Analysis of Flood Hydrograph to the Land Use Change on Flood Peak Discharge in The Sekanak Watershed

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Abstract. Land demands in urban areas are increasing with urbanization. To supply the urban land demand, various method are made including the over land function. The over land function if not properly planned will result in increased run-off in a watershed. The increased surface runoff will increase peak discharges and potentially cause flooding when capacity storages such as drainage and retention basins, as well as other low areas such as open areas and swamps are full. The effect of land use on peak discharge is a question that needs to be analyzed. The purpose of this study is to assess land use change and analyze peak flood discharge in the upstream of Sekanak watershed. The research methodology uses spatial analysis that is doing DEM (Digital Elevation Model) analysis to determine river flow limit and determining of watershed characteristics and analysis of land use change in year 2004 and year 2014 influence to flood peak discharge in Sekanak watershed, due to rainfall factor. Peak discharge analysis was conducted with Nakayasu Synthetic Unit Hydrograph. The result of this study is land use change increases the coefficient C value, causing the peak discharge in the 5 year return period to increase.

Keywords: flood hydrograph, land use, flood discharge.

1. Introduction

Human need for land increases along time. The increasing demand for land is directly proportional to the increasing population growth, especially in urban areas. To supply the urban land demand, various methods are made including over land function. Land use change causes a watershed to be disturbed. The disruption of the watershed is to increase peak discharge and potentially cause flooding at full capacity storage. Sekanak watershed is in the center of Palembang. The development of land use change in this area is growing rapidly with changes in land use of open area and absorption into the economic area. Based on the spatial plans of Palembang City 2012-2032, Lorok Pakjo Urban Village functioned as a residential area, trade and services, education, and new city development which has changed the function of land use in the upstream of Sekanak watershed. The change is predicted to change the runoff discharge. Meanwhile, in the spatial plans of Palembang City 2012-2032, flood control systems are developed with due regard to protection and preservation of functions and capacity of water resources in Sekanak watershed. Considering the impact of land conversion, the formulation of the problem in this research is how big the effect of land change in Sekanak watershed between year 2004 and 2014 to the change of flood peak discharge. The aims of the study are to reviewing the spatial land use change in the Sekanak watershed and to analyze the peak flood discharge in the upstream Sekanak sub-watershed.

The peak discharge of Sekanak watershed in 2004 was analyzed by Nakayasu Synthetic Unit Hydrograph method with 10 year return period is 40.05 m³/s and for 25 year is 45 m³/s [1]. In the
research entitled of Land Use Changes in Upstream Siak Basin by Hec-HMS method analysis states that the dominant land use changes are plantations of 28.8% and forests amounted to 34.4% [2]. Urban land demand is increasing in line with population growth and socio-economic activities. This increase in land needs is an implication of the increasingly diverse functions in urban areas that include the use of non-agricultural land such as settlements, government, trade and services as well as industry and agriculture/plantations. Over land functions that occur in urban and periphery areas are land that was originally designated as forest areas, water catchment areas and plantation agriculture transformed into a commercial area. The phenomenon of decreasing water catchment areas in urban areas provides a logical consequence that the greater change in the use of water catchment areas into urban (non-agrarian) uses will lead to phenomena and environmental degradation [3].

In areas where hydrological data are not available to decrease unit hydrograph, the unit hydrograph synthesis is based on the physical characteristics of the watershed. Commonly used methods are Snyder Method, SCS (Soil Conservation Service) Method, GAMA I Method, Limantara Method and Nakayasu Method. The method to be used in this research is the method of hydrograph of Nakayasu Synthesis Unit. The Nakayasu Synthesis Unit Hydrograph was developed based on several rivers in Japan [4]. The equation of the Synthetic Unit Hydrograph (SUH) of Nakayasu is:

$$Q_p = \frac{CA.R_0}{3.6(0.3T_p + T_{0.3})}$$

where:
- $Q_p$: peak discharge (m$^3$/s)
- $C$: flow coefficient
- $A$: watershed area (km$^2$)
- $R_0$: unit runoff (mm)
- $T_p$: time from start to peak flood (hour)
- $T_{0.3}$: time required by the decrease of discharge, from peak to 30% of peak discharge (hour).

The hydrological system is sometimes influenced by extraordinary (extreme) events, such as heavy rains, floods and droughts. The magnitude of extreme events is inversely proportional to the event frequency. The purpose of the frequency analysis of hydrological data is related to the magnitude of extreme events related to the frequency of occurrence through the application of probable distributions. The hydrological data being analyzed is independent and randomly distributed and statistically [5].

Rainfall intensity is defined as the height of rainfall that occurs during the period of rainwater concentrate. Analysis of rainfall intensity can be processed based on rainfall data that has occurred in previous years. Calculation of the intensity of rainfall can be used several empirical formulas in hydrology. The Mononobe formula is used when short-term rainfall data is not available, only 24 hours of daily rainfall data.

From the Mononobe method results obtained short-term rain, plotted in the form of IDF curves (Intensity-Duration-Frequency). The distribution of rain as a function of time describes the variation in depth of rain during the rain duration can be expressed in discrete or continuous form [6]. A simple way to make a hyetograph of the IDF curve is the Alternating Block Method (ABM). Hyetograph plan generated in this method is the rainfall that occurs within n sequence series of time intervals with duration $\Delta t$ during time $T_d = n \Delta t$.

Effective rainfall is part of the rain that becomes a direct flow in the river. This effective rain is equal to the total rain falling on the surface of the land then reduced to the loss of water. To get the effective rainfall need to look for the amount of water loss [6]. One way to find water loss to calculate direct flow is to use the $\Phi$ index method. The value of the $\Phi$ index is the average water loss rate caused by infiltration, surface storage and evaporation. To find the $\Phi$ index required flow discharge data, if flow discharge data is not available, effective rainfall can be calculated by SCS (The Soil Conservation Service) method.

The term geographic information system is a combination of three basic elements: system, information and geography. The term "geographical" is part of a spatial (spatial) and contains an understanding of a matter of two-dimensional or three-dimensional surface earth [7].
2. Research Methodology

2.1. Watershed characteristics analysis
At this stage of analysis is required data in the form of contour maps in the study area. The contour map to be used is a contour map of Sekanak watershed area with contour interval of 0.25 m. Furthermore, the contour map will be converted to DEM (Digital Elevation Model) and then analyzed to get the desired parameters and will be used for further analysis. From the DEM map data of the Sekanak watershed area then continued the analysis to get the value of river flow length, watershed boundary, stream order and outlet. So from the area of a watershed area obtained will be subdivided into several sub-watershed in accordance with the desired area.

2.2. Analysis of land use
Type of land use will be very influential to determine the magnitude of infiltration and runoff. The value of each land use varies depending on the different runoff coefficient factors. From the map of land use will be generated the value of the area of each region and the value of the runoff coefficient based on land use.

2.3. Rainfall analysis
The rainfall data used in this research is the maximum daily rainfall data from Ilir Timur I Rainfall Station, Meteorology Climatology and Geophysics Council from 2004-2014. Ilir Timur I rain station is considered to represent the research area.

2.4. Frequency analysis of rainfall data
The next is frequency analysis of rainfall data using normal distribution method, log normal, gumbel and log pearson type III. Then the result of frequency analysis is done by match test using Smirnov Kolmogorov method.

2.5. Time concentration analysis \((T_c)\)
To analyze the concentration time, used Kirpich formula in equation (2). The parameters needed to analyze the time of concentration include the flow length and slope where the parameters have been obtained from the watershed characteristics analysis.

2.6. Rainfall intensity analysis \((I)\)
To analyze rain intensity in Sekanak watershed used Mononobe formula in equation (3).

3. Results and discussion

3.1. Watershed characteristics analysis
The following is the result of DEM analysis on Sekanak watershed with contour interval 0.25 meter with area of 2 meter low and highest 17.002 meter. This DEM analysis is used for grouping sub-watersheds.

![Figure 1. DEM map of Sekanak watershed](image-url)
From the results of more specific analysis found that Sekanak watershed subdivided into 10 sub-watershed that are connected to each other.

![Figure 2. Sekanak sub-watershed map](image)

In this study, parameters of the upstream Sekanak sub-watershed are:
- area = 2.86 km²;
- upstream elevation = 6.7 m;
- perimeter = 7.06 km;
- downstream elevation = 2.9 m;
- total length flow = 4.67 km;
- difference elevation = 3.8 m;
- slope = 0.00197;
- longest stream length = 1930 m.

The parameters above obtained longest stream length. The longest stream length is then used to analyze the time of concentration.

3.2. Analysis of land use

The following is a land use map of 2004 and 2014 in the upstream Sekanak sub-watershed.

![Figure 3. Land use year 2004 map.](image) ![Figure 4. Land use year 2014 map.](image)

Furthermore, to know specifically about the area and coefficient of runoff from each land use can be seen in table 1 below.
Table 1. Value of land use in upstream Sekanak watershed 2004 and 2014

| Land Use     | C Value | Year 2004 | Year 2014 | Difference |
|--------------|---------|-----------|-----------|------------|
|              |         | Area (km²) | %         | Area (km²) | %         | (%)      |
| Grass        | 0.2     | 0.019     | 0.67      | 0.012      | 0.42      | -0.24    |
| Building     | 0.6     | 0.979     | 34.29     | 1.042      | 36.48     | 2.19     |
| Concrete     | 0.85    | 0.000     | 0.00      | 0.033      | 1.17      | 1.17     |
| Ponds        | 0.05    | 0.009     | 0.31      | 0.006      | 0.21      | -0.09    |
| Street       | 0.8     | 0.284     | 9.95      | 0.283      | 9.91      | -0.04    |
| Burial Ground| 0.2     | 0.053     | 1.84      | 0.053      | 1.84      | 0.00     |
| Tree         | 0.1     | 0.084     | 2.95      | 0.038      | 1.34      | -1.61    |
| Open Space   | 0.4     | 1.422     | 49.82     | 1.384      | 48.44     | -1.38    |
| Field        | 0.25    | 0.002     | 0.09      | 0.002      | 0.09      | 0.00     |
| Stream       | 0.05    | 0.001     | 0.03      | 0.001      | 0.03      | 0.00     |
| Empty Land   | 0.15    | 0.002     | 0.06      | 0.002      | 0.06      | 0.00     |
| SUM          |         | 2.86      | 100       | 2.86       | 100       |          |

The dominant land uses of year 2004 and 2014 are buildings and open spaces. The land use in 2014, which dominates land change is a tree. Land use that has a high C value such as Buildings increases while land use that has a low C value decreases. This cause an increase in the C value that causes the peak discharge increase.

3.3. Rainfall analysis

The following rainfall analysis is the annual maximum rainfall data from 2004-2014 which will be used for frequency analysis.

Table 2. Maximum annual rainfall data

| Number | Year | R (mm) |
|--------|------|--------|
| 1      | 2004 | 101    |
| 2      | 2005 | 57     |
| 3      | 2006 | 111    |
| 4      | 2007 | 78     |
| 5      | 2008 | 135    |
| 6      | 2009 | 150    |
| 7      | 2010 | 145    |
| 8      | 2011 | 114    |
| 9      | 2012 | 103    |
| 10     | 2013 | 147    |
| 11     | 2014 | 140    |

From the data above, it can be seen that the maximum annual rainfall that occurs from 2004 to 2014, the lowest annual rainfall at year 2005 was 57 mm while the highest at year 2009 reached 150 mm.

3.4. Frequency analysis of rainfall data

The following is the result of rainfall frequency analysis in 2004-2014.

Table 3. Recapitulation of rainfall statistics year 2004-2014

| Year | $x_i$ | $x_i - \bar{x}$ | $\log x_i$ | $\log x_i - \bar{x}$ |
|------|-------|-----------------|-------------|----------------------|
| 2004 | 101   | -15.45          | 238.84      | -3.691.21            |
| 2005 | 57    | -59.45          | 3,534.84    | -210,162.48          |
| 2006 | 111   | -5.45           | 29.75       | -162.28              |
| 2007 | 78    | -38.45          | 1,478.75    | -56,864.74           |
| 2008 | 135   | 18.55           | 343.93      | 6.378.41             |
After obtaining the parameters of rainfall statistics, next step is selection of distribution types. They are normal distribution, log normal, gumbel and log Pearson type III. Here is a comparison of distribution terms and results of calculation of rainfall frequency analysis.

| Number | Distribution Type          | Requirement          | Result          | Explanation   |
|--------|---------------------------|----------------------|----------------|---------------|
| 1      | Normal                    | Cs = 0               | 2.00 ± 0       | Rejected      |
| 2      | Log Normal                | Cs = 3 Cv + Cv²     | 0.85 > 0.272   | Rejected      |
| 3      | Log Pearson Type III      | Cs ≤ 0               | -0.72 > 0      | Accepted      |
| 4      | Gumbel                    | Cs ≤ 1.1396          | -0.72 < 1.1396 | Accepted      |
|        |                           | Ck ≤ 5.4002          | -0.30 < 5.4002 | Accepted      |

From the calculation of the table above, the type of distribution received is Log Pearson Type III and Gumbel, but used in this study is Log Pearson type III distribution because it has a smaller difference than the distribution of Gumbel. To find out whether the distribution of Pearson Log III has a match then the Smirnov Kolmogorov suitability test is performed. Smirnov kolmogorov fit test using 5% confidence degree, meaning that calculation result can be accepted with big 95% confidence, so the critical D value is 0.396. In the table, the value of Dmax is 0.1833 so that D max <D is critical, so the calculation with Log Pearson Type III is acceptable.

3.5. Rainfall design analysis
The calculation of rainfall design is done by using log Pearson type III method for rainfall in 2004-2014. The following is a table recapitulation of rainfall data of 2004-2014 with log Pearson type III.

| Return Period (Year) | K_{TR} | log X_T | X_T (mm) |
|----------------------|--------|---------|----------|
| 2                    | 0.2012 | 2.0763  | 119.21   |
| 5                    | 0.5295 | 2.1195  | 131.66   |
| 10                   | 1.0767 | 2.1914  | 155.37   |
| 25                   | 1.1817 | 2.2052  | 160.39   |
| 50                   | 1.3568 | 2.2282  | 169.12   |

The design rainfall used is a 5-year return period.

3.6. Rainfall intensity analysis (I)
To analyze the rainfall intensity in the upstream Sekanak sub-watershed used Mononobe formula in equation (3). After the short-term rain intensity, then made Intensity Duration Frequency (IDF) curve as shown below.
After getting the time of concentration and intensity of rain with IDF curve, then do hyetograph analysis by Alternating Block Method (ABM). The calculated of hyetograph is a maximum rainfall hyetograph of 2004 also the maximum design rainfall hyetograph of 10 year return period. The results of the rainfall hyetograph are as follows.

| Table 6. Maximum rainfall hyetograph of year 2004 |
|---|---|---|---|---|---|---|---|
| T_d | T_d | Δt | I_t | I_t | Δp | p_t | hyetograph |
| minute | hour | minute | mm/hour | mm | mm | % | % | mm |
| 5  | 0.083 | 0~5 | 183.5 | 15.3 | 15.3 | 63.00 | 9.14 | 9.24 |
| 10 | 0.167 | 5~10 | 115.6 | 19.3 | 4.0 | 16.37 | 63.00 | 63.63 |
| 15 | 0.250 | 10~15 | 88.2 | 22.1 | 2.8 | 11.49 | 16.37 | 16.54 |
| 20 | 0.333 | 15~20 | 72.8 | 24.3 | 2.2 | 9.14 | 11.49 | 11.60 |
| SUM | | | 24.3 | 100 | | 100 | 101.00 |

| Table 7. Hyetograph rainfall for a 5 year return period |
|---|---|---|---|---|---|---|---|
| T_d | T_d | Δt | I_t | I_t | Δp | p_t | hyetograph |
| minute | hour | minute | mm/hour | mm | mm | % | % | mm |
| 5  | 0.083 | 0~5 | 239.2 | 19.9 | 19.9 | 63.00 | 9.14 | 12.04 |
| 10 | 0.167 | 5~10 | 150.7 | 25.1 | 5.2 | 16.37 | 63.00 | 82.94 |
| 15 | 0.250 | 10~15 | 115.0 | 28.8 | 3.6 | 11.49 | 16.37 | 21.56 |
| 20 | 0.333 | 15~20 | 94.9 | 31.6 | 2.9 | 9.14 | 11.49 | 15.12 |
| SUM | | | 31.6 | 100 | | 100 | 131.66 |

3.7. Rainfall hyetograph analysis
After getting the time of concentration and intensity of rain with IDF curve, then do hyetograph analysis by Alternating Block Method (ABM). The calculated of hyetograph is a maximum rainfall hyetograph of 2004 also the maximum design rainfall hyetograph of 10 year return period. The results of the rainfall hyetograph are as follows.

3.8. Nakayasu synthetic unit hydrograph analysis
The calculation is performed with the following parameters:
- L = 1.93 km,
- C*A for year 2004 = 1.408 km²
- C*A for year 2014 = 1.452 km²

Do Nakayasu Synthetic Unit Hydrograph analysis calculation of Year 2004 and 2014. After the calculation results obtained, then plot the graphs as picture below.
3.9. Effective rainfall analysis using \( \Phi \) index method

To find \( \Phi \) Index required flow discharge data, because the flow discharge data is not available then used SCS (The Soil Conservation Service) method to calculate the effective rainfall. The SCS method can be used with the soil data of the Sekanak watershed. The soil type in the upstream of Sekanak Watershed is red podsolik. Because of the soil type is B, so the CN (Curve Number) value depends on the land use. CN = 71.17 for 2004 and CN = 71.61 for 2014. From the value of CN obtained, the S value is calculated i.e the maximum potential water retention by the soil mostly due to infiltration. \( S = 102.88 \) for 2004 and \( S = 100.70 \) for 2014.

After obtaining CN and S values, then searched for effective depth of rainfall, effective depth of rainfall count is effective depth of rainfall in each sub-watershed for maximum rainfall year 2004 and rainfall design of 5 year return period. Then do the effective rainfall calculation with \( \Phi \) index and the result as follows.

Table 8. Calculation of effective rainfall in 2004 with \( \Phi \) index method

| Minute | \( P \) (mm) | \( P_{e} \) (mm) | \( \Phi \) index | \( R_{eff} \) (mm) |
|--------|--------------|-----------------|-----------------|------------------|
| 5      | 9.24         | 1.41            | 48.50           | 0.00             |
| 10     | 63.63        | 12.67           | 48.50           | 15.13            |
| 15     | 16.54        | 0.17            | 48.50           | 0.00             |
| 20     | 11.60        | 0.86            | 48.50           | 0.00             |
| \( \Sigma \) | 101.00      | 15.13           |                 | 15.13            |

Table 9. Calculation of effective rainfall design of 5 year return period with \( \Phi \) index method

| Minute | \( P \) (mm) | \( P_{e} \) (mm) | \( \Phi \) index | \( R_{eff} \) (mm) |
|--------|--------------|-----------------|-----------------|------------------|
| 5      | 12.04        | 0.71            | 57.83           | 0.00             |
| 10     | 82.94        | 24.12           | 57.83           | 25.11            |
| 15     | 21.56        | 0.02            | 57.83           | 0.00             |
| 20     | 15.12        | 0.26            | 57.83           | 0.00             |
| \( \Sigma \) | 131.66      | 25.11           |                 | 25.11            |

3.10. Analysis of flood hydrograph

The calculation for hydrograph flood analysis is perform by multiplying effective precipitation which has been calculated into the unit hydrograph, in this study is the Nakayasu synthesis unit hydrograph. The following table is the hydrograph calculation of Sekanak subwatershed due to effective rainfall in 2004 and due to effective rainfall design of 5 year return period.
The peak time is at 27.95 minutes with a total peak discharge of 7.288 m³/sec.

Table 11. Calculation of flood hydrograph due to effective rainfall design of 5 year return period

| T (menit) | Q (m³/det) | R1 (mm) | R2 (mm) | R3 (mm) | R4 (mm) | Qtot (m³/det) |
|-----------|------------|---------|---------|---------|---------|---------------|
| 0         | 0.000      | 0.000   | 25.11   | 0.000   | 0.000   | 0.000         |
| 10        | 0.004      | 0.000   | 1.062   | 0.000   | 0.000   | 1.062         |
| 20        | 0.223      | 0.000   | 5.604   | 0.000   | 0.000   | 5.604         |
| 27.95     | 0.498      | 0.000   | 12.514  | 0.000   | 0.000   | 12.514        |
| 30        | 0.468      | 0.000   | 11.764  | 0.000   | 0.000   | 11.764        |
| 40        | 0.346      | 0.000   | 8.702   | 0.000   | 0.000   | 8.702         |
| 50        | 0.256      | 0.000   | 6.437   | 0.000   | 0.000   | 6.437         |
| 60        | 0.190      | 0.000   | 4.761   | 0.000   | 0.000   | 4.761         |
| 67.88     | 0.149      | 0.000   | 3.754   | 0.000   | 0.000   | 3.754         |
| 70        | 0.143      | 0.000   | 3.598   | 0.000   | 0.000   | 3.598         |
| 80        | 0.117      | 0.000   | 2.942   | 0.000   | 0.000   | 2.942         |
| 90        | 0.096      | 0.000   | 2.407   | 0.000   | 0.000   | 2.407         |
| 100       | 0.078      | 0.000   | 1.968   | 0.000   | 0.000   | 1.968         |
| 110       | 0.064      | 0.000   | 1.610   | 0.000   | 0.000   | 1.610         |
| 120       | 0.052      | 0.000   | 1.317   | 0.000   | 0.000   | 1.317         |
| 127.77    | 0.045      | 0.000   | 1.126   | 0.000   | 0.000   | 1.126         |
| 130       | 0.043      | 0.000   | 1.089   | 0.000   | 0.000   | 1.089         |
| 140       | 0.037      | 0.000   | 0.937   | 0.000   | 0.000   | 0.937         |
| 150       | 0.032      | 0.000   | 0.806   | 0.000   | 0.000   | 0.806         |
| 160       | 0.028      | 0.000   | 0.693   | 0.000   | 0.000   | 0.693         |
| 170       | 0.024      | 0.000   | 0.596   | 0.000   | 0.000   | 0.596         |
| 180       | 0.020      | 0.000   | 0.512   | 0.000   | 0.000   | 0.512         |

This peak discharge is greater than the peak discharge in 2004 because this is the design peak discharge for a 5 year return period. After the hydrograph calculation, then plotted in the hydrograph.
Figure 7. Flood hydrograph

The peak time of flood hydrograph at year 2004 and flood hydrograph due to effective rainfall design of 5 year return period is at 27.95 minutes with a peak discharge of 7.288 m$^3$/sec at year 2004 and 12.514 m$^3$/sec at effective rainfall design of 5 year return period. The peak discharge at 5 year return period is greater because of the effective rainfall.

4. Conclusion

The conclusions of this study are:

a. Land use that has a high C value such as buildings increases while land use that has a low C value decreases. This cause an increase in the C value that causes the peak discharge to increase.

b. Land use change in Sekanak sub-watershed from 2004 to 2014 did not change much, causing the peak discharge due to unit hydrograph is not much change but the peak discharge caused by effective rain is changing.

c. The peak time of flood hydrograph at year 2004 and flood hydrograph due to effective rainfall design of 5 year return period is at 27.95 minutes with a peak discharge of 7.288 m$^3$/sec at year 2004 and 12.514 m$^3$/sec at effective rainfall design of 5 year return period. The peak discharge at 5 year return period is greater because of the effective rainfall.

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