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AN ASSESSMENT OF FLOOD HAZARDS DUE TO THE BREACH OF THE MANGGARAI FLOOD GATE

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ABSTRACT: Central Jakarta is developed on a natural flood plain with a long history of flooding that leads to a series of flood control systems with Manggarai Gate at its center. Nowadays, as a regulator gate, Manggarai Gate is still good enough to control flood hazards in Central Jakarta. However, after operating for more than 100 years, it is necessary to measure the influence of increasing seismic activity, maximum rainfall, sedimentation rate, and solid waste problems on the potential of the Manggarai Gate breach. This study was made to identify flood hazards generated by the Manggarai Gate breach. An overtopping flow generated by excessive runoff is encountered as the gate breach mechanism. A mathematical model using HEC RAS to predict flood inundation due to the breach of Manggarai Gate in that area is presented in this paper. Due to the gate breach, the flood propagation was calibrated upon field observation data. The simulations were done for Q100 (692.6 m^3/s) with no breach mechanism; and Q100 with a breach mechanism. Based on that flood simulation, it is found that the flood inundated area for the gate breach scheme is approximately 259% compared to the scheme with no gate breach. Meanwhile, the hazard index for the gate breach scheme becomes 225% for the low level, 249% for the medium level, and 276% for the high level. Further study is needed to identify a proper measure to minimize gate breach-induced flood hazards.

Keywords: Flood hazard, Riverbank management, Flood control operation

1. INTRODUCTION

Central Jakarta is developed on a natural flood plain generated by the confluence of several rivers. The Flood event was already recorded since its development in 1619. Jakarta Flood control system was developed to control that natural flood plain in 1973 [1-7]. Manggarai Gate is designed as a regulator gate of peak deviation discharge from the Central Flood Control (CFC) System to Jakarta's West Flood Control (WFC) System [2-7,9]. The primary purpose of this regulator gate is to control the flood risk of Central Jakarta during the rainy season and ensure the water supply of central Jakarta during the dry season. In this case, the Manggarai gate should be operated as a reservoir sluice gate to detain excessive peak discharge compared to the bank's full capacity of WFC during the rainy season and as an intake to ensure the discharge of WFC greater than the dependable flow of central Jakarta [1-8] (see Fig. 1). However, until now there are still two potential threats that can stop the function of the Manggarai sluice gate, namely solid waste blockage and the gate breach. These threats could be generated by the influence of land-use change, climate change, and increasing earthquake risk as reported by several previous studies [1-15]. Previous research has indicated an increasing trend of maximum rainfall, sedimentation rate, and solid waste rate in CFC and WFC due to land-use change and climate change in the last two decades [1-10]. Those previous research also indicated that an increasing earthquake magnitude scale due to Indonesia's increasing tectonic plate activity had been observed in the last two decades [11, 12]. Meanwhile, Situ Gintung Dam, a younger Hydraulic Structure than Manggarai Gate reported, collapsed in March 2009 due to the overtopping and piping flow generated by excessive rainfall smaller than its design rainfall [13-15]. This event is shown that both the influences of land-use change and climate change on the extreme river flow not only in the Jakarta Area but also in other Indonesian Areas could not yet be well predicted using pure hydrologic methodology as long as the available data is incomplete [6, 13-14, 16-20]. Kardhana et al [21] reported that the hydrologic model where Satellite (Sadewa) data is used to predict the water level of Katulampa Barrage using long short-term memory (LSTM) recurrent neural networks (RNN) could give a good result compared to observed data of Katulampa Water Level. However further research is required to get a reliable and applicable hydrologic model prediction for the study area with limited data like Jakarta. The above discussion has the breach of Manggarai Gate is a high potential flood hazard scenario that should be encountered in improving flood risk reduction programs in the study area. A good enough prediction of flood propagation generated by dam break or gate breach has been discussed by several previous studies based on the physical model and or mathematical model [22-29].

Based on those studies, it is seen that there are several possible breach mechanisms of Manggarai Gate. However, the discussion of this paper focused on toping cases only [22-29]. This over-toping flow condition may occur due to the influence of the Solid Waste Blockages and or sedimentation on the upper part of the Manggarai gate. The sedimentation may occur whenever the regulator gate should retain the excessive runoff discharge to decrease the flood risk in the downstream part as it is in the reservoir [30]. Several previous studies have discussed the prediction of sedimentation rate and excessive maximum runoff for the urban area [31-34]. The prediction results would be useful for the stakeholder of the Jakarta Flood Control System, as discussed by previous research [35, 36].

Based on the highest recorded flood, the capacity of Jakarta flood control was improved to accommodate Q100. The improvement was carried out through river normalization programs in 2014 to increase the capacity of the Ciliwung River and the Manggarai Gate from *330 m^3/s to 507 m^3*/s [9].

Gaagai et al. concluded that the increasing flood discharges due to climate change could generate gate breaches as they are frequently not well considered in the design of gates [24]. Based on field observation of current and previous research, it is found that there is always solid waste accumulation on Manggarai Gate that generates backwater (25). However, this backwater was not well considered in the design of Manggarai Gate 100 years ago. The impact of climate change and solid waste accumulation in rising water levels could generate a Manggarai Gate breach with a higher risk of flood.

Dam breach characteristic has been discussed in detail based on experimental work and numerical model [22-29]. These previous researches have emphasized discussing the dynamics of variations in depth, velocity, and propagation time without discussing the breach mechanism. The discussion of the breach mechanism inducing flood at the Manggarai Gate is a study that has never been discussed before. Therefore, this study tries to highlight the pattern of flood hazards due to breaches that occurred at the Manggarai Gate as support for determining the plan for an early warning system for the City of Jakarta.

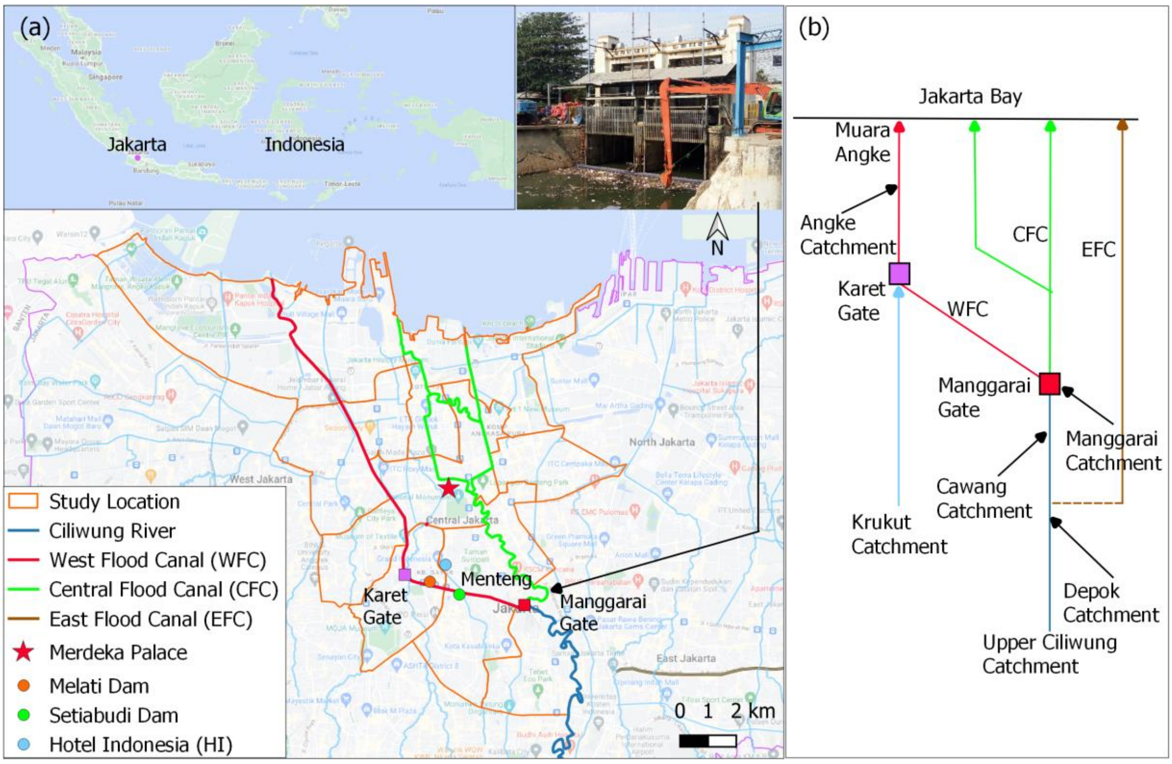

Fig 1. (a) Jakarta flood control (JFC) system (b) Connected drainage system to the JFC system

2. STUDY AREA

The study area is situated along the Ciliwung River to WFC within Jakarta. Geographically this area is located from 6°9'52" S to 6°10'6" S and 106°45'48" E to 106°51'45" E. The location consists of fourteen sub-districts historically affected by the Ciliwung River and WFC (Fig 1.a.). Among these fourteen sub-districts, Tebet, Tanah Abang, Grogol Petamburan, and Penjaringan sub-districts are the most vulnerable to annual flooding.

Manggarai Gate, the central topic of this study, is located within the Tebet sub-districts, the boundary between South and Central Jakarta. The upper ponding area of Manggarai Gate consists of the Matraman, Jatinegara, and Tebet sub-district, which are classified mainly as settlements with very dense populations. Meanwhile, the downstream inundated area of Manggarai Gate consists of Tanah Abang, Menteng, Setiabudi, and Grogol Petamburan, which are classified as areas with very high economic and social risk.

Several locations within the study area in Central Jakarta, such as Setiabudi Boulevard, Hotel Indonesia Roundabout, and National Monument (Monas), were flooded when an extreme flood came. These mentioned locations are some of the busiest areas in Central Jakarta.

Setiabudi area has seen rapid development due to its function as the center for economic activity and business. Two important train stations were constructed within this area bordering the WFC; one functions as a commuter line station and a Soekarno-Hatta airport line station. During extreme flood occurrences, the commuter line station has been flooded by the overflow of WFC and needs to stop its service. The expanding flood of Setiabudi Boulevard spread northward to Hotel Indonesia Roundabout and created heavy traffic congestion in Central Jakarta.

3. METHODOLOGY

The rainfall transformation into discharge hydrograph was performed using the HEC HMS software version 4.3. The daily rainfall data series used to perform the discharge simulation was taken from January 2009 to December 2019 and calibrated with the Manggarai Gate recorded discharge data. Hydrograph model calibration was computed using the discharge in February 2015 flood event. This choice was made due to the relatively low disturbance on the flow compared to the flood occurrence with a more significant discharge.

The flood model to measure hazard level was simulated utilizing the 1D - 2D coupled model of HEC-RAS version 6.0 as a well-recognized software to emulate flood occasions, as discussed in [8], [31], [34], which is also suitable for overtopping breach simulation [26], [27]. A DEM map with an 8.5 m resolution is used as a terrain map to create floodplain geometry. Field measurement data are applied to the DEM map to refine the river geometry. The recorded water level at the Manggarai Gate and historical inundation data are used to calibrate the flood model.

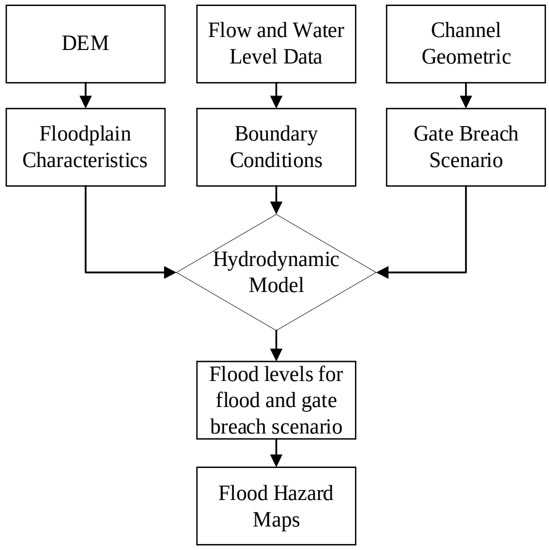

Fig 2. Methodology and computational procedure

Within HEC-RAS, flood inundation was analyzed by calculating the flood routing in the inundation area using the modified Pul's equation (eq 1). In this equation, the difference between inflow and outflow is the amount of storage change.

$$I - Q = \frac{dS}{dt} \tag{1}$$

With I as Inflow (m^3/s), Q as outflow (m^3/s), S as storage (m^3), and t as time (second).

These flood routing calculation results are used to analyze the distribution of floods in the inundation area in the HEC-RAS model. The basic equations used by HEC-RAS as equations for hydraulic simulations are continuity (eq 2) and momentum equations (eq 3).

$$\frac{\delta A}{\delta t} - \frac{\delta Q}{\delta x} - ql = 0 \tag{2}$$

$$\frac{\delta A}{\delta t} - \frac{\delta QV}{\delta x} + gA\left[\frac{\delta z}{\delta x} + Sf\right] = 0 \tag{3}$$

With Q as discharge (m^3/s), x as distance (m), t is time (second), A as cross-sectional area of flow (m^2), Sf as the slope of energy line, ql as lateral inflow (m^3/s), and V as velocity (m/s).

The flood simulation was performed using computational grid meshes with a dimension of 50. The computation of the mesh property is performed automatically on 2D flow areas by running a geometric model with the boundary conditions applied to the Ciliwung River from South Jakarta to Muara Angke, with several river outlets on the WFC as lateral inflow to the river model. Calibration of the model was performed by comparing inundation depth recorded on the Ciliwung Riverbank flood event.

The boundary conditions applied are hydrograph input from Cawang followed by several lateral inflows to model the entry of discharge from the land along the Ciliwung River channel (Fig 1.b.). The breach condition on the Manggarai Gate was performed in bank full capacity condition, with the whole section of the sluice gate failing.

Simulations were performed on the 100-year flood return period with the gate fully opened for the regular fluvial flood scenario and the gate opening of 1 m for the gate breach scenario. The gate breach model was performed with an overtopping approach at the gate. The equation used to model the gate breach was built with the same assumptions as a dam breach model. According to [28], the Froechlich equation is the best for making simulations with indeterminate conditions. Breach parameters determined using the Froechlich equation are shown in eq. (4) and (5).

$$B_{ave} = 0.27 K_0 V_w^{0.32} h_b^{0.04} \quad (4)$$

$$t_f = 63.2 \sqrt{\frac{V_w}{g h_b^2}} \quad (5)$$

Where B_{ave} is the width of the breach (m), t_f is the breach formation time (s), K_0 is a constant (1.3 for overtopping, 1.0 for piping), V_w is the reservoir volume at failure (m^3), and h_b is the depth of the final breach (m).

The identification of the flood hazard index was then carried out based on the guidelines issued by BNPB Indonesia (Perka BNPB No. 2 of 2012) [36]. Based on these guidelines, the flood index is divided into three based on depth; Low Index (D < 0.75 m), Medium Index (0.75 m < D < 1.5 m), and High Index (D > 1.5 m).

4. RESULTS AND DISCUSSION

The NSE value generated from the hydrologic model simulation performed with HEC HMS reaches 0.313 with an RMSE of 0.8 and a bias of 10.13% (Fig 3). This value was achieved because the rainfall data used in the model is a distribution applied using a 12-hour distribution approach and not actual rainfall data. To reach a better precision in the distribution model, better rainfall data within more sub-catchment divisions need to be considered.

The flood model was built based on the drainage capacity improvement program carried out in 2015. This increase in drainage capacity reduces the occurrence of the flooded area due to runoff from rivers. However, flooding due to a poor drainage network can still occur and is an important note for a more comprehensive flood modeling.

The HEC-RAS simulation performed with February 2015 discharge model was comparable to the existing water elevation recorded at the Manggarai Gate Station (Fig 4). The flood in February 2015 was not affected by much solid waste and sedimentation. Hence the discrepancy between the simulation result and the existing data was minimal.

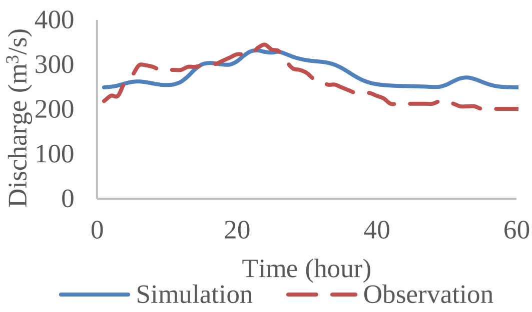

Fig 3. Hydrologic Model Calibration

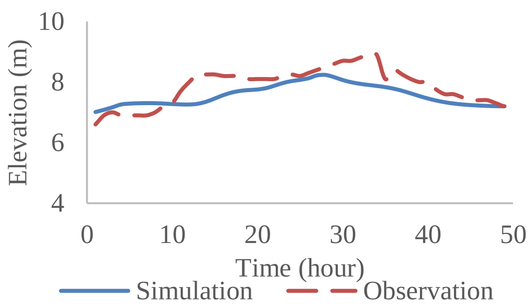

Fig 4. Hydraulic Model Comparison

Before 2015, flooding in the Central Jakarta area due to WFC runoff also occurred through the Sudirman area. The high-water level in the WFC overflows and hinders the discharge from the Thamrin drainage system into the WFC. 2013 flood occurrence was also recorded due to WFC overflow from the Sudirman area to the Thamrin area through Hotel Indonesia (HI) Roundabout (Fig 5.a.).

Several areas, such as the Sudirman area in Setiabudi District, are still subject to flooding even after improving drainage capacity. Flood in the Sudirman area again occurred in January 2020 due to heavy rainfall and submerged several roads and the Sudirman train station (Fig 5.b.). The rainfall, which was declared the heaviest rainfall in the last 50 years, also caused water to overflow to the Ciliwung-Cikini section of the CFC and inundated areas around the Merdeka Presidential Palace.

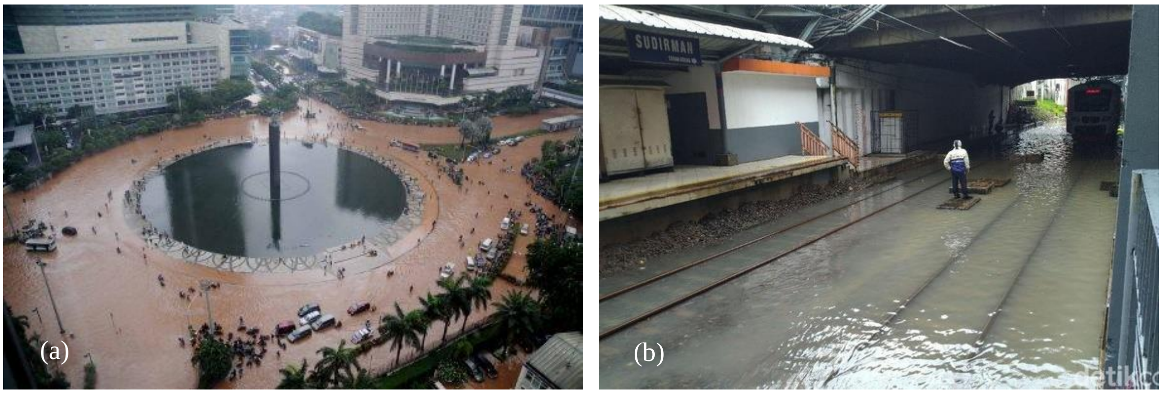

Fig 5. (a) Flood on Hotel Indonesia roundabout in 2013 [37], (b) Flood on Sudirman Station in 2020 [38]

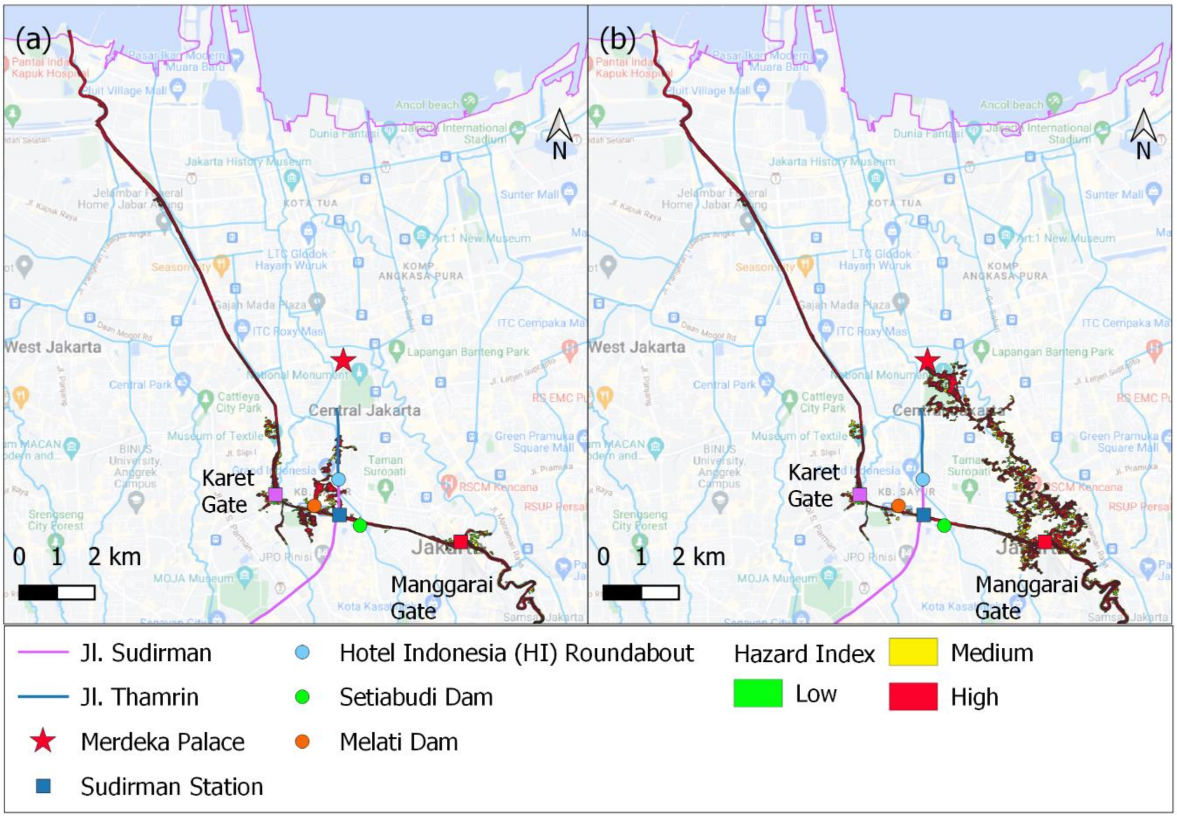

Fig 6. Flood hazard of (a) Q100 flood, (b) Q100 gate breach flood

Table 1. Hazard Index Criteria

Color	Depth (m)	Hazard Index
Green	<0.75	Low
Yellow	>0.75, <1.5	Medium
Red	>1.5	High

The Ciliwung-WFC regular fluvial flood due to a design discharge of 100 years (Q100) with peak discharge reaching 692.6 m^3/s causes inundation to occur in the Districts of surrounding Manggarai Gate, Sudirman Station to Hotel Indonesia Roundabout along Thamrin street (Fig 6.a.) with depth in the range of 0 – 5 m.

The gate breach in the discharge event of Q100 expands inundation to Central Jakarta through the CFC (Ciliwung-Cikini section) and reduces inundation in the Setiabudi area. The discharge that arises due to the release of the water volume detained at the Manggarai Gate causes the water depth that appears in the WFC on the Menteng section to exceed the capacity of the existing canal. This causes an overflow in the Menteng section, passes the water volume to the north, and converges with the Ciliwung-Cikini section on the CFC network. The influx of water volume into the CFC spreads the flood due to the gate breach further to the north, reaching areas adjacent to the Merdeka Palace. The overflow of water volume in the Menteng area resulted in most of the water volume leaving the WFC system and decreased flow in the WFC, causing floods in the Setiabudi area to occur less (Fig. 6.b.).

Based on the flood hazard classification of Indonesia (Table 1), the gate breach scenario at the Manggarai Gate had expanded the inundation to 259% compared to the inundation area of a regular fluvial flood Q100. The inundated area with the low hazard index grew to 225%, the medium hazard index to 249%, and the high hazard index to 276% (Table 2).

Table 2. Flood Hazard Area of Several Flood Scenarios

Hazard Level	Inundated Area (Ha)	
	Q100	Q100 Gate Breached
1	20	46
2	33	82
3	59	162
Total	112	290

Several factors need to be considered in the flood model simulation on the WFC section, including the presence of a reasonably large inflow from the Krukut River, which can affect the water depth in the WFC. In this simulation, the influx with a return period of 100-year from the Krukut River is placed as a discharge event which causes the water depth in the WFC to be relatively high. This setup causes the resulting flood conditions to be extreme. However, through this simulation, it can be stated that it is necessary to increase the WFC capacity. Raising the flood embankment in the Setiabudi area is essential to reduce the threat of regular fluvial flooding in the high flood return period (Q100). The flood barrier in the Menteng area to minimize the danger of flooding due to the Manggarai gate breach also needs to be reviewed.

Inundation due to the gate breach causes changes in the flood hazard occurrences. The difference in flood patterns causes different hazard patterns that question the effectiveness of the current flood infrastructures. It is necessary to carry out further studies on the solid waste blockage of the flood gate, sedimentation, the local rainfall effect, and the aggregation of several flood scenarios (fluvial, coastal, pluvial). These studies are needed to see the overall pattern of flood hazards in Jakarta and measure the effectiveness of the drainage and flood infrastructure designs. Thus, more detailed research on overflowing locations, condition changes along the canal sections, and the need to elevate WFC barriers to improve the future capacity against gate breach flooding while also considering Jakarta's land subsidence rate needs to be performed.

5. CONCLUSION

Floods that occur because of gate breaches due to the capacity exceedance produce a different pattern of inundation than regular fluvial flooding, changing the flood pattern of Central Jakarta. This change occurs due to the overflow of most water volume through the Menteng section of WFC, thus reducing floods in the Setiabudi area while moving the floods along the Ciliwung-Cikini section of CFC. Due to the gate breach, the flood pattern expands the inundation area to reach 259% of the inundation formed by the Q100 fluvial flood. The low hazard area grew to 225%, the medium hazard area to 249%, and the high hazard area to 276%. The differences in hazard expansion are pretty apparent that the existing flood protection program needs to be reviewed.

Modifying WFC barriers on Setiabudi and Menteng sections can be a solution to reduce water overflowing from WFC due to regular fluvial flooding and Manggarai Gate breach. However, further studies involving the details of the city's drainage channels and the effect of land subsidence are also needed to simulate the formation of inundation that is better and closer to actual conditions. A simulation of solid waste cumulation on the flood gate is also required to better measure the change in inundation due to backwater caused by solid waste clogging the flood gate.

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