Utilization of a pond in East Jakarta for a sustainable urban drainage system model

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Abstract. High population growth in the area of East Jakarta has led to more construction of settlements, including in several areas of East Jakarta, which includes Jalan Pengantin Ali in Ciracas Sub-District. When very heavy rains fall in the rainy season, this place is often flooded, while in the dry season there is a scarcity of raw water or clean water. This study examines the application of sustainable drainage systems with the technique of making a retention pond as a flood control alternative. The purpose is to hold water runoff during the rainy season so that it does not enter the river directly, and so that some of the collected water could be used to meet the clean water supply needs of the people. The calculation of rainwater potential used the height of the monthly average rainfall. The retention pond capacity was determined by the pool simulation method during the rainy season. The planned flood discharge was calculated using the Nakayasu HSS method. The obtained results indicated a peak discharge value with a return period of 2 years that amounted to 8.84 m³/sec. The planned retention pond area is 6380.94 m², with a retention pond height of 4 m, a dike slope of 1:1, and the elevation of the overflow base being at an altitude of 38.5 meters above sea level (masl). From the results of the HEC-RAS 5.0.6 software, an optimal overflow width of 2 m was obtained, with an outflow discharge of 4.55 m³/sec and a pond volume of 19530 m³. With the retention pond, flood peak discharge could be reduced by 4.29 m³/sec. This will allow the flood discharge in the rainy season to be reduced and increased clean water needs in the dry season to be met.

Keywords: Retention Ponds, Flood Control, Nakayasu Method.

1. Introduction

The East Jakarta area is one of the largest areas in the Jakarta Capital Region, with an area of 18,767.87 ha. Administratively, the area of East Jakarta is divided into 10 sub-districts; the East Jakarta area is comprised of 95% land and the remaining being swamps and rice fields, and it is also crossed by the Cakung drainage channel, Ciliwung River, Malang River, Sunter River, Cipinang River, Buaran River, and Jati Kramat River.

The high population growth in the East Jakarta region have led to the construction of more settlements, and this results in some areas in East Jakarta being always flooded during the rainy season. Floods in Jakarta have occurred since the Dutch colonial era. The first major flood occurred in 1621, followed by floods in 1654 and 1876.
Many locations are prone to flooding in the East Jakarta area, one of which is Jalan Pengantin Ali in Ciracas Sub-District. In this area, the flooding occurs not only in the rainy season, but also in the dry season, as a high amount of rainfall in some locations often results in inundation. This is due to the lack of water catchment areas and the rubbish that clogs the drainage channels, ultimately resulting in flooding.

To overcome floods due to local rain and upstream flow in East Jakarta, there are many approaches, such as through the construction of canals, river dredging, reservoir normalization, and drainage improvement. This research focuses on a sustainable drainage system, with the creation of a retention pond that is intended to be a reservoir for flowing water during the peak of the rainy season, flood control for when the Cipinang River overflows, and a water conservation infrastructure for replenishing ground water and raw water sources for local residents.

2. Methodology

2.1 Research Location
The scope of the research area is limited to Ciracas Sub-District, East Jakarta. Ciracas Sub-District has the following boundaries:
   a. With the Rambutan and Susukan Sub-Districts on the north side;
   b. With Pekayon Hamlet, Pasar Rebo Sub-District, and Kelapa Dua Wetan Village on the south side;
   c. With Cijantung and Pekayon Sub-Districts, and Pasar Rebo Sub-District and Susukan Sub-District on the west side; and
   d. With the Ceger and Cipayung Sub-Districts on the east side.

2.2 Climate Conditions
The location of this study has a tropical climate. Temperatures range from 26 °C - 31 °C, with more than 30% daily sun exposure. The annual average humidity is 90%. The climate type of the study area is B1 (between 7-9 wet months, and less than 4 dry months). This area is part of the A rain zone or region, where rain falls during most of the year and the highest rainfall is from November to February. However, the dry months occur from July to September.

2.3 Planned Rainfall Distribution Analysis
In this study, to find the value of the planned rainfall distribution, the Log-Pearson Type III method was utilized; the logarithmic probability equation will form a straight line on a chart and can be stated as the following mathematical model [2, 8]:

![Image of the flood of Jakarta in Year 1918](image-url)
\[ Y = \bar{Y} + k \times S \quad (1) \]

Where:
- \( Y \) = Logarithmic value of \( X \) (log \( X \))
- \( X \) = Rainfall (mm)
- \( \bar{Y} \) = Calculated average (preferably geometric mean) of the value of \( Y \)
- \( S \) = Standard deviation of the value of \( Y \)
- \( K \) = Characteristics of Log-Pearson Type III opportunity distribution

![Figure 2. The research location in East Jakarta](image)

### 2.4 Rainfall Intensity Analysis

To determine the planned flood discharge of this reservoir, it is necessary to obtain the bulk intensity value. Rainfall intensity is the height of rainfall that occurs at a time period where the water is concentrated [3, 4]. According to Utomo et al. [7], the analysis of rainfall intensity could be performed from data of rainfall that has occurred in the past. With the availability of daily rainfall data, the calculation of planned rainfall can be performed using the Mononobe empirical formula, as described below [3]:

\[ I = \frac{R_{24}}{t_c} \times \left[ \frac{t_c}{t} \right]^{2/3} \quad (2) \]

Where:
- \( I \) : Rainfall intensity (mm/hour)
- \( R_{24} \) : Maximum rainfall (mm)
- \( t_c \) : Concentration time (hours)
- \( t \) : Duration of rainfall (hours)
2.5 Analysis of Planned Flood Discharge

The flood discharge in this study was obtained by the Nakayasu HSS method. To make a flood hydrograph for a river, it is necessary to find the characteristics or parameters of the river flow area. The flow characteristics include the following [5]:

a. Time period from the beginning of rain to the peak of the hydrograph (time to peak magnitude).
b. Time from the centroid of heavy rain to the peak weight of hydrograph (time lag).
c. Hydrograph time period (base of hydrograph time).
d. Area of flow

e. The length of the main (longest) river channel.

The Nakayasu Synthetic Unit Hydrograph (HSS) is given in the form of the following equation [1]:

\[ Q_p = \frac{A \times R_o}{3.6 (0.3 T_p + T_{0.3})} \]  \hspace{1cm} (3)

Where:

- \( Q_p \) = Flood peak discharge (m³ / sec)
- \( A \) = Watershed area (km²)
- \( R_o \) = Unit rain (1 mm)
- \( T_p \) = Hydrograph peak time (hours)
- \( L \) = Length of main river (km)

2.6 Research Stages

The following are the stages of this research:

1. Determining the maximum daily rainfall.
2. Analysis of the planned rainfall distribution.
3. Analysis of rainfall intensity.
4. Determining the hourly effective rainfall by the ABM method.
5. Analysis of the Nakayasu HSS hydrograph.
6. Flood discharge analysis for return periods of 2, 5, 10, 20, 50, and 100 years.
7. Designing a retention pond that includes the area of the reservoir, inlet plan, and outlet plan.
8. Analysing the volume of the retention pond for water needed in the dry season.

3. Results and Discussion

3.1 Rainfall Data

For the research location of East Jakarta, there is only one rain station location for observing rainfall, which is the PWSCC Cawang post office station. The utilized rainfall data is composed of 10 years of rainfall data from 2007-2016; the highest daily rainfall occurred in 2013, which amounted to 149 mm as shown in the figure below:

3.2 Log-Pearson Planned Rainfall Distribution

In this study, the planned rainfall distribution was calculated with the Log-Pearson Type 3 probability distribution. Calculation of the distribution of Log-Pearson Type 3 utilized Equation 1. The calculation resulted in the following planned rainfall values (Table 1).
Figure 3 Annual rainfall in Ciracas Sub-District

Table 1. The Return Period of Rainfall Distribution by the Log-Pearson Type 3 Method

| Period (Years) | Log X | Sd Log X | Y | Xt=10 Y |
|---------------|-------|----------|---|---------|
| 2             | 2.072 | 0.132    | 2.031 | 107.46 |
| 5             | 2.072 | 0.132    | 2.152 | 141.85 |
| 10            | 2.072 | 0.132    | 2.243 | 175.00 |
| 20            | 2.072 | 0.132    | 2.303 | 201.08 |
| 25            | 2.072 | 0.132    | 2.364 | 231.06 |
| 50            | 2.072 | 0.132    | 2.455 | 285.06 |
| 100           | 2.072 | 0.132    | 2.546 | 351.67 |

3.3 Rainfall Intensity Analysis

The calculation of rainfall intensity used the Mononobe method with Equation 2, and the resulting average rainfall in Indonesia is approximately 6 hours. The planned rainfall distribution was first multiplied by the runoff coefficient to obtain the net rainfall. After obtaining the net rainfall value, the value of rainfall intensity was then calculated. The full calculations of net rainfall and rainfall intensity can be seen in the table below:

Table 2. The Net Rainfall of Ciracas Sub-District

| Time Period (Years) | Planned Rainfall (mm) | Flow Coefficient | Net Rainfall (mm) |
|---------------------|-----------------------|------------------|------------------|
| 2                   | 107.46                | 0.750            | 80.60            |
| 5                   | 141.846               | 0.750            | 106.38           |
| 10                  | 174.995               | 0.750            | 131.25           |
| 20                  | 201.082               | 0.750            | 150.81           |
| 25                  | 231.057               | 0.750            | 173.29           |
| 50                  | 285.055               | 0.750            | 213.79           |
| 100                 | 351.673               | 0.750            | 263.75           |
Table 3. The Mononobe Method for Rainfall

| t (hours) | 2         | 5         | 10        | 50        | 100       |
|-----------|-----------|-----------|-----------|-----------|-----------|
| 1         | 44.35     | 58.55     | 72.23     | 117.65    | 145.15    |
| 2         | 11.53     | 15.22     | 18.77     | 30.58     | 37.73     |
| 3         | 8.09      | 10.67     | 13.17     | 21.45     | 26.46     |
| 4         | 6.44      | 8.50      | 10.48     | 17.08     | 21.07     |
| 5         | 5.44      | 7.18      | 8.85      | 14.42     | 17.79     |
| 6         | 4.75      | 6.27      | 7.74      | 12.61     | 15.55     |

Figure 4. The Mononobe Method for Rain Intensity

3.4 The Hourly Rainfall Distribution with the ABM Method
The Alternating Block Method (ABM) is a simple way to create a hyetograph plan from the IDF curve. The depth of the rainfall was obtained by multiplying the intensity of the rainfall by its duration. The difference in successive rainfall depth values is the increase in rainfall in the time interval \( \Delta t \). The increase in rainfall (blocks) was sorted back into the time-series with maximum rainfall intensity. The maximum rainfall intensity becomes the middle of the duration of rain and the remaining blocks were arranged in descending order on the right and left sides of the middle block.

3.5 Calculation of the Synthetic Unit Hydrograph with the Nakayasu Method
The synthetic unit hydrograph with the Nakayasu method has been repeatedly applied to many watersheds in Indonesia. The results are still satisfactory even at present. The Nakayasu method uses the following parameters:
1. Catchment Area = 0.405 km²
2. Length of drainage (L) = 0.94 km
3. Effective rainfall (Ro) = 1.0 mm
4. Hydrographic coefficient (\( \alpha \)) = 2
   - \( \alpha = 2 \) (in normal drainage areas)
\( \alpha = 1.5 \) (in slow rising and fast falling hydrograph)
\( a = 3 \) (in fast rising and slow falling hydrograph)

The following are the results of the flood discharge calculations for various return periods.

Table 4. The Mononobe Method for Rainfall Intensity

| t (Hours) | ABM Method Rain Distribution for Hours (mm/hrs) | 2 | 5 | 10 | 50 | 10 |
|-----------|-----------------------------------------------|---|---|----|----|----|
| 1         |                                               | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2         |                                               | 1.43 | 1.89 | 2.33 | 3.80 | 4.68 |
| 3         |                                               | 44.35 | 58.55 | 72.23 | 117.65 | 145.15 |
| 4         |                                               | 1.49 | 1.97 | 2.43 | 3.96 | 4.88 |
| 5         |                                               | 1.33 | 1.76 | 2.17 | 3.53 | 4.35 |
| 6         |                                               | 1.20 | 1.59 | 1.96 | 3.19 | 3.94 |

Table 5. Summary of the Flood Hydrograph

| Time (hours) | Flood Discharge (m³/s) | 2 | 5 | 10 | 20 | 50 | 100 |
|--------------|------------------------|---|---|----|----|----|-----|
| 0.1          |                        | 0 | 0 | 0  | 0  | 0  | 0   |
| 0.3          |                        | 0.71 | 0.94 | 1.15 | 1.41 | 1.88 | 2.32 |
| 0.5          |                        | 8.84 | 11.67 | 14.39 | 17.57 | 23.45 | 28.92 |
| 0.7          |                        | 6.62 | 8.73 | 10.77 | 13.15 | 17.55 | 21.65 |
| 0.9          |                        | 3.85 | 5.08 | 6.26 | 7.65 | 10.20 | 12.58 |
| 1.1          |                        | 2.47 | 3.26 | 4.02 | 4.91 | 6.55 | 8.08 |
| 1.3          |                        | 1.65 | 2.17 | 2.68 | 3.27 | 4.37 | 5.39 |
| 1.5          |                        | 1.11 | 1.46 | 1.80 | 2.20 | 2.93 | 3.62 |
| 1.7          |                        | 0.80 | 1.06 | 1.31 | 1.59 | 2.13 | 2.62 |
| 1.9          |                        | 0.59 | 0.78 | 0.97 | 1.18 | 1.57 | 1.94 |
| 2.1          |                        | 0.44 | 0.58 | 0.72 | 0.87 | 1.17 | 1.44 |
| 2.3          |                        | 0.33 | 0.43 | 0.53 | 0.65 | 0.86 | 1.07 |
| 2.5          |                        | 0.24 | 0.32 | 0.39 | 0.48 | 0.64 | 0.79 |

Figure 5. Flood Hydrograph of the HSS Nakayasu Method
3.6 Retention Pond Design

The planned reservoir was modelled by the HEC-RAS software. The flood discharge used the HSS Nakayasu method with unsteady flow conditions (see Figure 6). The following are the parameters used for retention pond planning:

1. Land Area = 8013.37 m²
2. Pool area = 6380.94 m²
3. Embankment Elevation Plan = 40 masl
4. Basic El Channel Plan = 36 masl
5. High Retention Pool = 4 m
6. The embankment slope = 1:1
7. Top Area = 6380.94 m²
8. Lower Area = 5166.84 m²
9. Squall Base Elevation = 37.5 masl
10. Overflow Elevation = 38.5 masl
11. Maximum Water Level Elevation = 39.5 masl

The above data became the boundary input for modelling in the HEC-RAS software. The results of running the retention pond model can be seen in the image below:

![Figure 6 Schematic of Retention Pond Modelling](image)

![Figure 7. Results of Running the Model](image)
From the results of modelling, it was found that the optimal overflow width is 2 m with an outflow discharge of 4.55 m$^3$/second and a pond volume of 19530 m$^3$.

4. Conclusion
From calculations, the obtained peak discharge value for the 2-year return period is 8.84 m$^3$/sec. The planned retention pond area is 6380.94 m$^2$, the height of the retention pond is 4 m, the slope of the dike is 1:1 and the elevation of the overflow base is at an altitude of 38.5 meters above sea level. An optimal overflow width of 2 m is also achieved, with an outflow discharge of 4.55 m$^3$/second and a pond volume of 19530 m$^3$. The retention pond reduces flood peak discharge by 4.29 m$^3$/second. The surface flow in the rainy season can be decreased and increased needs for raw water in the dry season can be met.

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