Evaluation of Urban Flood Control Project –Case Study at Bendung Watershed in Palembang City, Indonesia–

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Abstract

Palembang City locates on a flat area where the altitude is between 12 and 30m above sea level. There are many small rivers that flow into a main river, Musi river. Due to the topographical configuration and a seasonal heavy rainfall, those rivers had been overflowed and the city had an inundation disaster. Bendung watershed is one of the nineteen watersheds in Palembang City, and the watershed also experiences the inundation disaster frequently due to the flood caused by a poor river maintenance and drainage system.

The local government of Palembang City has applied some flood control projects such as a normalization project to reduce the flood damages. These measures checked the river flow over the dike, but some areas still suffered from the flood damages due to their topography. Based on the current situation, this study evaluates the efficiency of the existing normalization project in this watershed to find a solution that reduces the flood in those areas. Furthermore, this study investigates the feasibility of infiltration-well system to overcome the flood in those areas. The feasibility study includes the cost and benefit analysis to realize the infiltration-well system for easing the inundation problem.

Keywords: Bendung watershed, Flood control, Normalization project, Infiltration-well system, Cost and benefit analysis

1. INTRODUCTION

Palembang City is one of cities in Indonesia, and it is now under the rapid economic growth. Its population is about 1.5 million. The rapid economic growth is encouraging an urbanization and land use changes[1)], those sometimes increase damages by river floods.

Palembang City locates on a flat area where the altitude is between 12 and 30m above sea level. There are many small rivers that flow into a main river, Musi river. Due to the topographical configuration and a seasonal heavy rainfall, those rivers had been overflowed and the city had an inundation disaster. Bendung watershed is one of the nineteen watersheds in Palembang City, and the watershed also experiences the inundation disaster frequently due to the flood caused by a poor river maintenance and drainage system.

Bendung river is one of the channels that play an important role in the drainage system of Palembang City. The river empties into the Musi river, and it is a kind of a natural drainage system.

A rapid urban growth brings the change of land use. The land use change sometimes increases a flood disaster if an appropriate measure is not taken on that area[2)]. The local government of Palembang City has applied some flood control projects such as a normalization project to reduce the flood damages. These measures checked the river flow over the dike, but some areas still suffered from the flood damages due to their topography.

Based on the current situation, this study evaluates the efficiency of the existing normalization project in this watershed to find a solution that reduces the flood in those areas. Furthermore, this study investigates the feasibility of infiltration-well system to overcome the flood. The feasibility study includes the cost and benefit analysis to realize the infiltration-well system for easing the inundation problem.

2. RESEARCH METHOD

2.1 Research Area and Data Collection

Fig. 1 shows the location of Bendung watershed in Palembang City. Bendung watershed is one of the eighteen watersheds in Palembang City, and the area of the watershed is about 14.5 km^2.

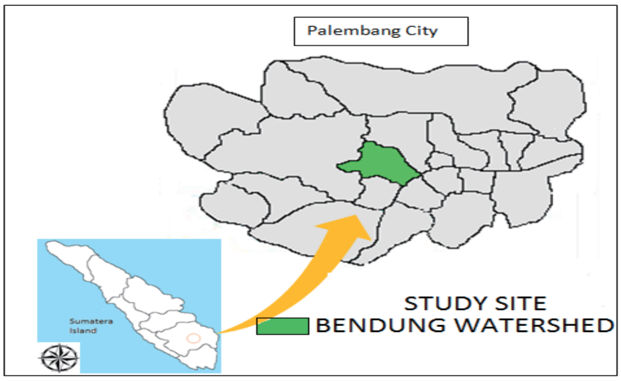

Fig. 1 Location of Bendung watershed in Palembang City

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In order to check the flood of Bendung river, a normalization project was applied along the river since 2014. This project excavated the river bottom and raised the crown height of the dike on both sides to increase the flow capacity.

The data needed in this research were primary data and secondary data. Primary data were obtained by direct observation in the field, such as the location of flood. The secondary data were obtained from official government, such as rainfall data and documents.

2.2 Analysis of Normalization Project

This study used the Hec-Ras model to evaluate the effectiveness of normalization project applied on Bendung watershed in Palembang City. This model at first determines the rainfall distribution with Smirnov-Kolmogorov method, and calculates the rainfall intensity. After that, the model calculates the design river discharge.

This study employed ten years rainfall data, measured by Palembang Meteorological and Geophysical Agency at Kenten Branch Station from 2009 to 2018. Table 1 shows the rainfall intensity obtained by Pearson Log Distribution III. Regarding the balance of flood control design in Palembang City, the normalization project chosen the return period as five years.

Table 1. Rain Intensity for each return period

Return Period (Year)	Rainfall Intensity (mm/hour)
2	74.759
5	88.973
10	96.431
20	105.634
50	110.587
100	115.376

A runoff coefficient is an important value in calculating the river discharge, and it has a different value depending on the land use condition[3]. Fig. 2 shows the current land use pattern in Palembang City. Based on the land use condition, this study calculated the representative runoff coefficient in Bendung watershed.

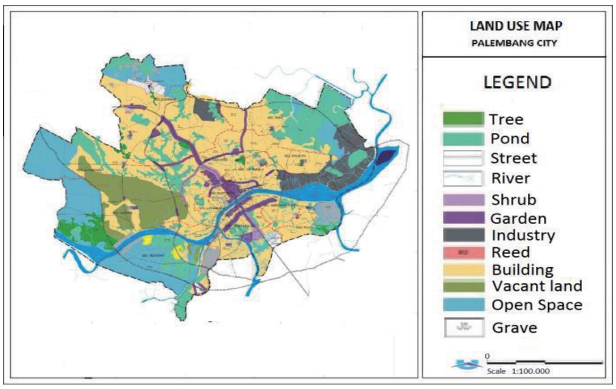

Fig.2 Current land use of Palembang City

Table 2 shows the coverage area of each land use, A, the runoff coefficient, C, and the product of them. The runoff coefficient takes different values depending on the land use condition. This study calculated the representative runoff coefficient with Eq. (1), and the results was 0.46.

$$C_w = \frac{\sum A*C}{\sum A} \quad (1)$$

Table 2. Calculation of representative runoff coefficient

Land use	A(m^2)	C	$A*C$
Open space	6,045,122.5	0.40	2,418,049.0
Tree	420,178.4	0.25	105,044.6
Reed	100,573.2	0.21	21,120.4
Shrub	93,710.1	0.30	28,113.0
Pond	62,056.1	0.35	21,719.6
Garden	117,452.4	0.20	23,490.5
Grave	101,105.7	0.15	15,165.9
Vacant land	11,525.3	0.80	9,220.2
River	95,349.1	0.30	28,604.7
Street	1,104,618.4	0.70	773,232.9
Building	6,294,732.7	0.50	3,147,366.4
Total	14,446,423.9		6,591,127.2

2.3 Analysis of infiltration well

An infiltration–well system[4], which penetrates rainwater to underground, is one of the measures to mitigate the inland flood disaster. Indonesian national standard states the general requirements for the infiltration well system[5].

This study employed Indonesian national standard to calculate the storage volume of infiltration well[6]. The volume of rain water that falls onto a catchment area is calculated by Eq. (2).

$$V_1 = \alpha \times C \times A_C \times R \quad (2)$$

Where α is a coefficient that is defined 0.855 in this study. C is a runoff coefficient, A_C is the area of total rooftop (m^2), and R is a design rainfall intensity (mm/day).

Eq. (3) is also used to calculate the volume of water that absorbed into the infiltration well.

$$V_2 = \frac{t_c \times A_t \times K}{24} \quad (3)$$

Where t_c is a duration time and it is calculated by $0.9*R^{0.92}/60$ (hour). A_t is a total surface area of well (m^2), and K is a soil permeability coefficient (m/day).

From the balance of inflow and outflow of infiltration well, the volume of water stored in the well is calculated as $V_3=V_1-V_2$. The total depth of infiltration well is calculated as $H_{total}=V_3/A_h$, where A_h means a cross section of the infiltration well. In the case of setting the design depth of the infiltration well as H_d, this means the volume in each well is equal to the product of A_h and H_d, the number of wells that needed to control the flood is calculated as $n=H_{total}/H_d$.

2.4 Analysis of cost and benefit

A benefit cost ratio, *BCR*, and a payback period, *PBP*, were calculated by the following equations. Details of benefits and costs that were taken into consideration were shown in the next chapter.

$$BCR = \frac{Total\ Benefit}{Total\ Cost} \quad (4)$$

$$PBP = \frac{Total\ Cost}{Annual\ Benefit} \quad (5)$$

3. RESULTS AND DISCUSSIONS

3.1 Evaluation of the normalization project

A design flood discharge was determined by Synthetic Unit Hydrograph method. This method needs data of the river length and its area of Bendung watershed.

The water level of two cases, before and after the normalization project, were compared to evaluate the performance of normalization project. Fig. 3 and Fig. 4 show the water level and dike height along Bendung river in the case of the design discharge.

Fig. 3 shows the result before the normalization project. The water level exceeds the height of the dike on both sides of upstream from about 1300m section. The river bottom becomes shallow at 1000m section and it reduces the river capacity.

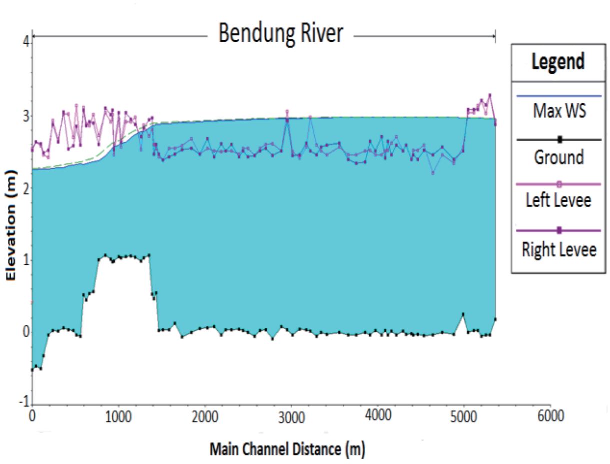

Fig.3 Water level and the height of dike along Bendung river before the project.

Fig. 4 shows the result of water level after the project. The capacity of the river flow becomes large by the normalization project and the water level is lower than the dike height on both sides along the river. The local government conducted field observation and hearing survey along the river, and any floods over the dike were never seen after the project. This means that the project shows good performance in checking the flood along Bendung river.

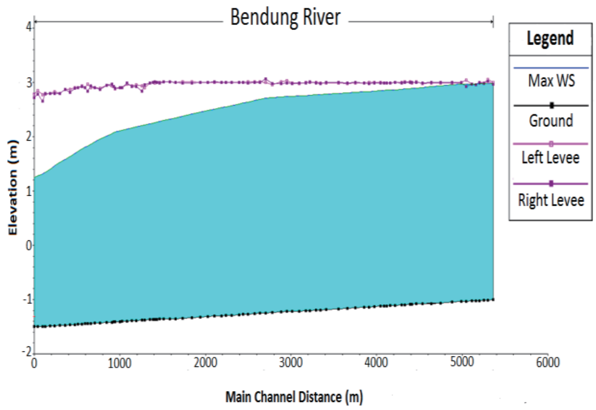

Fig. 4 Water level and the height of dike along Bendung river after the project

3.2 Evaluation of the infiltration well

Some areas in Bendung watershed are still suffering from the flood by inland water even after the normalization project due to the poor drainage. From the field survey, the local government recognized four areas as shown in Fig.5. Each area is1,150m^3, 1,215m^3, 1,175m^3, and 1,110m^3.

Fig.5 Location of areas that are suffering from flood by inland water

Regarding the topography of those areas, this study proposed the application of infiltration-well system to overcome the flood by inland water. The value of a soil permeability is the important factor in the application of the infiltration well[7)].

Table 3 shows the permeability of each area that was obtained by the field survey. Table 4 shows the volume of water that was calculated by Eq. (2). This calculation set the design rainfall as 88.97mm/day and the runoff coefficient as 0.95, respectively.

Table 3. Permeability value, *K*, in each area

Location	Permeability value, *K*, (cm/hour)
No.1	2.24
No.2	2.32
No.3	2.22
No.4	2.34
Average	2.28

Table 4. Calculated volume of water from rooftop to well

Location	Total rooftop area(m^2), Ac	Volume(m^3), V_1
No.1	12,715	918.86
No.2	14,705	1,062.67
No.3	15,155	1,095.19
No.4	12,505	903.68

In order to calculate the volume of water, V_2, from Eq. (3), both t_c and A_t should be set in advance. The duration time, t_c, is calculated as 0.93 hour from the design rainfall intensity, R. From the previous cases that are installed other site, this study calculated the total surface area of well, A_t, as 10.21m^2. On the other hand, the average of permeability is K=2.28cm/hour. Finally, V_2 is calculated as 0.283m^3.

From the balance of inflow and outflow of infiltration well, the volume of water stored in the well, V_3, is calculated inTable 5. Furthermore, Table 6 shows the number of wells required in each location. This study set the cross section of the infiltration well, A_h, is 0.786m^2, and the depth of each well, H_d, is 3m. Based on analysis, this infiltration-well system reduces 80% of inundation area by inland water.

Table 5. Volume of water stored in the well at each location

Location	V_1(m^3)	V_2(m^3)	V_3 (m^3)
No.1	918.86	0.283	918.58
No.2	1,062.67	0.283	1,062.39
No.3	1,095.19	0.283	1,094.91
No.4	903.68	0.283	903.40

Table 6. Number of infiltration wells

Location	V_3 (m^3)	H_{total}(m)	n
No.1	918.86	1,169	390
No.2	1,062.67	1,352	451
No.3	1,095.19	1,393	465
No.4	903.68	1,149	383

3.3 Cost and benefit analysis

(1) Cost and benefit for normalization project

In the calculation of costs and benefits for the normalization project, this study estimates the total benefits for 5 years. The total costs by the construction cost and its maintenance were also calculated for five years. The normalization project eliminates some renovation costs for the repairing of resident's houses, buildings, public facilities and infrastructures. Those costs are included as the benefit of the project in addition to the benefit for easing the damages on economic activities[8)].

Table 7 shows the list of the annual benefit obtained by the normalization project. The project brings the benefit of 1848 million Rupiah every year, and five times of this benefit becomes the total benefit by the normalization project for 5 years.

The initial construction cost for the normalization project was 5,900 million Rupiah. In addition to this, the maintenance costs, such as an excavation of the river, are needed every year. Table 8 shows the list of annual maintenance costs, and their total is about 608 million Rupiah.

Table 7. Annual renovation costs saved by the normalization project

Components	Saved Cost (*10^{6}Rp.)
HOUSING	
Houses	250.00
Building (school, office, etc.)	200.00
INFRASTRUCTURE	
Road	750.00
Water and Sanitation	24.00
Water Resources	24.00
ECONOMY	
Traditional Market	600.00
Total	1,848.00

Table 8. Annual costs for the maintenance of the normalization projects

Components	Price
MAN POWER	
Worker	4,687.50
Foreman	770.00
TOOLS	
Excavator	12,750.00
Supporting Tools	12,500.00
Total Cost	30,707.50
Profit for Contractors (10%)	3,070.00
Excavation for sedimentation	
Total excavation area : 18,000 m^3 Excavation cost :33,778.25 Rp./m^3	608,008,500,00

Fig.6 shows the cost and benefit ration calculated from Eq. (4). The ratio is 0.31 in the first, and it gradually increases more than 1.0 after 5 years. This means that the project shows its effectiveness against the cost after 5 years.

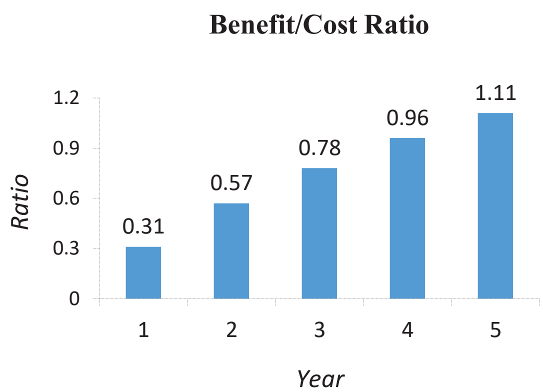

Fig.6 Cost and benefit ratio of the normalization project

(2) Cost and benefit analysis for infiltration well

The installation of the infiltration-well system saves some renovation costs, and those costs are included in an annual benefit by the project. Table 9 shows the list of the annual benefit obtained from the infiltration-well system. The annual benefit from the system is estimated as 2,515 million Rupiah.

This study assumed that 1.688 wells are constructed in the flood area, and half of them are firstly installed in the first year and the rest of them are in the second year. From this plan, a half of the annual benefit in Table 9, 1,257.5million Rupiah, will be saved in the first year. After the second year, annual benefit will be estimated 2, 515million Rupiah.

Table 9. Renovation costs saved by the infiltration wells for one year

Components	Saved Cost (*10^6Rp.)
HOUSING	
Houses	260.00
Building (school, office, etc.)	300.00
INFRASTRUCTURE	
Road	1,125.00
Water and Sanitation	40.00
Water Resources	40.00
ECONOMY	
Traditional Market	750.00
Total	2,515.00

The size of the infiltration well and the number of the well at each location were discussed in section 3.2. Table 10 shows the construction cost of the infiltration well. It includes the price of the building materials and the labor's cost. The construction cost for one infiltration well is calculated about 3.68 million Rupiah, and total construction cost becomes 6194.96 million Rupiah.

Table 10. Costs for construction of the infiltration well

Components	Cost (Rp)
Materials	
7.86 m^2 wall of red brick wells	718,875.60
1.25 m^2 red brick wall tub size	114,325.00
0.218 m^3RC plate	1,521,536.46
0.43 m^3 Well Fill	80,000.00
Other complementary materials	394,000.00
Sub-total cost of materials	2,828,737.05
Labors' cost (30% of above sub-total)	848,621.12
Total cost of one infiltration well	3,677,358.17

There are two kinds of maintenance costs. One is the cost to excavate the sediments in the infiltration well every year, and the other is the cost to replace the pipe every five years. Annual cost for excavating the sediments includes labors' cost and some other costs. The cost for each well is estimated 103,598 Rupiah, and 175.87 million Rupiah is needed to excavate all wells every year. The cost to replace the pipe includes the material costs and labors' cost. It is estimated that the cost is 138,050 Rupiah for one meter. The length of each well is assumed 12m, and total cost becomes 2,796.24 million Rupiah for every five years.

Fig.7 shows the cost and benefit ration calculated from Eq. (4). The ratio is 0.34 in the first year, and it gradually increases up to 4th year. The ration exceeds 1.0 four years after the installation of the infiltration well system. The ration decreases from 1.12 to 1.05 at the fifth year because of the replacement of the pipe for the maintenance.

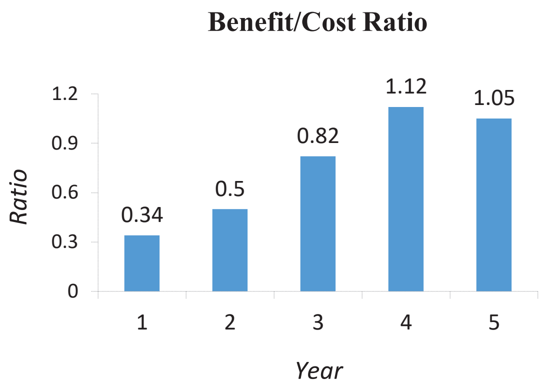

Fig 7. Cost and benefit ratio for the infiltration well

4. CONCLUSIONS

This study evaluated the efficiency of the existing normalization project in Bendung watershed. Based on Hec-Ras model and field observation, this study confirmed that the normalization project is preventing the flood along Bendung River. Based on the cost and benefit analysis of the project, this study confirmed that the benefit sufficiently exceeds the cost after five years from the beginning of the project.

On the other hand, some inundation areas remain due to the poor drainage condition. In order to clear this problem, this study investigated the feasibility of the infiltration-well system. Through the hydrological analysis, it was cleared that the infiltration-well system reduces 80% of inundation area by inland water.

Furthermore, the installation of the infiltration-well system seemed feasible in the discussion of the cost and benefit analysis. Based on the analysis of the system installation, this study confirmed that the benefit exceeds the cost after four years from the beginning of the system installation.

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