

Detection of Spatial Clusters of Flood- and Landslide-Prone Areas using Local Moran Index in Jabodetabek Metropolitan Area, Indonesia

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ABSTRACT

Floods and landslides are the most frequent natural disaster that occur throughout the world and resulting from the declining quality of the environment as known as environmental degradation. They are a serious threat to development and occur very often in Jabodetabek region, the largest metropolitan area in Indonesia. As the second biggest megacity in Asian, Jabodetabek is characterized by rapid urban development and expansion. However, unsustainable patterns of rapid urban development are enhancing vulnerability to environmental degradation. The rapid urban development and increase in the number of floods and landslides since the beginning of the 1990s are very important issues in terms of sustainable management of the urban environment. We have investigated the spatial distribution patterns of floods and landslides for the years 1996, 2000, 2003, 2008, and 2011. The results show significant changes in the spatial association of floods and landslides in some areas, detected by the Local Indicators of Spatial Association (LISA) statistics, and especially the Local Moran Index. Floods have the greatest impact on the urban environment, especially in Jakarta City and surrounding areas, particularly Tangerang, Bogor, and Bekasi. In addition, we found that Bogor has the highest vulnerability to landslides in the Jabodetabek region. Policy makers should pay attention to these areas to ensure sustainability of the urban environment in the future. This could play an important role in the successful application of environmental management in the Jabodetabek metropolitan area.

Key Words: Jabodetabek; Floods; Landslides; Local Moran Index; LISA Statistics; Spatial Cluster

INTRODUCTION

The rapid urban and economic growth in many developing countries has led to a serious deterioration in urban environmental conditions and the degradation is accelerating in some aspects. In many developing countries, development can be a greater priority than the environment. Slowing economic growth in the interest of protecting the environment might appear to be a worthy cause to richer countries, but is certainly not high on the agenda of developing countries. Tobey (1989) mentioned that, in developing countries, industrial growth without pollution control measures not only leads to the

deterioration in environmental quality and degrades natural systems, but may also increase poverty and, in turn, lead to what is called poverty-related pollution. Urban expansion, which can be seen from population growth and settlement expansion as well as lifelines over hazardous areas have increased the impact of natural disasters (Alexander 1995; Rosenfeld 1994). Urban environmental problems are threats to present or future human well-being, resulting from human-induced damage to the physical environment, originating in urban areas (DANIDA 2000).

Jabodetabek is the largest metropolitan area in Indonesia, which consists of Jakarta, Bogor, Depok,

Tangerang, and Bekasi, characterized by rapid urban development and expansion. Urban areas in Jabodetabek have been expanding mainly by land-use conversion, from agricultural lands to urban uses, especially around major cities. As a functional mega-urban system, Jabodetabek is still expanding and various activities are being developed. Diversity of economic interests and rapid development have a great spatial impact and decrease the carrying capacity of the environment, which is already exceeded for both land and water, especially in Java Island where Jabodetabek lies (Rustiadi et al. 2009). The spatial pattern in Jabodetabek is characterized by spatial inconsistencies that occur between existing land use and spatial plan, and between spatial planning and land capability (as a proxy of carrying capacity), especially in urban and surrounding areas. Previous studies state that land use inconsistencies in Jabodetabek represented 8.50% of the total area in 2001 (Nurhasanah 2004) and 10.21% in 2010 (Rustiadi et al. 2012). These inconsistencies and unsustainable patterns of rapid urban development in Jabodetabek have caused some problems and enhanced vulnerability to environmental degradation, which may affect the occurrence of anthropogenic disasters (floods, landslides, etc.).

The environmental situation is worsening in Jabodetabek over time, a phenomenon marked by a decline in environmental carrying capacity (Rustiadi et al. 2012; Rustiadi et al. 2009). According to the Indonesian National Board for Disaster Management, floods and landslides were the most frequent natural disaster in Indonesia during the period of 1815 – 2014, representing 20% to 40% of the total number of disasters. A flood, defined as an overflow of water that submerges what is usually dry land, is a natural event that can have far-reaching effects on people and the environment. It is due to heavy rainfall causing rivers and/or oceans to overflow their banks and/or shores, and can happen at any time of the year. A complex mixture of geological, geomorphological, and hydrological conditions can cause a flood and its threat to destroy people and the environment (Wu and Sidle 1995; Glade 1998). Increasing of urban development and human activities, such as road building, settlement expansion and deforestation, can significantly increase flood risk (Montgomery 1994; Chung et al. 1995).

Landslides are defined as the movement of a mass of rock, debris, or earth down a slope, under the influence of gravity (Cruden 1991; Cruden and Varnes 1996). They are one of the major natural hazards, and account each year for enormous property damage in

terms of both direct and indirect costs. Landslides can be triggered by a variety of external stimuli, such as intense rainfall, earthquakes, water level change, storm waves, or rapid stream erosion that causes a swift increase in shear stress or a decrease in shear strength of slope-forming materials (Cruden and Varnes 1996). In addition, as development expands into unstable hillslopes under the pressures of increasing population and urbanization, human activities such as deforestation or excavation of slopes for road cuts and building sites have become important landslide triggers.

The rapid urban development and increase of environmental degradation since the beginning of the 1990s, which cause disasters such as floods and landslides, has been a very important issue in terms of sustainable management of the urban environment. The objectives of this study are to identify the spatio-temporal distribution patterns and spatial clustering of floods and landslide-prone areas in Jabodetabek using Local Moran Index based on Local Indicators of Spatial Association (LISA) statistics.

STUDY AREA

Jabodetabek is located on Java, the most populated island in Indonesia. This metropolitan area consists of 3 regencies (*kabupaten*), 10 municipalities (*kota*), 178 districts (*kecamatan*), and 1495 villages (*desa*), where the regencies and municipalities are located in three different provinces, namely: DKI Jakarta, West Java, and Banten Province (Figure 1). In 2012, Jabodetabek was inhabited by more than 30 million people and had a population density around 4,500/km². This region contributes more than US \$60 billion (almost 60%) to the national GDP. It also has the highest GDP per capita among all metropolises in Java, estimated to ~ US \$2000, whereas the average GDP per capita in Java is around US \$950. The rapid growth of urban development can be ascertained from land use and cover change, especially in built-up areas. According to Rustiadi et al. (2012), the extent of built-up areas was still very limited in 1972 (around 6,500 hectares) and most of them were concentrated in Jakarta. Forty years later (in 2012), their number and extent had increased, covering a surface area of 200,000 hectares. Figure 2 provides additional information about the population distribution, land cover, and topographic and climatic conditions (slope, rainfall, and elevation) in each area of Jabodetabek.



Figure 1: Location map of Jabodetabek

DATA

The data used in this study include the total area that experienced floods and landslides, as well as the number of floods and landslide events. They were collected from PODES (village potential statistics), provided by the Central Bureau of Statistics (BPS) for the years 1996 2000 2003 2008, and 2011, and from GIS datasets based on administrative units. Spatial distribution pattern maps of floods and landslides were generated based on the total area that experienced floods and landslides in 1996 2000 2003 and 2008. LISA was applied along with the Local Moran Index using the number of flood and landslide events dataset in 2011. The unit of analysis in this study is kecamatan (district) level.

METHODOLOGY

We employed GIS analysis and Local Moran Index based on LISA statistics to investigate spatio-temporal distribution patterns and identify spatial clustering of flood- and landslide-prone areas in Jabodetabek. We applied the Local Moran’s Index using the Geographical Data Analysis (GeoDa) software.

Local Moran’s I is a measurement of local spatial autocorrelation based on the Moran’s I and was developed by Anselin (1995) as a LISA statistic. Anselin defines LISA statistics as having the following two properties: (1) “the LISA for each observation gives an indication of the extent of significant spatial clustering

of similar values around that observation and (2) the sum of LISAs for all observations is proportional to a global indicator of spatial association.” Global SA measured by Moran’s I, captures the extent of overall clustering that exists in a dataset. Local SA indicates the location of local clusters and spatial outliers.

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (Z_i - \bar{Z})(Z_j - \bar{Z})}{S_Z^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}}$$

$$I_i = \frac{\sum_{j=1}^n W_{ij} (Z_i - \bar{Z})(Z_j - \bar{Z})}{S_Z^2 \sum_{j=1}^n W_{ij}}$$

$$= (Z_i - \bar{Z}) \sum_{j=1}^n W_{ij} (Z_j - \bar{Z})$$

$$= (Z_i - \bar{Z}) \frac{\sum_{j=1}^n W_{ij} (Z_j - \bar{Z})}{\sum_{j=1}^n W_{ij}}$$

where:

- I = Global Moran’s Index
- I_i = Local Moran’s I
- Z_i = value of interest of variable Z for point i
- \bar{Z} = average value of Z
- W_{ij} = contiguity matrix; representing the proximity of point i ’s and point j ’s locations, with $W_{ii} = 0$ for all points
- n = total number of points
- S_Z^2 = variance of the observed values

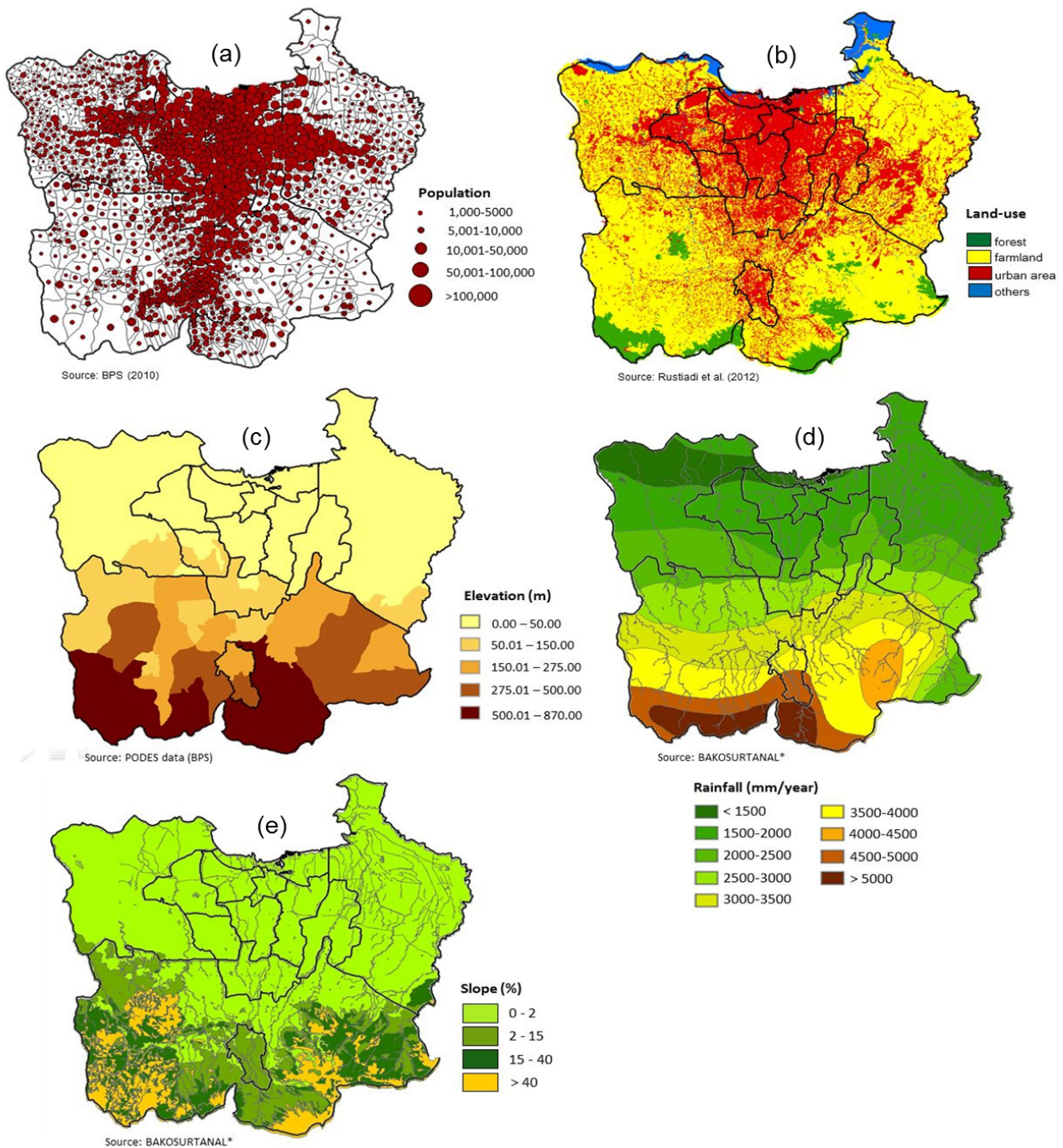


Figure 2. Thematic Maps of Jabodetabek: (a) Population; (b) Land cover; (c) Elevation; (d) Rainfall; and (e) Slope

We identified spatial clusters of flood and landslide prone areas by applying this analysis. Spatial clusters of flood and landslide prone areas will appear when the spatial association (SA) of its data has a positive value

(it can be high-high (HH) type or low-low (LL) type). On the other hand, SA also has a negative value (we called it “spatial outliers” for high-low (HL) type or low-high (LH) type). Positive SA exists when high values

correlate with high neighboring values or when low values correlate with low neighboring values. Positive SA operationalizes Tobler's First Law of Geography whereby closer areas are more similar in value than distant ones. In contrast, negative SA exists when high values correlate with low neighboring values and vice versa (Anselin 1995). In this study, we used queen contiguity as spatial weighting methods to detect the spatial association of floods and landslides in Jabodetabek. Under the queen criterion, areas are neighbors if they share either a border or point (e.g., on a grid, in addition to the four cells included under rook, the four cells sharing a corner with the central location are also counted as neighbors) (Anselin 2005).

RESULTS AND DISCUSSION

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' (Stern 2004; Dinda 2004; Stern et al. 1996). This relationship has been investigated since the 1990s after Grossman and Krueger (1995) and Selden and Song (1994) provided empirical evidence that the economic growth leads to a 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.

In this study, we investigated the relationship between the urban development and environmental degradation that occurred in the Jabodetabek area. Floods and landslides were chosen as representative examples of natural hazards and proxies of environmental degradation. Figure 3 shows the population trend and total area affected by floods and landslides in Jabodetabek between 1993 and 2011. We observed a fast growth of the total population, as well as rapid urban development and urban expansion, as previously reported by Rustiadi et al. (2012). However, the rapid urban development and population growth were also followed by a decline in environmental conditions. Figure 3 indicates an annual increase in the total area affected by floods and landslides. This means that the rapid urban development contributes strongly to environmental degradation.

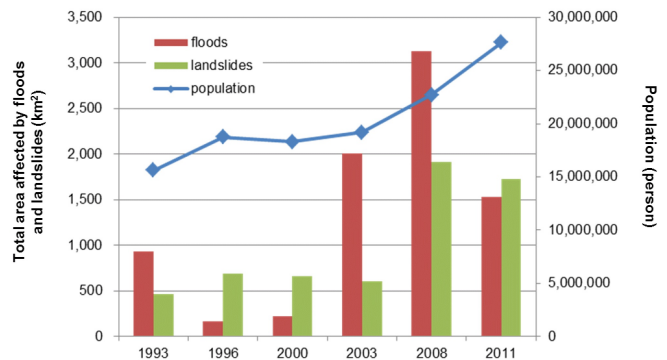


Figure 3: Population and total area affected by floods and landslides in Jabodetabek between 1993 and 2011

Spatio-temporal Distribution Patterns of Floods and Landslides

Natural disasters are complex and detrimental events that occur completely beyond people's control and are often indirectly aggravated by human intervention. Floods and landslides are the most widespread disasters that cause serious losses to life and livelihood. The increase of human intervention in nature and environment exacerbates the effect of triggering factors. Therefore, the frequency and intensity of flood and landslide occurrence will rise and lead to an increase in human and environmental loss rates.

Preparing flood and landslide maps is important to document the extent of flood and landslide phenomena in a region and to investigate the spatial distribution patterns of those occurrences. Furthermore, these maps can be developed to establish flood and landslide zoning as well as flood and landslide susceptibility and risk by including additional supporting data. Therefore, these maps and all supporting databases will be very useful tools for spatial planning. Spatial distribution patterns of floods and landslides in Jabodetabek in the years of 1996, 2000, 2003, and 2008 are shown in Figure 4 and 5.

Figure 4 indicates that the number of villages and the total area that experienced floods increased and spread widely from 1996 to 2008¹. In 2008¹, most of the floods occurred in Tangerang, Jakarta, and Depok, and some of them in the Bogor and Bekasi regions (Figure 4). In 2007, the floods were more widespread in Jakarta and surrounding areas and caused more human casualties

¹ PODES data published by BPS in 2008 consists of the data from 2007.

than similar disasters that struck in 2003 and 1996. One of the floods (which occurred in Jakarta and surrounding areas on February 1, 2007 and lasted ten days), resulted in at least 80 casualties (who were either swept away, electrocuted, or otherwise harmed). Material loss due to the destruction of businesses reached an estimated 430 million dollars. Up to 320,000 people were displaced for several days after the flood. All activities in the flooded region were paralyzed, telephone and internet networks were disrupted, and electricity shortages occurred in some submerged areas. Tens of thousands of people in Jakarta and surrounding areas were forced to evacuate. Most of the remaining population was trapped inside houses flooded to a depth of ~ 2 – 3 meters and could not be saved as rescue boats did not arrive. In the city, many areas were congested, including urban toll roads. Puddles up to four feet deep in the roads also disrupted access to a number of regions.

Floodwater eroded the streets of Jakarta and caused damage that aggravated the congestion. As much as 82,150 m² of roads across Jakarta suffered mild to severe damage, ranging from small holes and flaking asphalt to large pits. The most severe damage occurred in West Jakarta, where the total area of affected roads reached 22,650 m², followed by North Jakarta (22,520 m²), Central Jakarta (16,670 m²), and East Jakarta (11,090 m²) while the smallest was experienced by South Jakarta (only 9,220 m² affected). The budget required to rehabilitate the roads is estimated as Rp 12 billion (US \$1.04 million). Flooding also negatively impacted the railway lines. The trains to Tanah Abang Station did not work because the tracks around the station were inundated by ~ 50 cm of water overflowing from the Ciliwung River. About 1,500 homes in East Jakarta were damaged by the floods and washed away. Losses in Bekasi were estimated as ~ Rp 551 billion (US\$ 48 million). The biggest issue was the destruction of buildings, both houses

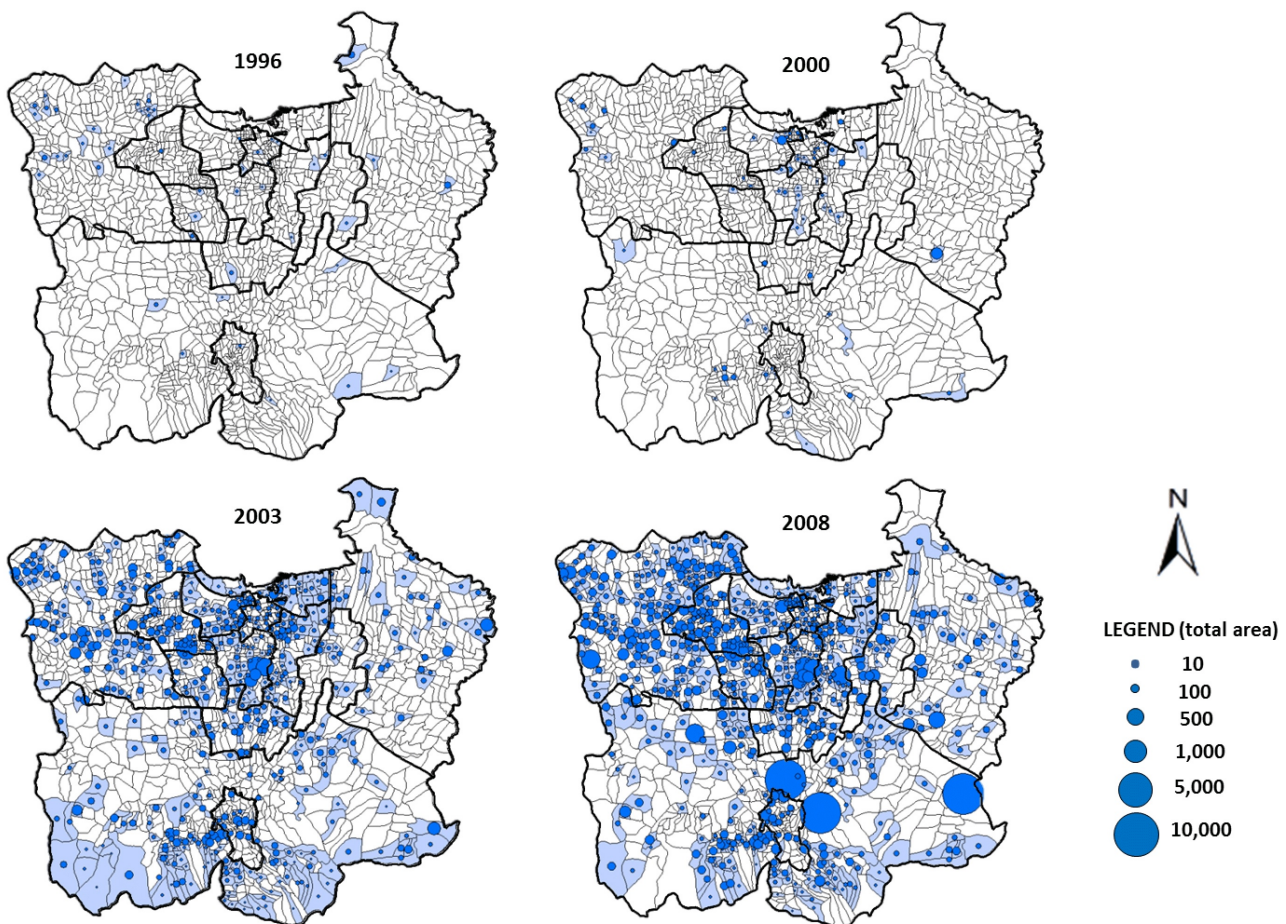


Figure 4: Distribution Patterns of Floods in 1996, 2000, 2003, and 2008

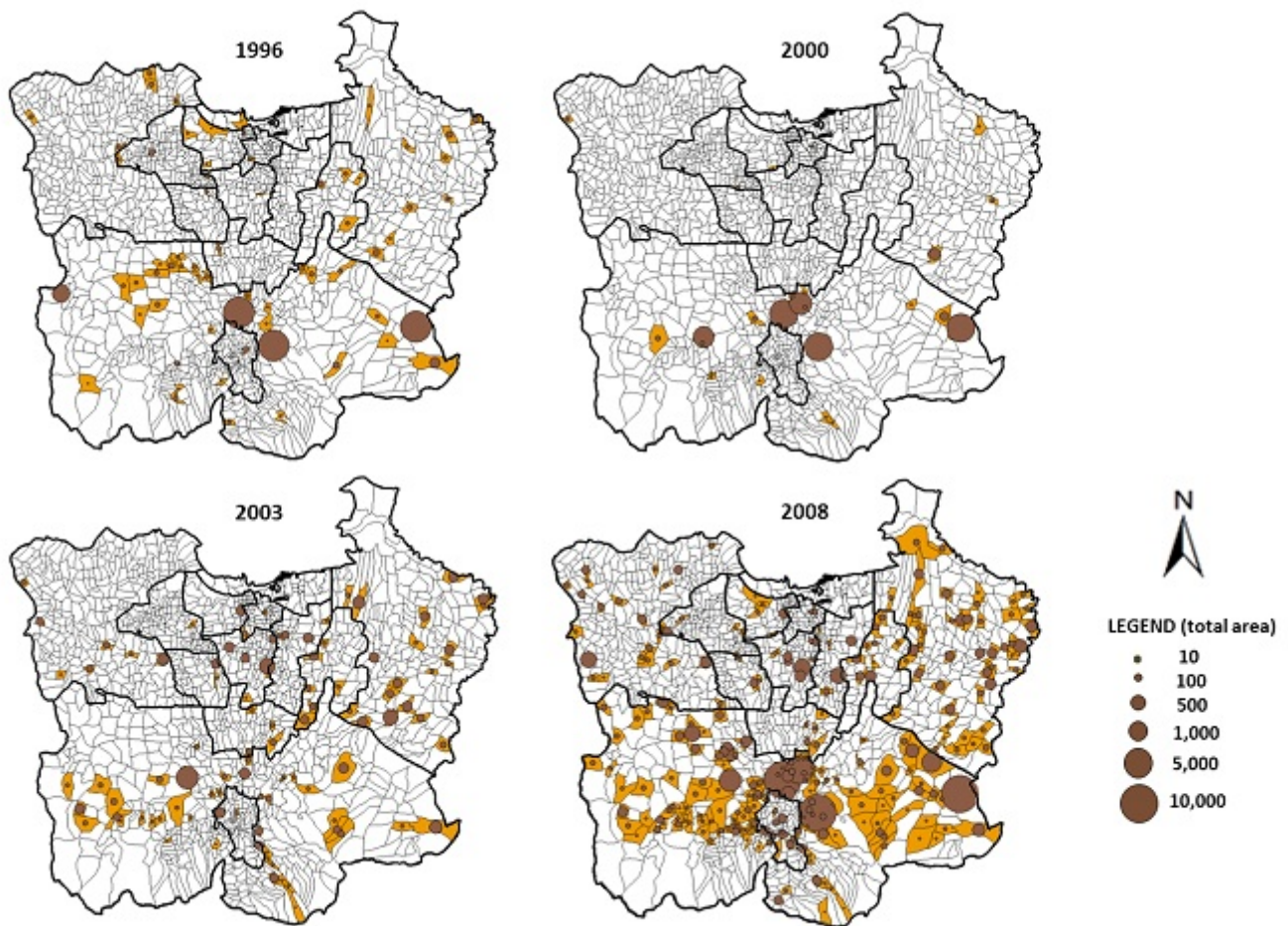


Figure 5: Distribution Patterns of Landslides in 1996, 2000, 2003, and 2008

and government offices. Moreover, 98 km of district roads were also damaged and at least 7,400 hectares of rice fields dried up. After the flood, respiratory infections, diarrhea, and skin diseases affected the citizens of Jakarta, particularly those who had been evacuated, because of the poor state of sanitation and bad weather conditions. Some cases of dengue fever and leptospirosis, consequences of waterlogging after the flood, were also identified.

Severe floods not only ruin homes and businesses and destroy personal property, but the water left behind also causes further deterioration of properties and belongings. The environment and wildlife are also at risk when damage to industries causes the accidental release of toxic materials. In addition, flooding not only disrupts many people's lives each year, but it frequently creates personal tragedies when people are swept away and drowned.

Figure 5 shows that the number of villages (desa) and the total area that experienced landslides also increased and spread widely from 1996 to 2008¹. In 2008¹, most of the landslides occurred in Bogor and some in Bekasi, whereas only a few occurred in Tangerang and Jakarta. Bogor is the only region of Jabodetabek that is located on a plateau. Most of the districts in the Bogor region are situated at high elevation (>275 meters) with slopes steeper than 15%, especially in the southern part of Jabodetabek. About 30% of Bogor's total area is located on very steep slopes (> 40%) and the highest elevation of the region is 870 meters above sea level (Figure 2 (c) and (e)). This is why most of the villages that experienced landslides are located in Bogor. In addition, the average precipitation in Bogor is 3,000-4,500 mm/year (see rainfall map in Figure 2 (d)), with some areas in the southern part of the region receiving more than 5,000 mm/year of rain. In

contrast, Jakarta, Depok, Tangerang and Bekasi are located in a flat area (lowland) with an average elevation less than 50 m, gentle slopes (2%), and low rainfall (<2,000 mm/year).

These observations indicate that rainfall is the primary factor of landslide initiation, particularly in Bogor. Landslides often occur when sloping areas become completely saturated by heavy rainfall, since, without the aid of mechanical root support, the water-saturated soil simply erodes away. In this case, Bogor was identified as the highest landslide risk area in Jabodetabek due to receive intensity of precipitation. This result showed that anthropomorphic activities also influence and become triggering factor. Overpopulation and uncontrolled urbanization which occurred in developing countries including this region sometimes result in settlement development on hillsides and on the banks of ravines, which may not be suitable for housing or other modifications (Bommer and Rodriguez 2002). Landslides could be caused by road construction and landscape modification that weakens structural support, leading to slope failure (Alimohammadlou et al. 2013). The other problems caused by the development of the transportation system (roads and railways) in the landslide prone areas.

According to Zezere et al. (1999), the cause of more than 20% of landslides is human intervention. With regard to civilization and urbanization expansion, human activities that reform and modify the environment will increase in order to enable the development and utilization of new facilities. These activities generally include processes such as excavation on slope body or toe, overloading by installation of residential infrastructure such as pipes, dynamic impact to obtain appropriate subgrade for various structures, construction of hydraulic structures on rivers, deforestation and land-use change for purposes of acquiring more territory, constructing or redirecting of irrigation and water transition channels, and air pollution due to industrialization. These human modifications may cause some natural phenomena that could inflict serious damage. The most serious events commonly start out as disturbance of slope balance and slope sliding, seismic stimulation and earthquake damage, which are aggravated by the intervention, drawdown of reservoirs caused by immediate inundation or intense rainfall, water leakage and heavy rainstorms due to climatic regime changes, and tsunamis. These occurrences may facilitate the increase of velocity and volume of landslides and therefore an increase in landslide intensity as measured by these two parameters (Glade et al. 2005).

In populated areas such as Jabodetabek, the occurrence of landslides would be very dangerous and may have severe impacts. Landslides that occur in vulnerable regions and civilization centers cause serious damages in various aspects of human life and natural environments. According to Herath and Wang (2009), landslides are the 7th greatest killer among natural disasters and contribute to about 17 % of mortalities (Kjekstad and Highland 2009). The impacts of landslides have increased in past decades because of the rapid growth of urbanization in Jabodetabek and in other developing countries. According to Schuster and Highland (2004), landslide damage to natural environments can be divided into two categories: 1) impacts on the global environment, which includes effects on people, homes and possessions, farms and livestock, industrial establishments and other structures, and life-lines; 2) morphological changes, land cover type (forest or grassland), and native terrestrial and aquatic wildlife.

Spatial Clustering of Floods and Landslide-Prone Areas

We employed LISA using Local Moran Index to indicate spatial clustering of floods and landslide-prone areas in Jabodetabek. Anselin (1995) mentioned that the LISA statistics serve two purposes. On one hand, they may be interpreted as indicators of local pockets of non-stationary or hot spots, similar to the G_i^* and G_i^* statistics introduced by Getis and Ord (1992). On the other hand, they may be used to assess the influence of individual locations on the magnitude of the global statistic and to identify "outliers". Thus, LISA maps are particularly useful to assess the hypothesis of spatial randomness and to identify local hot spots. A randomization approach is used to generate a spatially random reference distribution to assess statistical significance. The Local Moran Index implemented in GeoDa is a special case of a LISA statistic. The average of the Local Moran's I is proportional to the Global Moran's I value.

The data chosen in the LISA statistics analysis were: the number of flood events and the number of landslide events (Figure 6). Both show the intensity of flood and landslide occurrences in 2011. The data collected from PODES was published by BPS in 2011. LISA cluster maps and LISA significance maps of floods and landslides in 2011 are shown in Figures 7 and 8, respectively. The LISA maps in this study are formulated based on 999 permutations and a pseudo-significance level of $p = 0.05$.

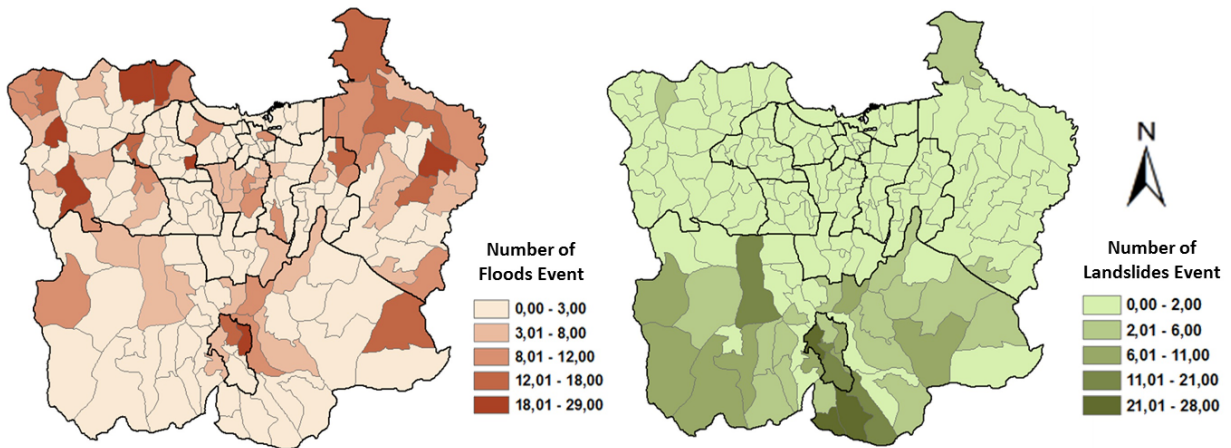


Figure 6. Spatial Distribution of Floods and Landslides in 2011

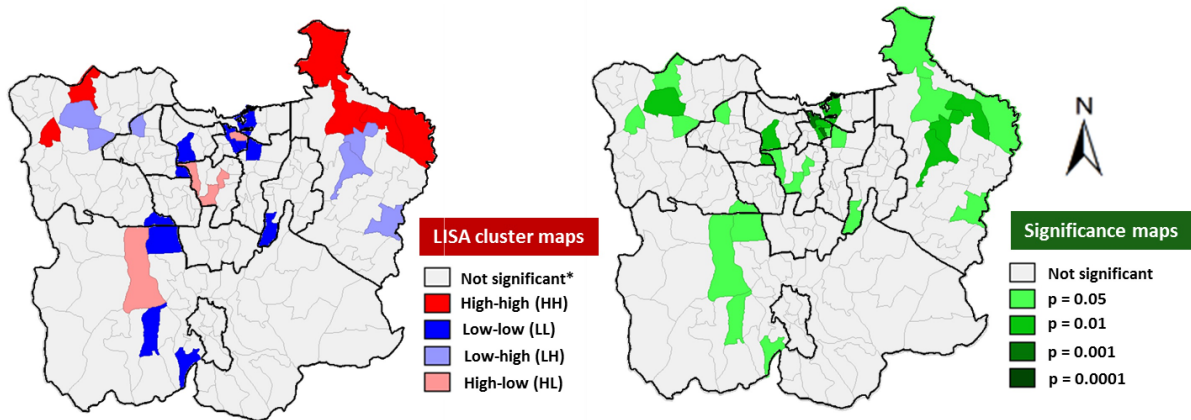


Figure 7. LISA Cluster Map and Significance Map of Floods in 2011

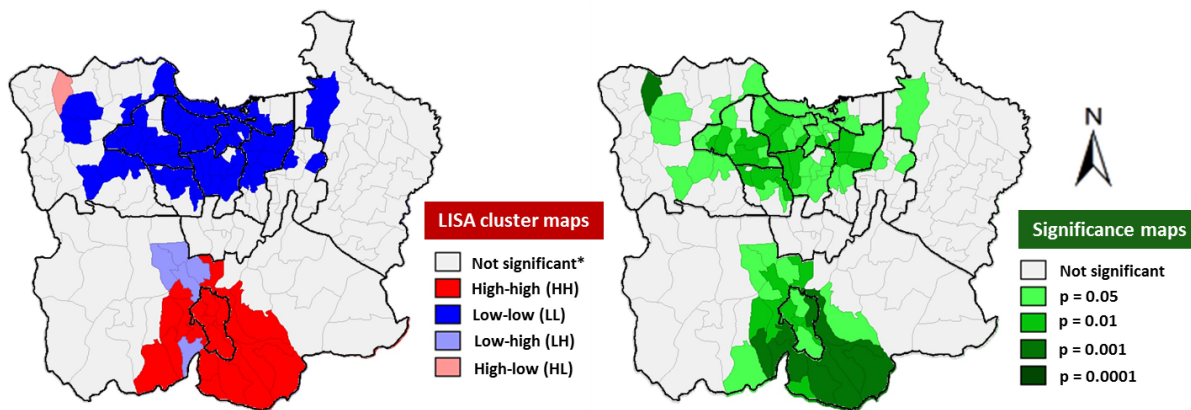


Figure 8. LISA Cluster Map and Significance Map of Landslides in 2011

The LISA cluster map is a map of significant clusters and spatial outliers, while the LISA significance map is a map of significance levels for the cluster map. The cluster map legend contains five categories: (1) Not significant (areas which are not significant at a default pseudo-significance level of 0.05); (2) High-High (high values surrounded by high values); (3) Low-Low (low values surrounded by low values); (4) Low-High (low values surrounded by high values), and (5) High-Low (high values surrounded by low values).

The results of the LISA application using Local Moran Index can be used to identify spatial clustering of floods and landslides in Jabodetabek. Since each index has an associated test statistic, we can also map the polygons that have a statistically significant relationship with their neighbors, and express the type of relationship. The red areas on the maps in Figures 7 and 8 represent a High-High (HH) cluster, which we called HH positive spatial association. This result appears when a high value representing a high total number of flood and/or landslide events is itself surrounded by other high values. It also indicates high positive spatial clustering. High positive spatial clustering of floods is observed in Bekasi and Tangerang, in the northeast and northwest part of Jabodetabek, whereas positive spatial clustering of landslides can be found in the Bogor region (southern part of Jabodetabek). Dark blue areas in those maps are Low-Low (LL) clusters, which we called LL positive spatial association. LL clusters appear when a low value representing a low total number of floods and/or landslides events is surrounded by other low values. On the contrary, Low-High (LH) and High-Low (HL) types of LISA cluster maps are categorized as a negative spatial association, which means that the value representing the total number of floods and/or landslide events is different from that of its neighbors. LH type occurs when a low value is surrounded by high values, whereas HL type appears when high values are surrounded by low values. Using LISA analysis, we can determine not only the Local Moran's I, but also the Global Moran's I. In this case, the Global Moran's I values for floods and landslides are 0.0618 and 0.3815, respectively. This means that the spatial association of landslide-prone areas (based on the number of landslide events) is more clustered than the spatial association of floods (which is more random).

CONCLUSION

The rapid growth of urban development accelerates degradation of some environmental aspects of the study

area. We detected the local spatial association of floods and landslides using LISA statistics, and found that Bekasi and Tangerang have a high vulnerability to floods, with a high positive spatial association of flood occurrence and intensity, whereas Bogor is highly vulnerable to landslides owing to its topographic and climatic conditions. The LISA cluster map of floods and landslides could be used as a preliminary result of flood and landslide zoning, which is beneficial to land use or spatial planning to avoid or minimize inappropriate urban developments in flood- and landslide-prone areas.

One alternative solution to managing and controlling the environment in urban flood-prone areas is to repair and expand man-made sewer systems and storm water infrastructure. Another strategy is to reduce impervious surfaces in streets, parking lots and buildings through natural drainage channels, porous pavement, and wetlands (collectively known as green infrastructure or sustainable urban drainage systems). Areas identified as flood-prone can be converted into parks and playgrounds that can tolerate occasional flooding. Ordinances can be adopted to require developers to retain storm water on site and buildings to be elevated, protected by floodwalls and levees, or designed to withstand temporary inundation. Property owners can also themselves invest in solutions, such as re-landscaping their property to divert flows away from their buildings and installing rain barrels, sump pumps, and check valves.

Thus, in order to reduce social and economic losses due to landslides, we can develop effective planning and management. These approaches include: (a) restriction on development in landslide-prone areas, (b) use of excavation, grading, landscaping, and construction codes, (c) use of physical measures (drainage, slope-geometry modification, and structures) to prevent or control landslides, and (d) development of warning systems (Slosson and Krohn 1982, Schuster and Leighton 1988, Schuster 1996). To address the landslide problem, the local government has to achieve a better understanding of land-slide hazards and make rational decisions on the allocation of funds for the management of these risks. In the case of Jabodetabek, the way to improve environmental quality is through political solutions. However, the most important measure would be the promotion of institutional change and an increase in the efforts of communities and NGOs to preserve the environment.

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