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The Effect of Changes in Land Use and Rainfall on Flood Discharge in Batang Watershed in 2012 and 2022

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ABSTRACT

The Batang Watershed is located in Kalidoni District and is one of the watersheds that frequently experiences flooding in Palembang. Kalidoni District had a population of 126,207 people in 2021, with an area of 27.92 km2. It is a flood-prone area with a high classification. This research aims to analyse the flood discharge of the Batang watershed in Palembang City using the Rational method based on changes in land use and the amount of rainfall that occurred in 2012 and 2022. The results of the analysis of flood discharge in the Batang watershed have increased from 2012 to 2021. Factors that lead to increased discharge include high rainfall, with a value of 144.33 mm in 2012 and 168.68 mm in 2022. Changes in land use in the Batang watershed in the form of residential buildings and roads have significantly increased. However, land use in Paddy fields and fields also experienced a significant increase, so many catchment areas are still available in the Batang watershed. The results of the flood discharge analysis with a return period of 10 years showed an increase in flood discharge of 33.01%; the flood discharge in 2012 was 22.23 m3/s, and in 2022 it was 29.68 m3/s.

1. Introduction

Flooding is an event of overflowing river water that is stagnant in low-lying areas and cannot be drained [1,2]. Factors causing floods can be natural factors and human factors. Natural factors are caused by high rainfall intensity in areas with low geographical structure. Human factors can be caused, among others, by population growth, which causes much development, resulting in increased surface runoff and waste [3-10].

Palembang City is the capital of South Sumatra Province, which topographically, includes lowlands with an altitude between 12-30 m above sea level, which the Musi River bisects with nineteen drainage systems, each of which serves a different catchment area unit, so Palembang City is prone to inundation or flooding [11]. On the Musi River, there are 21 watersheds in Palembang. The Batang watershed is one of the watersheds that often experiences floods in Palembang. Several

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watersheds often experience flooding in Palembang, including Lambidaro, Boang, Sekanak, Bendung, Buah, Juaro, Batang, Sriguna, Aur, and Kertapati watersheds [12].

Batang watershed is located in the Kalidoni sub-district of Palembang City. Kalidoni District had a population of 128.463 people in 2022, with an area of 27.92 km^2 [13]. In the last 10 years, the annual population growth rate from 2012 to 2022 reached 3,39% [13]. The increase in population around the watershed can cause changes in land use with increased development, resulting in reduced water catchment land because these buildings cover it [14].

Based on the map of flood-prone areas in Palembang according to the Palembang City Bappeda (2022), Kalidoni District is a flood-prone area with a high classification. The drainage system is not good enough, is a problem in the Kalidoni sub-district, and there is still a lack of public awareness of the surrounding environment and a lack of cooperation with parties who regulate the spatial planning system so that during the rainy season it can cause flooding [12].

Several researchers have previously conducted research on the leading causes of flooding due to changes in land use and climate change [14-17]. Based on research conducted by previous researchers, this research will analyse flood discharge due to changes in land use and rainfall intensity in 2012 and 2021 in the Batang watershed. This research aims to determine how much influence land use changes and rainfall intensity have on the Batang watershed. Several methods can be used to calculate flood discharge. Calculate flood discharge in the Batang watershed using the rational method [18,19]. The Batang Watershed has an area of 309,495 hectares based on SNI 2415-2016. The rational method can be used to calculate flood discharge with a watershed area of less than 5000 hectares, so it can be used to calculate flood discharge in the Batang Watershed, Palembang City.

2. Research Method

2.1 Land Use

Land use is a process of managing or arranging land use into several parts of the area with certain functions. According to the Basic Agrarian Law, Land Use is the structure and pattern of land use, whether planned or not, which includes land supply, land allocation, land use and maintenance [20]. Preparation of Detailed Spatial Planning and District/City Zoning Regulations, land use is classified into several parts, namely housing, trade and services, government, industry, public services, green and non-green open spaces, and others [21].

2.2 Analysis Hydrology

Hydrological analysis is the first step in the design of hydraulic buildings in the form of the probability of hydrological events in the form of planned discharge/rainfall [22-24]. In hydrological analysis, a very important factor is the magnitude of flooding that can occur with a certain repeat period (return period). The data needed to conduct hydrological analysis is rainfall data obtained from several rain recording stations with data recording for at least 10 years. Based on the frequency analysis, the maximum annual rain amount that may occur in a certain repeat period will be obtained, then the desired rain plan can be set for further calculations [22-24].

2.3 Frequency Analysis

This frequency analysis is based on the statistical nature of past event data to obtain the probability of the magnitude of the upcoming rainfall. The purpose of frequency analysis is to estimate the hydrological variables of the plan for a given recurrence period relating to extreme events against the frequency of their occurrence using the application of probability distributions [22-24]. In determining the rain plan, frequency analysis with various recharges is used based on the most appropriate distribution between the theoretical and empirical distribution of rain. In frequency analysis, maximum daily rainfall data is needed each year taken from rain measuring posts, both manually and automatically. Frequency analysis uses maximum daily rainfall data from the Kenten rain gauge station from 2002 to 2021 from the BMKG of Palembang (Meteorology, Climatology and Geophysics Agency). The rainfall data will be processed with various re-periods using probability distributions which will then be tested for suitability against the probability distribution.

Frequency analysis in hydrology uses distributions, namely normal, log normal, Gumbel, and log Pearson III, each distribution has different characteristics in describing extreme rainfall data patterns. In hydrological frequency analysis, it is essential to choose a distribution that suits the nature of the existing data, such as data that is extreme, asymmetrical, or has wide variations. Choosing the right distribution can provide more accurate estimates of extreme events.

Before proceeding to the flood discharge analysis stage, frequency analysis aims to test the distribution and statistical parameters so that a suitable method is obtained for the rainfall data used in this research [25]. After that, a suitability test was carried out using Chi-Square and Kolmogorov – Smirnov [26].

2.3.1 Normal distribution

In the calculation of the normal distribution, there are statistical parameters to be used, namely the amount of data (n), the average value ($\overline{x}$), and the standard deviation (Sd). The normal distribution Eq. (1) is as follows:

$$X_T = \overline{x} + K_{Tr}\, S \tag{1}$$

Where,
X_T = Rain plan period T year
$\overline{x}$ = Average value of rain data (X) mm
S = Standard deviation from rain data (X) mm
K_{Tr}= Frequency factor, the value depends with T (See Table of reduction variables Gauss

2.3.2 Log normal distribution

The calculation of the log-normal distribution is performed the same as the normal distribution, with the value of the X data converted into a logarithmic form. The log-normal distribution Eq. (2) is,

$$\log X_t = \log \overline{x} + K_{Tr}\, S_{\log x} \tag{2}$$

Where,
X_t = Rain plan with a return period T year
Log $\overline{X}$ = Average logarithmic value
$S_{\log X}$ = Standard deviation of logarithmic value
K_{Tr}= Frequency factor of log-normal 2 parameters, is a function of the coefficient of variation Cv and the return period

2.3.3 Gumbel distribution

The calculation of the distribution of lumps can use the following Eq. (3),

$$X_t = \bar{x} + \frac{Y_t + Y_n}{S_n}\, S \tag{3}$$

Where,
Log X_T = Plan rain logarithmic value with a return period T
Log $\bar{x}$ = Average value in logarithma
S_{Logx} = Standard deviation in logarithma
K_{Tr} = Frequency factor, the value depends on T

2.3.4 Log person III distribution

According to a researcher, the calculation of the log person III distribution uses the following Eq. (4),

$$\log X_t = \log \bar{x} + K_{Tr}\, S_{\log x} \tag{4}$$

Where,
X_t = Large variable with a return period of T years
$\bar{x}$ = Average rating
S = Standard deviation
Y_t = Reduced variate
Y_n = Average price of reduced variate
S_n = Standard deviation from reduced variate

2.4 Rainfall Intensity

Rainfall intensity is the height or depth of rainwater in a certain period of time where the water is concentrated in mm/hour. Rainfall intensity expresses the amount of rainfall in the short term by presenting a picture of heavy rain per hour. The amount of rainfall intensity varies depending on rainfall-runoff or the frequency of its occurrence. In general, rainfall intensity consists of hourly rain data using the Talbot, Sherman, or Ishiguro equations and daily rain data using the Mononobe and ABM equations. If daily rain data is available, you can use the Mononobe Eq. (5) as follows:

$$I = \frac{R_{24}}{24} \cdot \left(\frac{24}{tc}\right)^{2/3} \tag{5}$$

Where,
I = Rain intensity for t (mm/h)
R_{24} = Rainfall (mm/day)
tc = Concentration time (hours)

2.5 Flood Discharge Rational Method

This method is one of the methods used in calculating peak discharge. According to SNI 2415:2016 concerning procedures for calculating planned flood discharge, the rational method is a method that shows the relationship between runoff and rainfall [19,27], this method can be used in watersheds with an area of up to 5000 hectares [1]. The rational method discharge Eq. (6) is:

$$Q = 0{,}00278 \cdot C \cdot I \cdot A \tag{6}$$

Where,
Q = Peak flood discharge (m^3)
C = Drainage coefficient
I = Rain intensity for a certain repeat period (mm/hour)
A = Area of drainage area (Ha)

3. Methodology

This research is in the Batang watershed located in Kalidoni District, Palembang City (Figure 1). This watershed is directly adjacent to the Selicah, Juaro, Borang, and Aur watersheds. The Batang watershed has an area of 309,494 ha with a main river length of 2,342 meters.

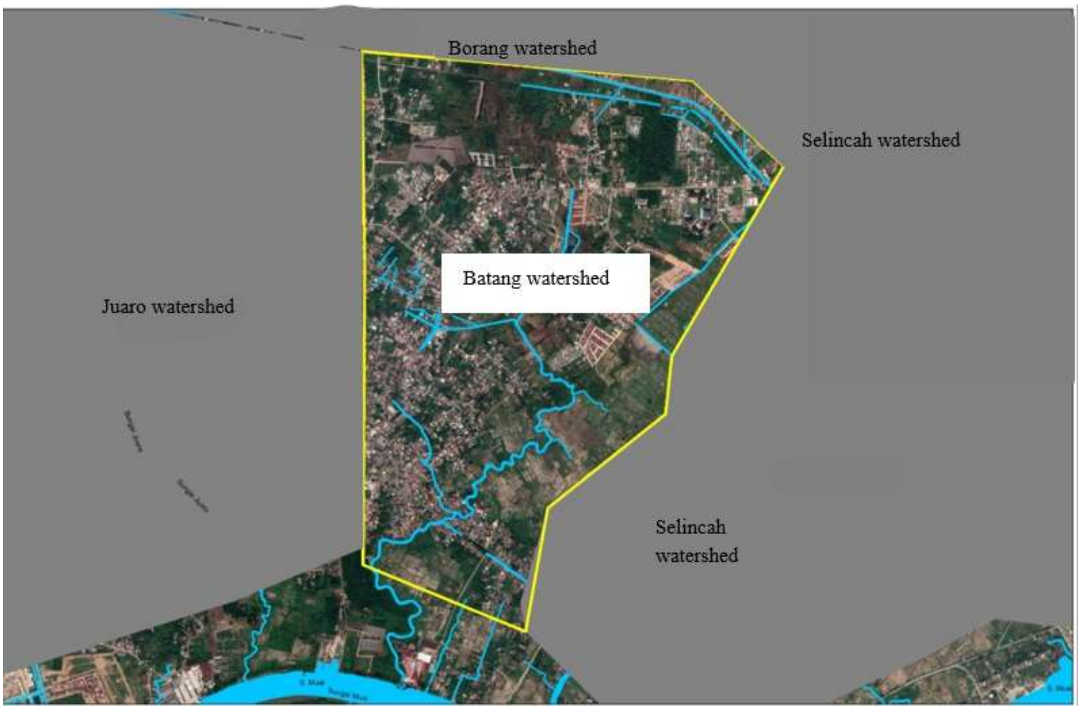

Fig. 1. Research location of Batang watershed Palembang City

3.1 Research Stage

After all the required data has been obtained, data processing can be carried out. Data processing in this study was carried out by hydrological analysis as a data analysis method used where rainfall data for the last 20 years obtained from the Kenten station BMKG was then processed so that in the end a rational method of discharge was obtained from the watershed. The following components in hydrological analysis include:

i. Maximum daily rainfall data from one nearest station is used in the Kenten area where it is obtained from BMKG with a period of 20 years (2002-2021) for average rainfall in 2012 and 2021.
ii. Determine precipitation plans by comparing the results of the normal distribution method, normal log distribution, Gumble distribution, and Pearson log distribution III.
iii. Distribution match testing was carried out with the Chi-Square Test method (Chi-Square Test) and Smirnov-Kolmogorov.
iv. Next, the calculation of rainfall intensity (I) is carried out using the formula from Mononobe.
v. Determine the land-use value of the trunk watershed using the Arc-GIS program and determine the runoff coefficient (C) based on land use.
vi. After all components are obtained, the discharge is calculated on the Batang watershed using the rational method. The calculated discharge is in the form of flood discharge in 2012 and flood discharge in 2021 in the Batang watershed.

4. Results and Discussion

4.1 Probability Distribution Analysis

Probability distribution analysis is a distribution of extreme events related to the frequency of events with a certain return period. Probability distribution analysis consists of the normal distribution, normal log distribution, Gumbel distribution, and Pearson III log distribution.

Tables 1 and 2 show the results of planned rainfall calculations with various types of distribution. Of all the distributions, the planned rainfall classification falls into the very heavy rain category. The characteristics of heavy rain are rainfall values above 100 mm per day. Based on these results, Goodness of fit test will be carried out to determine the kind of distribution suitable for flood discharge analysis.

Table 1
Recapitulation of planned rainfall for 2012

Return Period (Year)	Probability Distribution			
	Normal	Log-Normal	Gumbel	Log Pearson III
2	114,08	109,27	110,83	115,34
5	127,83	124,41	131,40	128,52
10	135,03	136,61	144,33	134,53
25	140,92	155,08	159,41	140,70
50	147,63	171,06	172,80	143,44
100	152,22	190,12	184,83	146,07

Table 2
Recapitulation of planned rainfall for 2021

Return Period (Year)	Probability Distribution			
	Normal	Log-Normal	Normal	Log Pearson III
2	115,83	109,19	110,15	110,74
5	139,85	124,33	146,09	136,65
10	152,44	136,52	168,69	154,27
25	162,73	154,97	195,04	177,09
50	174,46	170,94	218,42	194,57
100	182,47	189,99	239,45	212,46

4.2 Goodness of Fit Test

The goodness of fit test is carried out to find out the results of the probability distribution that are appropriate and acceptable for further calculations. There are two types of goodness of fit tests used in this study, namely the chi-square fit test and the Smirnov-Kolmogorov fit test.

4.2.1 Chi-Square test

The chi-square test is a type of suitability test that compares the calculated X^2 value with X^2cr obtained from the table to determine the probability distribution that will be used in calculating the planned rainfall and is listed in Tables 3 and 4.

Table 3
Chi-square test results in 2012

Distribution	X^2	X^2Cr	Information
Normal	2	5,991	Accepted
Log-Normal	2	5,991	Accepted
Gumbel	1	5,991	Accepted
Log Pearson III	2	5,991	Accepted

Table 4
Chi-square test results in 2021

Distribution	X^2	X^2Cr	Information
Normal	1	5,991	Accepted
Log-Normal	1	5,991	Accepted
Gumbel	2	5,991	Accepted
Log Pearson III	0	5,991	Accepted

4.2.2 Smirnov-Kolmogorov test

The Smirnov-Kolmogorov test is a probability distribution compatibility test by comparing the Δ value obtained from the calculation with the Δcr value obtained as indicated in the Tables 5 and 6.

Table 5
Smirnov-Kolmogorov test results 2012

Distribution	Δmax	Δcr	Information
Normal	0,714	0,409	Not Accepted
Log-Normal	0,767	0,409	Not Accepted
Gumbel	0,200	0,409	Accepted
Log Pearson III	0,900	0,409	Not Accepted

Table 6
Smirnov-Kolmogorov test results 2021

Distribution	Δmax	Δcr	Information
Normal	0,360	0,409	Accepted
Log-Normal	0,473	0,409	Not Accepted
Gumbel	0,093	0,409	Accepted
Log Pearson III	0,818	0,409	Not Accepted

4.2.3 Goodness of fit test summary

After the Smirnov-Kolmogorov and chi-square goodness of fit tests have been carried out, the results can be compared to obtain a probability distribution that will be used for further calculations. These results can be seen in the following recapitulation Tables 7 and 8.

Table 7
Compatibility test summary for 2012

Distribution	Statistical Parameters	Chi-Square Test	Smirnov-Kolmogorov Test
Normal	Not Accepted	Accepted	Not Accepted
Log-Normal	Not Accepted	Accepted	Not Accepted
Gumbel	Accepted	Accepted	Accepted
Log Pearson III	Accepted	Accepted	Not Accepted

Table 8
Compatibility test summary for 2021

Distribution	Statistical Parameters	Chi-Square Test	Smirnov-Kolmogorov Test
Normal	Not Accepted	Accepted	Accepted
Log-Normal	Not Accepted	Accepted	Not Accepted
Gumbel	Accepted	Accepted	Accepted
Log Pearson III	Accepted	Accepted	Not Accepted

Based on Tables 7 and 8, it can be concluded that in 2012 and 2021 the probability distribution used is the Gumbel distribution because the Gumbel distribution meets the requirements of the chi-square goodness-of-fit test and the Smirnov-Kolmogorov goodness-of-fit test. The Gumbel distribution was chosen because it results in a comparison of small deviation values against the values required in goodness of fit test. The next stage is analysing rainfall intensity using the Gumbel distribution.

4.3 Rainfall Intensity

Rainfall intensity is one of the parameters in the calculation of flood discharge. In calculating the intensity of rainfall can use the Mononobe method. Rainfall intensity is one factor that causes flooding in an area. Based on the calculation analysis results, Table 9 shows that rainfall intensity has increased in the last ten years.

Table 9
Recapitulation of rainfall intensity in 2012 and 2021

Return Period (Year)	I (mm/jam)	
	2012	2021
2	54,049	53,717
5	64,080	71,244
10	70,388	82,266
25	77,744	95,118
50	84,270	106,520
100	90,138	116,774

Based on the table above, the percentage change in rainfall intensity in 2012 and 2021 is obtained, namely that in the 2-year return period there was a decrease in rainfall intensity of 0.61%.

However, in the 5-year return period to the 100 years, there is an increase in rainfall intensity ranging from 10 to 30%. The increase in rainfall intensity is due to the increase in temperature that has occurred in the last 10 years, where high temperatures can trigger high intensity rain.

4.4 Land Use

Changes in land use can affect existing catchment areas. Obtaining the area value of land use in the Batang watershed was carried out using the ArcGIS 10.8 program. The land use map obtained from PUPR is a land use map for Palembang City. To obtain a land use map in the Batang watershed, is done by cutting a portion of the Palembang city land use map from the Batang watershed map using the tools clip on geoprocessing. The following is a land use map of the Batang watershed in 2012 and 2021:

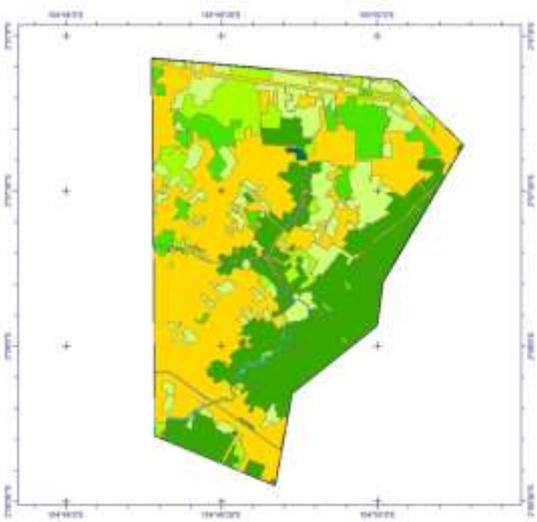

Fig. 2. Land use area in 2012

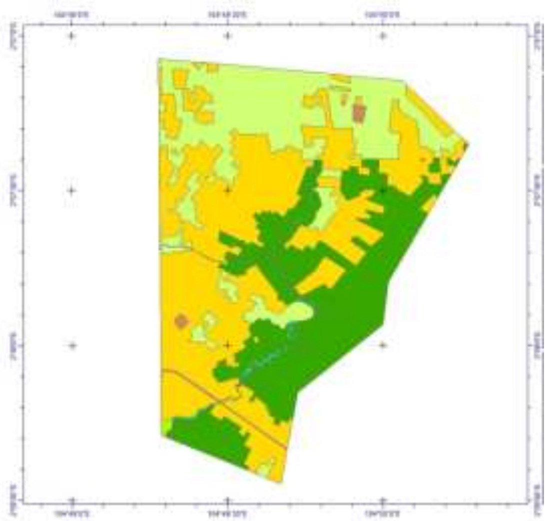

Fig. 3. Land use area in 2021

The following is Table 10 of the land use area of the Batang Watershed in Palembang City in 2012 and 2021.

Table 10
Land use area in 2012 and 2021

Land Use	Area (Ha)		Change (%)	Category
	2012	2021		
Shrubs	23,177	0,544	-97,653	High
Pond	0,237	0	-100	High
Field	50,258	77,225	+53,658	High
Trees/Forest	21,434	0	-100	High
Residential	131,308	138,896	+5,779	Low
Swamp	0,583	0	-100	High
Paddy field	82,376	91,234	+10,753	Low
Road	0,289	0,560	+93,851	High
River	1,972	1,972	0	-
Business	0	1,145	+100	High

Based on Table 10, land uses are still the same between 2012 and 2021 but with areas that have changed, including shrubs, settlements, fields, rice fields, roads, and rivers. Apart from that, there are different land uses between 2012 and 2021, including in 2012, there were still pond areas, trees/forests, and swamps, but in 2021, these areas do not exist and have been replaced by roads and trading areas. The percentage of changes in land use in the Batang watershed, namely in the form of shrubs, decreased by 97.65%, settlements increased by 5.779%, fields increased by 53.658%, rice fields increased by 10.753%, and roads increased by 93.851%.

Changes in land use in a watershed can affect the size of flood discharge. The higher the green area in a watershed, the greater the absorption area which can reduce the magnitude of flooding in that watershed and vice versa. In the Batang City of Palembang watershed, land use in the form of residential buildings and roads has increased quite significantly. However, land use in the form of paddy fields and fields has also increased quite significantly, so that there are still many catchment areas in the Batang City of Palembang watershed.

4.5 Flood Discharge

Calculation of flood discharge using the rational method. In the calculation of flood discharge using the rational method, several parameters were needed, namely the runoff coefficient (C), rainfall intensity (I), and the area of the Batang watershed (A), where these parameters have been calculated before.

Based on the analysis of discharge calculations (Table 11), it appears that due to changes in rainfall intensity and land use from 2012 to 2021, flood discharge in the Batang watershed experienced changes in 2012 and 2021. Changes in land use affect the soil's ability to seep and increase water discharge. In each period of flood discharge there is an increase in discharge of around 13.11% to 47.44%.

Table 11
Results of the 2012 and 2021 flood discharge calculations

Return Period (Year)	Q flood 2012 (m^3/dt)	Q flood 2021 (m^3/dt)
2	17,08166893	19,32120123
5	20,25184728	25,62518685
10	22,24549472	29,58960885
25	24,57013279	34,2122147
50	26,63258166	38,31345019
100	28,48729804	42,001604

5. Conclusion

Based on the analysis that has been carried out, it can be seen that the flood discharge in the Batang Watershed in Palembang City has increased as described from 2012 to 2021. The increase influenced the increase in rainfall intensity; another factor that causes an increase in flood discharge is changes in land use. There will be an increase in settlements, trade, and road construction in 2021. There will be a significant decrease in the area of trees and swamps, which can result in reduced infiltration areas around the Batang Watershed in Palembang City, causing a change in the runoff coefficient value, which is one of the parameters in calculating the discharge rational method flooding which resulted in an increase in flood discharge in the Batang Watershed of Palembang City from 2012 to 2021.

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