12. IMPACT OF LAND USE CHANGE, LAND SUBSIDENCE AND CLIMATE CHANGE ON FLOOD INUNDATION IN JAKARTA, INDONESIA

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The risks associated with land use and climate change are a common concern, especially in relation to their potential impact on many cities around the world. Jakarta, Indonesia is a typical urbanized Asian city where flooding presents a challenge. This study quantified the impacts of land use change, land subsidence and climate change using a flood inundation model to analyze several future urban-growth and climate-change scenarios. A physical rainfall-runoff and flood inundation model was developed to understand the flood inundation mechanism in Jakarta and to investigate the impact of land use change, land subsidence and climate change on flood inundation. Sea-level rise was assessed simultaneously to determine flooding from the ocean. The analysis indicated that the combination of climate change and urban development amplified the mean future flood risk in Jakarta. The results also showed large uncertainty for the future flood risk from future urban-growth and climate-change scenarios. Therefore, we conclude that a flood mitigation plan should consider land subsidence, land-use change, and climate change.

Key Words : *Jakarta, climate change, land use change, land subsidence, sea level rise, flood inundation.*

1. INTRODUCTION

Floods in Indonesia are considered to be one of the major natural disasters. The city of Jakarta has experienced many floods in the past, such as those in 1996, 2002, 2007, 2013, 2014, 2015, and 2017. The flood in February 2007 resulted in more than 80 deaths, and 40% of the area in Jakarta was inundated, causing power outages across the city. The flood event in 2013 caused similar levels of havoc, leading to more than 40 deaths, 45,000 refugees, and significant economic damage. Extreme flooding events in Jakarta may become more frequent due to a combination of urbanization in the upstream region[1)] and the effects of climate change[2)].

Many factors contribute to the high flooding risk in Jakarta. According to Bricker et al[3)] the reduced capacity of the drainage system by debris clogging flood gates is one possible factor related to flooding. Kure et al[4)] emphasized that the shortage of capacity flow in the lower Ciliwung River is one of the factors for the flooding in the lower sections of Jakarta. Moe et al[1)] pointed out that the urbanization of the Ciliwung River Basin is contributing to an increase in river flow, and evaluated the effects of land use change using a numerical simulation.

In response to a large flood in 1918, the Ministry of Public Works commissioned a large-scale infrastructure project to protect the city from future flooding. The Directorate General of Water Resources at the River Basin Organization of Ciliwung-Cisadane oversaw this project. The plan was to construct a floodway in the shape of a horseshoe surrounding Jakarta to drain excess

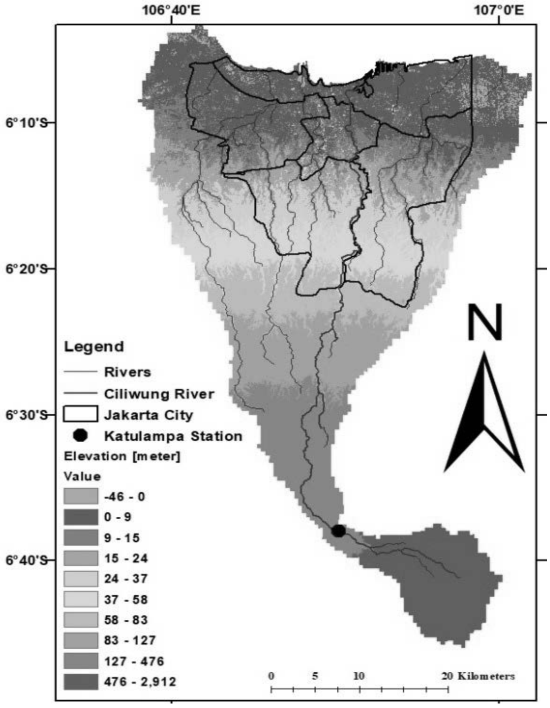

Fig. 1 Study area

water from the city. The West Canal (Banjir Kanal Barat) was constructed in 1919 and still functions today. However, the construction of the East Canal (Banjir Kanal Timur) was heavily delayed due to financing problems and the need to clear heavily populated areas, and was only recently completed. Countermeasures to reduce flood damage in Jakarta have been proposed and implemented, such as the Cengkareng drainage system. However, these countermeasures did not consider the regional effects of climate change on flooding in Jakarta.

It is thus important to examine the effect of future changes to the river and canals in Jakarta and its hydrological cycle as a result of climate change, and to quantify these effects so that we might better mitigate future flooding events. Therefore, we present a study that quantifies the effects of both land use change, land subsidence and climate change on the flood inundation in Jakarta using a flood inundation model.

2. STUDY AREA

Jakarta as the capital city of Indonesia, which is located in the northwest coast of Java Island, has 13 main rivers flowing through the region and the longest one is Ciliwung River as shown in **Figure 1**. The target area selected in this study includes Jakarta and the Ciliwung River basin totally covering 1,346.6 km^2.

3. METHODOLOGY

(1) Rainfall Runoff and Flood Inundation Model

The model proposed by Kure et al[4),5)] was used for the rainfall runoff simulation. This model is based on the kinematic wave theory for a hillslope, and it computes surface and subsurface flows based on the geological and hydrological characteristics at each subbasin. Model parameters are determined based on digital elevation model (DEM) and soil datasets.

Using a subbasin delineation tool in ArcMap (ver.10.1) and DEM data, 40 subbasins with an area ranging from 0.04 km^2 to 88.6 km^2 were delineated. Slope gradients at individual subbasins in the target area are mostly mild ranging from 2–16 degrees. The soil parameters were obtained from FAO data using the method set out by Kure et al[6)].

Flood routing in rivers and drainage systems were conducted based on the one-dimensional flow simulation with a dynamic wave description by solving the vertically integrated equations of conservation of continuity and momentum (the Saint-Venant equations). The Saint-Venant equations for conservation of continuity and momentum are written as follows:

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=q_l \tag{1}$$

$$\frac{\partial Q}{\partial t}+\frac{\partial\left(\alpha\dfrac{Q^2}{A}\right)}{\partial x}+gA\frac{\partial h}{\partial x}+\frac{gn^2|Q|Q}{R^{4/3}A}=0 \tag{2}$$

where Q is the discharge, A is the area of cross-section, q_l is the lateral inflow or outflow distributed along the x-axis of the watercourse, n is the Manning's roughness coefficient, α is the momentum distribution coefficient, g is the acceleration of gravity, R is the hydraulic radius, and h is the water level. The lateral flow (q_l) shown in Eq. (1) were simulated using the aforementioned rainfall-runoff model.

For the flood inundation, the unsteady two-dimensional flow equations consisting of the continuity equation and momentum equation are numerically solved in the flood inundation simulation. For detailed information, see references[1)].

(2) Data

The project authority of JICA provided cross sections of the rivers, as well as details of the drainage systems of both rivers and canals. We obtained rainfall data from radar rainfall infor-

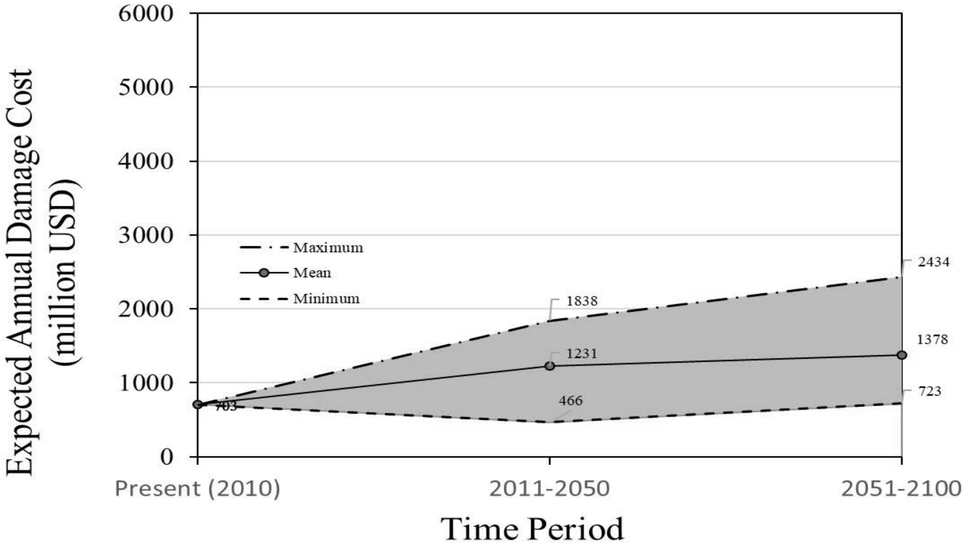

Fig. 2 Projection of expected annual damage costs (EADC) in the near future (2011–2050) and far future (2051–2100) considering climate change without the sea level rise[2)]

mation provided by BPPT, the Agency for the Assessment and Application of Technology. The water levels of the Ciliwung River and the Jakarta flood inundation map were provided by BPBD. In addition, the Ministry of Public Works supplied the land-use maps in the study area.

(3) Future Land Use Change Scenarios

We investigated the effects of changes in land use on flooding in Jakarta by predicting future land use using the SLEUTH model[7)], which estimates urban growth based on historical slopes, land use, exclusion, urban growth, ransportation, and hill-shade data. Varquez et al[8)] applied SLEUTH to Jakarta under both the RCP8.5-SSP3 (worst-case) and RCP2.6-SSP1 (compact-growth) scenarios. In this study, the RCP8.5-SSP3 scenario was used for the future land use situations.

(4) Future Land Subsidence

We used the land elevation data provided by Moe et al[2)] to evaluate land subsidence. We assumed that historical land subsidence speeds in the target area varied linearly over time. Therefore, in this paper we simultaneously evaluated not only land use change, but also climate change and land subsidence.

(5) Future Sea Level Rise

Future sea level projection was provided from Takagi et al[9)] who concluded that land subsidence would be the main driver of coastal floods in the north coastal area of Jakarta by projecting the sea level rise under future climate change and land subsidence conditions. However, their study did not consider river flooding due to heavy rainfall, so we considered flood events from the ocean and the river, including the possibility of these occurring at the same time.

(6) General Circulation Model Outputs of Future Rainfall

Future rainfall data were provided by Januriyadi et al[2)] who used the future rainfall data from eight general circulation models (GCMs) and three emission scenarios (RCP 2.6, RCP 4.5, and RCP 8.5) to assess the effects of climate change in the future. GCM output bias was corrected using the inverse of the CDF of GCMs with observation distribution parameters.

(7) Flood Damage Costs Calculation

Januriyadi et al[2)] used a global modeling approach to estimate the cost of future flood damage. The expected annual damage costs (EADC) were calculated to explain the severity of the flood risk. Additionally, a global approach was used to estimate the asset values by comparing the common parameters (e.g., gross domestic production (GDP) or population). This method is used to estimate the flood damage costs after the flood inundation simulation in this paper.

4. RESULTS

We explore the future flood risk under future scenarios (i.e., climate change with and without sea lever rise, land use change and land subsidence). The EADC was used to represent the change

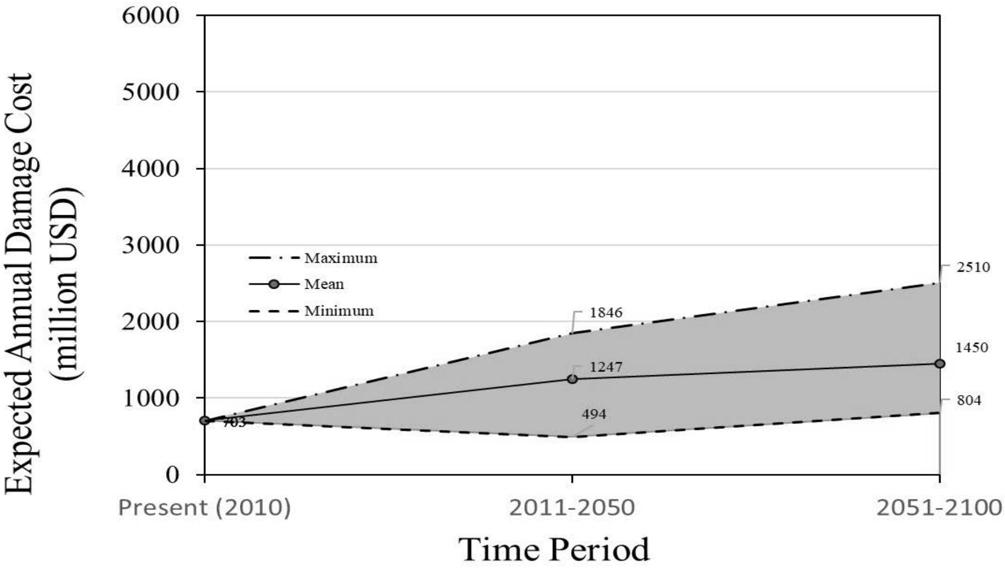

Fig. 3 Projection of expected annual damage costs (EADC) in the near future (2011–2050) and far future (2051–2100) considering climate change with the sea level rise

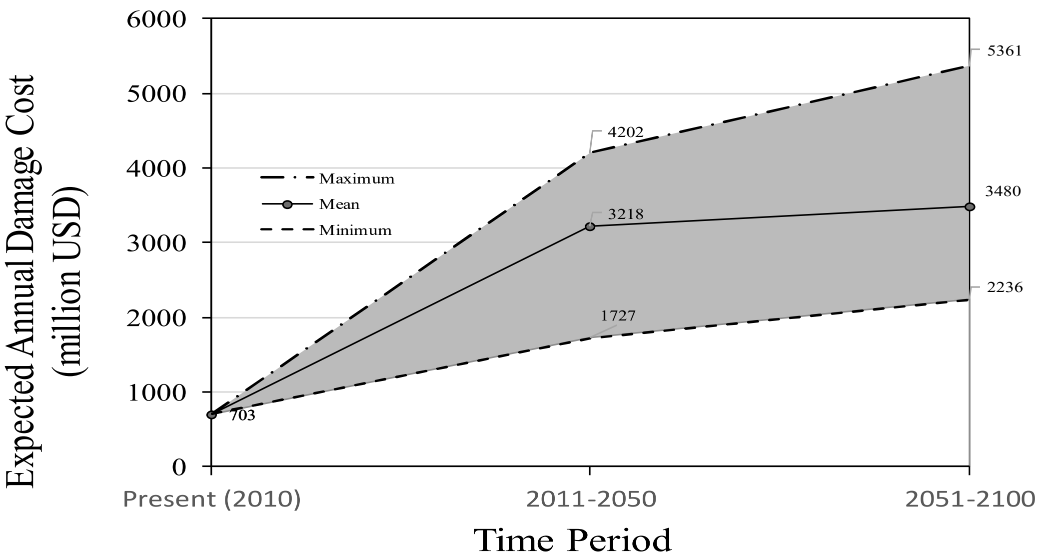

Fig. 4 Projection of expected annual damage costs (EADC) in the near future (2011–2050) and far future (2051–2100) considering climate change without the sea level rise, land use change and land subsidence.

in flood risk. **Figure 2** represents the change in the EADC due to the climate change without the sea level rise, and **Figure 3** shows the change in the EADC due to the climate change with the sea level rise. Climate change alone increases the mean of the EADC for the near future by 75 – 161%. The far future has a more severe flood risk and higher uncertainty compared to the near future, as indicated by the significant increase in the mean value of the EADC by 96 - 246%. It can be found from **Figure 3** that the sea level rise also increase the future flood risks in Jakarta. **Figure 4** shows the change in the EADC due to the climate change without sea level rise, land use change and land subsidence. It was found that the combination of urban development and climate change significantly increases the future flood risk. Results for the near future indicate that the value of the EADC increases by 77-358%. Similarly, results for the far future indicate the value of the EADC significantly increases by 106-395%. These results indicate that the combination of urban development and climate change could increase future flood risks. Also, impacts of the land use change and land subsidence on the flood inundation in Jakarta are much larger than these of the climate change including the sea level rise.

5. CONCLUSIONS

In this paper a flood inundation model and a flood damage cost model were employed to estimate the changes in future flood risk under various scenarios considering climate change and urban development in Jakarta. Based on the analysis, the combination of climate change and urban development amplified the mean future flood risk in 2050. All drivers could also increase the uncertainty of future flood risks. Moreover, the results indicate that future flood risk could be more severe and more uncertain in the far future.

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