Effectiveness of Situ for Ciliwung Flood Mitigation in Bogor Regency

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Abstract. Bogor Regency is one of Regencies in Jabodetabek area that is experiencing rapid urban growth. This condition impacted the decreasing conditions of 39’s from 95’s urban small lakes or locally known as ‘situ’. This research aims to analyze the effectiveness of situ Kebantenan and situ Cikaret as Ciliwung flood mitigation measure in the Bogor Regency. The SWAT model was employed for quantification the water balance of situ and watershed management. The simulation results of the water balance analysis indicated that the monthly average of volume of Situ Kebantenan and Situ Cikaret (2008-2015) were 136,955 m³ and 508,907 m³, the annual inflow Situ Cikaret were 24,693,822 m³/year and outflow were 25,177,593 m³/year, precipitation were 648,520 m³/year, evaporation were 166,543 m³/year, delta storage (1,794) m³/year, respectively. The result of hydrological responses analysis on application of situ and watershed management scenarios that combined the structural and non-structural measures was the best scenario for decreasing maximum discharge at situ outlet which is decreased 41% discharge. So that, in order to enhance the effectiveness of situ for Ciliwung flood mitigation, the combination of the structural and non-structural management of 13 situ’s in Ciliwung river basin within the Bogor Regency is recommended that can increase the storage capacity from 1.8 million m³ to 4.7 million m³.

1. Introduction
Urban lakes or locally known as situ currently threatened. Thus far 203’s of situ spread in Jabodetabek with total area 2,337.10 ha have decreased to 1,462.78 ha from 2007 until 2011 [1]. Situ that experienced the most extensive decline occurred in Bogor, Depok, Bekasi and Tangerang. Nearly 10% until 50% of them were lost and experienced decreasing in capacity due to siltation, expansion of agricultural areas to littoral zones, waste, weed expansion, occupation of riparian situ to industrial area, transportation and settlements [2], [12], [15]. Unlike natural aquatic system, situ designed to accept surface water runoff or as the last point of runoff water treatment [16].

Bogor regency is one of Regencies in Jabodetabek that has the most situ, namely 95 situ. But 39’s of situ were damaged both lightly to severely damaged. The land use change into built-up area due to urbanization caused decreasing 15.39 ha of situ riparian during 2007 until 2011 [4]. If this condition
continues to occur, it will affect the function of situ as water retention. The existence of situ resulted in decreasing capacity for flood peak discharge because of its location in the upper and middle regions of four rivers (Ciliwung, Cisadane, Angke Pasanggrahan and Bekasi).

Currently, most of situ topic research focused on the distribution of situ in Jabodetabek [3], aspects of biology [5], water quality [4, 2], and institutional management [16]. The topic on situ as part of urban hydrological system that functions as flood mitigation in Jabodetabek is still limited. Therefore, situ water balance modelling using Soil Water Assessment Tool (SWAT) is very interesting in order to illustrate the importance of situ management as part of urban hydrology. This research aims to analyze the effectiveness of situ Kebantenan and situ Cikaret as Ciliwung flood mitigation measure in the Bogor Regency.

2. Research Methods

2.1. Research Location

The research was conducted from September - December 2017 in Situ Cikaret and Kabantenan-Bogor Regency (Figure 1), followed by data processing and analysis at the IPB Campus from January to September 2018. This region was chosen because of the role of this region as catchment areas and the existence of situ conservation program to increase storage capacity as a mitigation of the Ciliwung River flood.

![Figure 1. Research location](image1)

2.2. Tools and Material

This research used Software ERDAS Imagine v14, ArcGIS v10.2, GPS, ArcSWAT 2012.10_3.18 Beta version, Google Earth, Microsoft Office 2013. The material used in this study consists of several numerical data and spatial data. The spatial data are DEM (Digital Elevation Model) West Java 30 x 30 m resolution; source of SRTM imagery, Ciliwung Watershed Map scale 1:25,000; source of BPDAS Citarum-Ciliwung, Land characteristic Ciliwung watershed map scale 1:250,000, source of the Land and Agro-Climate Research Center-2014, Land use map, source of the Forestry Planning Agency of the Ministry of Environment and Forestry (Table 1).

The numerical data consist of climate data: average daily rainfall data for 8 years (2008-2015) obtained from 6 stations namely BMKG Citeko station, Gadog Rain station, Gunung Mas rain station, Katulampa River Gauge, Depok UI rain station and Cibinong rain station; daily maximum and minimum temperature data (°C) for 10 years (2007-2017) from BMKG Citeko station, daily air humidity data (%) for 10 years (2007-2017) from BMKG Citeko station, daily solar radiation data (MJ m² days⁻¹) for 10 years (2007-2017) from BMKG Citeko station, daily wind speed data (ms⁻¹) for 10 years (2007-2017) from BMKG Citeko station because unavailability data. The observation river
discharge data from Katulampa River Gauge and Kampung Kelapa River Station for 2 year (2013-2014) used for calibration and validation model. Detail Engineering Design (DED) merging Situ Kabantenan and Situ Cikaret, sources for BBWS Ciliwung Cisadane used for hydrological responses analysis on application of situ and watershed management scenarios.

| Spatial Data          | Scale     | Source                                           | Year |
|----------------------|-----------|--------------------------------------------------|------|
| DEM                  | 1:25,000  | SRTM imagery 30 m                                | 2013 |
| Ciliwung Watershed   | 1:25,000  | BPDAS Citarum-Ciliwung                           | 2014 |
| Land use             | 1:250,000 | Forestry Planning Agency of the Ministry of Environment and Forestry | 2014 |
| Land characteristic  | 1:250,000 | Land and Agro-Climate Research Center            | 2014 |

2.3. Research Procedure

The SWAT (Soil Water Assessment Tool) is a spatial and temporal model that can simulate water, sediment, nutrients and transfer of dissolved materials in the catchment area on a daily or sub-daily scale. SWAT can be integrated directly with GIS through ArcSWAT. The use of the SWAT model to simulate situ water balance / urban lakes was adopted from Setegn et al. (2008) who used the SWAT model to simulate the Lake Tana water balance in Ethiopia and Zhang et al. (2016) water balance on the Poyang Lake China lake. Water balance analysis is used to determine the difference between the incoming water discharge (inflow discharge) and the outflow (outflow discharge). In a simple calculation, the water balance is a change between input and output during a certain time either in the form of storage, consumed or exited [15]. The input component of the water balance reservoir in SWAT consists of precipitation (Vpcp), inflow (Vflow in), and initial stored water (V stored), while the output component consists of evaporation (Vevap), outflow (Vflow out) and water lost from a body of water (Vseep) [8]. The hydrological cycle simulated by SWAT is based on equation (1) water balance for the reservoir.

\[
V = V_{\text{stored}} + V_{\text{flow in}} - V_{\text{flow out}} + V_{\text{pcp}} - V_{\text{evap}} - V_{\text{seep}} \tag{1}
\]

Where, \( V \) is the amount of water collected at the end of the day \((m^3)\), \( V_{\text{stored}} \) is the amount of water that was stored in previous day \((m^3)\), \( V_{\text{flow in}} \) is the amount of water entering situ \((m^3)\), \( V_{\text{flow out}} \) is the amount of water that comes out from situ \((m^3)\) and \( V_{\text{seep}} \) is the number of days lost from a body of water \((m^3)\). Calibration test and validation using statistical methods using the coefficient of determination model \((R^2)\) and model efficiency model \((\text{NSE})\) [8] [7]. The model equation used are equation (2) and equation (3).

\[
R^2 = 1 - \frac{\sum_{i=1}^{n}(Q_{\text{obs},i} - Q_{\text{cal},i})^2}{\sum_{i=1}^{n}(Q_{\text{obs},i} - \bar{Q}_{\text{obs}})^2} \tag{2}
\]

\[
\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(Q_{\text{obs},i} - Q_{\text{cal},i})^2}{\sum_{i=1}^{n}(Q_{\text{obs},i} - \bar{Q}_{\text{obs}})^2} \tag{3}
\]

Where \( Q_{\text{obs},i} \) is the observation discharge \((m^3 \text{ s}^{-1})\), \( Q_{\text{cal},i} \) is the simulation discharge \((m^3 \text{ s}^{-1})\), \( Q_{\text{obs}} \) is the average discharge of observation \((m^3 \text{ s}^{-1})\), and \( \bar{Q}_{\text{cal}} \) is the simulation average debit \((m^3 \text{ s}^{-1})\). \( R^2 \) values range from 0 to 1, if the \( R^2 \) value approaches 1, it means that there is a close relationship between simulation data and observation data. NSE values range from 0 to 1, where values close to 1 indicate that the performance of a model is good. The category of efficiency model values with NSE [6]. After the model has been successfully calibrated and validated, the model will be to use to analyze...
the hydrological responses to various situ management scenarios. This study will analyze 5 management scenarios as scenario 1 or connecting situ Cikaret and Kabantenan with the channel, scenario 2 or the situs dredging, scenario 3 or the situs basin conservation, scenario 4 or the worst-case scenario with the assumption that decreasing condition of situ riparian because the sedimentation from urban area near the situs, and scenario 5 or the best scenario for situ and basin management.

Table 2. Model Efficiency Value Criteria with NSE

| Criteria          | NSE          |
|-------------------|--------------|
| Very Good         | 0.75 < NSE < 1.00 |
| Good              | 0.65 < NSE < 0.75 |
| Satisfaction      | 0.50 < NSE < 0.65 |
| Not satisfaction  | NSE < 0.50   |

3. Result and Discussion

3.1. General Condition of Situ Cikaret and Kabantenan

The simulation of water balance of Situ Cikaret and Kabantenan was completed using the ArcSWAT, whereas model calibration and validation were done by manual calibration. The average volume from 2008-2015 that can be accommodated by situ Cikaret with a total area of 21.70 ha, an normal storage capacity 452,300 m$^3$, an average depth of 2.50 meters with maximum depth 7.00 meters around 508,907 m$^3$ per day or 70% of the total storage capacity at emergency spillway (722,610 m$^3$) can be showed in Figure 2. The average amount of volume that can be accommodated by situ Kabantenan with an area of 4.71 ha, an average depth of 2.50 meters and maximum depth of 3.25 meters around 136,955 m$^3$ or 83% of the total volume capacity at the emergency spillway (164,502 m$^3$) can be showed in Figure 2.

Figure 2. Monthly Average Storage of Situ Cikaret (a) and Situ Kabantenan Year 2008-2015 (b)

The average amount of rainfall in the Situ Cikaret and Kabantenan catchment areas covering an area of 1,135.89 Ha was 3,190.69 mm during 2008-2015. Situ Cikaret and Kabantenan are those that are not directly related to the Ciliwung River but connected to Cikumpa river as Ciliwung tributary. The simulation results of the water balance analysis indicated that the monthly average of volume of Situ Kabantenan and Situ Cikaret (2008-2015) were 136,955 m$^3$ and 508,907 m$^3$, the annual inflow Situ Cikaret where 24,693,822 m$^3$/year and outflow were 25,177,593 m$^3$/year, precipitation were 648,520 m$^3$/year, evaporation were 166,543 m$^3$/year, delta storage (1,794) m$^3$/year, respectively. Over
a period of 7 years (2008-2014) the inflows from the catchment area was greater than the outflows. This condition happened because the amount of input from the Situ Cikaret and Kabantenan catchment has an influence especially when the rainy season. It produces surface runoff from catchment area and flows into situ [12]. The increase of inflows experienced a significant increase in 2013 to 2014, as seen from the increase in the amount of rainfall that occurred in the catchment area.

In this research also analyzed the existing conditions of each component of the water balance during dry years or Elnino events in 2009, the wet year or year of flood events in 2013 and the normal year or 2010. The year 2013 is said to be a wet year based on flood events that occurred in Depok due to overflowing of Cikumpa River in August 2013 [10]. Flood events in August 2013 can be seen from the increase in Situ Cikaret's water balance component which was significant from the previous month, especially in the inflow, outflow and precipitation components (Figure 3).

![Figure 3. Situ Cikaret Water Balance Component](image)

Figure 3. Situ Cikaret Water Balance Component (a) Situ Inflow (b) Situ Outflow (c) Precipitation (d) Evaporation (e) Delta Storage in Situ Cikaret in Dry, Wet and Normal Year
In August in the year of the flood event, it was also seen that a surplus condition occurred in the delta storage of situ 5,954,84 m$^3$ where inflow of situ was greater than outflow. In the dry year or 2009, it can be seen that rainfall began to decline in May and continued to decline until September. This is also related to the pattern of changes in Situ Cikaret volume where in May, there were minus conditions or conditions where inflow was smaller than outflow and then at break-even until September, this was also related to the increase in evaporation in that months.

When viewed from the existing conditions of each component of Situ Kabantenan water balance (Figure 4) during the year of the dry season or the ElNino events in 2009, it was seen that the value of the inflow, outflow and rainfall components was lower than in normal years (2010) and years of flooding (2013). Decreasing the value of inflow, outflow and precipitation components of Situ Kabantenan begins in May to October. Increased evaporation also occurs this year compared to wet years and normal years.

Figure 4. Situ Kabantenan Water Balance Component (a) Situ Inflow (b) Situ Outflow (c) Precipitation (d) Evaporation (e) Delta Storage of Situ Kabantenan in Dry, Wet and Normal Year
For wet year events, especially related to the occurrence of floods in August 2013 in Depok City, this can also be seen from the water balance in situ Kabantenan, which is the inflow, outflow and precipitation. The situ outflow value is greater than the situ inflow value. When viewed from the delta storage in the wet year, from July to October the water comes out of it into an outflow and there is no change in the volume of situ.

3.2. Hydrological Response Based on Situ Management Scenario

After the model has been successfully setup, then model has been calibrated to help reduced the uncertainty simulated result. Manual calibration is done by trial and error some parameter by comparison of observed river discharge data from Kampung Kelapa River Station and simulation data. Optimizing some hydrologic parameter was done on groundwater parameter (gw), routing parameter (.re) and management parameter (.mgt) [9]. Calibration on Cikumpa catchment area hydrology model was done for 2014 period, and then validation was done for 2013 period. The calibration value are NSE = 0.55 and R² = 0.58. The validation value are NSE = 0.49 and R² = 0.54. The value of R² and NSE is good criteria base on general performance ratings for recommended statistic [6] and the model can use for other purposes.

After calibration and validation process, the model ready to analyze the hydrological responses to various situ management scenarios. This scenario based on Cibinong Situ Front City Plan from Bappeda Kabupaten Bogor. Scenario 1, connecting situ Cikaret and Kabantenan with the channel of connecting with a length of 1,500 meters 80 meters wide or a storage volume of 240,000 m³ so that the total storage can be accommodated from Situ Cikaret and Kabantenan to 832,200 m³. Scenario 2, the dredging is as deep as 5.00 meters so that the average depth is 7.50 meters with the aim of increasing the reservoir capacity to triple the original capacity or 1,860,750 m³. Scenario 3, or the Situ Cikaret and Situ Kabantenan basin conservation scenarios assuming that the planned connecting of Situ Cikaret and Kabantenan has problems due to the process of land acquisition and funding.

The storage capacity is the same as the normal storage of both situ, which is 592,200 m³. Water and land conservation are carried out on land use, such as dryland agriculture, management with slopes of 8-25% conserved with agroforestry, dry land agriculture which is in the situ riparian area and river conserved with reforestation, application green technology such as bioretention in cluster residential and green roof in government and private building. The sampling for application of bioretention in cluster residential such as Wonderland Palace, Norinland Cibinong, Kinan City, Pesona Telaga Cibinong and Nirwana Estate Residence. The sampling for application of green roof in government building such as Bogor regency government office, Health office, Cibinong district court, Ministry of ATR / BPN or Land agency office, Office of public works and spatial planning, Cibinong City Mall. Scenario 4 or the worst-case scenario with the assumption that decreasing condition of situ riparian because the sedimentation from urban area of Cibinong and occupation of riparian situ. Scenario 5 or scenario combination of scenarios 1,2 and 3 assuming that this scenario is the best scenario for situ and basin management. This scenario was carried out by combining the structural management and non structural management. The capacity from Situ Cikaret and Kabantenan becomes 2,760,750 m³ or 2.76 million m³ and the conservation of catchment area is 1,135.89 Ha or 45% of the Cikumpa subbasin.

The results of comparative analysis of hydrological responses based on situ and basin management showed that the decreasing maximum discharge of outlet situ in a row was scenario 5 (decreased 41% discharge), scenario 2 (decreased 14% discharge), scenario 1(decreased 11% discharge), scenario 3 (decreased 10% discharge) and scenario 4 (increased 20% discharge). The best scenario recommendation for Bogor Regency to enhance the effectiveness of situs as Ciluwung flood mitigation was situ management scenario that combine the structural management such as situ dredging, connecting Situ Kabantenan and Cikaret and the nonstructural management such as water and land conservation such as agroforestry, reforestation in riparian of situ, green technology application (bioretention and green roof) in cluster settlement and government office or scenario 5.
Table 3. $Q_{flow \, out}$ situ outlet in various situ management scenarios

| Scenario                              | $Q_{flow \, out}$ situ outlet max existing (m$^3$/s) | $Q_{flow \, out}$ situ outlet max scenario (m$^3$/s) | Volume Situ Cikaret (m$^3$) | Volume Situ Kabantenan (m$^3$) | Total Volume (m$^3$) |
|---------------------------------------|---------------------------------------------------|---------------------------------------------------|---------------------------|-------------------------------|----------------------|
| 1. Connecting Situ                    | 7.14                                              | 6.37                                              | 692,300                   | 139,900                       | 832,200              |
| 2. Dredging Situ                      | 7.14                                              | 6.14                                              | 1,507,500                 | 353,250                       | 1,860,750            |
| 3. Situ and basin conservation        | 7.14                                              | 6.43                                              | 452,300                   | 139,900                       | 592,200              |
| 4. Decreasing riparian of Situ        | 7.14                                              | 8.56                                              | 241,200                   | 56,520                        | 297,720              |
| 5. (1+2+3)                            | 7.14                                              | 4.22                                              | 2,407,500                 | 353,250                       | 2,760,785            |

The application of a combination scenario can be recommended to be applied in 13’s situ in the Ciliwung watershed in Bogor Regency in particular and 95’s situ in the Bogor regency in general. The results of 13 situ’s in Ciliwung river basin within the Bogor Regency show a total surface area of 57.18 ha, total storage capacity 1,842,781 m$^3$. From the simulation it can be seen that the maximum discharge reduction at the outlet situ ranges from 41% or 2.92 m$^3$/s with the application of a combination scenario. Then, if 13’s situ in Bogor Regency that are included in the Ciliwung watershed are carried out both structural and non-structural management has an impact of increasing the water capacity up to 4,701,881 m$^3$ or 4.70 million m$^3$. This amount with a total inundation area that can be utilized at 57.18 ha and an average depth of 3.20 meters to 8.20 meters so that the decrease in maximum outlet discharge can be reach 5.84 m$^3$/s. Ciawi Dam designed has a storage volume of 5.80 million m$^3$, normal inundation area at 500.18 ha, height from riverbed at 55 meters, investment up to 1,219 trillion [11]. If compared to the capacity of the Ciawi Dam, an increasing of 13 situ’s in Ciliwung river basin within the Bogor Regency can reach 81% of the planned capacity of the Ciawi Dam and will be cheaper than Ciawi Dam development.

4. Conclusions
The SWAT model simulation was done for the periods of 2008–2015 while it used land use information of 2014. The average monthly volume of Situ Kabantenan from the simulation were 136,955 m$^3$. The average of volume Situ Cikaret from the simulation were 508,907 m$^3$. The results of comparative analysis of hydrological responses based on situ and basin management showed that the decrease in maximum discharge of outlet situ in a row was combination scenario (decreased 41% discharge), dredging situ (decreased 14% discharge), connecting situ (decreased 11% discharge), Situ and basin conservation scenario (decreased 10% discharge) and decreasing riparian of situ scenario (increased 20% discharge). The result of hydrological responses analysis on application of situ and watershed management scenarios that combined the structural and non-structural measures was the best scenario for decreasing maximum discharge at situ outlet as compared to the scenarios that did not integrate the different components. If 13 situ’s in Ciliwung river basin within the Bogor Regency are carried out both structural and non-structural management has an impact of increasing the water capacity up to 4,701,881 m$^3$ or 4.70 million m$^3$. If compared to the capacity of the Ciawi Dam, an increasing of 13 situ’s in Ciliwung river basin within the Bogor Regency can reach 81% of the planned capacity of the Ciawi Dam and will be cheaper than Ciawi Dam development.

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Acknowledgments

Conclusions

Hydroinformatic Laboratory-LIPI

SWAT
6. References

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