Flood-Prone Map Projection and its Relationship Analysis with City Growing Map using Geographical Information System Approach: A Case Study of Flood and Urban Expansion of Jabodetabek, Indonesia

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Abstract. *Extensive un-managed rapid city expansion extremely making flooding in many ways, which lead to huge losses and become one of a typical big-city disease, especially in developing countries. One of the great examples is in Jabodetabek (Jakarta and its surrounding area). Flood and city expansion predicted having a strong connection like diabetes and obesity. This research aims to visualize an updated Jabodetabek flood-prone map, presents which area of Jabodetabek will be flooded then compare it with the city growth map to see how these maps relate to each other. City growth detection was developed using SaTScan to see how the city significantly changes by years. Scoring using AHP, re-classifying, and weighting overlay method. ArcGIS was used to make Jabodetabek flood-prone map with rainfall pattern, land use, slope, drainage status, river buffer zone, and soil permeability capability used as the flood factors. The map-to-map comparison method was used to catch visually the differences and the similarity of the city growth map and flood-prone map. The result indicates that Jabodetabek flood is affected by many flood factors combination, high intensity of rainfall, rapid and un-managed land use and strongly supported by bad drainage condition. Flood and city growth seem correctly have a strong connection like diabetes and obesity. In one part, this city is the center of everything for Indonesia, which is why the city keeps growing and extended its development. However, the flood accelerated together with this city expansion. The trend of flood increases in several places, where the built-up area increased.*

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1. Introduction

Jabodetabek (Jakarta and its surrounding area) has been experienced extensive un-managed rapid urban/city expansion [1] which extremely making flooding in many ways (Fig. 1). Floods are inevitable in Jakarta, and no area seems immune from 'flash' floods that hit even the most affluent areas of the city.

Fig. 1 Rapid Urban Population (A) and Flood (B) in Jabodetabek [14]

Jabodetabek had Rp. 5.2 trillion losses cause of 2020 flood events [2] and will be Rp. 36 trillion losses predicted in 2027 [3]. Since the distribution of the flood is always changing over times and there are several issues or limitations to capture earth surface condition using remote sensing especially in a disaster period [4]. A better way to see how the flood condition would be by identifying factors of the flood itself and making a flood-prone map projection.

Flood and city expansion predicted have a strong connection like diabetes and obesity. This research aims to analyze and visualize an updated Jabodetabek flood-prone map using several parameters which considered have contributions to this city flood event. A flood-prone map could illustrate the area of Jabodetabek that will be flooded, one of the best solutions to solve the flood problems in a city with urban expansion phenomena. Then, the city growth map with flood-prone map produced was compared to see how these two maps relate to each other.

2. Methodology

2.1 Jabodetabek's Built-up Area Changes Detection

This research was developed using SaTScan to see how the city significantly changes by years (city growth). "Built-up area" is defined as the presence of buildings (roofed structures). Two big steps of this research are first, identification built-up area using remote sensing approach Google Earth Engine (GEE) and secondly, built-up area changes detection using SaTScan (Fig. 2) [5]. SaTScan Bernoulli based model could simply detect which area in 2017 that significantly changes with 2010 (having the p-value < 0.05 and > 0.95 and being surrounded by areas that have the same characters).

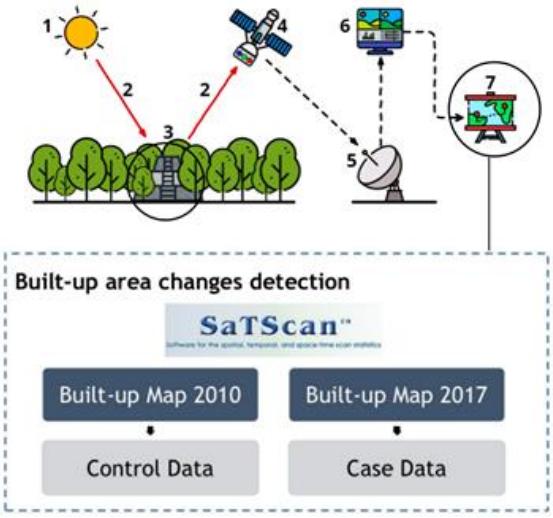

Fig. 2 Built-up area identification and built-up area changes detection Scheme

2.2 Jabodetabek Flood-Prone Projection

Scoring, re-classifying, and weighting overlay method ArcGIS were used to make Jabodetabek flood-prone map with rainfall pattern, land use, slope, drainage status, river buffer zone, and soil permeability capability as the flood factors (Fig. 3). These factors were selected based on consideration several researches [9][11][12][13] which collected from Indonesia's official map using SPOT-6 satellite from 1.5 meter resolution and other official observation researches which transformed into map data.

Score of each parameter was considered by using the analytic hierarchy process (AHP) [6]. The Analytic Hierarchy Process (AHP) is an effective tool for dealing with complex decision making, and may aid the decision maker to set priorities and make the best decision by reducing complex decisions to a series of pairwise comparisons, and then synthesizing the results.

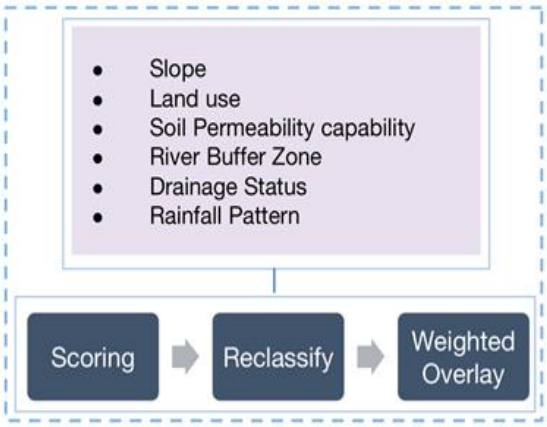

Fig. 3 Flood-prone map projection step

2.3 Relationship between Flood and City Growth

Comparing maps is an important issue in environmental research. There are many reasons to compare maps:

(i) to detect temporal/spatial changes or hot-spots

(ii) to compare different models, methodologies or scenarios

(iii) to calibrate, validate land-use models

(iv) to analyze model uncertainty and sensitivity

(v) to assess map accuracy

Traditionally, map-to-map comparisons implement visual [7]. Map to map comparison is the finest and simplest method to comparing the maps. This method is capable to catch visually the differences and the similarity between city growth map and flood-prone map. The research analytical framework can be seen in Fig. 4.

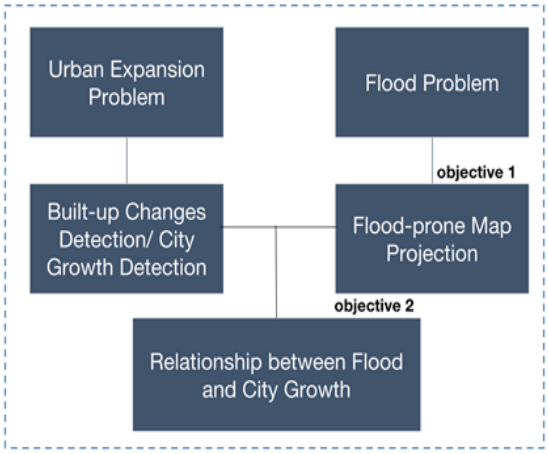

Fig. 4 Research Analytical Framework

3. Results and Discussions

3.1 Flood Parameter Score

AHP and experts' opinion show that drainage is the aspect that most affluent to the flood in this city, followed by slope, rainfall, and land use (Fig. 5). This result was in line with several papers which mentioned that flash floods hit this city basically due to many factors but it was strongly supported with bad drainage conditions as well. Bad drainage contributes around 65 percent to the 2020 flood event [8].

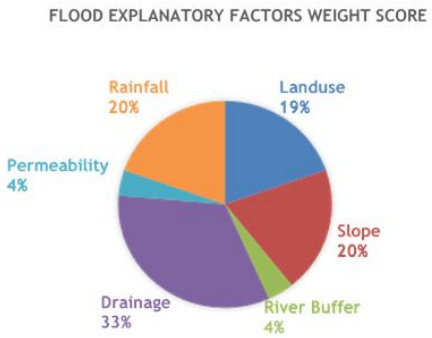

Fig. 5 Jabodetabek flood explanatory factors score

3.2 Jabodetabek flood-prone areas

The six factors selected have been transformed into raster data and weighted overlay to produced flood-prone map. Then this map was categorized in five levels of risk namely very low, low, medium, high, and very high zones of the flood. Very high area means: the area with high precipitation, bad drainage status, consist of many built-up areas and located in the lower slope and some part cause it nears to the river. Almost all areas in Jabodetabek predicted will be attacked by flood since this city condition/ flood explanatory factors support it to be flooded areas with high class area as the dominant one (Fig. 6).

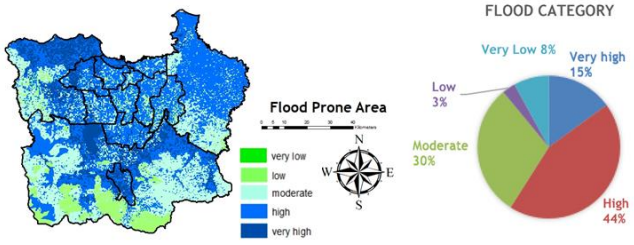

Fig. 6 Jabodetabek Flood-Prone Map With Each Category Area Percentage

3.3 City Growth Map

One of the things that triggers flooding is the reduction in land that functions as water absorption [8]. Jabodetabek experienced changes in land use from greenery land and open land to build land around 441 km^2 (2010-2017) or around 63 km^2/year [5] (Fig. 7).

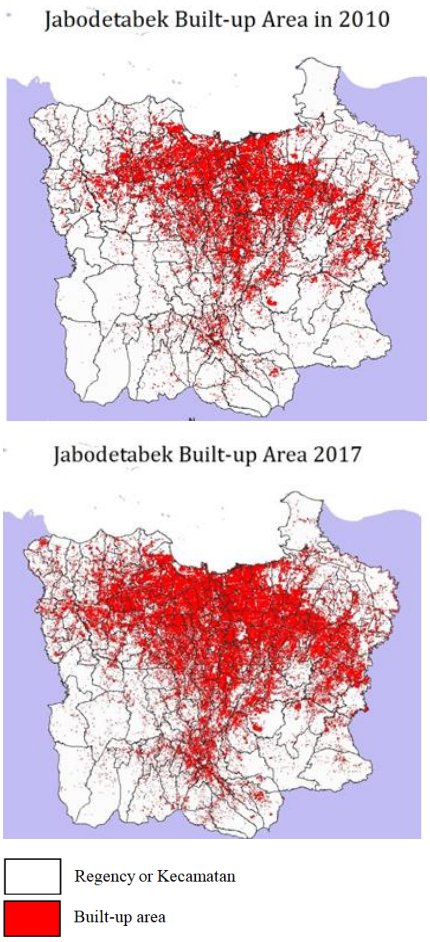

Fig. 7 Jabodetabek built-up areas: in 2010 and 2017

SaTScan produced 5 clusters (80 subdistricts/Kecamatan) which categorized as a "Significantly Changed Area". This research concluded that the city growth mostly in the area within the red circles (Fig. 8).

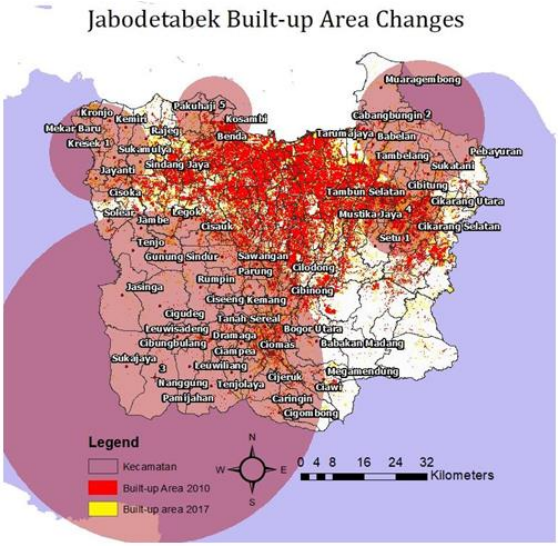

Fig. 8 The area with highest grow rate of Jabodetabek City Growth 2010-2017

Changes in land cover have an impact on changing hydrological properties such as flow coefficient, flow rate, and flow hydrograph characteristics. The function shifts of land influences changes in flood discharge through the ability of the soil to absorb rainwater. This change also causes a reduction in surface runoff and accelerates the flow of water towards the river channel. Water that directly flows into the river channel causes additional water discharge in a short time. Then, if the river discharge exceeds the capacity, this can cause flooding which generally occurs during the rainy season. Thus, Jabodetabek which experiences increasing built-up land is in line with its flood index.

3.4 Relationship between Flood and City Growth

Map-to-map comparison used to answer the relationship between flood and city growth also to validate the flood-prone map area projected. The validation has been done by visual comparison between this flood-prone map and previous researches result in 2008 [9] which presents an obvious trend between the flood and the city growth (Fig. 9).

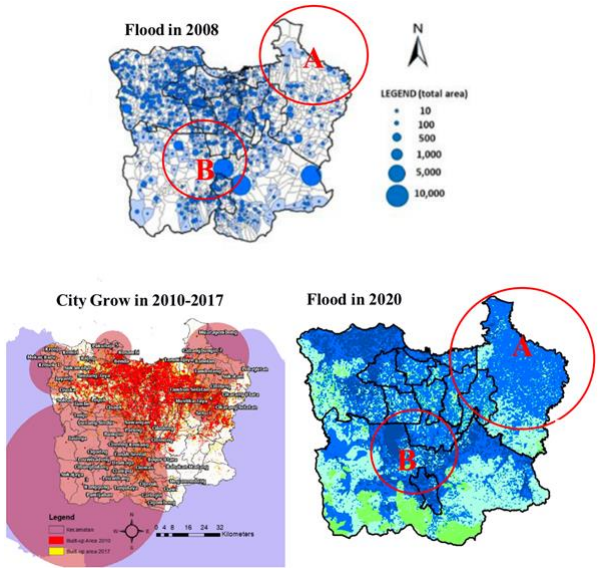

Fig. 9 Jabodetabek Flood-Prone Map with Each Category Area Percentage

Physical observation to where the trend of flood increase in several exact places of built-up areas increased was considered. The map-to-map comparative results indicates that in several location of built-up areas proved make any contribution to flood-prone area (circle A and B), cause the flood condition predicted getting bigger from 2008 to 2020. Built-up land in floodplains/flood-prone area is a vital indicator of the socio-hydrological system, and its dynamics are key to understanding and managing flood risk.

Flood in 2008 was employed by LISA using Local Moran Index to indicate spatial clustering of floods and landslide-prone areas in Jabodetabek [9]. This can be concluded even using different method, we can see similar pattern of flood area between in 2008 and 2020.

The increasing dramatic urban growth in flood-prone areas proved makes the bigger flood-prone in the next years. Changes in land cover have huge impact on changing hydrological properties. Several previous studies on the relationship between urban and economic growth and environmental conditions have argued that the degree of environmental degradation and economic growth follows an inverted U-shaped relationship. This U-shaped relationship is known as the 'Environmental Kuznets Curve' [10] which provided empirical evidence that the economic growth leads to gradual degradation of the environment in its initial stages and, once a certain level of growth is reached, it leads to an improvement in the environmental conditions. This research is still in developing to answer more accurately how the connection between city growth and flood event using statistical GIS method.

Conclusions

This city flood is the effect of many flood factors combination and complexity, high intensity of rainfall, rapid and un-managed land use and strongly supported by bad drainage status. Jabodetabek flood categorized as dangers situation. In one part, this city is the center of everything for Indonesia, that is why the city keeps growing and extended its development. However, the physical observation shows flood accelerated together with this city expansion. The trend of flood increase in several exact places where built-up area increased. Built-up land in floodplains is a vital indicator of the socio-hydrological system, and its dynamics are key to understanding and managing flood risk.

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Biographies

Dianti Farhana Kamasela is an Indonesian researcher. She completed her Double Master degree in Mahidol University, Thailand and Kyoto University, Japan. She interest in researches related to landuse changes analysis. Currently, she is continuing her study in Environmental Engineering, Kyoto University projecting land allocation under climate change mitigation scenario using combination of integrated assessment model and GIS approach.

Suwanna Kitpati Boontanon was born in Bangkok, Thailand. She completed her Ph.D. from Kyoto University. She is an Associate Professor in Environmental Engineering at Mahidol University, Thailand, having a joint appointment in the position of Associate Professor at the Graduate School of Global Environmental Studies, Kyoto University, Japan. She is the leader of the Emerging Contaminants and Environmental Innovation Research Laboratory that aims for an in-depth understanding of the fate and behaviors of emerging contaminants and their risk assessment as well as the development of innovative water and wastewater treatment technology to enhance water quality and minimize energy consumption.

Izuru Saizen is a Professor at Graduate School of Global Environmental Studies, Kyoto University, Japan. He received a PhD from Kyoto University in 2001. His research interests extend across a broad range of GIS applications in regional analysis, such as land use/cover changes. Recently, He is interested in the application of multivariate- and geo-statistics, and GIS techniques in regional planning especially in the developing countries as well as regional revitalization in Japan.