Numerical simulation of the water level of the channel and the Kalidami boezem by pump operation

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Abstract. Analysis of water level in a reservoir such as Boezem is needed. The purpose of this research is to find out whether the procedures implemented in managing the Boezem are appropriate to deal with various situations. To do this, a simulation is needed so that the movement of water in the channel to the Boezem can be analyzed. This research was conducted at Kalidami Boezem in the city of Surabaya which has an area of 20,936.69 m² with an average depth of Boezem of 3.8 m. The simulation is carried out using the Storm Water Management Model (SWMM 5.1) application with rain data on February 25, 2020 and a 5-year return period rainfall data. The simulation results show that the model constructed has been calibrated based on the RMSE method and produced an error value of 0.11. Because the model has been well calibrated, it will be possible to do next simulation to see how the Channel and Boezem are performing to deal with various scenarios that might be encountered later on. Based on the results of hydraulic simulation using a 5-year return period rainfall data, it can be seen that within 45 minutes, Kalidami Boezem has been filled with water.

1. Preliminary
Kalidami Boezem is an estuary of various channels in the city of Surabaya. Boezem has an area of 2.09 Ha and a water storage capacity of 61,971 m³. The function of Boezem is as a pond to collect rainwater and waste water coming from various sewers before being discharged to the sea. Because it is located at the estuary of various channels in the city of Surabaya, it can be seen that the elevation of the land at the Kalidami Boezem location is relatively low. In the upper part of Boezem, there is a primary channel, the Kalidami channel which is one of the important channels in the city of Surabaya. This channel has a length of 44,65.27 m with different river widths between 11-35 m. The position of the channel is parallel to Jl. Kertajaya, Surabaya City.

Based on Local Government Regulation No. 12 of 2014 concerning Urban Planning of Surabaya in 2014-2034, it can be seen that Boezem and Kalidami Channel have a vital function for the City of Surabaya. As a flood controller, the Kalidami Channel functions to drain wastewater and rain water from the catchment area, various secondary channels and tertiary channels around the Kalidami channel. Waste water and rainwater that enter this channel will be directed to the sea in the eastern part of Surabaya by passing Kalidami Boezem. Because the Kalidami Channel and Boezem have very important functions, especially to prevent flood in the eastern part of the city of Surabaya, an analysis of the water flow that enters the channel and Boezem becomes very necessary. With this research, it is expected that information will be obtained related to the movement of water flow in the Kalidami Channel and
Boezem. In addition, information on the performance of water pumps that are operated to deal with various conditions such as the 5-year return period rainfall that might occur at the location will also be obtained.

1.1 Research purpose
The purpose of this study was to conduct a water level simulation at the Kalidami Boezem using hydrological and hydraulic modeling tools, namely SWMM 5.1. This research was conducted to determine whether the model made was in accordance with the real conditions based on the recording of the Boezem water level on February 25, 2020. Then, the resulted model will be analyzed using the 5-year return period rainfall data obtained based on the results of rain data processing from several rain stations that affect the catchment area around the Kalidami Channel and Boezem.

2. Literature review

2.1 Surabaya city drainage system
Development of the Surabaya City drainage system has been carried out by dividing its service area through the establishment of several regional sections. Based on Article 36 of Local Government Regulation No. 12 of 2014, it can be seen that Surabaya City has divided its service area into 5 Regional Areas which include:

1. Region of Genteng
2. Region of Gubeng
3. Region of Jambangan
4. Region of Wiyung, and
5. Region of Tandes

Each regional area is divided into three parts, namely primary system, secondary system, and tertiary system. In this case, Kalidami Channel is primary channel that is connected with several secondary channels, including (Surabaya City Government Regulation: 2014):

1. Pucang Anom Timur
2. Pucang Adi
3. Kertajaya X
4. Unair
5. Srikana
6. Karang Menjangan
7. Dharmahusada Indah
8. Wisma Permai II
9. Mleto
10. Raya ITS/Sawahan
11. ITS Barat
12. Bhaskara.

2.2 Flood
The human need for water cannot be denied. Some regions in Indonesia experience water scarcity, especially during dry season. However, when rainy season comes, these areas are often flooded due to the enormous volume of water caused by rain. The large number of land changes and the reduction in infiltration sites are often a source of flood. This often happens in big cities where infiltration sites are usually much reduced so that the areas become very dependent on reliable drainage to drain the large volume of water in the areas.

Flood is a condition where the discharge/volume of water flowing in a river and drainage channel is above its drainage capacity (Rosyidie, 2013). In Indonesia, known as a tropical country, the rainy season usually occurs in January-February. With this, there will come a sense of worry both in the community and government. Rainfall in this period is usually higher than the other months (Rosyidie, 2013).
2.3 Modeling using SWMM 5.1

SWMM 5.1 is an application developed by U.S. Environmental Protection Agency (EPA). SWMM is a model used to simulate dynamic rainfall that can cause runoff which can then be measured in terms of quality and quantity, especially for urban areas (SWMM User's Manual Version 5.1: 2015). Modeling with SWMM is carried out based on various hydrological processes, such as rainfall with time variations, evaporation on the surface of the water, rainfall in the reservoir area and infiltration of rainfall that enter the water unsaturated soil layer, taking into account the presence of runoff and the existing drainage system (Suprapto, 2018). Thus, it can be seen that this application has advantages because it can do both modeling of hydrological and hydraulic elements as well in one application.

2.4 Thiessen polygon

Each rain station located around the study site will have a different effect on the paint area. The Thiessen Polygon is one method for determining which rain stations will affect water runoff on the surface of a catchment area. The working principle of this method is to assign weight based on the area of the sub-catchment area to the associated rain station. Weighted average for each rain station is determined by the area of the affected area based on the polygons formed (illustrated by the presence of axis lines on the connecting lines between two rain stations that are close together) (Ningsih, 2012). The method of calculating the average rainfall using the Thiessen Polygon method is by using the following calculation formula:

\[ d = \frac{A_1 d_1 + A_2 d_2 + A_3 d_3 + \ldots + A_n d_n}{A} = \sum \frac{A_i d_i}{A} \]  

(1)

Where:

- \( A \) : Area (km²)
- \( d \) : Value of average rainfall
- \( d_1, d_2, d_3, \ldots, d_n \) : Rainfall value at the rain station 1, 2, 3… n
- \( A_1, A_2, A_3, \ldots, A_n \) : The area covered by the rain station 1, 2, 3… n.

2.5 Root mean square error (RMSE)

One important thing in determining whether a model that is made suitable for use as a reference for analysis is to first measure the error rate. According to Astari (2018), RMSE is the average value of the sum of the squares of the error results of the analysis. A fairly high level of sensitivity is an advantage of the RMSE method.

To calculate the error value of the water level model on Kalidami Boezem, then it can use this RMSE method which is calculated with the following calculation formula:

\[ RMSE = \sqrt{\frac{1}{n} \sum e_i^2} \]  

(2)

Where \( n \) is the number of samples used to measure the error value of the observation water level data and the water level value generated from the model \( e_i, i=1,2,3\ldots n \).

2.6 Gumbel distribution

In hydrology, there are several types of distribution that are very well known among researchers, including the Normal Distribution, Log-Normal Distribution, Log-Pearson III Distribution, and Gumbel Distribution. To be able to use them in a study, it is necessary to test each of these distribution models. The testing mechanism is done by using the goodness of fit test method, namely by doing the chi-square test and the Smirnov-Kolmogorov test.

In a previous study, according to Sari (2017) based on the Chi-Square and Smirnov-Kolmogorov test results, it is known that one type of distribution can be used to analyze the performance of the
Kalidami Channel, which is the Gumbel Distribution. The calculation of the rain return period using the Gumbel Distribution method can use the following formula:

\[ X_T = \bar{X} + s \cdot K \]  (3)

Where:
- \( X_T \) : Estimated value of rainfall that is expected to occur with a T-year return period.
- \( \bar{X} \) : The average value of the variate
- \( s \) : Standard deviation of variate values
- \( K \) : The frequency factor is a function of the return period and the type of frequency distribution

where the probability factor \( K \) is expressed by the following equation:

\[ K = \frac{Y_n - Y_{Tr}}{S_n} \]  (4)

Where:
- \( Y_n \) : reduced mean with \( n \) amount of data
- \( S_n \) : reduced standard deviation of \( n \) data
- \( Y_{Tr} \) : reduced variate

Where the value of \( Y_{Tr} \) can be calculated with the following equation:

\[ Y_{Tr} = -\ln \left( -\ln \frac{T_r - 1}{T_r} \right) \]  (5)

Where \( T_r \) is return period.

2.7 Novelty

This study has an update from previous studies because in previous studies there were two pump houses named Kalidami Boezem Pump House and Kalidami Screw which had 5 sluice gates and 5 pumps, while the conditions in this study were only one pump house namely Pump House Kalidami Boezem. Then, this study is also different from previous studies because it has measured the Boezem dimensions directly so that there are some differences in data for example the Boezem depth value. In addition, this study also uses rain data from the rain station located at ITS which has fairly detailed rain data that is per 5 minutes and has been integrated with recording water levels directly so that the model can be calibrated.

3. Research methods

3.1 Research sites

Kalidami Boezem is located in the District of Mulyorejo, Surabaya City, East Java Province at coordinates 7°16'26.8" S 112°48'14.4" E or -7.274111, 112.804000. As shown in the map image above, the location of this research study is close to sea waters located at the east of Surabaya.

3.2 Spatial analysis

Catchment area data used in this study were obtained from the Dinas Pekerjaan Umum Bina Marga dan Pematusan Kota Surabaya based on the Surabaya Drainage Master Plan (SDMP) in 2018-2038. This study uses a number of sub-catchment areas that are approximately 4 m above sea level, and will provide runoff water into the Kalidami Channel and Boezem.

At the Kalidami Channel and Boezem locations there are several rain stations scattered around the catchment area. Based on the Thiessen Polygon concept and supported by the GIS (Geographic Information System) technology, it will be known that there are two rain stations that can affect the Kalidami Channel and Boezem namely the Gubeng and Keputih Rain Stations.
3.3 Hydrological and hydraulic analysis

Kalidami Channel and Boezem Modeling are done by combining hydrological and hydraulic data obtained during the study. These data are as follows:

3.3.1 Rain data. Rain data are obtained by the Rain Station of the Sepuluh Nopember Institute of Technology which publishes weather information on page https://wunderground.com/dashboard/pws/ISURABAY4. These data are fairly good and can be used for simulating water pumps in the Kalidami Channel and Boezem because they have a time step per 10 minutes. These data will then be processed into hourly rain data so that they can be inputted into the SWMM 5.1 application. The return period rainfall data used in this study are to use rainfall data with a return period of 5-year in accordance with the rules of hydrological planning in the Ministry of Public Works Regulation No. 12 of 2014 concerning the Implementation of the Urban Drainage System. Following are the 5-year return period rainfall data of 122.99 mm with duration of 4 hours which will be used for the analysis of the Kalidami Boezem and Channel hydraulics. Calculations made to produce rain data for this return period are calculated using the Gumbel Distribution.
3.3.2 Catchment area data. These data include the size of the catchment area, slope, impervious area and others. The size of the catchment area used in this study is 982.81 Ha with a total sub-catchment area of 33 units.
Table 1. Sub-catchment area.

| Sub-catchment | Area (Ha) | Sub-catchment | Area (Ha) |
|---------------|-----------|---------------|-----------|
| 1             | 270.28    | 18            | 65.05     |
| 2             | 4.02      | 19            | 18.85     |
| 3             | 7.06      | 20            | 18.25     |
| 4             | 121.45    | 21            | 7.00      |
| 5             | 6.33      | 22            | 12.64     |
| 6             | 6.51      | 23            | 24.46     |
| 7             | 15.26     | 24            | 20.71     |
| 8             | 7.40      | 25            | 90.42     |
| 9             | 14.40     | 26            | 33.54     |
| 10            | 22.33     | 27            | 4.22      |
| 11            | 15.78     | 28            | 13.41     |
| 12            | 13.27     | 29            | 5.41      |
| 13            | 12.28     | 30            | 71.00     |
| 14            | 2.15      | 31            | 20.32     |
| 15            | 7.46      | 32            | 4.07      |
| 16            | 9.30      | 33            | 29.92     |
| 17            | 8.25      | Total         | 982.81    |

3.3.3 Cross section and geometry boezem data. These data include cross section, Kalidami boezem geometry, slope and others. The following is an example of a cross section and the geometry of the Kalidami Boezem schematically in the SWMM 5.1 application.

3.3.4 Water pump data. The water pump located in Kalidami Boezem has a very important function. This is due to the frequent occurrence of tidal conditions every day. Therefore, to continue being able to drain wastewater coming from the center of Surabaya, a water gate and water pump are needed at Kalidami Boezem. At the pump house located at the Kalidami Boezem site, there are 7 flood pumps with capacity of 3 m$^3$/s. The following is the pump curve from the pump.

3.3.5 Calibration of Simulation Results. The modeling results obtained using the SWMM 5.1 application will be matched with the data recording of the water level that occurred on February 25, 2020. Then, the error rate of the model formed will be measured using the RMSE method. The data used are obtained directly through field observation at Kalidami Boezem on that date.
3.3.6 Flowchart. In general, the stages of conducting research from beginning to end can be seen in the following flowchart:

![Flowchart](image)

**Figure 8.** Flowchart research methodology.

4. Results and discussion

4.1 Kalidami channel
The Kalidami channel is a primary channel located in Surabaya that functions to flow water from the center of Surabaya to the sea in the eastern part of Surabaya. In the figure above, the initial condition of
the Kalidami channel has an average depth of 0.3 m originating from the domestic disposal of the area around the channel.

![Initial conditions of the Kalidami channel (SWMM simulation).](image)

**Figure 9.** Initial conditions of the Kalidami channel (SWMM simulation).

This initial condition will be intervened by an increase in water level caused by the falling rain in the catchment area. The following is the results of the Kalidami channel simulation on February 25, 2020 at 21:00 where on that day there was a fairly high rainfall of 84.6 mm starting at 15:04 with the highest peak intensity at 16:04 Western Indonesia Time.

![Condition of Kalidami channel after the simulation (SWMM simulation).](image)

**Figure 10.** Condition of Kalidami channel after the simulation (SWMM simulation).

Based on the results of the simulation it can be seen that for rainfall condition below 100 mm which is equal to 84.6 mm, the Kalidami Channel and Boezem are sufficiently filled with water. The highest increase in water level occurred at 18:30 WIB since the rain began.

4.2 Model calibration results

By entering the hydrological and hydraulic data that have been obtained into the SWMM 5.1 application, we will get the results of a simulation of the rise in the water level of Kalidami Boezem. Then, based on the results obtained, it can be calculated how deviating the results of the simulation are when compared with observation of the water level of Kalidami Boezem on February 25, 2020.

The following is a comparison chart between the depth values based on observation on February 25, 2020 compared with data on the results of simulated water level generated by the SWMM 5.1 application.
Based on the values obtained, the calibration results using the RMSE method will produce a value of 0.11. The RMSE value is good enough because it is below 1 and close to 0. Because the Kalidami Channel model has been calibrated, various scenarios in the resulting model can be carried out such as by replacing 5-year return period rainfall data to see performance pumps and water level profiles on the channel.

4.3 Simulation with 5-year return period rainfall data
The following is the simulation result of the Kalidami Channel system using 5-year return period rainfall data in SWMM 5.1 application.

Based on the simulation results with the assumption of rain at 15:00 which occurred for 4 hours and the same water pump settings as in the previous discussion, it can be seen that the water level at Kalidami Boezem reached its peak at 15:45. Then, it was discovered that the water level at the Boezem began to decrease gradually at 19:30.

5. Conclusion
Based on the analysis and discussion above, several conclusions can be written as follows:
1. The water level of Kalidami Boezem on February 25, 2020 increased due to quite high rainfall which is 84.6 mm.

2. The error value generated from the water level data in the model compared to the field observation data measured using the RMSE method gives a pretty good value that is equal to 0.11. It shows that the resulting model has been able to adequately describe the real conditions that occur in Kalidami Boezem.

3. Based on the simulation results using a 5-year return period rainfall, it can be seen that the Kalidami Channel has a capacity that is not large enough to hold the incoming water runoff. It can be seen that only in the span of 45 minutes, the Kalidami Channel has been flooded.

References

[1] EPA United States Environmental Protection Agency 2015 *Storm Water Management Model User’s Manual Version 5.* EPA/600/R-14/413b

[2] Pemerintah Kota Surabaya 2014 *Peraturan Daerah Kota Surabaya Nomor 12 Tahun 2014 Tentang Rencana Tata Ruang Wilayah Kota Surabaya Tahun 2014-2034*

[3] Rosyidie A 2013 Banjir: Fakta dan Dampaknya, Serta Penngaruh dari Perubahan Guna Lahan *J. Perencanaan Wilayah dan Kota* 24

[4] Suprapto M, Yusuf M A, Prilbista A S, 2018 Analisis Sistem Drainase untuk Penanganan Genangan di Kecamatan Magetan Bagian Utara *e-Jurnal MARIKSI TEKNIK SIPIL* 231

[5] Ningsih D H U 2012 Metode Thiessen Polygon untuk Ramalan Sebaran Curah Hujan Periode Tertentu pada Wilayah yang Tidak Memiliki Data Curah Hujan *J. Teknologi Informasi DINAMIK* 17

[6] Astari K F, Hendri A, and Fauzi M 2018 Analisis Pasang Surut Perairan Dumai Menggunakan Metode Admiralty *Jom FTEKNIK* 5

[7] Upomo T C and Kusumawardani R 2016 Pemilihan Distribusi Probabilitas pada Analisa Hujan Dengan Metode Goodness Of Fit Test *J. Teknik Sipil & Perencanaan* 18

[8] Basuki, Winarsih I, and Adhyani N L 2009 Analisis Periode Ulang Hujan Maksimum dengan Berbagai Metode *J. Agromet* 23 76-92

[9] Kementerian Pekerjaan Umum 2014 *Peraturan Menteri Pekerjaan Umum Nomor 12/PR/M/2014 Tentang Penyelenggaraan Sistem Drainase Perkotaan* (Indonesia: Kemen. PUPR)