MAPPING SPATIAL URBAN RAINFALL EXTREMES UNDER VARIOUS RETURN PERIODS IN KUALA LUMPUR FOR SUSTAINABLE URBANIZATION

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Abstract
Kuala Lumpur is a city characterized by a warm and humid climate throughout the year. Extreme rainfall occurrences and catastrophic floods in the city often have an impact on social, economic, and environmental structures. Rapid development and increase in population density caused the city more vulnerable to harmful consequences. The objective of this study is to estimate the return period and level of extreme rainfall in Kuala Lumpur. In this work, observed extreme rainfall of Kuala Lumpur was investigated over more than 30 years. The data were statistically analyzed using Generalized Extreme Value (GEV). Extreme rainfall assessment is viewed from the perspective of spatial analysis. Return periods of 20, 50, and 100 years of extreme rainfall showed an increasing trend. Four different rainfall aggregation periods considered in this study are 1, 3, 12, and 24 hours. At intervals of 20, 50, and 100 years, the spatial extreme rainfall distribution in Kuala Lumpur showed similar distributions for 1 hour to 24 hours. The three zones most vulnerable to flash floods caused by extreme rainfall identified: City Center, Damansara-Penchala, and Wangsa Maju-Maluri. Extreme rainfall analysis is crucial as it depicted the extreme rainfall behaviour in Kuala Lumpur for design planning purposes in sustainable urbanization and therefore devising strategies for future projected disaster risk.

Keywords: *Extreme value theory, Generalized Extreme Value, extreme rainfall, design rainfall.*

INTRODUCTION

Development is often the benchmark of a country's progress. The vibrant urbanization process in the cities of the country seems endless. The growth in population led to increased use of land to accommodate population and demand. The development is to ensure the construction of industrial areas, commercial hubs, residential areas, and road construction indirectly contribute to the physical changes. Hence, the physical changes of the environment caused implications for urban development, which contributes to the factors of environmental disasters (Anuar & Azlan Shah, 2016). The rapid urbanization process in Kuala Lumpur has also made the phenomenon of flash floods a serious environmental issue arising from the physical changes of the environment.

The flash flood phenomenon in Kuala Lumpur is closely linked to rapid development and has seen the reduction of green areas and forests as well as the replacement of natural surfaces with roofs and concretes that have restricted water absorption rates. Flash floods are already synonymous with Kuala Lumpur that due to various factors.. The major factor is urbanization and the second factor is natural factor comprising lithology, terrain, heavy rainfall, and river drainage system (Angel et al., 2018) and (Norashikin et al., 2018).

Urbanization influenced climate and hydrological cycles with soil closures and surface albedo, thereby additional heat released to the atmosphere and air pollutants emitted which caused the interactions with clouds and radiation (Marshall, 2005) and (Shouraseni & Fei, 2009). Research studies highlighted that high aerosol disruption leads to evaporation, which alters the rainfall locally and hence, the organization of stratocumulus clouds can be changed (Feingold et al., 2010) (Hailong & Graham, 2009). The presence of aerosols in convective clouds complicates the natural interactions of dynamic, thermodynamic, and microphysical processes. Thus, an imbalance in the energy cycle in the climate system leads to an increase in temperature and intensity of rain. The interaction of environmental components is known as dynamic and constantly changing with space and time.

The increased incidence of flash floods and landslides are due to increased rainfall intensity (Siti Jahara et al., 2021) and (Syafrina et al., 2015). Extreme rainfall phenomena are discussed globally due to its major caused of human losses associated with natural disasters as well as large-scale socioeconomic losses, especially in urban areas. Extreme rainfall has intensified since 1981 in urban areas of Kuala Lumpur compared to in its surrounding rural areas (Yafei et al., 2020). Some researchers predicted the increased precipitation and extreme rainfall worldwide (Niyogi et al., 2017) (Oliveira & Lima, 2019) (Zou & Ren, 2015). Thus, the rapid growth of the population created problems in sustainable development while maximizing the potential for destruction due to extreme rainfall.

The measurement of the rainfall return period is closely related to extreme rainfall and flash flood. Evaluation of the rainfall return period is very important in predicting the likelihood of extreme rainfall in the future. The frequency analysis is one of the most significant statistical approaches for predicting the likelihood of future extreme events with the reference of previous data (Nur Khaliesah et al., 2019). The extreme rainfall analysis has not received much coverage other than visual or graphical interpretation, in which difficult for decision-makers to resolve rainfall issues. The analysis should be conducted to minimize the effects of extreme rainfall in Kuala Lumpur. Extreme rain knowledge, as well as the use of statistics, are indispensable in sustaining the urban management and planning.

In this regard, this research studied on the issues highlighted for depth understanding because of its significant impact on the social, economic, and infrastructural aspects of the city. This study will pave the way of state-of-the-art research area on this extreme rainfall for return period and its level particularly in Kuala Lumpur. The objective of this study is to estimate the duration and extent of extreme rainfall in Kuala Lumpur.

METHODOLOGY

Study Area

Kuala Lumpur is the heartbeat of the Malaysian capital and is the most advanced and compact city in Malaysia. Kuala Lumpur is located in Peninsular Malaysia in the middle of the state of Selangor located at 3° 8 'North and 101° 41' East. Kuala Lumpur is the capital and largest city in Malaysia with an area of 244 square kilometres. It is located within Klang Valley that borders the Titiwangsa Range to the east, some of the lowlands to the north and south and the Straits of Malacca to the west. Klang and Gombak rivers run through the centre of this metropolitan city. The Klang River Basin is Malaysia's fastest growing drainage basin.

A valley denominated after the Klang River called Klang Valley embodies the unique features of the city (Tariqur Rahman et al., 2018). The rainfall is abundant during the inter monsoonal period around March to April and September to October and it is additionally kenned that convective rainfall frequently occurs on the West Coast of Peninsular Malaysia. (MMD, 2009).

The city of Kuala Lumpur was chosen as the study location because it serves as the country's economic and social hub. Kuala Lumpur's rapid development has a complex impact on the city's physical environment. The main goal of this study is to investigate the relationship between the phenomenon of extreme rainfall and flooding, as well as to evaluate the development design perspective using extreme rainfall analysis.

Data Sets

This study is based on the rainfall data based on hours and the data obtained for the period of 30 to 42 years, from 1976 to 2017. Nine stations are selected as the study stations in this research. Record availability data varied by the station, in which certain stations recorded a high percentage of data loss. The missing data percentage was less than 15% and the data were considered missing in this study (Mardhiyyah et al., 2015). Only extreme values are considered in this study, so the extreme value data is considered to be available. The basic information of the data source and percentage of the data as shown in Figure 1 and Table 1.

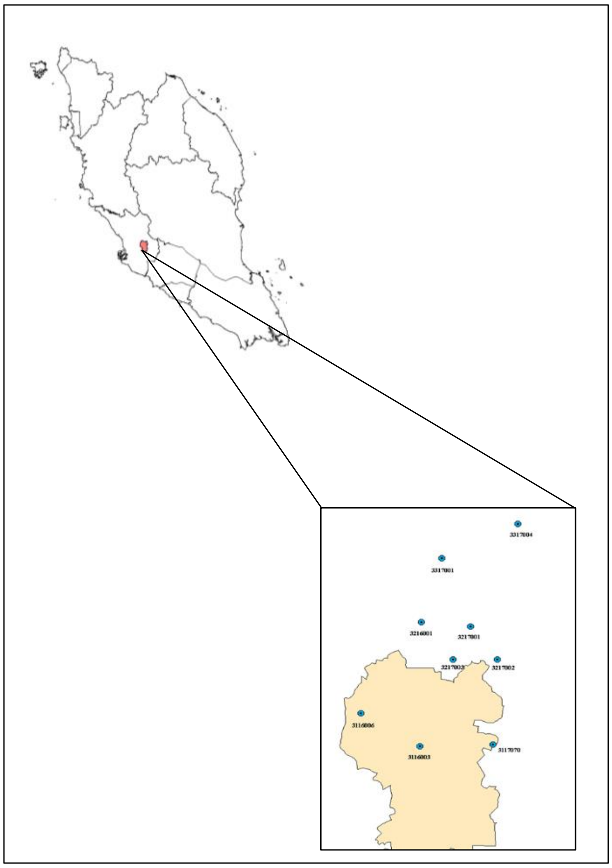

Figure 1. Study Location

Table 1. Station Information

Station ID	Station Name	Latitude (U)	Longitude (N)	Gaps (%)
3116003	Ibu Pejabat JPS	3° 09' 05"	101° 41' 05"	2.4
3116006	Ladang Edinburgh	3° 11' 00"	101° 38' 00"	2.4
3117070	Pusat Penyelidikan Ampang	3° 09' 11"	101° 44' 56"	2.4
3216001	Kg. Sg. Tua	3° 16' 20"	101° 41' 10"	11.9
3217001	Ibu Bekalan KM16	3° 16' 05"	101° 43' 45"	0
3217002	Empangan Genting Kelang	3° 14' 10"	101° 45' 10"	2.4
3217003	Ibu Bekalan KM11	3° 14' 10"	101° 42' 50"	0
3317001	Air Terjun Sg. Batu	3° 20' 05"	101° 42' 15"	0
3317004	Genting Sempah	3° 22' 05"	101° 46' 15"	14.3

Generalized Extreme Value (GEV)

Various methods are used through various distribution functions to identify the characteristics of rainfall distribution. The selection of the best probability distribution function using rainfall data is of interest to researchers in the field of hydrology. Most of the theory of probability applied in hydrology includes Normal Distribution, LogNormal, Pearson III, Log-Pearson III, Exponential, Gumbel, Generalized Extreme Value (GEV), Generalized Pareto Distribution (GPD), Generalized Logic and Power Law. Extreme Theory Value was first discovered by Fisher and Tippett (1928), and Gnedenko (1943) formulated the maximum block of distribution of Extreme Value (EV) with the incorporation of three single models, Gumbel, Frechet and Weibull introduced by Jenkinson (1955).

The continuous development of extreme rainfall is gaining attention in Malaysia and some researchers found that GEV is the most suitable source for analyzing extreme rainfall in Malaysia (Annazirin et al., 2013); (Noratiqah et al., 2013); (Syafrina et al., 2019). Accordingly, the GEV distribution is chosen in this study to analyze the extreme rainfall in the study area. The GEV distribution is then divided into three; namely Gumbel, Frechet and Weibull. This GEV distribution consists of three types of distributions:

Type I (EV1) extreme distribution for κ = 0, Type II (EV2) distribution for $\kappa < 0$ and Type III for $\kappa > 0$ (Martins & Stedinger, 2000). The analysis of extreme rainfall distributions is classified into annual Extremes (AE) and Partial Duration (PD) series (Wan Zawiah et al., 2009). The AE method involved the selection of the maximum annual rainfall value. GEV is widely used in extreme events such as floods, droughts, sea levels and storms (Syafrina et al., 2019). The probability density function and the cumulative distribution function for the GEV distribution are, as equations (1) and (2):

$$f(x) = \frac{1}{\alpha}\left(1 - \frac{\kappa}{\alpha}(\chi - \varepsilon)\right)^{\frac{1}{\kappa}-1} eksp\left(-\left[1 - \frac{\kappa}{\alpha}(\chi - \varepsilon)\right]^{\frac{1}{\kappa}}\right) \tag{1}$$

$$F(x) = \begin{cases} eksp\left(-\left(1 - \frac{\kappa}{\alpha}(\chi - \varepsilon)\right)^{\frac{1}{\kappa}}\right), & if \;\; \kappa \neq 0 \\ eksp\left(-eksp\left(-\frac{1}{\alpha}(\chi - \varepsilon)\right)\right), & if \;\; \kappa = 0 \end{cases} \tag{2}$$

The ε, α and κ parameters are referred to location, scale, and shape parameters, respectively. The value of the κ parameter affected the range of random variables χ. When the value of κ is negative, the variable X is in the range $\varepsilon + \frac{\alpha}{\kappa} < \chi < \infty$, thus suitable for analysis of extreme conditions such as maximum rainfall. However, if the value of κ is positive, the variable X is within the range $-\infty < \chi < \varepsilon + \frac{\alpha}{\kappa}$, and has the upper limit here, thus its best suited to the study of extreme condition such as the minimum streamflow. If the parameter value is κ = 0, the GEV distribution is the Gumbel distribution and is also known as the Extreme Type 1 (EV1) distribution. The quantile function known as the cumulative distribution function of the GEV distribution is represented by:

$$Q(F) = \varepsilon + \frac{\alpha}{\kappa}\left(1 - (-\ln(F))^{\kappa}\right) \tag{3}$$

Extreme rainfall return values during the T-year, xt can be obtained when the estimates of parameter values of ε, α and κ are obtained. The rainfall period, xt is expressed as follows:

$$x_t = \varepsilon + \frac{\varepsilon}{\kappa}\left(1 - \left(-\ln\left(1 - \frac{1}{T}\right)\right)^{\kappa}\right) \tag{4}$$

Estimation of extreme rainfall over the 100-years period can be generated using GEV. The 100-years extreme events expected to occur with a probability of 1/100 at a return level are estimated. The estimation for the distribution parameters used in this study by using the L-moment method. The L-moment method is an appropriate parameter estimation method for estimating extreme parameters for small data samples (Richard M. & Neil M., 1993). Generally, the location parameter (ε) indicated the average of something or the position of the distribution. The positive ε parameter value indicated that the distribution position is shifted to the right whereas the negative ε value indicated that the distribution position shifts to the left. The scale parameter (α) in turn demonstrated the scattering size of the distribution. While, the shape parameter (κ) denoted as the shape or inclination of the angle of distribution whether it is inclined to the left or to the right. A large κ value will make a sloping distribution to the right and a small κ value will influence the sloping distribution to the left.

Goodness of Fit

Three goodness of fit tests were conducted in this study, namely, Kolmogorov-Smirnov Test (KS) test, Anderson Darling test (AD) and Chi-square test. The theoretical distribution is selected as the most appropriate model for extreme rainfall forecast in each data set, along with test statistics, by observing the significance values (p-values), as well as critical values for significant levels. The best distribution will be selected by identifying the p-value of the AD test that is greater than the significance level of 0.05 as well as the largest p-value of each distribution. The chi-square test is to be assessed at a significance level of 0.05. The lowest chi-square statistical value yielded a large p-value, and this proved the best fit. Comparison of statistics with KS, AD and Chi-square tests respectively for the goodness of fit showed that the most suitable distributions for each station are L-moment values (0.997,0.920 and0.648). All three tests suited at the 0.05 significance level proved GEV distribution is consistent with the extreme rainfall data set.

Kolmogorov-Smirnov Test (KS)

The KS test is performed by comparing the observed distribution and the frequency distribution obtained from the alternating process distribution of the update. This test is used to determine whether the sample is derived from the hypothetical continuous probability distribution function. The test is based on the largest vertical difference between the theoretical and empirical cumulative distribution functions. For random variables X and samples (x1, x2, ... xn) the empirical cumulative distribution function X (Fx (x)) is represented by equation (5):

$$F(x) = \frac{1}{n}\sum_{i=1}^{n} I(x_i \le x) \tag{5}$$

that is, *I* (condition) = 1 if true and vice versa.

The two cumulative distribution functions F_x and F_y, the Kolmogorov-Smirnov test statistics (D_+ and D_-) are represented by:

$$D_+ = {}^{max}_{\ \ x} \left(F_x(x) - F_y(x)\right) \tag{6}$$

$$D_- = {}^{max}_{\ \ x} \left(F_y(x) - F_y(x)\right) \tag{7}$$

Anderson Darling Test (AD)

The Anderson Darling (AD) test presented by Anderson and Darling (1954) is one of the adaptive goodness tests used to select the non-parametric distributions in this study. According to Stephens (1976), the AD tailoring efficiency test provides a better fit than the Pearson chi-square test for small data samples. AD statistical tests can be represented as:

$$AD = -n - \frac{1}{n}\sum_{i=1}^{n}(2i-1)\,[\ln F(y_i) - \ln(1 - F(y_{n+1-i}))] \tag{8}$$

with i = 1,2, ..., n.

F(.) is the cumulative distribution function of a particular distribution, yi is the observation of -i and n is the number of observations. The best distribution will be selected by identifying the Anderson Darling test p-value greater than the significance level of 0.05 as well as the largest p-value for each distribution.

Chi-square Test (CS)

CS test is calculated based on the difference in the frequency of the observation distribution and the frequency produced by the distribution of the alternating process of the update. Pearson chi-square adaptability test is represented as the following equation:

$$X^2 = \sum_{i=1}^{nc}\frac{(O_i - E_i)^2}{E_i} \tag{9}$$

O_i = observation frequency,

E_i = the frequency produced by the distribution of the process of alternating updates for the extreme and nc = the number of cases.

This study set the CS test to be assessed to have a significance level of 0.05. The lowest chi-square statistical value yielded a large p-value, and this proved the best fit.

Spatial Interpolation Techniques

There are several modules in GIS applications to conduct interpolation analysis including Inverse Distance Weighted (IDW), Kringing, Spline and Topo to Raster (Fatih && Faruk, 2019). The IDW method is based on the assumption that the surface to be interpolated should be affected by the nearest point and at least by the farthest point. The IDW interpolation method is a good medium to foster understanding and analyze rainfall incidence (Muhammad Fikri & Nor Eliza, 2016). The IDW method is utilized in this study to visually examine the spatial correlation and extreme rainfall analysis.

Nine rainfall stations have been used to analyze the distribution rainfall depth pattern by using the IDW spatial interpolation technique in this study. The increment values of all the return periods of different extreme rainfall events are estimated and interpolated utilizing the IDW method to prepare a contour map to display the spatial variability in increment values.

RESULTS AND DISCUSSION

Determination of GEV for Extreme Rainfall

Extreme rainfall data according to the time interval is then matched to the GEV Distribution. The GEV is fitted to extreme rainfall time series obtained from the rain gauge stations. The parameters of the fitted distribution are estimated by the L-moments, as in Table 1.

Table 1. Parameter Estimation Using L-Moments

Hour	Parameter	Station ID								
		3116003	3116006	3117070	3216001	3217001	3217002	3217003	3317001	3317004
1	ε	67.7	65.9	67.9	53.6	60.6	60.1	62.5	64.4	58.6
	α	11.4	21.1	15.0	12.2	13.1	14.3	16.4	13.1	14.3
	κ	-0.03	-0.30	-0.21	-0.28	-0.11	-0.15	-0.25	-0.22	-0.20
3	ε	79.9	81.5	82.0	65.6	80.6	79.6	82.3	80.6	74.0
	α	14.9	25.0	18.9	14.1	15.2	17.4	18.7	15.2	13.4
	κ	0.00	-0.35	-0.15	0.00	-0.05	-0.24	-0.33	-0.05	0.03
12	ε	86.4	87.2	92.8	71.3	87.1	89.1	88.0	90.0	81.2
	α	17.1	26.0	21.6	15.1	16.2	21.5	18.0	18.0	15.0
	κ	0.00	-0.36	-0.30	0.00	-0.09	-0.35	-0.11	0.00	0.00
24	ε	97.2	97.8	103.0	93.4	98.8	96.7	99.6	100.3	93.7
	α	18.3	36.3	23.7	14.5	18.2	23.7	24.9	20.7	14.9
	κ	0.00	-0.17	-0.12	0.00	-0.11	-0.17	0.00	0.00	0.00

In general, the location parameter, ε indicated the average of the distribution. A positive parameter value ε demonstrated the position of the distribution shifts to the right and the negative value of ε showed the position of the distribution shifts to the left. The scale parameter, α in turn indicated the size of the distribution. Whereas, the shape parameter, κ demonstrated the tendency of the skewness of distribution either sloping to the left or to the right. A large value of κ displayed a sloping distribution to the right and a small value of κ affected the sloping distribution to the left.

Goodness of Fit

Nine sets of extreme rainfall data matched the theoretical distribution of extreme values that best suited the KS goodness of fit test. The theoretical distribution selected as the most suitable model for extreme rainfall forecast in each data set, along with the observed significance values (p-values), and critical values for significant levels are expressed in Table 2.

Table 2. Goodness of Fit (GoF)

Hour	Parameter	Station ID								
		3116003	3116006	3117070	3216001	3217001	3217002	3217003	3317001	3317004
1	KS	0.947	0.312	0.477	0.438	0.771	0.665	0.632	0.65	0.354
	AD	0.147	0.412	0.871	0.711	0.327	0.87	0.698	0.753	0.601
	CS	0.050	< 0.0001	0.379	0.132	0.045	0.254	< 0.0001	0.124	< 0.0001
3	KS	0.833	0.529	0.404	0.987	0.605	0.319	0.196	0.154	0.916
	AD	0.003	0.190	0.439	0.754	0.01	0.333	0.555	0.590	0.548
	CS	0.099	< 0.0001	0.098	0.014	0.055	0.227	< 0.0001	0.0026	0.334
12	KS	0.886	0.506	0.235	0.984	0.682	0.211	0.811	0.715	0.785
	AD	0.017	0.198	0.591	0.826	0.009	0.778	0.433	0.005	0.786
	CS	0.648	< 0.0001	0.001	0.051	0.214	0.024	0.107	0.006	0.156
24	KS	0.742	0.234	0.178	0.568	0.81	0.363	0.737	0.786	0.254
	AD	0.004	0.002	0.007	0.525	0.39	0.432	0.058	0.011	0.214
	CS	0.110	< 0.0001	0.043	0.621	0.233	0.115	< 0.0001	0.275	0.128

The best distribution will be selected by identifying the p-value of the AD test to be greater than the significance level of 0.05 and the largest p-value of each distribution. This study set the CS test to be assessed at a significance level of 0.05. The lowest chi-square statistical value yielded a large p-value, and this proved the best of the best fit. Comparison of statistics with KS, AD and KKD tests respectively for the goodness of fit test showed that the most suitable distribution for each station is L-moment values (0.987, 0.871 and 0.621). All three test suitability tests at the 0.05 significance level proved that the GEV distribution was consistent with the extreme rainfall data set.

Estimation and Mapping of the Extreme Rainfall Return Period

The frequency of extreme rainfall often results in disasters and impacts on life. The extreme rainfall phenomenon in Kuala Lumpur has notable impacts on economic, social, and environmental. This phenomenon is difficult to predict and is comonly associated with high rainfall intensity, as extreme rainfall usually occurred over a short period.

In general, all stations showed an increasing trend for each recorded extreme rainfall period and recorded some peaks for the highest extreme rainfall. The increase in the trend of extreme rainfall is first detected around the 1980s and showed a steadily increased. The increase in extreme rainfall can trigger the phenomenon of flash floods around the city of

Kuala Lumpur, which in turn is also capable of causing landslides. Extreme rainfall is a major cause of natural disasters as it led to severe erosion, potentially increased soil loss and rapid sediment movement and lead to landslides and flash floods, and consequently posed a threat to life and property (Römkens et al., 2002) (Santiago & Sergio M., 2006).

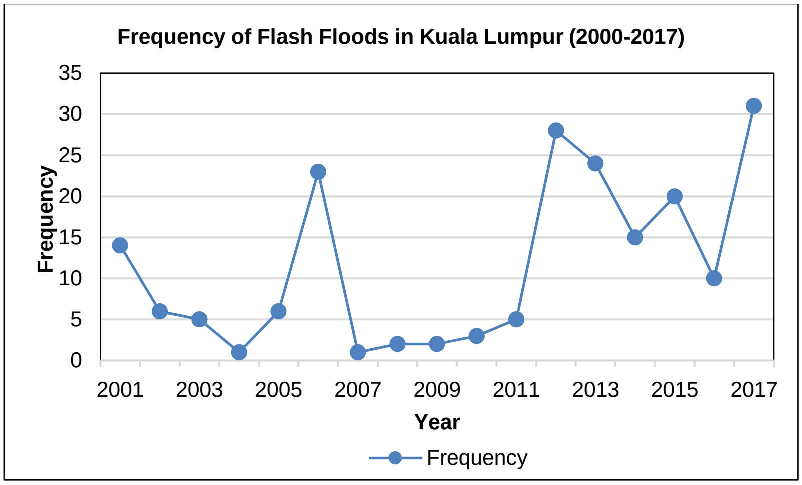

Figure 2. Frequency of Flash Floods in Kuala Lumpur (2000-2017)

Figure 2 shows the frequency and increase of flash floods that occurred in Kuala Lumpur for a period of 17 years from 2000 to 2017. A total of 201 cases of flash floods occurred in Kuala Lumpur during that period. Three maximum peaks were detected and 24 and 29 cases recorded respectively in 2005 and 2011. It can be observed that the third peak detected as the highest frequency recorded in 2017 with 31 cases of the flash floods that occurred in Kuala Lumpur. From 2006 to 2010, the number of flash flood events recorded was low with less than 5 cases, yet showed the increasing trend. The highest recorded rainfall of 113.4mm in 2013 for one hour. The frequency classification of flood areas has been carried out and it was found that the City Center of strategic zones as the most frequently experienced flash floods (Tariqur Rahman et al., 2018). The rapid development and population density was clearly influenced the frequency events of flash floods.

Flash floods occurred frequently during the inter monsoonal period in April and May, and October and November. The inter-monsoons were characterized by multifaceted wind patterns as well as unstable atmospheric conditions. Skies are usually clear and cloudy in the morning and this helps the formation of thunderstorms in the afternoon. Convection clouds and stratus clouds produced different rainfall intensities (Nordila et al., 2006). Convection clouds typically bring convection rains, which are dense in a short period of time. The intensity of rainfall depends on the processing of water vapour in the clouds. High-intensity rainfall has the tendency to occur over a short period of time in the tropics, while the low-intensity rainfall has a longer duration. Convection rain is divided into three types based on duration and intensity, namely rain episode less than six hours, and high intensity, medium, medium-term rain episodes (between 6 and 72 hours) and high intensity and long term episodes (about 1 week) with low increase intensity value. Types of rainfall (1) are widely detected in urban areas and caused flash floods (Barnolas & Llasat, 2007) (Nordila et al., 2006).

Return Levels of Extreme Rainfall for 20, 50 and 100 Years Return Period

The GEV distribution has proven to be appropriate in this study to determine the value of extreme rainfall estimation for the return periods of 20, 50 and 100 years. The return level obtained from the series of extreme rainfall return periods that formulated by selecting the highest value of extreme rainfall estimation, as shown in Table 3.

Table 3. Highest Value of Extreme Rainfall Estimation

P = 1/T	Return periods T-years, x	1 hour (mm)	3 hours (mm)	12 hours (mm)	24 hours (mm)
0.05	20	101.2	132.4	163.3	191.2
0.02	50	107.7	147.0	186.7	236.2
0.01	100	113.4	159.2	204.7	277.9

Information on spatial variation from the extreme rainfall estimation is crucial for ungauged locations. Accordingly, the manipulation of GIS data and capabilities in providing geographic and statistical representations of space is used to map the extreme rainfall distribution in the study area for the return period at different time intervals. The strategic zone of Kuala Lumpur is as shown in Figure 3.

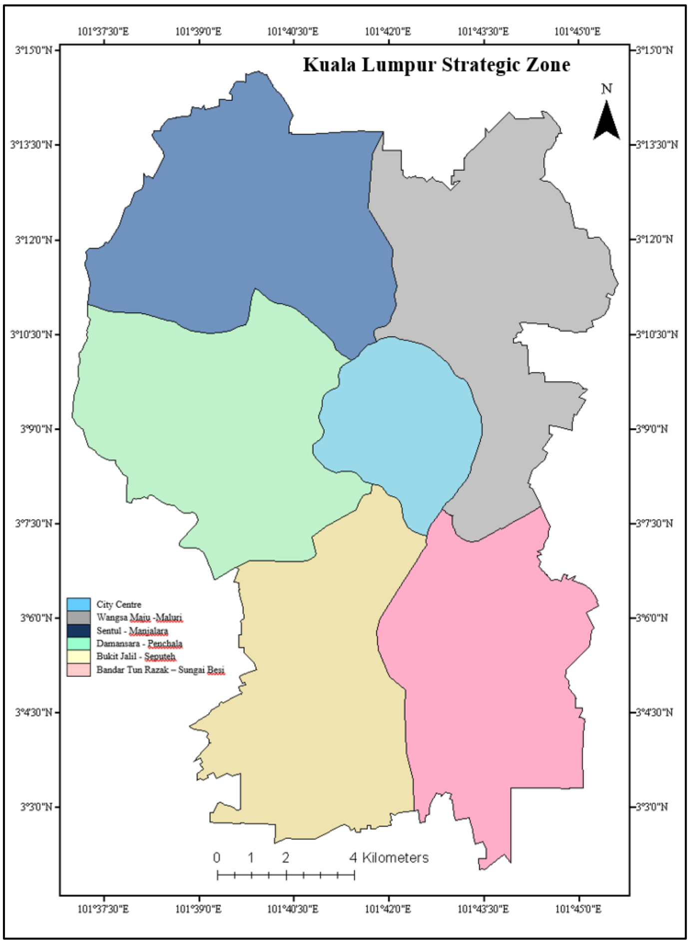

Figure 3. Kuala Lumpur Strategic Zones

Extreme Rainfall for a Return Period of 20 Years

The series of extreme rainfall for a return period of 20 years is shown in Figure 4. The highest estimated rainfall in the one-hour interval is estimated at 101.2mm. The City Center zone maintains the main focus during the 20-year return period, followed by the Damansara-Penchala and the Wangsa Maju-Maluri zones. At one-hour intervals, the three zones estimated extreme rainfall of 98.5mm, 101.0mm and 100.5mm. The other three zones involved Bukit Jalil-Seputeh, Bandar Tun Razak-Sg. Besi and the Sentul-Manjalara showed high rainfall estimates at the intervals of less than six hours, around 101.2mm to 148.6mm. Although these other three zones are not included in the focus zone, it is found that these zones are also vulnerable to flooding.

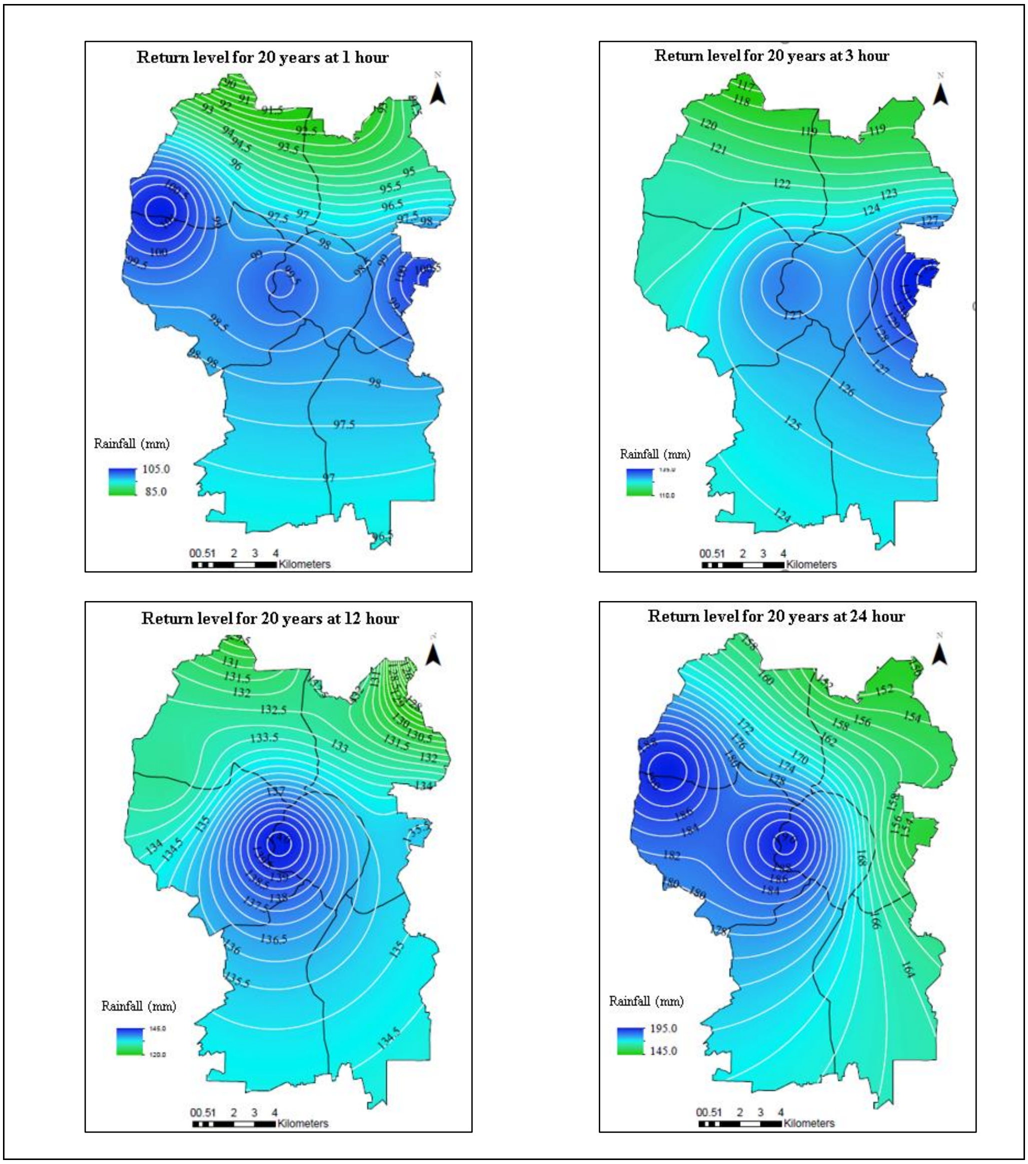

Figure 4. Return Level for 20 Years at Various Hour

Rainfall Design for A Period of 50 Years to 200 Years

Rainfall design for a period of 50 years to 200 years is considered to be in a large range (Johnson & Smithers, 2019). This study is important for high-risk hydraulic structure design as it is more suitable in predicting flooding for a period of 100 years and maximum likelihood (Green et al., 2016). The series of extreme rainfall for 50 years return period is shown in Figure 5. At intervals of less than six hours, the estimated maximum rainfall over a period of 50 years is at 107.7mm to 147.0mm. The City Center zone indicated as a high concentration and high-risk zone of experiencing the phenomenon of extreme rainfall. Next, both Damansara-Penchala and Wangsa Maju-Maluri zones are expected to be the second-highest zones. Over a 50-year period, the anticipated maximum rainfall at more than six-hour intervals ranged from 186.7mm to 236.2mm, with a concentration on the City Center zone.

A return period of 100 years of extreme rainfall over a short interval is expected at 113.4mm to 159.2mm. At intervals 12 to 24 hours, extreme rainfall is expected at 204.7mm to 277.9mm. Following that, the period of 100 years of extreme rainfall is depicted in Figure 6.

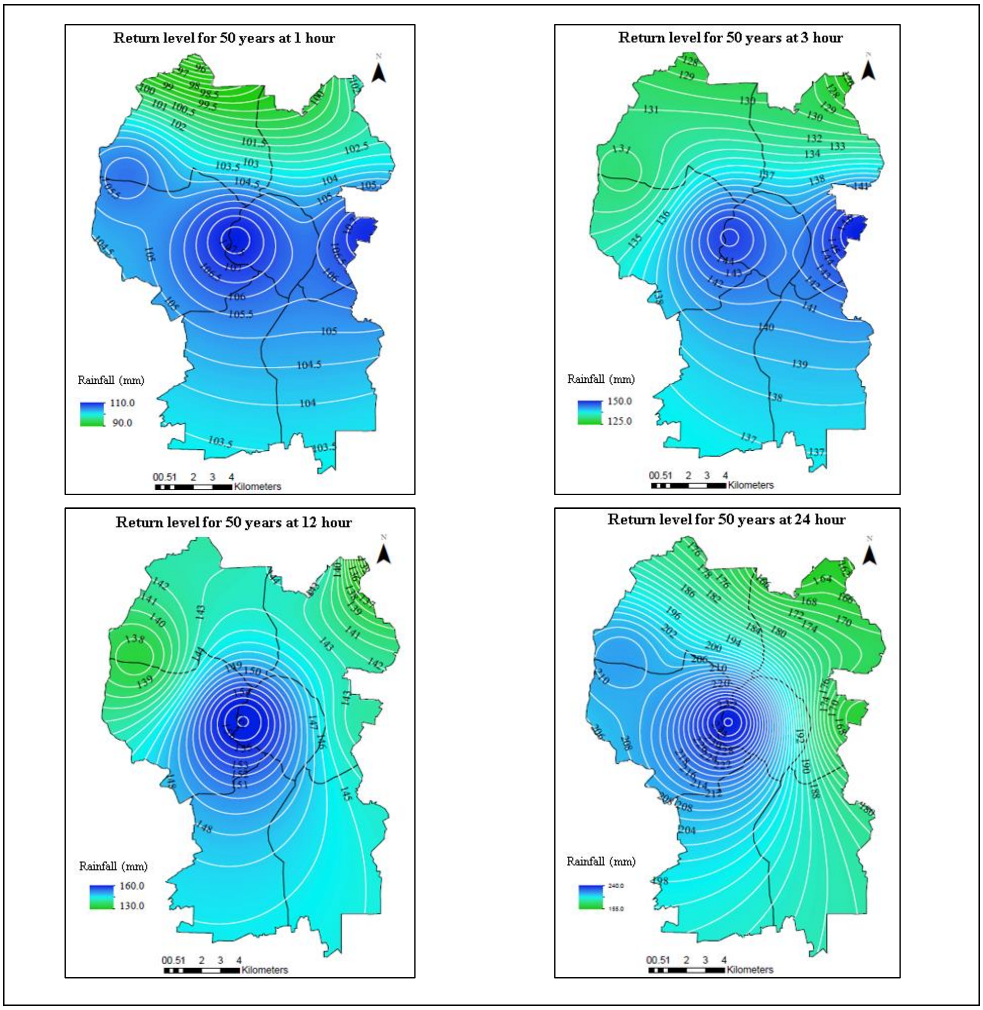

Figure 5. Return Level for 50 Years at Various Hour

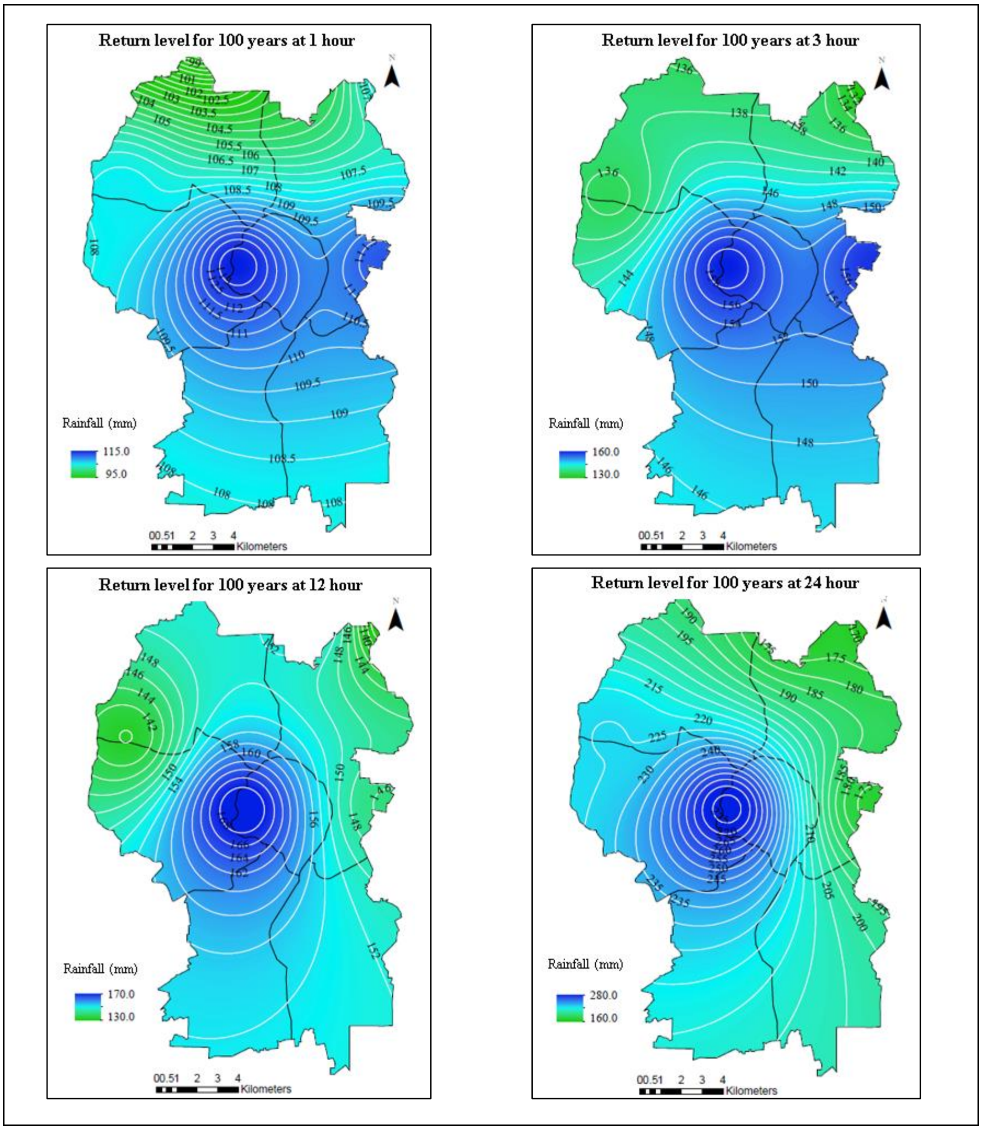

Figure 6. Return Level for 100 Years at Various Hour

CONCLUSION

Return periods maps were developed to evaluate spatial analysis for 20, 50 and 100 years. All values of the extreme rainfall return period in this study formulated three critically critical zones that are vulnerable to flooding. The three zones most at risk of flash floods due to extreme rainfall, namely the City Center, Damansara-Penchala and followed by Wangsa Maju-Maluri. The extreme rainfall map is able to see the extent of spatial distribution, besides being able to estimate the possibility of disasters occurring in the locations. This study also contributed to the identification of stable and non-critical zones for sustainable urbanization.

Mapping the return period from extreme rainfall was performed to gain a better understanding of the data, which is used to determine the long-term risks The extreme rainfall analysis map provided the research area's susceptibility as well as indicated the stable areas with different types of development and socio-economic activity. This study provided the input on the resilience of new infrastructure designs for the future in particular involving extreme rainfall, critical for risk assessment, encouraging the development of better risk models, and significantly reducing the destruction caused by rainfall-related disasters (Pereira et al., 2010). It will aid in the planning, strategizing, and formulating appropriate policies to mitigate the risks to environmental sustainability.

The focus of the current solution should consider adaptation, vulnerability and resilience to disasters. Specific solutions that should be given attention to structure the solutions by taking into account the balance that can be matched with natural changes. The development of the study required the integration of disaster risk and risk management approaches with comprehensive development design as well as considering several aspects such as social, cultural, ethical, political, economic and legal.

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