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The Effectiveness of Structural Mitigation to Flood Disaster Reduction in Tebet, Matraman, and Jatinegara Sub-District of Jakarta City

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ABSTRACT

Floods are the dominant colour of the interaction of human activities and natural mechanisms that occur every year in the city of Jakarta. Various efforts have been made to reduce flooding in Jakarta, but flooding is still the dominant colour, especially on the banks of the Ciliwung River. On the banks of the Ciliwung River, Tebet, Matraman and Jatinegara sub-districts are the three areas that experienced the most severe overflows of the Ciliwung River. Flood mitigation efforts in these three areas have been carried out in the form of increasing the drainage capacity of the Manggarai Gate and normalizing the river in the form of dredging and construction of embankments. However, this effort is not optimal because the implementation of normalization is hampered by social conflicts. This paper discusses mitigation efforts in the form of normalization and combination with retention ponds which are carried out by simulating flooded areas. Completion of the normalization of the Ciliwung River is not the best solution to deal with flooding in Jakarta. The flood volume which usually occupies the flood area flows quickly due to changes in the geometry of the river and causes changes in the hydrograph peak and causes flooding in the downstream part of the study area causing an increase in inundation area in Manggarai up to 200%. On the other hand, the use of retention/storage ponds on limited land has been able to reduce flood inundation by 10%. Therefore, staging in the planning and construction of flood mitigation infrastructure needs to be considered and planned thoroughly.

Key words: *Flood mitigation, Riverbank management, Flood control operation, HEC-RAS, 1D-2D coupled model.*

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INTRODUCTION

Flooding is a chronic problem in Jakarta that has existed since the pre-colonial period. This is due to the city of Jakarta's natural floodplain, which is crossed by 13 rivers. The city of Jakarta's rapid rate of urbanization has led to a significant intervention of natural space into built-up space, resulting in a large population affected by floods each year. The Ciliwung River, the largest river that runs through Jakarta, is not immune to this problem (Farid, 2017; Formanek, 2014; Kusuma, 2010).

The Kampung Melayu region in Jakarta's Jatinegara sub-district is a well-known flooded area that floods every year. This is not the only region with a significant risk of flooding. Several more areas along the banks of the Ciliwung River in three sub-districts, Matraman, Tebet, and Jatinegara, are also at risk of flooding.

These three sub-districts are part of the Ciliwung River Basin, which flows from the highlands of Bogor Region through Depok City and subsequently into the center of Jakarta City. The Ciliwung River used to run north through central Jakarta, emptying into Jakarta Bay via Ancol (Farid, 2017; Formanek, 2014; Kusuma, 2010; Kusuma, 2011; Papagiannaki, 2015). Since the previous century, the flow has been channeled westward to the West Flood Canal (WFC), which is controlled at the Manggarai Gate and collects hydrological loads from many other major rivers before draining into Muara Angke. However, due to the increasing hydrological burden of high upstream discharge, the Manggarai Gate's performance is subpar. (Sukiyoto et al, 2022)

Several earlier studies (Kusuma, 2010; Papagiannaki, 2015; Papagiannaki, 2015) found that land-use change (LUC) and climate change had a major impact on rainfall distribution, peak discharge, and flood dangers in the Ciliwung River. To further understand the consequences of both land use and climate change, a more comprehensive study that can show the relationship between each influence and extreme rainfall and runoff discharge patterns is required (Kusuma, 2011; Kuntoro, 2017; Archer, 2018). This comprehensive investigation is one of the prerequisites proposed for more reliable flood prediction based on numerical model work (Farid, 2017; Kusuma, 2010; Kusuma, 2011; Diakakis, 2012; Febi, 2019).

The increased hydrological load is exacerbated by the drainage network's decreased hydraulic conveyance capacity, further compromising the flood infrastructure's ability to regulate discharge from upstream Ciliwung to the WFC. Uncontrolled sedimentation, solid waste buildup, land-use change, and land subsidence are other issues related to the inadequate performance of flood infrastructure (Farid, 2017; Formanek, 2014; Kusuma, 2010). Previous research has linked these issues to the impact of unmanaged urbanization (Kusuma, 2011; Papagiannaki, 2015), which is not just prevalent in the Jakarta Metropolitan Area (JMA) but also in other parts of Indonesia.

More research was performed to better understand Jakarta's flood characteristics in order to design an alternate flood management strategy. Several experiments have been conducted to lower peak discharge utilizing rain collection (Juliana, 2017a,b), but they cannot greatly reduce flooding risk. Another study concluded that at least 244.71 hectares of green space must be constructed along the riverbanks to minimize the elevation of flood inundation in the Ciliwung watershed (Ali, 2016). Increasing the capacity of the Manggarai Gate was also investigated (Zulfan, 2015), with the conclusion that increasing the sluice capacity by 150 m^3/s reduces the upstream sluice's water level by 1 m but does not appreciably lessen the risk of flooding.

Effective land-use planning is the most effective way to reduce flood risk in Jakarta (Budiyono, 2016; Sarminingsih, 2014). A successful adaptation plan to minimize flood susceptibility should include a combination of flood protection infrastructure, nature-based solutions, and risk financing schemes (Jongman, 2015; Gaviria, 2013; Lee, 2019; Farooq, 2019).

Several structural solutions, including normalization, flood barrier construction, additional floodgates, polder systems, and huge flood reservoirs, have been implemented in the field to reduce flood hazards (Formanek, 2014). However, the impact of such interventions remains unsatisfactory due to the region's complicated social, economic, and policy constraints, which prohibit structural changes from being completely implemented. For example, in an ongoing canalization project, completion was postponed due to an ambiguous property purchase.

JMA is a strategic economic location, and flood danger puts a significant strain on its socioeconomic activities (Farooq, 2019; Asdak, 2018). However, the optimality of structural flood prevention measures is limited, and there is an urgent need for complementary flood risk reduction approaches. This study investigates the changes that have happened as a result of flood mitigation measures on the Ciliwung Riverbanks, as well as their implications for flood structural mitigation efforts on the Ciliwung Riverbanks.

Figure 1. Historical Flood of (a) February 2007 event, b) January 2020 event

LOCATION OF STUDY

The study area is in South Jakarta, between 106 ° 49' 35"E and 106 ° 53' 57" E, and 6 ° 11' 21"S to 6 ° 14' 58" S. This area consists of three sub-districts, Tebet, Matraman, and Jatinegara, which are directly bordered by the Ciliwung River to the east and north, with a portion of the territory inundated by the Ciliwung River overflow (Figure 1.a.b.). The riverbanks in all three places are densely packed with villages that are annually inundated by the Ciliwung River's overflow. Following the worst flood in Jakarta's history in

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February 2007, river normalization, which included dredging and the construction of river embankments, was conducted in these three regions in 2015. However, the implementation of normalization was hampered by the formation of social disputes, particularly in the investigated sub-districts of Manggarai, Kebon Manggis, sections of Kampung Melayu, and Bukit Duri Village.

The Manggarai Flood Gate is located downstream of this location and serves as a regulator and indication of flooding for the City of Jakarta. It is also a landmark for flood management in the city of Jakarta. After the residential district, the Manggarai Train Station is the second-largest landmark in this area. As a result of this station area, Manggarai Village was designated a transit-oriented development area.

The geography of the riverbanks is a moderate slope with an elevation increase at the Manggarai train station. The majority of the village area is designed as a residential district, with high-density dwellings dominating. Some of the regions that have embankments are lowlands that were historically inundated. Flooding in this area has greatly decreased since it was embanked. However, in January 2020, several of these places, including the Bukit Duri region in the Tebet sub-district, experienced flooding to a depth of 2.5 meters as the Ciliwung River discharge overtook the erected embankment.

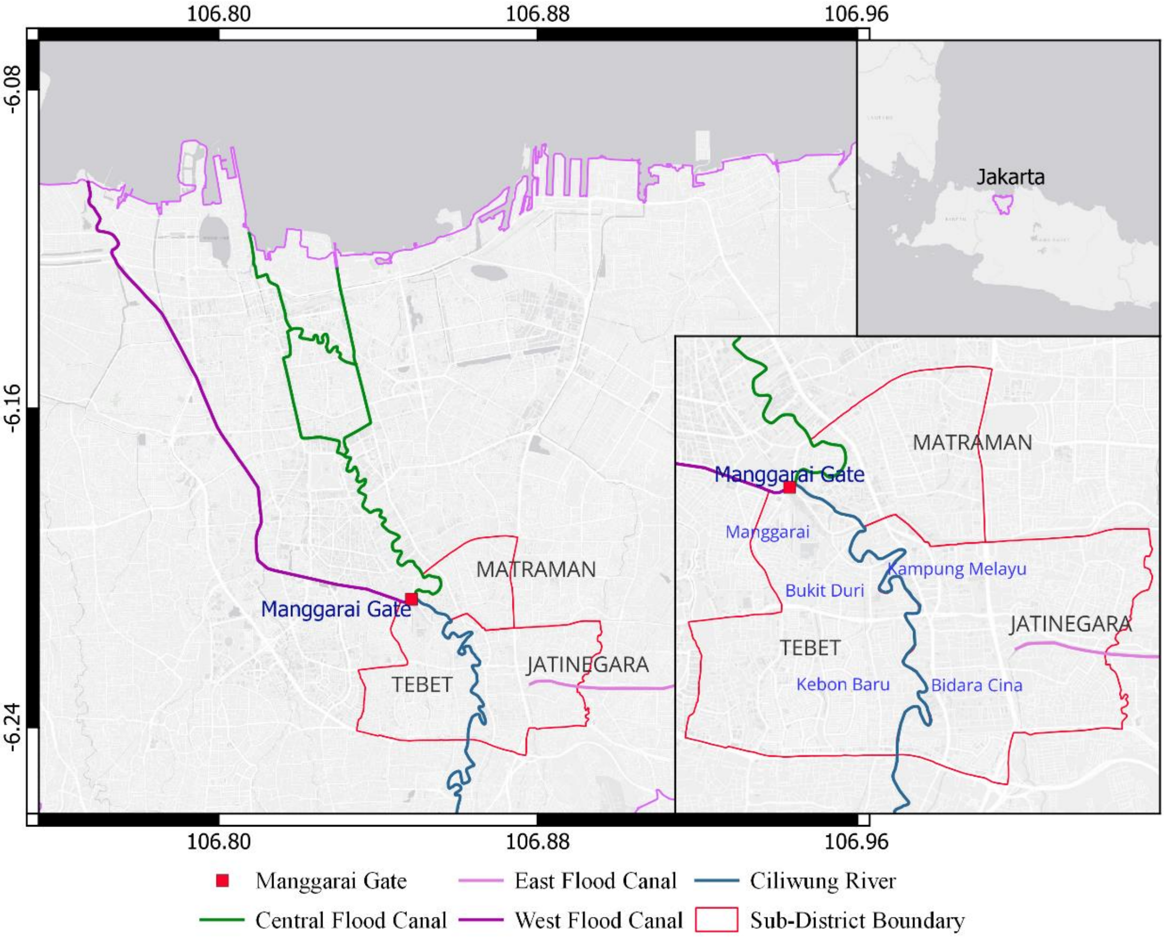

Figure 2. Study Location

METHODOLOGY

Flood simulation is used to calculate the flood danger level for flood risk analysis. Floodplain geometry is created using the HEC-RAS 1D-2D coupled model and a DEMNAS map with an 8.33 m resolution as a terrain map (Asdak, 2018; Gunawan, 2017; Farid, 2020; Imanuddin & Wicaksono, 2023). Details of the river geometry are applied to the terrain map using field measurement data to approximate the existing river geometry pattern. The flood model is calibrated using recorded water level data at the Manggarai Flood Gate and historical inundation data.

Existing flood inundation data is taken from the Jakarta Water Resource Agency and news sources using data from affected RWs (Rukun Warga). The data obtained is in the form of inundation depth points recorded from the smallest administrative unit area (RW) affected by flooding, rather than a definition of the inundated area. This necessitates model calibration with historical data via preliminary comparisons with flood model simulation outcomes.

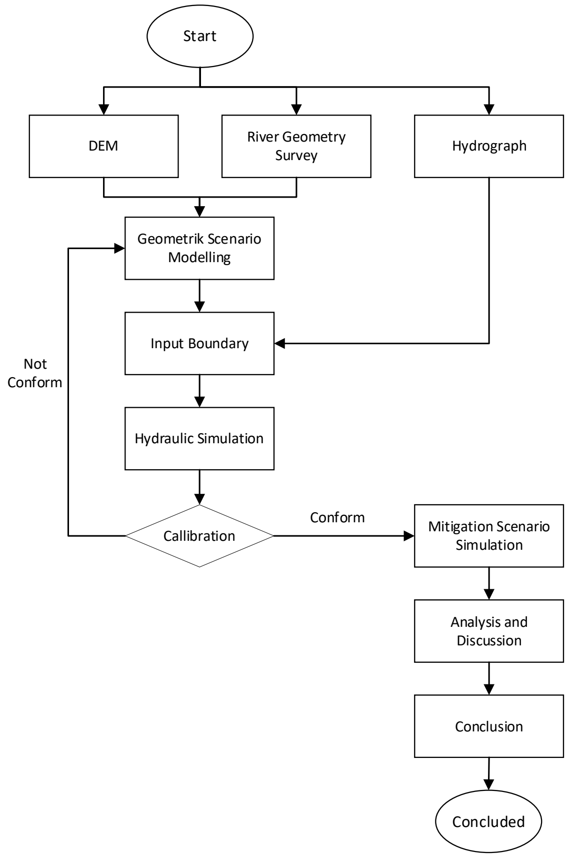

Figure 3. Methodology

RESULTS AND DISCUSSION

As a flood-prone location, the Ciliwung Riverbank from MT. Haryono to Manggarai Flood Gate floods annually due to overflow. Flooding occurs as a result of reduced river capacity due to silt and riverbank occupancy. The 2007 flood was the most massive surge yet recorded in this area. This flood was the most significant documented flood in Jakarta in the last century, inundating up to 60% of the Jakarta area. There are already several studies and projects underway to boost the Ciliwung River's drainage capacity in order to combat flooding. In 2015, the installation of the Manggarai floodgate capacity was one of the initiatives to improve the drainage capacity of the Ciliwung River.

This new gate was constructed following flooding for more than a week in February 2014. The addition of this floodgate can enhance the floodgate's drainage capacity from 330 m^3/s to 550 m^3/s. Despite the fact that the floodgate enlargement should reduce the water level upstream of the floodgate by 1 m, (Zulfan, 2015) flooding in Manggarai Village occurs on an annual basis.

Overflow from the Ciliwung River has continued since the river normalization effort was halted in 2015 owing to social tensions. The controversy arose as a result of residents' refusal to leave the Ciliwung Riverbanks, prompting local administrations to postpone executing the normalization program until a later date. Not only does Manggarai Village face difficulties in transferring riverbank communities, Similar things happen in Kebon Manggis Village and Kampung Melayu Village. This issue, which results in discharges greater than 330 m^3/s, might still cause floods in several places.

Floods in 2020 demonstrate that floods occurred in nearly all study locations. However, due to the river's normalization, which included dredging and the construction of flood embankments, the flood delineation area was not the same as it was in 2007 (Figure 4.a.b.). Normalization initiatives aided in mitigating storm effects and limiting the degree of flooding in affected areas. However, it is apparent that flooding remains a major issue in the region.

The expansion of submerged areas is caused by regions with relatively low elevations to the river body in Manggarai Village's north and southeast. Floods can also enter Manggarai Village through drainage outlets in the eastern half of the village, forming a larger inundation area around Manggarai Station.

A similar event happened in the Kebon Manggis area as a result of the Ciliwung River's unfinished normalization efforts. At the time of the 100-year return period discharge, several localities in Kampung Melayu and Bukit Duri were also experiencing Ciliwung River floods. When the river overflows, areas with low elevations on the riverbanks are still vulnerable to flooding. Furthermore, sections that have not been normalized are located downstream, causing a narrowing of the river cross-section and backwater, particularly during the 100-year return period discharge. It is critical to maintain normalization efforts in these areas in order to lower the risk of flooding and improve overall flood safety.

River normalization, which includes digging river channels and embanking river banks, is an effort to boost the Ciliwung River's capacity. The Ciliwung River's existing capacity can only sustain a 25-year return period discharge; thus, when a return period discharge happens, such as the February 2007 and January 2020 floods, the

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Ciliwung River's banks will be flooded.

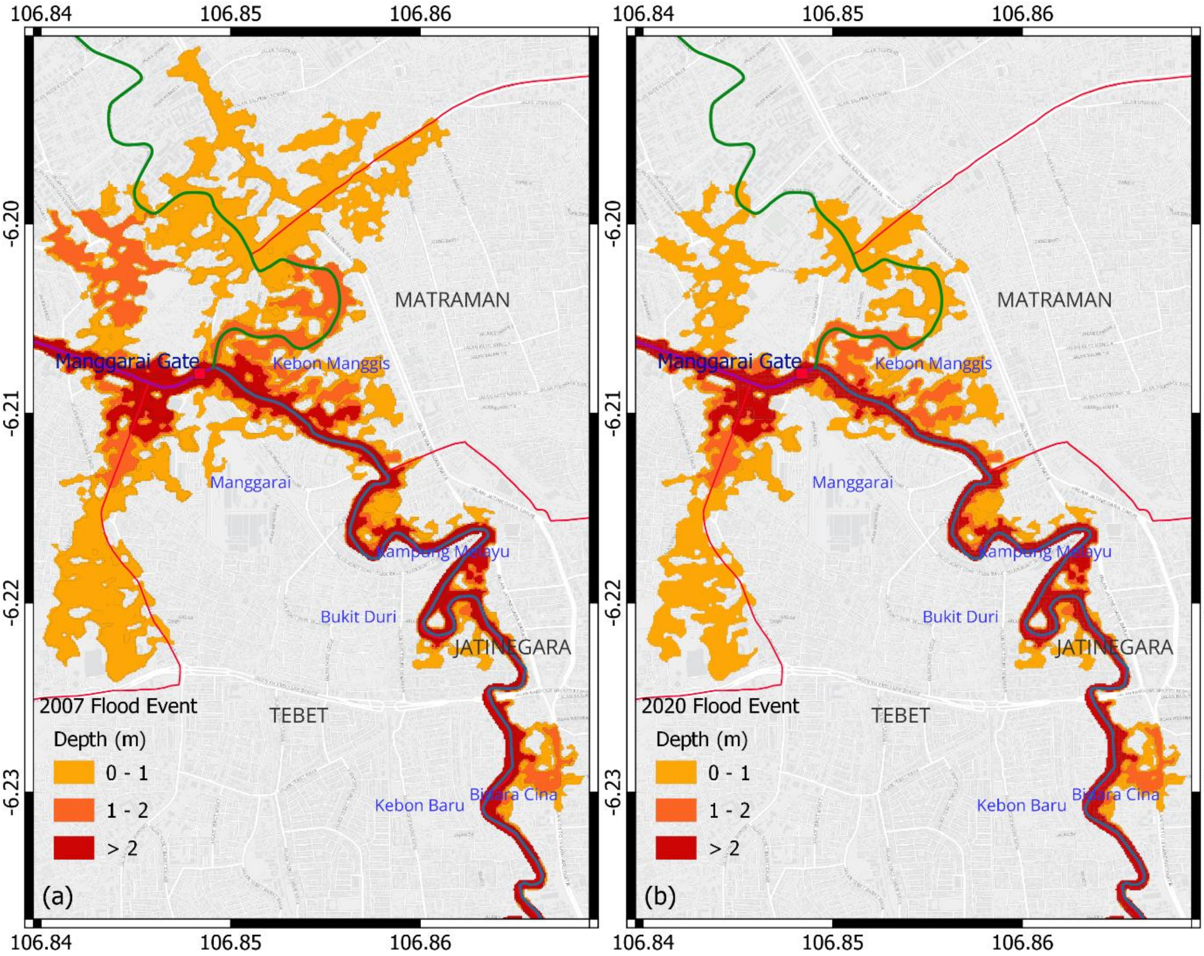

Figure 4. Flood inundation of (a) 2007 flood event, (b) 2020 flood event

The completion of the Ciliwung River's normalization can help lessen the possibility of river overflows on most of the river's banks. Nonetheless, simulations using the 100-year return period discharge model suggest that flooding continues to occur in various places, including Kampung Melayu, Kebon Manggis, and Manggarai. The completion of river normalization in the Bidara Cina and Kebon Baru sectors, on the other hand, has the potential to reduce river runoff (Figure 5.a.b.).

The existing river discharge spots have been embanked, resulting in less flooding in the Bidara Cina and Kebon Baru districts. Because of this countermeasure, the river's water discharge does not reduce due to runoff, resulting in a greater volume of water received by the Kampung Melayu region in the downstream part. The meandering nature of the river channel in the Kampung Melayu area reduces the velocity gradient and increases the depth of flow in this section of the river, causing it to overflow. Parts of this area are still not protected from floods due to the lower elevation of Kampung Melayu, even if total flood inundation in this area has been minimized.

The Manggarai and Kebon Manggis regions were also affected by the increase in flooding in parts of the Kampung Melayu area. The increase in flooding in these two regions was caused by the river channel's water output not reducing due to overflow into the flood zones in the higher reaches of these two areas. Nonetheless, the river's normalization reduces the extent of flood inundation in the Kebon Manggis area.

Flooding in the Manggarai area has intensified due to a decrease in the volume of water reaching this area, resulting in overflowing floods across bridges and roadways with constant height. This significantly increases flood inundation in this area. It is critical to continue monitoring the effectiveness of flood mitigation measures and to identify any further efforts that may be required to combat flooding in these locations.

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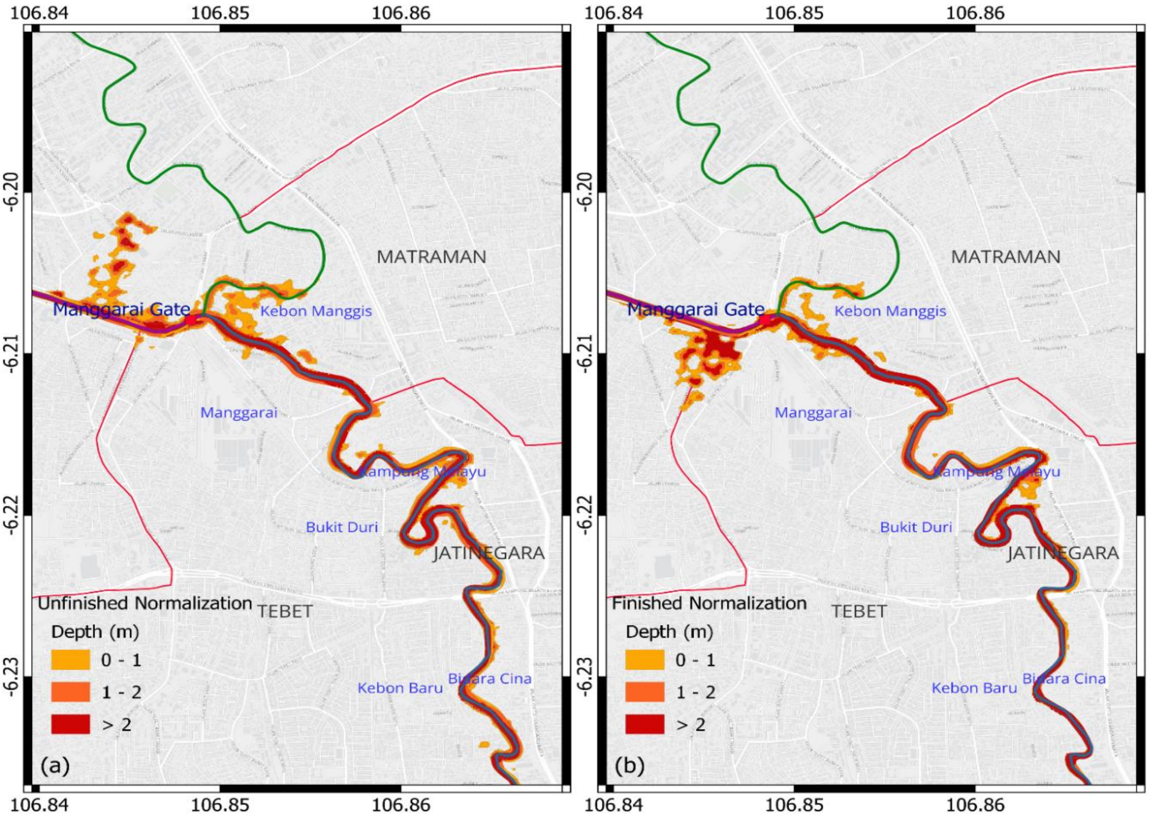

Figure 5. Flood inundation of (a) existing condition (unfinished normalization), (b) finalized river normalization

Flooding in the Manggarai area has intensified due to a decrease in the volume of water reaching this area, resulting in overflowing floods across bridges and roadways with constant height. This significantly increases flood inundation in this area. It is critical to continue monitoring the effectiveness of flood mitigation measures and to identify any further efforts that may be required to combat flooding in these locations.

To entirely eliminate flooding in the study region, current flood zones totaling 11 hectares must be addressed. Difficulties in managing flood zones owing to social disputes in the form of community opposition to being evacuated from riverbanks must also be addressed correctly in order to improve the government's options for effectively reducing floods.

Another visible effort to avoid flooding is to reduce peak discharge by tapping the discharge using retention ponds along the river. Because there are no retention ponds in the study region, efforts must be made to convert land into retention ponds. Land conversion in the study region can take advantage of the government's green zone rather than freeing up private land, which has a high risk of social conflict. Using government green zones instead of private land helps reduce social strife, but it's still important to make sure the land conversion is environmentally sustainable and doesn't impact local ecosystems.

The reduction in flood area that this technology can achieve is insufficient. It can, however, show a decrease in the flooding that happened. Reducing peak discharge helps to lessen flood inundation in all study regions (Figure 6.a.). The storage volume obtained by converting the green zone, however, has not been able to considerably reduce inundation.

There aren't many green open spaces in the study region that could be transformed into retention ponds or storage. Conversions were planned to take place in city parks, which were few in the study areas. Parks in the six villages close to the Ciliwung River that can be transformed into retention ponds were only able to reduce the peak 100-year return period flow to 518 m^3/s from the original 536 m^3/s.

The study area's high degree of land occupancy contributes to the restricted area that can be converted. The study area, which is largely used for residential purposes, is difficult to get to. Rejection from the community is another issue

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that the government is still dealing with, similar to the issue of property acquisition for river normalization. Nonetheless, the construction of retention and storage ponds has demonstrated that this endeavor is capable of reducing overall flooding in the study area. This is also demonstrated by the use of retention and storage ponds in river normalization systems (Figure 6.b.). The reduction in flood inundation that occurred following the river's normalization can be mitigated by lowering the peak discharge. This demonstrates that building retention and storage ponds is superior for reducing flooding in the long run.

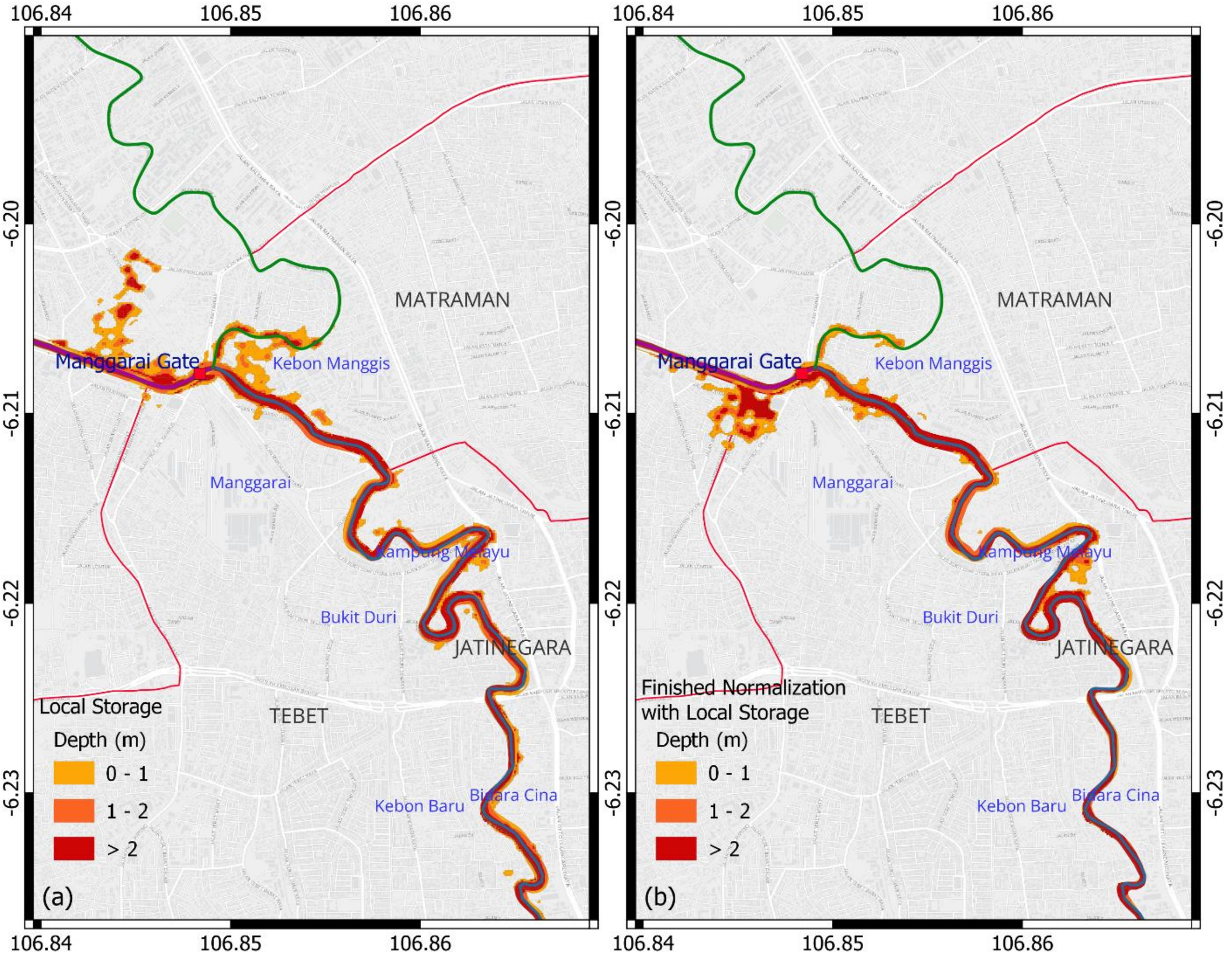

Figure 6. Flood inundation of (a) existing condition with long storage addition, (b) finalized river normalization with long storage addition

While transforming public parks into retention ponds may help minimize peak flow, the impact on the community and the environment must be considered. The loss of green spaces and recreational areas may have a negative influence on the local community and local ecosystems. It is also crucial to note that lowering peak discharge through retention ponds is only one method in a comprehensive flood management plan. Other techniques, such as strengthening drainage systems, enacting land use laws, and raising public awareness, may be required to effectively minimize flood risk in the studied area.

Although flooding in the research area can be minimized after river normalization is complete, a 200% increase in inundation area identified in the Manggarai area (Figure 7) must be addressed effectively. To solve this issue, it may be important to reconsider the design and implementation of river normalization procedures to ensure that they do not have unexpected downstream implications. This could entail doing more research and simulations to better understand the possible implications of various flood control measures, as well as identifying any necessary changes to the present methods.

The development of retention ponds/storage in the study region must also be well planned to avoid potential flood flooding. Converting restricted green zones into retention ponds/storage has demonstrated that in almost all studied regions, at least 10% of the inundation area may be reduced. As a result, this initiative can be expanded to prevent floods in general.

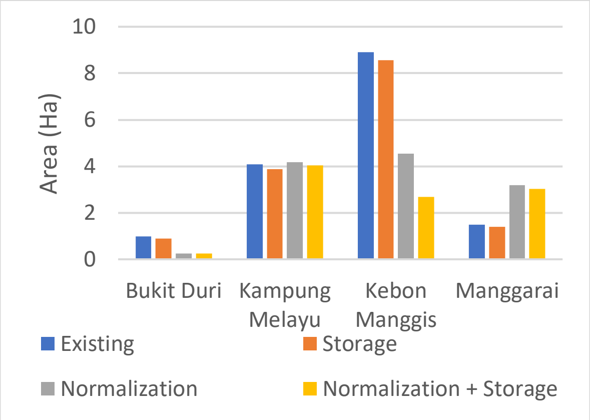

Figure 4. Flood Inundation Area of Ciliwung Riverbank

Identifying places that can be acquired for use as retention ponds must be done carefully, taking into account potential disputes in the neighborhood. Another factor to consider while developing retention and storage ponds is the use of subsurface storage in government facilities. Construction of retention ponds or storage in other regions upstream of the study area or along the Ciliwung River channel should also be considered in order to lower overall flood discharge and thereby reduce flooding in the long run. Because capturing the flood discharge along the Ciliwung River can prevent flooding not only in the research area but also in other areas along the Ciliwung River channel, in addition, further flood control measures downstream, such as the construction of levees or the installation of pumps or other flood control equipment, may be required to offset the increased risk of flooding in these areas in the future.

CONCLUSIONS

Due to the unpredictability of the eventual solution policy, a practical flood solution could be used by reorganizing land use into flood management infrastructures, according to a flood assessment based on both field data and mathematical model results. Redevelopment of this area from settlements to a river dyke as part of a river normalization scheme can help to lessen flood inundation in the area. The completion of river normalization in the research region reduces flood inundation in the Bidara Cina, Kebon, Baru, Bukit Duri, and Kebon Manggis areas while increasing flood inundation by 200% in the Manggarai area.

Due to the limited amount of space that can be converted, the construction of a retention pond in the study region can reduce the area of inundated floods that occur in practically all of the investigated area by 10%. Comprehensive area planning, including upstream and downstream planning, as well as flood mitigation infrastructure staging, are required to effectively prevent floods. Changes in flood patterns caused by changes in rainfall patterns, watershed land cover, and the ability to apply flood management zoning management must also be investigated further to determine the adaptability of the designed system to potential changes.

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