Flood Control Reduction Analysis using HEC-RAS due to Local Floods in Central Jakarta

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Abstract. There are two types of floods in Jakarta: upstream flooding and local flooding. In general, floods in DKI Jakarta are caused by local floods. The main cause of this flood is the occurrence of high rainfall, poor drainage system, and land subsidence. This study will analyse the local flood that occurred in Gunung Sahari, Central Jakarta. Judging from the existing conditions, sedimentation occurs in the drainage channels. This sedimentation causes a reduction in the existing channel capacity. Based on a hydrological and channel capacity analysis, the existing drainage channels are designed based on annual rainfall i.e. return period 1-2 years, which is 133.10 mm/day. Flood modelling is done for existing conditions. Based on the results of modelling, floods that occur in locations between 50 cm - 100 cm. Due to dense housing conditions, widening and normalizing the channel is difficult. Therefore, flood reduction will be assisted by pumps. The pump will be installed in the downstream of the main drain, which is connected to Mati River. This pump is designed with a capacity of 0.5 m^3/ sec. Based on the results of modelling, with a largest pump capacity of 0.5 m^3/sec, flooding is only reduced by 5 cm - 7 cm. Due to the lack of effectiveness of the pump, retention ponds will be designed to reduce surface runoff. Retention ponds are designed with an area of 1 ha and a depth of 1.5 m. Modelling is done in the presence of a retention pond. With the addition of retention ponds, annual flooding for the 2-year return period on Gunung Sahari could be reduced. Therefore, the discharge that will be received by the drainage channel will be smaller than the capacity of the channel itself and the flood will be completely reduced.

1. Introduction
Climate change nowadays is difficult to predict, especially in Special Capital Region (DKI) Jakarta. As a result, erratic climate change are causing more frequent extreme rainfall. This increase in the likelihood of extreme rainfall and its intensification creates a higher risk of damaging flood events [1]. Aside of climate change, the land subsidence is more significant than climate-related factor in increasing flood damage [2]. The highest rate of land subsidence with 6 cm/year occurred in eastern part and western part of north area of Jakarta, some part West Jakarta, Central Jakarta, and South Jakarta [3]. In the case, that land is in progress in Jakarta, it causes flood due to inner water because inundation water accumulated in developed area is not properly discharged to the river and sea.

Each year, the flooding occurs in various parts of the DKI Jakarta. One of the recent floods occurred on January 1, 2020. The Meteorology, Climatology and Geophysics Agency (BMKG) measured 377
mm (14.8 inches) of rainfall in a day at Halim Perdana Kusuma Airport Rainfall Gauge [4]. Daily rainfall that occurs is the largest rainfall over the past 24 years [4]. High rainfall intensity starting from New Year's Eve and continued through the night. According to BNPB data, major flood on January 1, 2020 had caused at least 16 people died, 5126 refugees, and considerable economic losses [5]. Handling flood problems in DKI Jakarta requires planning for facilities and infrastructure for effective flood control, to reduce inundation and flooding points as well as their impacts [6].

Based on its river system, the upstream river system in DKI Jakarta located in Bogor Regency. So that the morphology of DKI Jakarta is a downstream area, which is a lowland. In general, this lowland is a natural floodplain. If there is a high discharge in its rivers, flooding will occur. There are two types of floods in Jakarta: upstream flooding and local flooding. In general, floods in DKI Jakarta are caused by local floods. The main cause of this flood is the occurrence of high rainfall, poor drainage system, and land subsidence. This study will analyse the local flood that occurred in Gunung Sahari, Central Jakarta. Judging from the existing conditions, sedimentation occurs in the drainage channels. This sedimentation causes a reduction in the existing channel capacity. The drainage system in Gunung Sahari is integrated and connected with Dead River. Thus, flood modelling with unsteady conditions is needed. In this study, 1-D flood modelling will be carried out with the help of HEC-RAS software. HEC-RAS is one of the flood modelling software that has been approved by FEMA [7]. HEC-RAS is designed to perform one-dimensional and two-dimensional hydraulic calculations for a full network of natural and constructed channels, overbank/floodplain areas, levee-protected areas; etc [8]. The models are widely used for flood study such as flood risk mapping [9], flood damage assessment [10], and flood related engineering [11].

2. Method
In general, the flood modelling flowchart in this study can be seen in the Figure 1 below.

![Flood Modeling Flowchart](image)

**Figure 1. Flood Modeling Flowchart**

Flood modelling using HEC-RAS is a 1-D model where the program output results in the form of water flood elevation and flood depth. The governing equation of HEC-RAS 1-D model is the momentum equation and continuity equation. The following equations are mathematical expression of continuity and momentum equations [12].

**Governing Equations:**

**Continuity Equation**

\[
\frac{\partial A}{\partial t} + \frac{\partial q}{\partial x} = q_1
\]

**Momentum Equation**

\[
\frac{\partial q}{\partial t} + \frac{\partial (uq)}{\partial x} = gA \frac{\partial h}{\partial x} - \frac{g q^2 (q|q|)}{k h A}
\]

where:

- \( A \) = Area (km\(^2\))
- \( Q \) = Discharge (m\(^3\)/s)
- \( q_1 \) = Lateral Flow (m\(^3\)/s)
2.1. Study Area
Central Jakarta is the centre of government and business activities in DKI Jakarta. Central Jakarta is bordered by North and West Jakarta on the north side. On its east side, bordered by East Jakarta, south side bordered by East Jakarta and South Jakarta, and west side bordered by West Jakarta. The surface of central Jakarta is flat, located about 4 m above sea level and has an area of 48.13 Km². The location of this study is in the village of Gunung Sahara Utara, Sawah Besar Subdistrict can be seen in the Figure 2 below.

![Figure 2. Study Location](image)

2.2. Model Setup
1. Drainage Network
Drainage system networks are needed in 1-D modelling. Appropriate drainage network data can improve the accuracy of the flood model results. Following (Figure 3) is the appearance of drainage network patterns.
2. Boundary Condition
The required boundary conditions for the 1-D flood model are flood discharge, water level elevation, and rating curves. The following (Figure 4) are the boundary conditions used in the model.

Table 1. Flood Discharge Analysis

| No. | Catchment         | Catchment (Ha) | Cr  | tc (min) | Return Period | I (mm/hour) | Q (m³/s) |
|-----|-------------------|----------------|-----|----------|---------------|-------------|----------|
| 1   | Gunung Sahari Mid | 10.69          | 0.85| 36.37    | 2             | 64.43       | 1.63     |
| 2   | Gunung Sahari Up  | 4.31           | 0.85| 19.09    | 2             | 99.02       | 1.01     |
| 3   | Gunung Sahari Down| 4.40           | 0.85| 27.67    | 2             | 77.30       | 0.80     |

The flood discharge in the Table 1 above is obtained using rational method.
3. Results and discussion

3.1 Existing Condition

Based on the existing condition of the Drainage System at Gunung Sahari, the direction of the water flowing toward the Ciliwung River. Yet, the condition of Ciliwung Riverbanks has now been elevated by installing river embankments. Thus, the flow cannot flow into Ciliwung River. Meanwhile, other problems are blockage and sedimentation in the channel that cannot be normalized. Modelling is done with a return period of two years to get the existing capacity of the channel.

Based on (Figure 5), the existing drainage channels are designed based on annual rainfall i.e. return period 1-2 years, which is 133.10 mm/day. Flood modelling is done for existing conditions. Based on the results of modelling, floods that occur in locations between 50 cm - 100 cm. The existing channel capacity in the Gunung Sahari itself is 0.06 m³/s. Meanwhile, the discharge received by the drainage channel for the two-year return period is 0.78 m³/s. This results show that the drainage channel capacity is also inadequate.

![Figure 5. Existing Condition](image)

3.2 Flood Control Condition

Due to dense housing conditions, widening and normalizing the channel is difficult. The alternative for flood reduction is to draw water flow to be discharged into the dead river with the addition of a pump. The pump will be installed in the downstream location of the drainage channel. This pump will pump the flow to the dead river that can be seen in the Figure 6 below.
Based on modelling results (Figure 7), the maximum effective pump capacity is 0.5 m³/s. This is due to the slope of the negative channel towards the dead river. The height of the flood water that can be reduced in Gunung Sahari is only 5 - 7 cm.

Due to the lack of effectiveness of the pump, retention ponds will be designed to reduce surface runoff (Figure 8). The location of the retention pond plan is in the land owned by PD. Dharma Jaya. Retention pond are designed with an area of 1 ha and a depth of 1.5 m. The dimensions of the retention pool are as follows:

- Catchment Area = 431,000 m²
- Retention Pond Area = 10,000 m²
- Retention Pond Depth = 1.5 m
- Retention Pond Volume = 15,000 m³
The volume of flood discharge received by retention ponds for rain $D = 1$ hour is $2760$ m$^3$. With a retention pond capacity of $15,000$ m$^2$, the pool can hold a volume of rain for $\pm 5.4$ hour. For a two-year return period, the pond is only filled with water as high as $28$ cm. The following is an overview of the results of the 1-D model with a retention pond.

Based on modelling results in the presence of a retention pond, annual flooding for the 2-year return period on Gunung Sahari could be reduced. From the picture above (Figure 9), the flood discharge that will be received by the channel is reduced from $0.78$ m$^3$/s to $0.03$ m$^3$/s, as for the channel capacity itself is $0.06$ m$^3$/s. Hence, the discharge that will be received by the drainage channel will be smaller than the capacity of the channel itself and the flood will be completely reduced.

4. Conclusion
Based on a hydrological and channel capacity analysis, the existing drainage channels are designed based on annual rainfall i.e. return period 1-2 years, which is $133.10$ mm/day. Flood modelling is done for existing conditions. Based on the results of modelling, floods that occur in locations between $50$ cm - $100$ cm. Due to dense housing conditions, widening and normalizing the channel is difficult. Therefore, flood reduction will be assisted by pump. The pump will be installed in the downstream of the main drain, which is connected to Mati River. This pump is designed with a capacity of $0.5$ m$^3$/sec. Based on the results of modelling, with a largest pump capacity of $0.5$ m$^3$/sec, flooding is only reduced by $5$ cm - $7$ cm. Due to the lack of effectiveness of the pump, retention ponds will be designed to reduce
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