Adaptation to Future Flooding in a Lowland City, - A Case of Jakarta City -

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Abstract

Hydrological model and inundation model are applied to Chilliun River Baisn including Jakarta City, capital of Indonesia to evaluate countermeasures as the adaptation in the future. For the future projection, rainfall data was made using 8 GCMs with statistic downscaling and bias correction. Future scenarios were prepared for land use change, land subsidence and 3 RCPs. Structural and non-structural countermeasures were evaluated as the adaptation for flooding. Only landuse change to 2050 increases 99% flood damage cost (almost double from current situation) and only land subsidence to 2050 increase 95% one. The combination of land use change and land subsidence makes 226% higher damage cost in 2050 than current one. This calculation shows the emphasis of both influences. Heavier downpour makes higher damage cost by flooding. Only future rainfall increases 77% and 99% on mean flood damage (annual expected damage costs) in around 2050 and 2100, respectively. However, the range of damage cost by each GCM is large and some models show the decrease of damage cost in 2050. The combination of land use, land subsidence and climate change shows 5 times damage cost to current situation.

Keywords: GCMs, Landuse control, Land subsidence, RCPs, Retention pond

1. Introduction

In 2013, WG2/AR5 newly added the issue of regional climate change, and reported on many issues, especially in Asia. Among them, the population increase was remarkable, and the future risk of the mega-city with more than 10 million people was emphasized. Many large cities in lowland areas have extremely high flood hazards, which explains a large risk of economic loss for future climate change. At the UN World Conference on Disaster Risk Reduction 2015, disaster vulnerability of developing countries with high disaster risk of climate change were mainly discussed. The Asia-Pacific Adaptation Network (APAN) has highlighted the problem of vulnerable urban areas. Therefore, it is necessary to analyze the importance, sensitivity, mutual influence, effectiveness of individual countermeasures, comprehensive countermeasures, etc. of each problem in a huge city using digital map information. Large cities in developing countries are vulnerable to climate change due to technical and financial problems, and it is necessary to consider regional adaptation measures matching the region. Proposing adaptation measures based on cost-benefit can contribute to solving environmental problems in Asia according to economics view and comparison with policies including not only disasters but others.

Jakarta Special Province, which is the study area, is the capital of Indonesia and one of the mega cities in Asia with a population of over 9.5 million. The details of the study area and Jakarta Special Province are shown in Figure 1. There are 13 rivers flowing through Jakarta, and the main one is the Ciliwung River (basin area: 485 km^2, flow path length: 145 km, and altitude: 0-2681m). The Ciliwung River basin has an obvious rainy season (November-April) and a dry season (May-October), and most floods occur from January to February. Most of the sources of inundation in Jakarta are floods from the Ciliwung River and inland flooding in northern Jakarta industrial and commercial areas and coastal areas.

The Capital Jakarta city is on the rapid economic development but lacks sufficient infrastructure, and is facing the challenge how to mitigate and adapt the massive flood damage that occurs once every five years. In recent years, floods have occurred almost every year during the rainy season from January to February. Since a large-scale flood occurred in 2013, floods have occurred in Jakarta in consecutive years 2014 and 2015. In the flood that occurred in January 2020, 67 people were killed, resulting in serious human damage.

The Capital Jakarta city, Indonesia has many deaths by floods even recently. To prevent this issues, effective adaptation and mitigation measures will be taken for Jakarta, Indonesia, where the future flood risk is extremely high due to the fact that the population is still increasing, land subsidence continues, and tropical rainfall is heavier by climate change. The purpose of this research is to evaluate adaptation for future floods.

2. Methodology

A flood inundation model was developed in order to quantitatively evaluate not only the effects of global warming but also the effects of urbanization and ground subsidence in Jakarta city, which is facing to more serious for flood inundation damage. The flood inundation model consists of hydrological model part with distributed rainfall runoff calculation process and flow routing in the river channel based on one-dimensional indeterminate flow calculation, and inundation model part based on two-dimensional non-uniform flow calculation. The model parameters were calibrated using past inundation records and radar rainfall data as input rainfall [1][2].

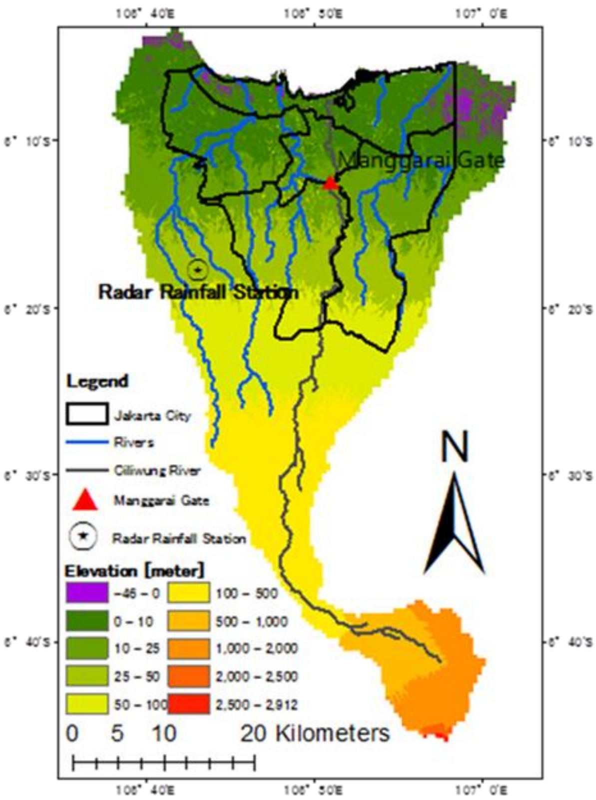


Figure. 1: Ciliwung River Basin

The elevation data was spatially high-resolution calculated using JAXA's 30 m mesh. For future rainfall, we utilize 8 GCMs (General Circular Model: CNRM-CM5, IPSL-CM5A-LR, GFDL-ESM2M, MPI-ESM-LR, MIROC-ESM-CHEM, CanESM2, CSIRO-Mk3-6-0, HadGEM2-AO) with statistic downscaling and bias correction. Future scenarios were prepared for land use change, land subsidence and 3 RCPs (Representative Concentration Pathway: 2.6, 4.5, 8.5).

We calculated the damage reduction amount of multiple adaptation measures. Here, the green infrastructure (GI) that greens the rooftops and walls of the building, the Garuda Project (GP) that is a new landfilling areas with a long seawall in the coastal area, and the residence control in the areas adjacent to rivers and canals (RC), recharge wells (RW) that permeates a large amount of flood water into underground, and conversion of high-risk inundation area to a retention pond connecting a river channel) (RRP) were evaluated as adaptation measures. The details of the calculation method are by Fajar et al.[3].

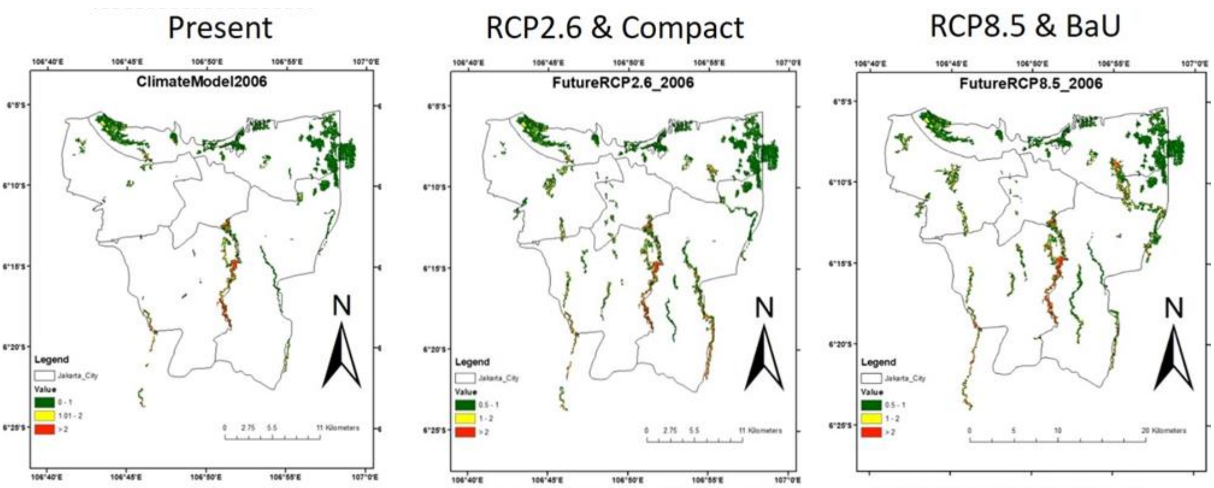
For GI, the rainfall loss of 2 mm per rainfall event was applied to the roof and wall area. The cost of GI was calculated as 75 USD/m^2 from the existing data (Toho Leo Company). The GP expressed the construction of a landfill area with a seawall by lowering the coastal water level, which is the boundary condition at the downstream end of flood calculation, by 1 m. The cost was 99 Million IDR for the seawall construction cost per m from the existing project. The RC is set within a range of 30 m on both banks of the river, and the cost is the building cost in that area. The area widened from the river channel is excavated to a depth of 6 m such as a reservoir. Assuming that 200 wells/km^2 will be installed in the whole area of RW, the cost of IDR 70,000 is estimated from the past report for the penetration of 1 m^3. For RRP, the asset value of the retention pond area was used as the cost. A total of 14.5 km^2 of the area was secured as the retention pond at the three upstream areas where floods were frequent. As an evaluation of the above adaptation measures, the amount of damage reduction and cost effectiveness were estimated.

3. Results and discussion

Figure 2 shows the results of calculations that considered extreme heavy rainfall during global warming and urban expansion. Extreme rainfall obtained by dynamic downscaling of the regional meteorological model WRF is used. These heavy rains consider not only global warming but also the effects of heat islands evaluated by an energy budget model. From the results, it became clear that the scale of flood increases due to the effects of global warming and heat islands. In addition, the best scenario (RCP2.6 & Compact city), the worst scenario (RCP8.5 & BaU) and an increase in the inundation area were confirmed, and there was concern that the expansion of the city and global warming would further worsen the flood risk. The reason why there is not much difference between the best scenario and the worst scenario is that the expansion of urbanization is significant even in the best scenario within the basin.

However, the above extreme heavy rainfall is downscaling dynamically using WRF, and the calculation load is extremely high and a long calculation time is required to calculate many scenarios on a 100-year scale. Therefore, we carry out statistical downscaling and consider multiple scenarios over a long period of time. Figure 3 shows the calculation results of 24 ways (8 GCM, 3 RCP scenarios) in the future 100 years. It was shown that due to climate change alone, the annual expected damage amount increases by 77% and 99% in 2050 and 2100, respectively. The damage amounts shown in this report are the expected flood damage amounts. Next, it was shown that the damage amount increased by 360% or more in both 2050 and 2100 by adding the scenario of land use change and ground subsidence. In other words, the amount of damage caused by land subsidence and land use change is more serious than climate change.

2050) with land use, and land subsidence status. A summary of the obtained results is shown in Table 1. The adaptation measure with the largest mitigation ratio is the combination of the retention pond



Flooded area: 36.4km² **Flooded area: 48.2km²** **Flooded area: 52.9km²**

Figure. 2: Flooded areas by simulation for present, the best and the worst scenarios.

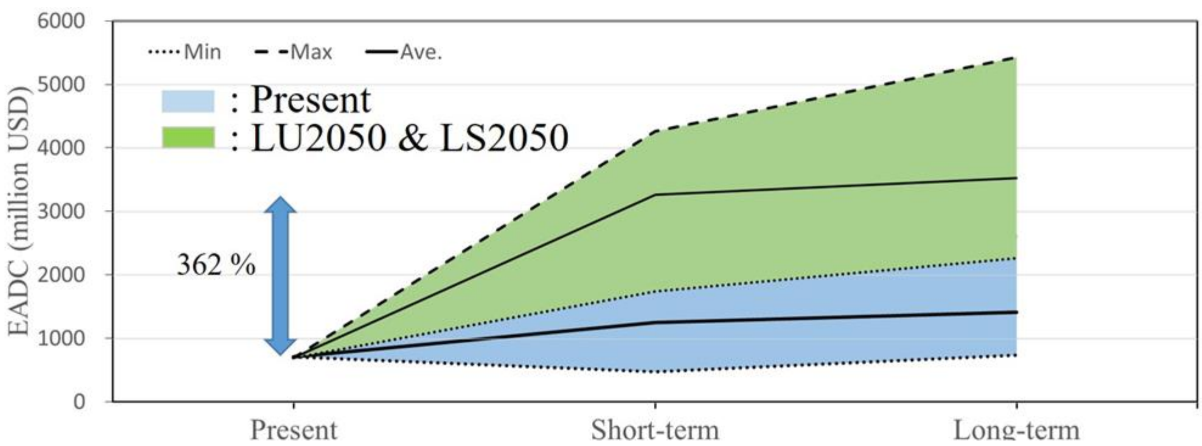


Figure. 3: Damage cost change in the future

(RRP) and the seepage well (RW), which

the current climate, the reduction rate of residential restrictions (RC) is large (33%), but in the 2050 period, the effect of basin (RRP) is large (31.5%). On the other hand, the effect of green infrastructure (GI) is low (2.6% in the future). The effect of the Garuda Seawall (GP), which is considered to be a large project, is not so great (11% in the future).

In addition to the above five adaptation measures (Green Infrastructure (GI), Garuda Project (GP), Residence Restriction (RC), Infiltration Well (RW), Reservoir (RRP)), we consider combination of RW and RRP. Totally the effects of the six adaptation measures are evaluated. We calculated the damage mitigation ratio for the current and the future climate (around

Table 1: Effect of adaptation options for present and future conditions.

	Reduction ratio of damage cost [%]	
Adaptation	Present	Future (Short-term)
GI: Wall and roof greening	−2.1	−2.6
RW: Recharge wells	−8.6	−5.6
GP: Landfilling in beach zone	−16.4	−11.1
RRP: Retention pond	−31.5	−33.2
RC: Residence control	−33.0	−29.0
RRP + RW	−34.1	−36.0

4. Conclusions

GCMs and some scenarios can evaluate options for the future adaptations. In the case of Jakarta city, the cost of the adaptation is too high to implement the flood management. Actually, Indonesian government has decided the capital relocation to solve not only flood problem but also transportation and environment problems. However, we can evaluate options quantitatively and discuss the issues comprehensively using numerical simulation. We should proceed more discussion on those options.

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