to standardize the comparison, the interval in HP 26 (DID, 2018) was converted to 30 minutes and 60 minutes for the durations of 180 minutes and 360 minutes, respectively.

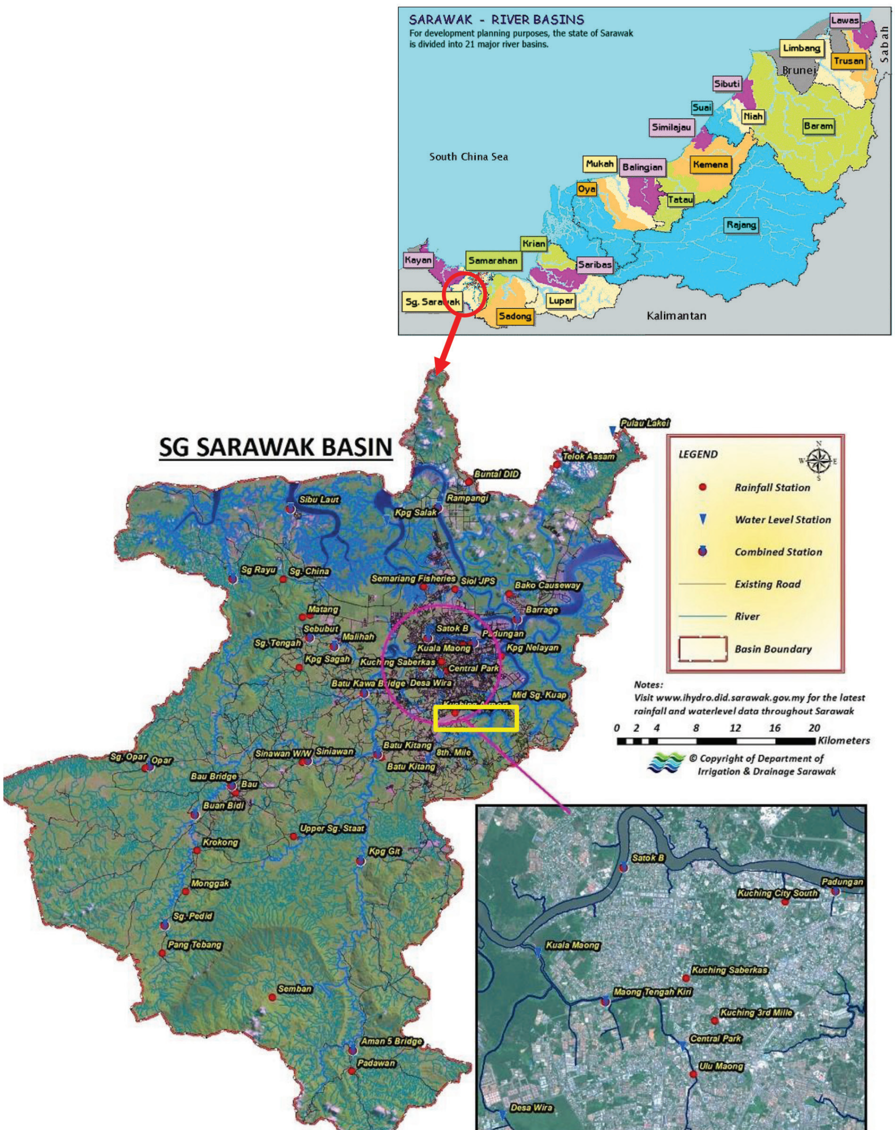


Figure 1: The location of Sarawak River Basin as compared to Sarawak map and Kuching Airport rainfall station (in yellow box) (DID, 2021)

Table 1: Recommended interval for design RTP (DID, 2000)

Storm Duration (minutes)	Number of Time Intervals	Time Interval (minutes)
10	2	5
15	3	5
30	6	5
60	12	5
120	8	15
180	6	30
360	6	60

To develop the RTP, the 10 most intense rainfalls for each of the durations (10 minutes, 15 minutes, 30 minutes, 60 minutes, 120 minutes, 180 minutes and 360 minutes) were selected. An example of RTP development for 15 minutes duration is shown in Table 2.

Column 1 shows the date of the event and column 2 shows the total rainfall for the 15 minutes duration. The 10 most intense rainfalls for the duration were then ranked from the highest to lowest as shown in column 3.

Hence, the rainfall amount of 19.5 mm was ranked first while the amount of 11.5 mm was ranked tenth which is the lowest.

Columns 4 to 6 shows the amount of rain in each interval. Columns 7 to 9 showed the rank of each rainfall interval where the highest amount of rainfall in the interval was ranked first and followed with the next highest amount of rainfall.

The rank of each rainfall interval was calculated to find its mean (see bottom of columns 7 to 9). The mean calculated for the rank of each rainfall interval for the 15-minutes rainfall duration analysis were 2.5, 1.15 and 2.35, respectively. They were assigned a rank for the mean as 3, 1 and 2, respectively. Columns 10 to 12 showed the percentage of rain interval of each rank. The percentage of rain was obtained based on the amount of rainfall in that interval.

For example, for the first rank, the total rainfall was 19.5 mm and the highest rainfall among the three intervals was 9.5 mm which is 49% of the total rainfall. New rank was assigned based on the mean and percentage of rainfall and finally the percentage was converted to a fraction (see bottom of columns 7 to 9).

This fraction can be used to plot the RTP. All the previous steps were repeated to develop the RTP for the other standard durations.

Finally, a comparison between the newly developed RTP for Kuching city from the current study was compared with the published recommendation from MSMA (DID, 2000) and HP 26 (DID, 2018). The developed RTP for Kuching city will be normalized before the comparison can be done with the normalized RTP in HP 26 (DID, 2018). This was done by using the Alternating Block Method introduced by Chow *et al.* (1988) where the block of maximum incremental depth is positioned in the middle of the required duration and the remaining blocks of rainfall are arranged in descending order, alternatively to the right and left of the central block.

For comparison, the percentage of difference in the fraction for each interval block was calculated using Equation 1. The same method of comparison was used by Samat *et al.* (2015) to compare the RTP developed in their study of the Kuantan River Basin with the value published in MSMA2 (DID, 2012) for Region 2 (Pahang). Also, to determine whether the published RTP tends to under predict or over predict as compared to the current study, the results of the numerator in the Equation 1 was observed.

However, only the magnitude values (ignoring the positive and negative signs) of percentage difference were taken into consideration of the overall mean percentage difference for each duration of the RTP. Samat *et al.* (2015) took the differences of more than 20% between the compared RTPs as unacceptable.

$$\% \, difference = \frac{Fraction \, value \, of \, published \, RTP - Fraction \, value \, of \, current \, study}{Fraction \, value \, of \, published \, RTP} \times 100\% \quad (1)$$

Table 2: Analysis of 15 minutes duration for Kuching Airport rainfall station

1	2	3	4	5	6	7	8	9	10	11	12
Date	**Rain (mm)**	**Rank**	**Rain (mm) at 5 Minutes Interval**			**Rank of Each Rainfall Interval (Mean Rank for Intervals with Same Rainfall Values)**			**% of Rain for the Interval**		
			1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
07.11.14	19.5	1	1.5	8.5	9.5	3	2	1	49	44	7
30.12.14	17.5	2	4.5	11.5	1.5	2	1	3	66	26	8
06.10.15	16.5	3	2.5	10	4	3	1	2	61	24	15
18.11.13	14.5	4	5	8	1.5	2	1	3	55	35	10
16.11.11	14.5	5	0.5	11	3	3	1	2	76	21	3
29.03.11	14.0	6	4.5	8	1.5	2	1	3	57	32	11
24.04.12	14.0	7	3	9.5	1.5	2	1	3	68	21	11
11.12.16	13.0	8	4	8	1	2	1	3	61	31	8
06.04.16	12.5	9	0.5	6	6	3	1.5	1.5	48	48	4
04.04.17	11.5	10	2.5	6	3	3	1	2	52	26	22
			Mean			2.5	1.15	2.35	59	31	10
			New rank			3	1	2	1	2	3
			Rainfall pattern (in % as per new rank)			10	59	31			
			Design temporal pattern in fraction			0.10	0.59	0.31			

Results and Discussion

The graphical representation for the fraction and RTP for the non-normalized various durations developed for Kuching city in the current study are as shown in Figure 2 (a) to Figure 2 (g). The detail of the fractional value for each interval for the various durations is as shown in Appendix 1.

From Figure 2, the RTP patterns mostly showed type R1 according to the classification by Mu *et al.* (2019) namely for the durations 30 minutes, 60 minutes, 120 minutes and 360 minutes. Type R1 tends to have peak rainfall early in the rainfall process. For the duration of 180 minutes, it follows the type R2, duration of 10 minutes follows type R3 and duration of 15 minutes follows type R4 according to the classification by Mu *et al.* (2019).

For type R1 and R3, both studies by Mu *et al.* (2019) and Hou *et al.* (2017) have shown that earlier peaks in the rainfall corresponds to larger

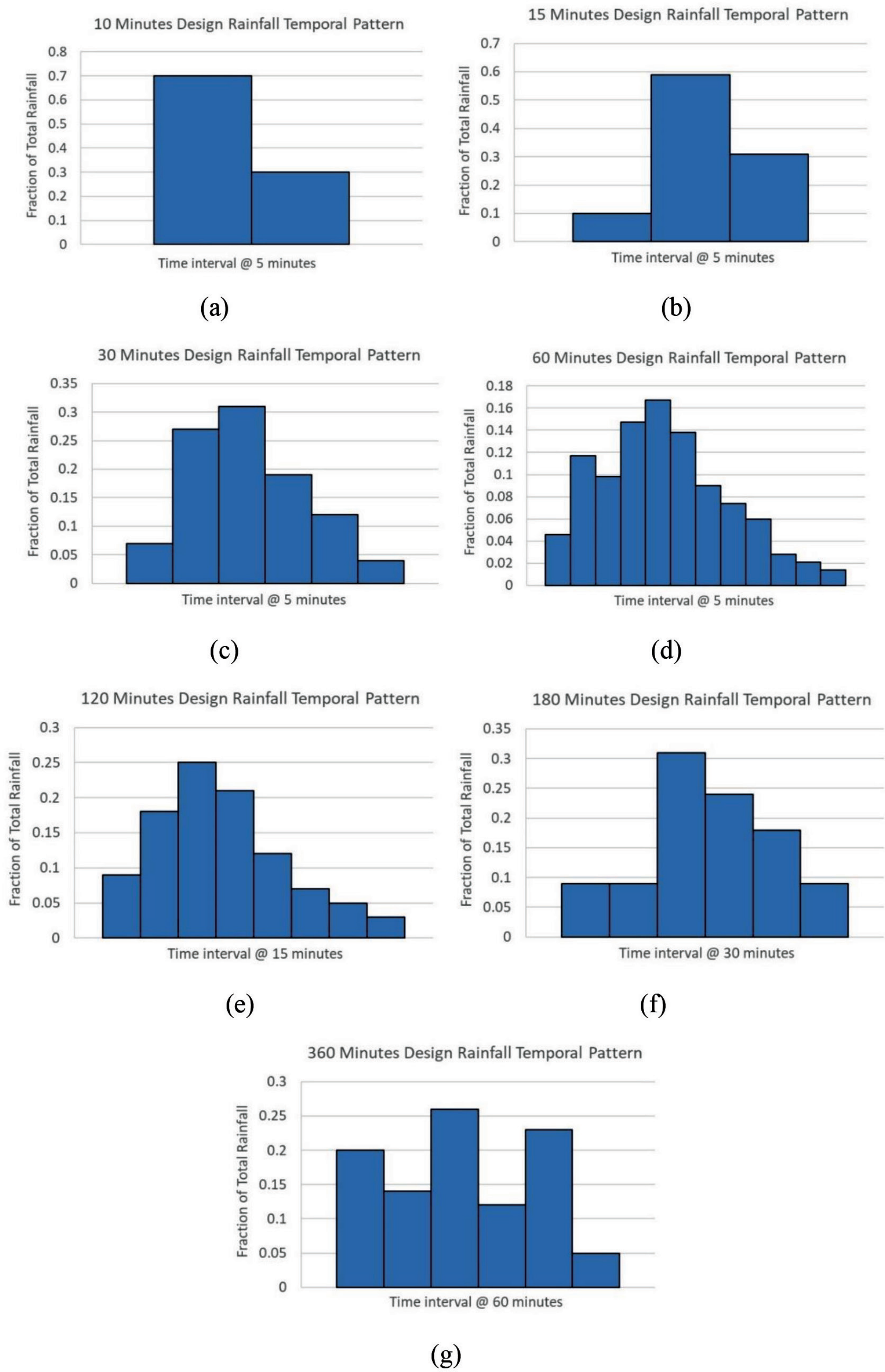


Figure 2: Non-normalized rainfall temporal patterns for Kuching city for different durations: (a) 10 minutes, (b) 15 minutes, (c) 30 minutes, (d) 60 minutes, (e) 120 minutes, (f) 180 minutes and (g) 360 minutes

inundation areas as compared to other types of patterns. This is due to the peak rainfall in the early process of the rainfall event resulted in faster flow generation which tends to generate larger inundation areas.

For type R4, the rainfall process is smooth and the process lasts for whole rainfall duration and the distribution of the intensity for the process is like a normal distribution. For this type of pattern, Mu *et al.* (2019) has found that when the peak rainfall is in the middle, it generates a maximum water depth, but the smallest inundation area as compared to other type of patterns. Hence from understanding the type of RTP, urban flood can be predicted through meteorological data gathering and modelling simulation.

This will enable the identification of flood prone areas for flood risk management and reducing the impact of the flood towards a sustainable city as outline in Goal 11 of the Sustainable Development Goal (SDG).

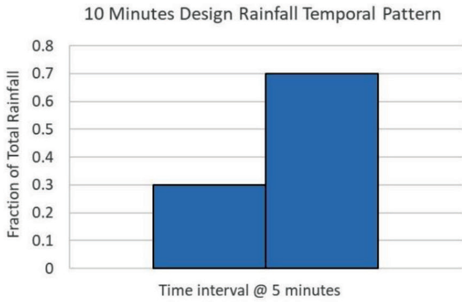
Figure 3 shows the normalised RTPs for Kuching city. The normalization was done so that comparison can be made with the RTP published in HP 26 (DID, 2018). RTPs were normalized to have a normal distribution with peak rainfall in the middle. This will produce maximum water depth (Mu *et al.,* 2019) which corresponds with the peak discharge.

This peak discharge is useful for most conventional design on water related infrastructure. The detail of the normalized fraction value for each interval for the various durations is as shown in Appendix 2.

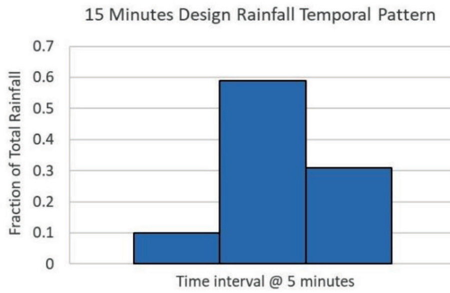
Table 3 shows the comparison between the non-normalized fraction RTPs developed from the current study with the one published for East Coast of Peninsular Malaysia and recommended by MSMA (DID, 2000) to be used for design purposes for Kuching city. However, to standardize the comparison later with the one published by HP 26 (DID, 2018); only the RTPs with durations of 15 minutes, 30 minutes, 60 minutes, 180 minutes and 360 minutes were compared. Comparisons were made in terms of percentage differences for each of the fractions and for each durations following Equation 1.

Looking into the fractional value of the RTP for East Coast of Peninsular Malaysia (DID, 2000), it can be classified that most of the durations were of type R1 according to the classification by Mu *et al.* (2019) namely for the durations of 30 minutes, 60 minutes, 120 minutes and 180 minutes. The duration of 10 minutes and 360 minutes can be classified as type R3 while the duration of 15 minutes was type R4. As mentioned earlier, type R1 and R3 with the peak rainfall being early in the process will generate larger inundation area as compared to the other type.

From Table 3, generally all the RTP durations recommended by MSMA (DID, 2000) have huge differences as compared to the site specific RTP developed in the current study. The mean percentage differences for each of the durations ranged from 26.8% to 53.0%. Overall, 75.8% of the fractions had more than 20% differences in value between the RTP from current study and that of East Coast of Peninsular Malaysia (DID, 2000). It was also observed that 51.5% of the fractions were under predicted by MSMA (DID, 2000). Since most of the RTPs recommended by MSMA (DID, 2000) were of either type R1 or R3, they were under predicted at the beginning of the rainfall process which resulted in smaller inundation area being generated when the RTPs were used for flood simulation.



(a)



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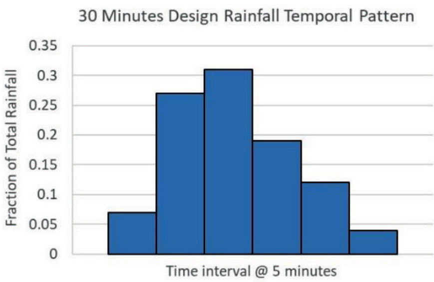

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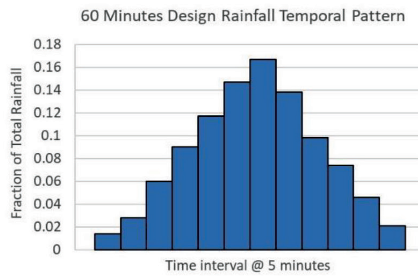

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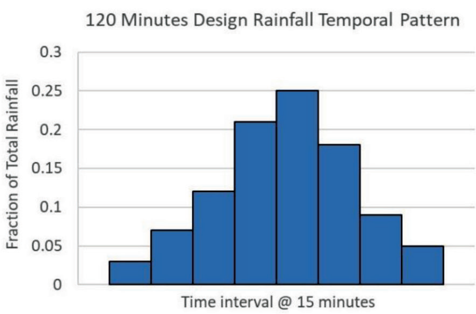

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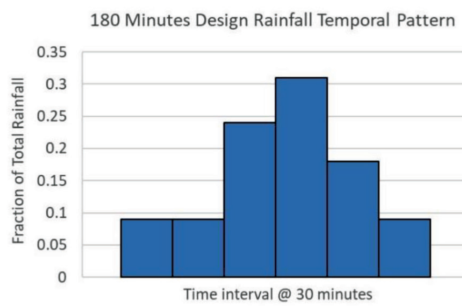
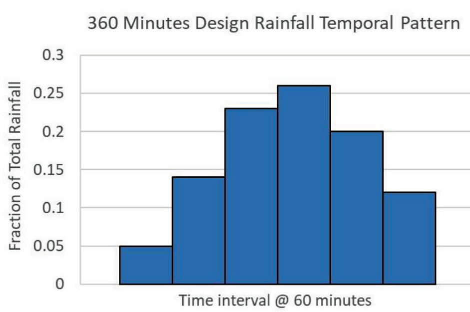


(f)



(g)

Figure 3: Normalized rainfall temporal patterns for Kuching city for different durations: (a) 10 minutes, (b) 15 minutes, (c) 30 minutes, (d) 60 minutes, (e) 120 minutes, (f) 180 minutes and (g) 360 minutes

Table 3: Comparison of RTP between the current study with Urban Stormwater Management Manual (MSMA) for East Coast of Peninsular Malaysia (DID, 2000) recommended for Kuching city

No. of Block	15 minutes		30 minutes		60 minutes		180 minutes		360 minutes	
	CS	**MSMA**	**CS**	**MSMA**	**CS**	**MSMA**	**CS**	**MSMA**	**CS**	**MSMA**
1	0.100	0.320 *68.8%*	0.070	0.160 *56.3%*	0.046	0.039 *-17.9%*	0.090	0.190 *52.6%*	0.200	0.290 *31.0%*
2	0.590	0.500 *-18.0%*	0.270	0.250 *-8.0%*	0.117	0.070 *-67.1%*	0.090	0.230 *60.9%*	0.140	0.200 *30.0%*
3	0.310	0.180 *-72.2%*	0.310	0.330 *6.1%*	0.098	0.168 *41.7%*	0.310	0.190 *-63.2%*	0.260	0.160 *-62.5%*
4			0.190	0.090 *-111.1%*	0.147	0.120 *-22.5%*	0.240	0.160 *-50.0%*	0.120	0.120 0.0%
5			0.120	0.110 *-9.1%*	0.167	0.232 *28.0%*	0.180	0.130 *-38.5%*	0.230	0.140 -64.3%
6			0.040	0.060 *33.3%*	0.138	0.101 *-36.6%*	0.090	0.100 *10.0%*	0.050	0.090 44.4%
7					0.090	0.089 *-1.1%*				
8					0.074	0.057 *-29.8%*				
9					0.060	0.048 *-25.0%*				
10					0.028	0.031 *9.7%*				
11					0.021	0.028 *25.0%*				
12					0.014	0.017 *17.6%*				
Mean % diff	*53.0*		*37.3*		*26.8*		*45.9*		*38.7*	

*CS = Current Study, MSMA = Urban Stormwater Manual for Malaysia (DID, 2000). The number in italic represent the difference in % as calculated using Equation 1

Table 4 shows the comparison between the normalized fraction RTPs from the current study with the recommended normalized temporal pattern for Region 2 by HP 26 (DID, 2018). As stated by Mu *et al.* (2014), RTP with peak rainfall in the middle will yield the maximum water depth. Hence, RTP was normalized to obtain the maximum water depth that can be generated by the RTP. From Table 4, generally the RTP recommended by HP 26 (DID, 2018) will have a huge mean percentage difference values ranging from 24.9% to 46.9% when compared to the RTP from the current study. Overall, 72.7% of fractions have more than 20% differences in value between the RTP from the current study and HP 26 (DID, 2018). Also observed was 54.5% of the fractions were over predicted by HP 26 (DID, 2018). Over predicted RTP values especially for the peak rainfall would increase the generated maximum water depth/flood depth predictions. Hence, using an over predicted flood depth for the design might increase the cost of flood related infrastructure.

Table 4: Comparison of normalized RTP between the current study with HP 26 (DID, 2018) Region 2 recommended for Kuching city

No. of Block	15 minutes		30 minutes		60 minutes		180 minutes		360 minutes	
	CS	HP 26	CS	HP 26	CS	HP 26	CS	HP 26	CS	HP 26
1	0.100	0.321 *68.8%*	0.040	0.136 *70.6%*	0.014	0.053 *-73.6%*	0.090	0.109 *17.4%*	0.090	0.125 *28.0%*
2	0.590	0.354 *-66.7%*	0.120	0.168 *28.6%*	0.028	0.072 *61.1%*	0.090	0.164 *45.1%*	0.090	0.170 *47.1%*
3	0.310	0.325 *4.6%*	0.270	0.179 *50.8%*	0.060	0.082 *26.8%*	0.240	0.211 *-13.7%*	0.240	0.188 *-27.7%*
4			0.310	0.183 *-69.4%*	0.090	0.086 *-4.65%*	0.310	0.212 *-46.2%*	0.310	0.194 *-59.8%*
5			0.190	0.178 *-6.74%*	0.117	0.095 *-23.2%*	0.180	0.186 *3.23%*	0.180	0.178 *-1.12%*
6			0.070	0.156 *55.1%*	0.147	0.098 *-50.0%*	0.090	0.118 *23.7%*	0.090	0.145 *37.9%*
7					0.167	0.098 *-70.4%*				
8					0.138	0.096 *-43.8%*				
9					0.098	0.093 *-5.4%*				
10					0.074	0.084 *11.9%*				
11					0.046	0.076 *39.5%*				
12					0.021	0.067 *68.7%*				
Mean % diff		*46.7*		*46.9*		*39.9*		*24.9*		*33.6*

*CS = Current Study, HP 26 = Hydrological Procedure No. 26 (DID, 2018). The number in italic represents the difference in % as calculated using Equation 1

From both Table 3 and Table 4, the normalised RTP from HP 26 (DID, 2018) was observed to be closer in terms of the fractional value to the site specific RTP from the current study than the non-normalised comparison with RTP from MSMA (DID, 2000). This was deduced from the mean percentage differences for each of the durations. Furthermore, in terms of flood mitigation, a slightly over predicted flood depth or flood area used in the design is better than under predicted. From the findings of the comparison between the RTPs, it can be deduced that accurate RTP is important in the sustainable design and management of floods, especially in sensitive urban areas like Kuching city to reduce the adverse effect due to floods. This is in line with Sustainable Development Goal 11: Sustainable Cities and Communities.

Conclusion

Rainfall temporal patterns (RTP) with different durations is important for rainfall distribution in flood calculations. For this purpose, mostly published RTPs in design manuals are derived from a large number of rainfall stations for a region. However, this may raise doubts in terms of accuracy, especially for major urban areas which are sensitive to flash floods. Hence, in the current study, a site specific RTP has been developed for Kuching city. The developed RTP was then compared with existing recommended RTP as published in MSMA (non-normalised) and HP 26 (normalised).

From the comparison, most of the fractions in the published RTPs have more than 20% differences when compared with the site specific RTP from the current study. Further studies can be conducted by using data from more rainfall stations located in Kuching city to obtain the mean RTP which is a more accurate representation. Besides that, study on climate change effects on the RTP can be conducted by comparing the RTP for the same site at different year or decade intervals.

Acknowledgements

The authors would like to acknowledge and thank Universiti Malaysia Sarawak for the financial support under the Malaysia Comprehensive University Network grant (Grant No. GL/F02/MCUN/15/2020). The authors also would like to express their gratitude to the Department of Irrigation and Drainage, Sarawak for the rainfall data used in this study.

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Appendix

Appendix 1: Non-normalised fraction of rainfall in each time interval for Kuching city

Duration (minutes)	Fraction of Rainfall in Each Time Period											
10	0.300	0.700	-	-	-	-	-	-	-	-	-	-
15	0.100	0.590	0.310	-	-	-	-	-	-	-	-	-
30	0.040	0.120	0.270	0.310	0.190	0.07	-	-	-	-	-	-
60	0.014	0.028	0.060	0.090	0.117	0.147	0.167	0.138	0.098	0.074	0.046	0.021
120	0.030	0.070	0.120	0.210	0.250	0.180	0.090	0.050	-	-	-	-
180	0.090	0.090	0.240	0.310	0.180	0.090	-	-	-	-	-	-
360	0.050	0.140	0.230	0.260	0.200	0.120	-	-	-	-	-	-

Appendix 2: Normalised fraction of rainfall in each time interval for Kuching city

Duration (minutes)	Fraction of Rainfall in Each Time Period											
10	0.700	0.300	-	-	-	-	-	-	-	-	-	-
15	0.100	0.590	0.310	-	-	-	-	-	-	-	-	-
30	0.070	0.270	0.310	0.190	0.120	0.040	-	-	-	-	-	-
60	0.046	0.117	0.098	0.147	0.167	0.138	0.090	0.074	0.060	0.028	0.021	0.014
120	0.090	0.180	0.250	0.210	0.120	0.070	0.050	0.030	-	-	-	-
180	0.090	0.090	0.310	0.240	0.180	0.090	-	-	-	-	-	-
360	0.200	0.140	0.260	0.120	0.230	0.050	-	-	-	-	-	-