Computing urban flooding of meandering river using 2D numerical model (case study : Kebon Jati-Kalibata segment, Ciliwung river basin)

Dian Indrawati^{1,*}, Bagus Yakti², Agustin Purwanti¹, and Rono Hadinagoro¹

¹Civil Engineering Department, Faculty of Engineering, Universitas Jenderal Achmad Yani, Cimahi, Indonesia

²PT. Bantardawa Consult, Bandung, Indonesia

Abstract. This research is an extension from a previous study titled modelling the diversion channel at Kalibata-Kebonjati meandering segment in Ciliwung watershed. Based on <http://pusatkrisis.kemkes.go.id> data, there are five sub districts that were flooded because of the rainfall in 5 February 2018 i.e : Pasar Minggu, Pancoran, Cilandak, Jagakarsa and Tebet. Their flood levels were achieved 300 cm, and the worst disaster happened in Pancoran, at Kebonjati to Kalibata segment in particular. Thus, this segment needs to manage accurately with appropriate structures. Formerly, the last study using 1D HEC-RAS, but the model has several lackness related to the rates of meandering velocities and discharges at the river edges, whereas, these numbers have significant effects for river scouring. Since several studies which applied 2D and 1D/2D coupling hydraulics modelling have been providing satisfactory results on complex river, this research was redeveloped and compared the meandering segment by using 2D HEC-RAS and Coupling 1D/2D HEC-RAS. Using rainfall data from three stations (Bendung Gadog, FT UI and Gunung Mas), the models indicated better results comparing with 1D model beside relations between velocity and discharge, respectively. Further, a diversion channel and stilling basin will be held in order to manage the flooding and scouring issues.

1 Introduction

As a capital city of Indonesia, Jakarta encounters severe problems related to water management specially annual flooding. Based on <https://bpbkd.jakarta.go.id> data, there are more than 7 (seven) times flood disasters occurred and inundated 15 sub districts every month in a year. Another data held by <http://pusatkrisis.kemkes.go.id> data per February 14th 2018, there are five counties were flooded by 5 February rainfall i.e Pasar Minggu, Pancoran, Cilandak, Jagakarsa and Tebet with 10 – 300 cm of flood level. The worst disaster happened in Pancoran, at Kebonjati to Kalibata segment in particular.

Formerly, the hydraulics modelling used 1D HEC-RAS. But there are several lacks related to flood characteristics, specially velocities and discharges, when being compared with observation data [1].

This study aims to achieve an optimal modelling in order to provide basis data and to decide the most appropriate structure for manage flooding. Several studies had conducted in order to reduce flooding that claimed could be ruining until billions dollars per years [2,3].

Others studies implied, when comparing 1D and 2D Numerical model in complex condition, for some cases, 1D approach is commonly may not be sufficient [1,4]. On

the other hand, a 2D model was successfully used to simulate a high-magnitude outburst flood in Kverkfjöll, Iceland [5] or using Shallow Water Equation [6]. However a full 2D model may be consuming time and facing stability fragile issue, thus, the coupling method that combines 1D approach in the river and 2D approach for the overland flow effectively succeed for large and complex river system with good results [4,7-10].

Ciliwung watershed are large and complex, therefore a coupled 1D-2D model and 2D model will be used for simulating the flood in order to obtain an effective and efficient solution for flood management in this area.

2 Study area

Ciliwung is one of commodious watershed which is mostly located in the capital city of Indonesia. Therefore, the administration boundaries made the watershed becomes equally important as capital city of Jakarta itself. Based on spatial analysis, Ciliwung watershed has 438.34 km² area and 116.32 km main river length, respectively.

The area covers 8 districts in Metropolitan Jabodetabek, such as : North Jakarta (31.09 km²), West Jakarta (6.69 km²), Central Jakarta (34.88 km²), East Jakarta (31.33 km²), South Jakarta (36.87 km²), Depok

* Corresponding author: author@e-mail.org

City (57.95 km²), Bogor City (35.48 km²) and Bogor (203.46 km²).

This is a dense region, so an inappropriate conditions will become significant problems for its people and Indonesia governments.

Fig. 1. Ciliwung Watershed

3 Methodology

Main objective focus of these modelling i.e for comparing two schemes of hydraulics modelling (2D and coupling) in Ciliwung river specially at the meandering segment, the methodology of this certain problem is shown on Figure 2.

Fig. 2. Methodology of modelling

From groundstation climate data and watershed characteristics, the hydrology model will be developed in order to obtain upper boundary condition for hydraulics model. Due to fact that the particular segment located far away from the sea, model will use a calculated rating curve for the lower boundary. Furthermore, hydraulics river characteristics will be applied for others model variables.

Next, the coupling and 2D hydraulics models have been developed, then a comparison between model characteristics specially discharge and velocity will be started to identify.

The rainfall data have been obtained from three ground stations i.e Gunung Mas, FT UI and Bendung Gadog and calculated by Polygon Thiessen method in order to obtain area rainfall as follows :

Table 1. Weighting area for each rainfall station

Rainfall Station	Area (Ha)	Percentage (%)
Gunung Mas	9852.72	30.86
FT UI	11,955.95	37.44
Bendung Gadog	10,121.39	31.70

Fig. 3. Weighting area of polygon thiessen

The method shows that FT UI rainfall station has larger effect compared with two others stations, eventhough not very significant (37.44%).

From the stations weighting, the maximum annual rainfall data was calculated as follows :

Table 2. Maximum daily precipitation of Ciliwung Watershed

Year	Maximum Daily Precipitation (mm)
2005	119
2006	84
2007	121
2008	62
2009	95
2010	84
2011	89
2012	68
2013	77
2014	80
2015	61

Since the hydraulics computings will be held along 11.824 km length from Pancoran/Kramatjati until Tebet sub district, the upper boundary is the hydrograph with 319.30 km² area and 84.73 km river length. On the other hand, the lower boundary calculated by rating curve and the long river alignment is divided by 190 cross section per 62.56 meter in average.

Fig. 4. Hydraulics model delineation

The calculation of profile in 1D modelling conducted by energy equation for solving water surface difference

between cross section with standar step method procedure. As follows :

$$Z_2 + Y_2 + \frac{\alpha_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \quad (1)$$

Where Z_1 and Z_2 are the elevation of the main channel inverts (m), Y_1 and Y_2 are the depth of water at cross sections, V_1 and V_2 are the average velocities (m/sec), α_1 and α_2 are the velocity weighting coefficients, g is the gravitational acceleration (m/sec²) and h_e is the energy head loss.

$$h_e = L\bar{S}_f + C \left| \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right| \quad (2)$$

Where L is the discharge weighted reach length, $\bar{S}_f$ is representative friction slope between two sections and C is the expansion or contraction loss coefficient.

L derived from average value of cross section reach lengths for flow in the left, main channel and right overbank respectively.

Since the energy equation is not applicable for modelling water surface in critical depth condition, HEC-RAS is applying momentum equation for solving this problems with functional equation as follows :

$$\frac{Q_2^2 \beta_2}{g A_2} + A_2 \bar{Y}_2 + \left(\frac{A_1 + A_2}{2} \right) L S_0 - \left(\frac{A_1 + A_2}{2} \right) L \bar{S}_f = \frac{Q_1^2 \beta_1}{g A_1} + A_1 \bar{Y}_1 \quad (3)$$

Whereas the flow in 1D equation assumed as a gradually varied because the basis premise hydrostatic pressure distribution exists at each cross section and total energy head is the same for all points in a cross section, these equation is limited for modelling flow in the curb river section. It is the Navier-Stokes equation which been used for describe the motion of fluid. Combining the momentum equation in two dimensional form of the Diffusion Wave Approximation with mass conservation yields, known as the Diffusive Wave Approximation of the Shallow Water (DSW) equations.

$$\frac{\partial H}{\partial t} + \frac{\partial(hu)}{\partial x} + \frac{\partial(hv)}{\partial y} + q = 0 \quad (4)$$

Where t is time, u and v are the velocity components in the x dan y direction respectively and q is the source/sink flux term.

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -g \frac{\partial H}{\partial x} + v_t \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - c_f u + f v \quad (5)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -g \frac{\partial H}{\partial y} +$$

$$v_i \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - c_f v + fu \quad (6)$$

Where u and v are the velocities in the Cartesian directions, g is the gravitational acceleration, ν_t is the horizontal eddy viscosity coefficient, c_f is the bottom friction coefficient, R is the hydraulic radius and f is the Coriolis parameter.

4 Hydrological Modeling

Based on an analysis of spatial map that distributed by National Mapping Agency of Indonesia (BIG), the landuse coefficient is 0.75.

Fig. 5. Discharge in varied returned periods of Ciliwung Watershed

Therefore, using Nakayasu SUH, flood discharge was estimated for several years of return periods. The graph results show that flood discharge varies from 254.01 m³/sec, 325.73 m³/sec, 373.22 m³/sec, 433.22 m³/sec, 477 m³/sec, and 521.91 m³/sec for 2, 5, 10, 25, 50 and 100 years of return periods, respectively.

5 Hydraulics model

The model is used to simulate existing condition using 2 flooding scenarios i.e 2 and 50 years of return period.

The model input are the topography data, river network and cross section for 1D simulation and combined with Digital Elevation Model (DEM) for 30 x 30 m grid size conducted from NASA SRTM.

5.1. Coupling 1D and 2D numerical model

The inundation maps of the existing condition for the flood discharge with return periods of 2 and 50 years are shown in Figure 6 and 7.

Based on the simulation results, inundation area for 2 years of return period is located in Pancoran (33.94 Ha), Kramat Jati (38.97 Ha), Jatinegara (50.46 Ha), Tebet (59.73 Ha), and Matraman Subdistricts (11.72 Ha).

On the other hand, inundation area for 50 years of return period is located in Pancoran (36.82 Ha), Kramat Jati (42.44 Ha), Jatinegara (51.23 Ha), Tebet (60.69 Ha), and Matraman Subdistricts (11.72 Ha).

Fig. 6. Inundation map for discharge in 2 years of returned period (coupling)

Fig. 7. Inundation map for discharge in 50 years of returned period (coupling)

5.2. 2D numerical model

The inundation maps of existing condition from the flood discharge with return periods of 2 and 50 years are shown in Figure 8 and Figure 9.

Fig. 8. Inundation map for discharge in 2 years of returned period

Fig. 9. Inundation map for discharge in 50 years of returned period

Based on the simulation results from existing condition, inundated area for a 2 years return period is 171.13 Ha and located in Pancoran (36.93 Ha), Kramat Jati (40.94 Ha), Jatinegara (35.09 Ha), Tebet (45.36 Ha), Menteng (0.11 Ha) and Matraman Subdistricts (12.69 Ha). The other 2D model results area of inundation for 50 years return period is 243.86 Ha and located in Pancoran (50.87 Ha), Kramat Jati (57.72 Ha), Jatinegara (47.92 Ha), Tebet (63.45 Ha), Matraman (22.43 Ha) and Menteng Subdistricts (1.47 Ha).

6 1D AND 2D numerical modelling

Eventhough 1D model previously succeed for modelling diversion canal and its impact for decreasing flood in Kebonjati-Kalibata segment, it is obviously important for comparing 1D and 2D hydraulics existing model related to flood characteristics specially in meandering part.

The flood elevation for 2 and 50 years of returned periods calculated as follow :

Table 2. Comparison between water elevation of 1d and 2d numerical model in existing meander section

Returned Periods	1D (m)	2D (m)
2 years	21.17	13.05
50 years	23.33	14.61

7 Model characteristics database

After numerical computing simulation, the next step is developed model characteristics database from various simulation and can be illustrated at figures below :

Fig. 10. Comparison of Q2 discharge between coupling and 2d hydraulics model

Fig. 11. Comparison of Q50 discharge between coupling and 2d hydraulics model

Fig. 12. Comparison of Q2 velocity between coupling and 2d hydraulics model

Fig. 13. Comparison of Q50 velocity between coupling and 2d hydraulics model

A necessary requirement for developing the larger database system which deployed using the results of numerical modelling. But the several flood characteristics show that coupling model results higher values than 2D model.

8 Conclusion and future work

In summary, the 1D and 2D hydraulics modelling obviously resulted differ values. In meandering section, the gap between them for 2 and 50 years of returned periods achieved 61.64 – 62.62%.

Beside that, there is an indication about the possibility of relationship between coupling model and 2D model

based on flood characteristics i.e : velocity and discharge. The ratio between models spared between 0.21 – 0.27 at inner curve and 0.27 – 0.57 at outer curve for discharges and 0.22 – 0.43 at inner curve 0.18 – 0.35 at outer curve for velocities.

For future work, in order to manage flood disaster that annually occurred on its segment, it is important to develop diversion canal. Furthermore, since from previous work that 1D HEC-RAS model had faced problems related to velocity and hydraulics jump at the end of canal [1], it is also considerable for applying stilling basin at the outlet of canal.

This research is funded by Institute for Research and Community Services (LPPM) Unjani and supported by Public Work Regional Office of DKI Jakarta Province for project title as “Planning and Detail Designed of Management Ciliwung River from Manggarai Watgate to its Upstream” for the topography data.

References

1. D. Indrawati, I. K. Hadihardaja, M.B Adityawan, F. Taufik and S. Pahrizal, *Diversion canal to decrease flooding (case study : Kebon Jati-Kalibata Segment, Ciliwung River Basin)*, SIBE (2017)
2. P. Wijayanti, X. Zhu, P. Hellegers, Y. Budiyo and E. C. Ierland, *Estimation of river flood damages in Jakarta, Indonesia*, Nat Hazards J, pp. 1059-1079 (2017)
3. Y. Budiyo, J. C. Aerts, D. Tollenaar and P. J. Ward, *River flood risk in Jakarta under scenarios of future change*, Natural Hazards and Earth System Sciences J. E **16**, pp. 757-774 (2016)
4. B. Lin, J. Wicks, R. Falconer and K. Adams, *Integrating 1D and 2D hydrodynamic models for flood simulation*, Water Management J. E **159**, pp. 19-25 (2006)
5. J. Carrivics, *Application of 2D hydrodynamic modelling to high-magnitude outburst floods : An example from Kverkfjoll, Iceland*, Journal of Hydrology E **327**, pp. 186-199 (2005)
6. E. Mignot, Paquier and S. Haider, *Modelling floods in a dense urban area using 2d shallow water equations*, Journal of Hydrology E **327**, pp. 186-199 (2005)
7. D. Indrawati, Y. Suryadi, D. Saputro, I. Taufik and M.B Adityawan, *Evaluation of flood management plan on Cilemer river basin, Indonesia*, European Water J. E **57**, pp. 49-56 (2017)
8. I. K. Hadihardaja, D. Indrawati, Y. Suryadi and N. S. Griggs, *Decision support system for predicting flood characteristics based on database modelling development (case study : Upper Citarum, West Java, Indonesia)*, Suistainability Today, WIT press (2012)
9. S. Patro, C. Chatterjee, S. Mohanty, R. Singh and N. Raghuwashi, P. S, C. Chatterjee, S. Mohanty, R. Singh and N. Raghuwashi, *Flood inundation modelling using MIKEFLOOD and remote sensing data*, Indian Soc. Remote Sens. J. E **37**, pp. 107-118, 2009

10. D. Indrawati, *Studi pengembangan model jaringan syaraf tiruan untuk indeks banjir berdasarkan fungsi karakteristik hidrotopografi dan spot banjir secara spasial (studi kasus DAS Citarum Hulu)*, Thesis (2011)