Analysis of the effect of land use on flood height in Balikpapan city (case study: Posindo sub-basin)

R M Kadaryanti*, A N Dewanti, A Ghozali

Department of Civil Engineering and Planning, Institut Teknologi Kalimantan, Indonesia

*E-mail: rossa.margareth@lecturer.itk.ac.id

Abstract. One of the problems with infrastructure in the City of Balikpapan is the inadequate drainage system and is one of the causes of flooding in the City of Balikpapan. Drainage problems in the city of Balikpapan concentrated in the central area of the city, one of which system of drainage that is located in the city center is the Ampal/Klandasan Besar Basin. In that drainage system, there is one of the sub-basin where the majority of its land use is built-up area, namely the Posindo Sub-basin. This study aims to analyze the effect of land use on high floods that occurred in the Posindo Sub-basin. Flood discharge due to rain was analyzed using the HEC-HMS program. The results of the hydrological discharge of the HEC-HMS model are compared with the cross-sectional capacity of the channel so that the flood height above the channel is obtained. Based on the analysis of channel capacity and flood discharge, the results show that the drainage channel in the Posindo Sub-basin is unable to drain the hydrological discharge due to rain without overflow.

1. Introduction

Balikpapan City is one of the big cities in eastern Indonesia and is included in the province of East Kalimantan. This condition makes the City of Balikpapan the potential as a national sea transportation node, national air transportation node, a mainstay area and an integrated economic development area [1]. This has an impact on the development of the City of Balikpapan which is moving rapidly in various sectors. The development of the city should also be supported by the ability of the provision of infrastructure and urban facilities, one of the problems that occur is the unavailability of urban drainage infrastructure and facilities by their needs, resulting in flooding in some locations. This condition is due to land clearing for settlement resulting in reduced water catchment areas, thus increasing rainwater runoff, and increasing sediment in rivers and channels.

Following the drainage master plan for the City of Balikpapan, the drainage system for the City of Balikpapan is divided into 16 drainage systems, each of which consists of primary, secondary, and tertiary channels. Based on the City of Balikpapan Mid-Term Plan (RPJMD) 2016-2021, the flood control program is one of the priority programs of the Balikpapan City Government with a target of reducing flood points from 51 points in 2016 to 35 points in 2021. Until the end of 2018, there are still 47 flood points where most of them are concentrated in 3 drainage systems, namely the Ampal/Klandasan Besar system, the Sepinggan system, and the Klandasan Kecil system [2]. The Balikpapan City Government has made efforts to compile a flood control plan in the intended drainage system by referring to the drainage master plan. Various efforts have been made to overcome the problem of flooding, the majority of which only overcome short-term problems in the form of cleaning sedimentation and garbage, as well as carrying out maintenance and repair of drainage construction [3].
One of the problems that occur in the Posindo Sub-watershed is flooding due to drainage channels that are unable to drain the flood discharge without overflow. This condition is influenced by land use and heavy rainfall intensity. Based on these conditions, it is necessary to carry out an analysis related to the effect of land use in the Posindo Sub-watershed on the flood height in the channel. This can be a reference or reference related to further strategic steps that can be taken by the Balikpapan City government. This study aims to analyze the effect of land use on the flood height in Balikpapan City (Case study: Sub-watershed Posindo). The objectives of this research are:

1. Analyzing the intensification of land use in the study area
2. Analyze the flood discharge in the study area
3. Analyzing the flood height in the study area

2. Methods
2.1 Land use intensification analysis
At this stage, land use identification and an analysis of land use suitability were carried out in the study area with the City of Balikpapan Spatial Planning (RTRW).

2.2 Analysis of rainfall distribution
At this stage, identification of the type of distribution that best suits the conditions of the rain distribution in the research area is carried out. Statistical parameter analysis includes the calculation of the following variables: 1) Average value ($\bar{X}$); 2) Standard deviation ($S$); 3) Coefficient of variation ($C_v$); 4) The slope coefficient ($Cs$); 5) Sharpness coefficient ($C_k$).

2.3 Return period rainfall analysis
The calculation of the return period rainfall uses the Gumbel Type I distribution equation as follows:

$$X = \bar{X} + (k \cdot S)$$

with:

- $X$ = estimated value expected to occur in a certain return period
- $S$ = standard deviation
- $\bar{X}$ = the average value of events
- $k$ = frequency factor $k$ for the extreme price of Gumbel

2.4 Rain Distribution Analysis
In the analysis of rainfall distribution, the rainfall calculation is done at the 0th hour to the t-hour by using the following formula:

$$RT = xR_t - [(t - 1)xR(t - 1)]$$

with:

- $RT$ = t-hour rainfall (mm)
- $R_t$ = Average rainfall at t-hour (mm)
- $T$ = Rainy time from the beginning to t-hour (hour)
- $R(t-1)$ = Average rainfall from the beginning to (t-1) hour (mm)

2.5 Analysis of flood discharge with the HEC-HMS program
In this study, the HEC-HMS program was used for hydrological analysis of the Posindo Sub-watershed using a hydrological approach in the field. The data used in the HEC-HMS modelling are area effective rainfall data, channel length, and the area of the Posindo Sub-watershed. The result of model simulation is the number of synthesis unit hydrograph [4]. Calculations with the HEC-HMS auxiliary program are carried out by making a watershed model, which is a drawing of a basin model and inputting data on rainfall, land use, and so on.

2.6 Hydraulic discharge analysis with the HEC-RAS program
The calculations are carried out using the HEC-HMS auxiliary program. Modelling of channel flow profile conditions will be carried out using the help of the HEC-RAS program. In this modelling is done
by applying the flood hydrograph resulting from the HECHMS hydrological modelling. The results of the hydraulic analysis using the HEC-RAS assistance program are water surface elevation data in the channel section [5].

3. Result and discussion
3.1 Description of the research area
Posindo Sub-basin is a small part of the Ampal Basin. The Posindo basin consists of 6 secondary channel segments which lead to the Inhutani secondary channel. Table 1 is the location and schematic of Posindo Sub-basin.

![Figure 1. Posindo sub-basin schematic map.](image)

The Posindo sub-basin has an area of 113,156 hectares with Inhutani main channel. This sub-basin has 6 catchments with different areas as shown in Table 1. Each catchment area has a channel that runs runoff water directly to the main river.

| No. | Sub-basin          | Area of sub-basin [Ha] | Average of land slope [%] |
|-----|--------------------|------------------------|--------------------------|
| 1   | BDS 2              | 26.049                 | 3.610                    |
| 2   | BDS 1 Segmen 1     | 15.931                 | 10.224                   |
| 3   | BDS 1 Segmen 2     | 15.721                 | 9.872                    |
| 4   | Kampung Buton      | 5.605                  | 9.016                    |
| 5   | Posindo            | 14.954                 | 8.354                    |
| 6   | Manunggal Selatan  | 3.201                  | 7.310                    |

3.2 Analysis of land use intensification
Based on the results of the primary survey it was found that the land use in the study areas varied in each of the handling areas. In this part, land use analysis is carried out within the scope of the sub-basin area to be handled so that it is known the percentage of built up and non-built up area as well as the suitability of the City Spatial Plan for Balikpapan in 2012-2032.

The Posindo sub-basin area is included in the secondary channel of Jalan Penegak and Posindo resident. The total area of this sub-basin is around 113 ha. Based on the results of the field survey it was found that land use in the study area was dominated by residential and settlement land use with a percentage of 55.05%. While the use of green open space is 18%. Then, if seen from the classification of built up area and non-built up area, this region still has non-built up area at 29% of the total area. This condition allows this region to still have good water absorption, although runoff is not evenly distributed.

Based on the review of the spatial plan of the Balikpapan City Spatial Plan for 2012-2032, it is known that there are 3 main designations in this area, namely settlements, urban forests, and trade and services. Although from the existing land use this area still has a large amount of non-built up area, the
development of the built up area was found to be incompatible with the designation of the spatial plan. The results of this land suitability analysis found 1.31% of land use is not following the intended designation. This is a result of the allotment of urban forest land that has been built up by housing and trade and services. In this region, land suitability was also found to be quite suitable because the existing land use did not contradict the designation of the spatial plan such as the allotment of housing used for trade and services. These land uses are commonly found along Jalan Kampung Buton and Jalan Manunggal. Picture of built up and non-built up area (open field and vegetation) of the Posindo Sub-basin can be seen in Figure 2.

3.3 Flood point distribution
The distribution of flood points is used as the basis for justification of flood handling and for comparison of the results of calculating flood discharge that occurs in the study location. Based on the results of the survey that had been conducted, it was confirmed in the field that the area was affected by the flood. The duration of inundation that occurs in the Posindo Sub- watershed is 120 minutes when it rains with a duration of 120 minutes. The Posindo sub- watershed area has 2 flood areas with an estimated inundation area of 0.0323 km$^2$. The description of the distribution of flood points can be seen in Figure 3.
3.4 Flood discharge analysis
Hydrological discharge analysis was carried out to obtain the planned flood discharge size for the 5 year return period. Flood discharge analysis aims to determine the amount of discharge due to rain that overflows the Posindo watershed. In the analysis process, the flood discharge is obtained from the calculation of rainfall plans for a return period of 5 years, the calculation of the flow coefficient, and the characteristics of the watershed covering the area, length of the river, etc. From this analysis, it is obtained the hydrological discharge value/flood discharge that flows in the channels in the Posindo sub-basin.

3.4.1 Analysis of precipitation rain return period. The return period rainfall calculation aims to determine the rain intensity of the return period plan of 2 to 100 years. Based on the rain data obtained, the following calculations are made:

3.4.2. Mean value:
\[ \overline{X} = \frac{\sum X}{n} = 136.99 \]

3.4.3. Standard deviation:
\[ S = \sqrt{\frac{(X - \overline{X})^2}{n - 1}} = 39.86 \]

Calculation of rainfall period is re-written in Table 2.
Table 2. Gumbel distribution return period rainfall.

| Return period | Value of variant correction | Frequency factor | Xmax |
|---------------|----------------------------|-----------------|------|
| [year]        | [Yt]                       | [K]             | [mm] |
| 2             | 0.37                       | -0.15           | 131.09 |
| 5             | 1.50                       | 0.92            | 173.60 |
| 10            | 2.25                       | 1.62            | 201.74 |

For the analysis of the flood reduction study in the Posindo Sub-watershed, a 5 year return period was used. This is by the initial planning of the secondary channel in Balikpapan City. The 5 year return period was also chosen according to the channel plan in the Posindo sub-basin.

3.4.2 Flood discharge analysis with HEC-HMS assistance program. The distribution of rain based on rainfall data is only obtained daily data, while to get the discharge using the HEC-HMS program, data is needed in seconds and hours. Converting the daily rainfall data to hourly rainfall requires an existing hourly rainfall data model.

![Figure 4. Catchment area model of Posindo sub-basin.](image)

In this study, the HEC-HMS program was used for hydrological analysis of the Posindo Sub-watershed using a hydrological approach in the field. Calculations with the HEC-HMS auxiliary program are carried out by making a watershed model, which is a drawing of a basin model and inputting data on rainfall, land use, and so on. The depiction of the water catchment area model and schematic map of the direction of flow in the Posindo Sub-watershed can be seen in Figure 4.

Figure 4 illustrates the Posindo watershed model in the HEC-HMS. This modeling consists of 6 sub-watersheds and 6 channels which are part of the DAS. Each channel segment has a different catchment area as presented in Table 3. In this analysis, the SCS method (surface runoff estimation method) is used as the loss rate method (water loss process). Loss rate method is a model for calculating water loss that occurs due to the infiltration process and reduction of storage. SCS developed an empirical curve number parameter that assumes various factors from soil layer, land use, and porosity to calculate the total rainfall runoff [6]. In contrast to the hydrograph transformation of runoff units, a synthetic unit hydrograph from SCS (soil conservation service) is used. The main parameter required is the time lag, namely the time lag between the weight of the effective rain and the gravity of the hydrograph.

One of the factors that influence the amount of runoff discharge is the value of the coefficient of flow (CN). This coefficient aims to determine the ratio of the percentage of the amount of water that overtakes the soil surface and absorbs it into the soil. This coefficient value can also change according to the conditions of the influencing factors, namely the type of land and land use. The value of the CN (curve number) varies from 100 (for waterlogged surfaces) to about 30 (for non-waterproof surfaces with high
infiltration values). CN values are obtained from the results of land classification based on their use. To find out the CN value in each sub-watershed, it is necessary to calculate the combined CN and the results can be seen in Table 3.

Table 3. Curve number sub-basin.

| Sub-basin          | Area [m²]  | Combined CN |
|--------------------|------------|-------------|
| BDS 2              | 260577.52  | 84.52       |
| BDS 1 Segmen 1     | 159319.05  | 82.09       |
| BDS 1 Segmen 2     | 157209.59  | 82.27       |
| Kampung Buton      | 56049.71   | 80.95       |
| Posindo            | 149265.53  | 82.98       |
| Manunggal Selatan  | 32009.60   | 82.46       |

Table 3 is the result of calculating the value of the flow coefficient of each of the Posindo sub-watersheds. From the Table, it is known that the average CN value in the sub-watershed is 82.60. A CN of 82.60 means that 82.60% of the rainwater that falls on the soil surface will flow into runoff and the remaining 17.40% will seep into the soil through the infiltration process.

3.4.3. Modeling of the Posindo sub-basin. In this research, the HEC-HMS program is used for hydrological analysis of Posindo sub-basin using a hydrological approach in the field. The results of the running process in the form of output data consist of hydrographic graphs at each control point that is equipped with the amount of discharge at each point and the discharge data at the Posindo sub-basin. In the previous discussion, it was explained that the Posindo sub-basin has six sub-basin with different channel lengths and lengths. The area and length of the channels for each sub-basin to be included in the HEC-HMS model are written in Table 4.

Table 4. Area and dan river length of sub-basin.

| No. | Sub-basin          | Area [km²] | River       | River length (L) [m] |
|-----|--------------------|------------|-------------|---------------------|
| 1   | BDS 2              | 0.260      | S.BDS 2     | 513.53              |
| 2   | BDS 1 Segmen 1     | 0.159      | S. BDS 1 Segmen 1 | 314.78              |
| 3   | BDS 1 Segmen 2     | 0.157      | S. BDS 1 Segmen 2 | 247.68              |
| 4   | Kampung Buton      | 0.056      | S. Kampung Buton | 266.45              |
| 5   | Posindo            | 0.150      | S. Posindo  | 584.76              |
| 6   | Manunggal Selatan  | 0.032      | S. Manunggal Uta | 363.09              |

Table 4 is the data that will be entered into the HEC-HMS modeling to obtain runoff discharge values. This data is a compiler of the watershed model in HEC-HMS. This data will be converted into hydrological elements that represent the Posindo River Basin physical. There are two hydrological elements used in this modeling, these elements are the channel (river) and sub-basin.

3.4.4 Modeling Results of Posindo sub-basin. From the HEC-HMS modeling using the SCS method, the runoff (hydrological) discharge value is obtained by Table 5. Based on Table 5, it is obtained the value of runoff discharge (hydrology) that flows in each channel in the Posindo Sub basin. In the channel section, namely upstream discharge channel obtained BDS 2 1.00 m³/sec and increased significantly in the downstream channel that is Manunggal Selatan at 3:20 m³/sec. The results of this analysis were
carried out without considering the base flow. This is following the conditions of the field, where the entire channel is a city drainage channel that does not have the baseflow.

Table 5. Maximum hydrological discharge of sub-basin.

| No. | River               | Hydrological discharge (maximum) [m$^3$/sec] |
|-----|---------------------|---------------------------------------------|
| 1   | S.BDS 2             | 1.00                                        |
| 2   | S. BDS 1 Segmen 2   | 1.30                                        |
| 3   | S. BDS 1 Segmen 1   | 2.60                                        |
| 4   | S. Kampung Buton    | 1.30                                        |
| 5   | S. Posindo          | 3.20                                        |
| 6   | S. Manunggal Selatan| 3.20                                        |

3.5 Drainage channel cross section capacity analysis

Analysis of the cross-sectional capacity of the channel aims to determine the channel capacity compared to the flood discharge that flows in the channel. This comparison aims to determine the ability of the channel to drain the flood discharge that occurs. If the channel capacity is greater than the hydrological discharge, the river is free from overflow or flooding [7]. If the cross-sectional capacity value of the channel is smaller than the value of the flood discharge, it means that the channel is unable to drain the flood discharge due to rainwater without overflow. This condition can also be said to be a flood condition. The Posindo sub-watershed has flood problems caused by increased built-up areas, silting and narrowing of the channels due to sedimentation. The results of the analysis of the existing conditions based on the dimensions of each channel and the proportion of current land use show an overflow of water as in Table 6.

Table 6. Drainage channel capacity.

| No. | River               | Channel Dimensions | Water speed | Channel capacity |
|-----|---------------------|--------------------|-------------|-----------------|
|     |                     | wide (m)           | high (m)    | (m$^3$/sec)     |
| 1   | S.BDS 2             | 1.00               | 0.50        | 0.23            | 0.12            |
| 2   | S. BDS 1 Segmen 2   | 1.60               | 1.00        | 0.17            | 0.27            |
| 3   | S. BDS 1 Segmen 1   | 2.00               | 1.50        | 0.32            | 0.96            |
| 4   | S. Kampung Buton    | 1.30               | 0.70        | 0.48            | 0.44            |
| 5   | S. Posindo          | 2.00               | 1.50        | 0.82            | 2.46            |
| 6   | S. Manunggal Selatan| 2.00               | 1.50        | 0.94            | 2.82            |

Based on Table 6, the results of the analysis of existing conditions, the canal dimensions in the Posindo Sub-watershed have dimensions varying from 1 x 0.5 m to 2 x 1.5 m. Sub-basin channel capacity is between 0.12 m$^3$/sec up to 2.82 m$^3$/sec. Channel capacity is related to the channel's ability to drain hydrological discharge due to rain. When compared with the value of hydrological discharge is 1.00 m$^3$/s up to 3.2 m$^3$/s, it can be concluded that the drainage channels on Posindo Sub-basin not able to drain discharge hydrology due to rain without overflowing. Table 7 obtains an overview of the height and discharge of overflowing water.

Table 7 shows the six channels that became the observation points experiencing overflows because the channel capacity is smaller than the hydrological discharge flowing into the channel. The height of the overflow or flooding of the channel varies between 3.79 m -1.40 m.
Table 7. Height and overflow discharge.

| No. | River                  | Channel Dimensions | Channel capacity | Overflow discharge | Water level | Freeboard | Flood level | Status   |
|-----|------------------------|--------------------|------------------|--------------------|-------------|------------|-------------|----------|
| 1   | S.BDS 2                | 1.00  0.50         | 0.12             | 0.89               | 4.29        | 0.30       | 3.79        | Flood    |
| 2   | S. BDS 1 Segmen 2      | 1.60  1.00         | 0.27             | 1.03               | 4.25        | 0.30       | 3.25        | Flood    |
| 3   | S. BDS 1 Segmen 1      | 2.00  1.50         | 0.96             | 1.64               | 4.22        | 0.30       | 2.72        | Flood    |
| 4   | S. Kampung Buton       | 1.30  0.70         | 0.44             | 0.86               | 4.17        | 0.30       | 3.47        | Flood    |
| 5   | S. Pos indo            | 2.00  1.50         | 2.46             | 0.74               | 4.02        | 0.30       | 2.52        | Flood    |
| 6   | S. Manunggal Selatan   | 2.00  1.50         | 2.82             | 0.38               | 2.90        | 0.30       | 1.40        | Flood    |

4. Conclusion

Based on studies that have been carried out in the Posindo sub-basin area, it is known that the land use intensification in the Posindo Sub-basin by 71% is a built-up area with the dominance of land use are housing and settlements, and land use mismatch is obtained by 1.31%. Based on the land use condition, it is obtained that the planned flood discharge for a 5-year return period flows in the upstream Posindo sub-basin channel of 1.00 m³/sec and downstream of 3.20 m³/sec. Floods in the Posindo sub-basin are caused by a lack of channel capacity to drain the flood discharge. The flood height that occurs in the channel varies between 3.79 m - 1.40 m.

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References

[1] Pemerintah Kota Balikpapan 2012 *Materi Teknis Penyusunan Rencana Tata Ruang Wilayah Kota Balikpapan Tahun 2012-2032*.

[2] Pemerintah Kota Balikpapan 2016 *Dokumen Informasi Kinerja Pengelolaan Lingkungan Hidup Daerah Tahun 2016*.

[3] Wong T and Brown R R 2008 *Transitioning to Water Sensitive Cities: Ensuring Resilience through a new Hydro-Social Contract* (Edinburgh: IWA Publishing).

[4] Hydrologic Engineering Center 2002 *HEC-HMS Hydrolic Modelling System (User's Manual)*.

[5] Hydrologic Engineering Center 2002 *HEC-RAS River Analysis Sistem (User's Manual)*.

[6] Ponce V M and Hawkins R H 1996 *J. Hydro. Eng.*, 1 (1) 11-19.

[7] Suripin 2007 *Sistem Drainase Kota yang Berkelanjutan*.