Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering
Compte Rendu de la 9ième Conférence Nationale Américaine et
10ième Conférence Canadienne de Génie Parasismique
July 25-29, 2010, Toronto, Ontario, Canada • Paper No 1246

FIRE-FOLLOWING EARTHQUAKE RISK OF JAKARTA

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ABSTRACT

Fire-following earthquake (FFE) phenomenon has been observed in Indonesia, but it has not received much attention. This study is an attempt to address the FFE risk for Jakarta, the largest city in Indonesia; Jakarta faces both earthquake and fire hazards and is vulnerable to both hazards. The score-based risk analysis is conducted using readily available and easy-to-update data to provide an initial FFE risk for each urban village. The risk analysis algorithm is described in detail. The FFE risk appears to be the higher for urban villages in the northern part of Jakarta, and decreases for those in the southern part.

Introduction

Jakarta is the capital city of Indonesia, with a night-time population of about 9 millions and an area of about 660 km^2 (JPSO 2008b). Based on the Indonesian seismic code for buildings (NSA 2002), the 475-year return period peak ground acceleration for Jakarta varies up to 0.30g. Jakarta also faces fire hazards with an average of one fire ignition in residential area everyday (JPSO 2008b). Therefore, the combination of both hazards – fire following earthquake (FFE) – should be addressed appropriately. However, it is noted that the Governor Decree No 67 / 2008 on Disaster Management – Technical Guidance (GoJ 2008) does not address FFE as a hazard.

This paper begins with a summary of FFE incidents in Indonesia, followed by a discussion on earthquake and fire hazards of Jakarta. The FFE vulnerability of Jakarta is then analyzed, by addressing the fire spreading risk and fire suppression capability. The paper concludes with the general spatial trend of the FFE risk of Jakarta.

Fire Following Earthquake in Indonesia

Between year 2007 and 2009, based on news reports, there were at least 4 recorded FFE incidents. Brief description of those incidents is as follows:

- On 6 March 2007 at 10:49 am local time, an M 5.8 earthquake occurred in the Sumatra fault. The epicenter was at 0.46°S, 100.36°E near Padang Panjang, West Sumatra at a depth of about 20 km. Human losses were 58 people dead and at least 2,500 homes were damaged and destroyed. It was reported that there were 4 ignitions:

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- In Koto Singkarak, the earthquake knocked over kerosene-based cooking equipment in a coffee stall, and the fire spread to a collapsed bordering elementary school. Four elementary school students were killed.
    - In Bukit Tinggi, the earthquake knocked over cooking equipment and candles in three locations, and the fires consumed more than a hundred houses and shops.
- On 12 September 2007 at 6:00 pm local time, an M 8.4 earthquake occurred in the Sumatra subduction zone. The epicenter was at 4.67°S, 101.13°E, 105 km offshore southwest of Bengkulu at a depth of about 10 – 30 km. In Bengkulu Province, human losses were 13 people dead and at least 2,500 homes were damaged and destroyed. A fire occurred in a fast food stall on 4th floor of a shopping mall in Padang (West Sumatra Province).
- On 7 January 2008 at 12:12 pm local time, an M 6.2 earthquake occurred in the New Guinea subduction zone. The epicenter was at 0.68°S, 134.18°E, 21 km northeast of Manokwari, West Papua at a depth of 31 km. Human losses were about 10 people dead and 20 people reported injured. The earthquake knocked over kerosene-based cooking equipment, and the fire consumes 20 wood houses.
- On 30 September 2009 at 5:16 pm local time, an M 7.9 earthquake occurred in the Sumatra subduction zone. The epicenter was at 0.84°S, 99.65°E, 57 km west of Padang Pariaman, West Sumatra at a depth of 71 km. Human losses were more than 1,100 people dead, 1,700 people reported injured, and over 6,500 displaced. At least 190,000 homes were damaged and destroyed. In Padang, the closest urban area to the epicenter, the earthquake caused ignitions in 10 locations, but the details of the fires were not available.

It is of interest to compare the 30 September 2009 earthquake with another large urban area earthquake striking Yogyakarta and Central Java on 27 May 2006 at 5:53 am local time. Human losses were over 5,700 people dead, about 40,000 people reported injuring, and at least 250,000 houses were damaged and destroyed. However, no ignitions were reported after the earthquake. With a relatively comparable of damaged and destroyed houses, the former earthquake which occurred before dinner time caused many ignitions, while the latter which occurred before breakfast time caused no ignitions. These facts appear to highlight the dependence of FFE on the time of day of the earthquake occurrence.

Jakarta and Earthquake and Fire Hazards

Jakarta from the geotechnical engineering viewpoint has bedrock layer at depths of about 200 – 300 m. The surficial geomaterials typically become softer towards Jakarta Bay in the north. In addition, Jakarta is a relatively topographically flat area, and steep slopes could only be found in few riverbank areas in the southern part of Jakarta.

Jakarta based on the 2000 Population Census (JSPO 2008a) was divided into five (5) municipalities (south, east, central, west, north) (See Fig. 1.), consisting of 42 onshore and 1 offshore *kecamatan* or districts. At a lower governmental level, there were 261 onshore and 4 offshore *kelurahan* or urban villages. In this paper, only the 261 onshore urban villages were considered. The onshore area of Jakarta is 661.5 km^2.

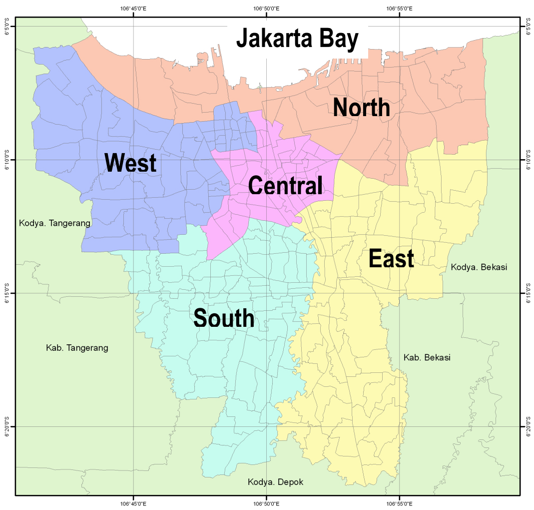

Figure 1. Municipalities of Jakarta.

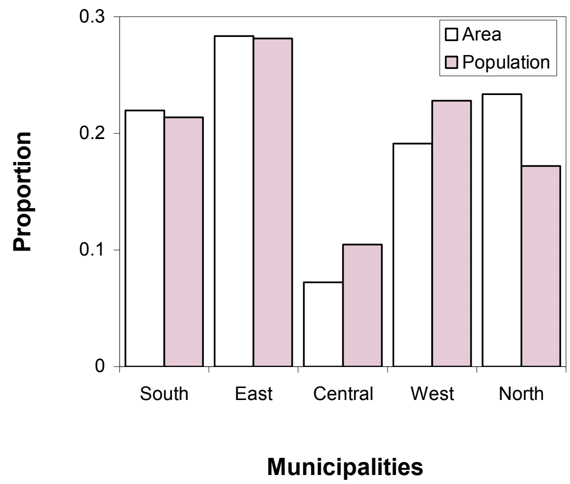

Figure 2. Proportion of area and population

Fig. 2 shows the proportion of area and population of Jakarta. In South Jakarta and East Jakarta, the proportion of area is about the same as the proportion of population. However, in Central Jakarta and West Jakarta, the proportion of area is less than the proportion of population. In North Jakarta, the former is about 25% greater than the latter.

The earthquake hazard for Jakarta has been identified in many studies. Jakarta, as prescribed in the Indonesian seismic code for buildings (NSA 2002), lies on an area with a 475-year return period peak base acceleration of 0.15g. The peak ground acceleration (PGA) values for hard, medium, and soft soils are 0.18g, 0.23g, and 0.30g, respectively. Furthermore, the seismic microzonation map of Jakarta developed by Santoso and Sengara (2007) indicates that most urban villages in South Jakarta and East Jakarta are within the hard to medium soil classes, those in Central Jakarta are within the medium to soft soil classes, and those in West Jakarta and North Jakarta are within the soft soil class.

In year 2006 and year 2007, on average there was a fire outbreak in the residential area everyday (JPSO 2008b). The number of burned houses in each fire varied significantly, and Table 1 shows that the average number of burned houses varies from one municipality to the other. Most of the fire outbreaks were due to electrical problems (65%), while the others were due to cooking equipment (10%), cigarettes (5%), and other types of ignitions. A news media search was conducted to examine further large fires in residential areas, and ten burned houses in each fire were used as the criterion for large fires. In the period between January 2008 and July 2009 (19 months), there were 43 large fires in 33 urban villages. The statistical distribution of the urban villages involved in these fires is shown in Fig. 3. A comparison between Figs. 2 and 3 indicates that large fires occurred disproportionately in West Jakarta and North Jakarta, followed by Central Jakarta. In urban village of *Penjaringan* (North Jakarta) there were 4 large fires in that 19 month period, while in urban village of *Rawa Buaya* (West Jakarta). Five other villages in Central, West, and North Jakarta experienced 2 fires.

Table 1. Average number of houses burned in a fire outbreak in residential area.

Municipality	2006	2007
South Jakarta	3.32	1.83
East Jakarta	2.85	20.69
Central Jakarta	3.78	11.37
West Jakarta	2.78	9.73
North Jakarta	20.52	34.48
All	5.95	15.10

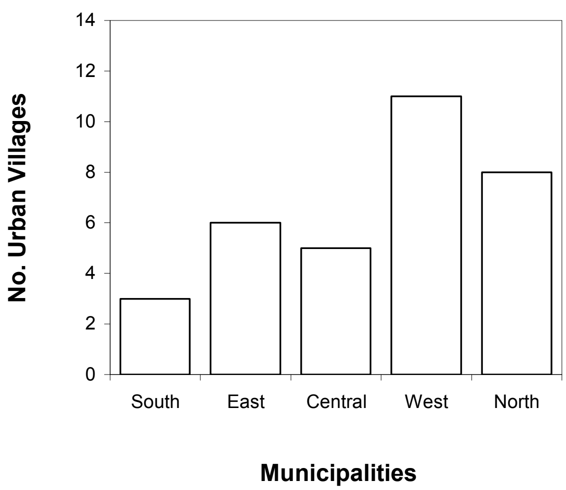

Figure 3. Large residential fires in Jakarta (January 2008 – July 2009).

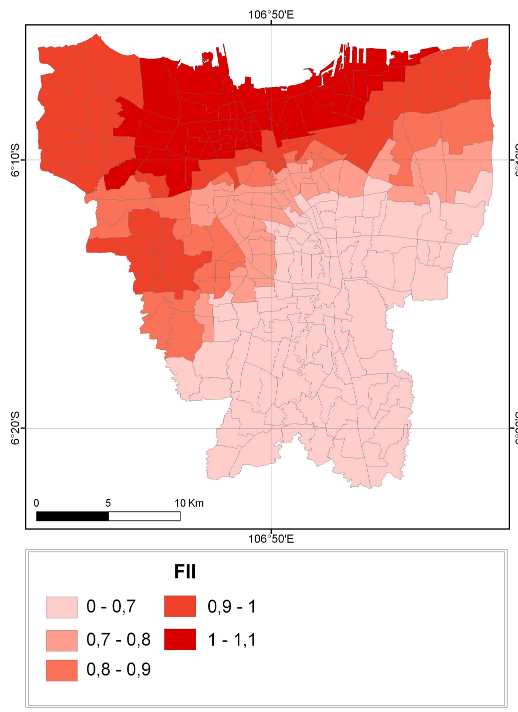

Figure 4. Fire Ignition Index spatial distribution.

Fire-Following Earthquake Risk Analysis

The fire-following earthquake (FFE) risk analysis has progressed significantly (e.g. Scawthorn 2003, Eidinger 2004), and the ignition models, spread/suppression models, and integrated models available are summarized by Lee et al. (2008). In addition, FFE scenarios have been developed for major cities (e.g. Scawthorn 2008). For Jakarta, however, most of the advanced models are not applicable as the availability of the required data is insufficient (Prakoso 2008). Therefore, a score-based FFE risk analysis at present is the best alternative to provide an initial estimate of FFE risk of Jakarta.

The FFE risk in this paper is analyzed using an algorithm which follows the logic of the FFE algorithm proposed by the GESI Pilot Project (GHI and UNCRD 2000). The algorithm consists of three parts: fire ignition, fire spread, and fire suppression capability. Significant modifications were done including: 1) the analysis was conducted at urban village level using readily available and easy-to-update data, and 2) the fire suppression capability was adjusted to be compatible with the fire suppression infrastructure and actual practices in Jakarta. In each fire part, all factors are scaled to remove their units and make it possible to combine them. The FFE risk is represented by FFE Risk Index (FRI):

$$\text{FRI} = \text{FII} \times \text{FSprI} \times \text{FSupI} \quad (1)$$

in which FFI = Fire Ignition Index, FSprI = Fire Spread Index, and FSupI = Fire Suppression Index.

Fire Ignition

Fire ignition as in the GESI Pilot Project (GHI & UNCRD 2000) is assumed to be simply correlated to the peak ground acceleration of a location. Fire ignition is represented by Fire Ignition Index (FII):

$$\text{FII} = (\text{PGA} / 1.05g) \times 4.0 \quad (2)$$

in which PGA = 475-year return period peak ground acceleration. It is noted that the 1.05g factor represents the maximum PGA possible, adopted from the GESI Pilot Project (GHI & UNCRD 2000). The spatial distribution of FII is shown in Fig. 4.

Fire Spread

Three key characteristics are assumed for a fire to spread: building types, building density, and wind speed. These characteristics are combined using by Fire Spread Index (FSprI):

$$\text{FSprI} = \text{FHS} \times \text{PDS} \times \text{WSS} \quad (3)$$

in which FHS = Flammable House Score, PDS = Population Density Score, and WSS = Wind Speed Score.

For building types, the ‘percentage of buildings which are highly flammable’ parameter in the GESI Pilot Project (GHI & UNCRD 2000) is adopted. The 2000 Population Census (JSPO 2008a) has two building material categories: largest portion of wall material and largest portion of roof material (wall materials considered flammable: wood and bamboo walls; roof material considered flammable: metal and wood roofs). Furthermore, the percentage of houses in an urban village is calculated for both building material categories, and the maximum percentage is used as the ‘percentage of building which are highly flammable’. The percentage varies from 0.5% to 62.4%, with median and mean values of 14.7% and 17.3%, respectively. Fig. 5 shows the statistical distribution of the percentage. The ten most flammable urban villages were located in North Jakarta (7 urban villages), East Jakarta (2), and Central Jakarta (1). The relationship between the percentage and Flammable House Score (FHS) is as follows:

$$FHS = (\text{Percentage of Highly Flammable Houses}) \times 4.0 \quad (4)$$

The population density for the entire Jakarta in year 2000 was 12,821 people/km^2. However, the population density of the 261 urban villages varies from 693 to 76,503 people/km^2, with median and mean values of 14,875 people/km^2 and 18,556 people/km^2, respectively. Fig. 6 shows the statistical distribution of the population density. The ten densest urban villages (all > 48,000 people/km^2) were located in West Jakarta (5 urban villages), Central Jakarta (4), and East Jakarta (1). Prakoso (2007) shows that the population density is strongly, consistently throughout Jakarta correlated to the house density. On average, each house accommodates about 4 people (House Density = 0.2631 Population Density, $r^2 = 0.98$). The relationship between the population density and Population Density Score (PDS) is as follows:

$$PDS = (\text{population density} / 40{,}000 \text{ people/km}^2) \times 4.0 \quad \text{for population density} < 40{,}000 \text{ people/km}^2 \quad (4a)$$

$$PDS = 4.0 \quad \text{for population density} \geq 40{,}000 \text{ people/km}^2 \quad (4b)$$

It is noted that the 40,000 people/km^2 factor was adopted from the GESI Pilot Project (GHI & UNCRD 2000).

The wind speed in Jakarta was analyzed based on data from five metrological stations in and surrounding Jakarta. Adopting the GESI Pilot Project (GHI & UNCRD 2000), the Wind Speed Index is determined using the following:

$$WSS = (AWS / 40 \times 4.0) + 1.0 \quad (5)$$

in which AWS = average wind speed in km/hour. In general, urban villages in the northeast part of Jakarta have the highest WSS, while those in the southwest part have the lowest WSS.

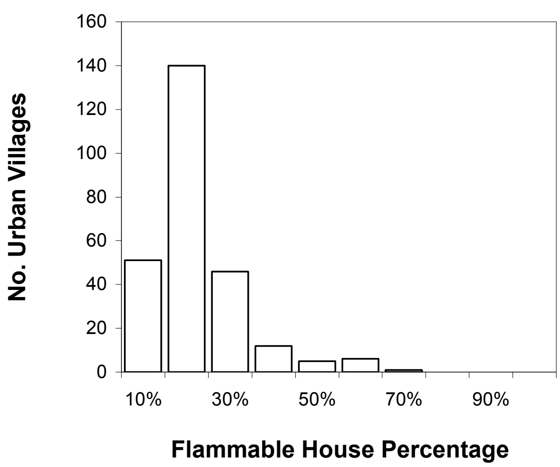

Figure 5. Percentage of highly flammable houses.

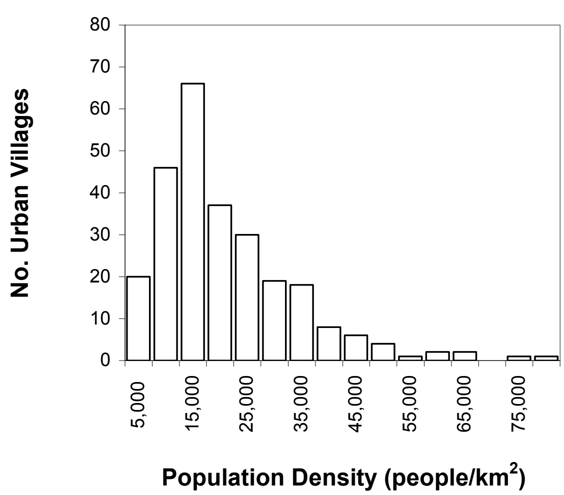

Figure 6. Population density

Fire Suppression Capability

Four key characteristics are assumed for fire suppression capability: availability of water, institutional capacity, ease of city access, and general city emergency response preparedness. These characteristics are combined using by Fire Suppression Index (FSupI):

$$FSupI = 0.5 + (WUAS + IICS + IAS + EMS) / 32 \quad (6)$$

in which WUAS = Water Unavailability Score, IICS = Institutional Incapacity Score, IAS = Inaccessibility Score, and EMS = Emergency Management Score. It is noted that WUAS and IAS are calculated based on the data available in the digital map of Jakarta developed by Indonesia National Coordination Agency for Surveys and Mapping.

There are 13 rivers and creeks in Jakarta and, therefore, Jakarta has relatively reliable post-earthquake sources of water. In this study, a more specific water availability criterion is set; for each urban village, the percentage of area within 500 m of sources of water is used as the parameter. Fig. 7 shows the statistical distribution of the percentage. The Water Unavailability Score (WUAS) is determined using the following:

$$WUAS = 0.0 \qquad \text{for percentage} \geq 90\% \quad (7a)$$

$$WUAS = 4.0 \qquad \text{for percentage} \leq 50\% \quad (7b)$$

$$WUAS = \text{linear interpolation} \qquad \text{for percentage} = 50\% - 90\% \quad (7c)$$

The numbers of fire fighting equipment and fire stations are only about 140 units and 80 stations, respectively. Clearly, these numbers are not adequate for a 660 km^2 city. Furthermore, the fire fighting equipment and fire stations are not well distributed; Central Jakarta has disproportionately higher densities for both compared to the others. In this study, the fire fighting institutional capacity is calculated based on the average distance of five closest fire stations to the urban village centroid. Fig. 8 shows the statistical distribution of the average distance. The Institutional Incapacity Score (IICS) is determined using the following:

$$IICS = 0.0 \qquad \text{for average distance} \leq 1 \text{ km} \quad (8a)$$

$$IICS = 4.0 \qquad \text{for average distance} \geq 4 \text{ km} \quad (8b)$$

$$IICS = \text{linear interpolation} \qquad \text{for average distance} = 1 \text{ km} – 4 \text{ km} \quad (8c)$$

Inaccessibility of urban villages is measured from the ratio of the length of streets accessible to fire fighting equipment to its area or the accessible street density. Fig. 9 shows the statistical distribution of the density. The Inaccessibility Score (IAS) is determined using the following:

$$IAS = 0.0 \qquad \text{for accessible street density} \geq 20 \text{ km/km}^2 \quad (9a)$$

$$IAS = 4.0 \qquad \text{for accessible street density} \leq 0 \text{ km/km}^2 \quad (9b)$$

$$IAS = \text{linear interpolation} \qquad \text{for accessible street density} = 0 \text{ km} – 20 \text{ km} \quad (9c)$$

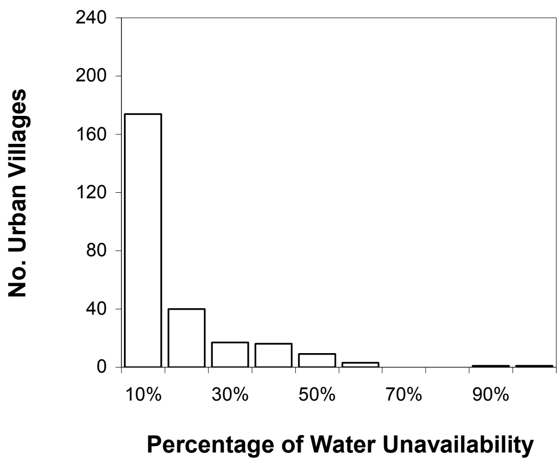

Figure 7. Proportion of area within 500 m from sources of water.

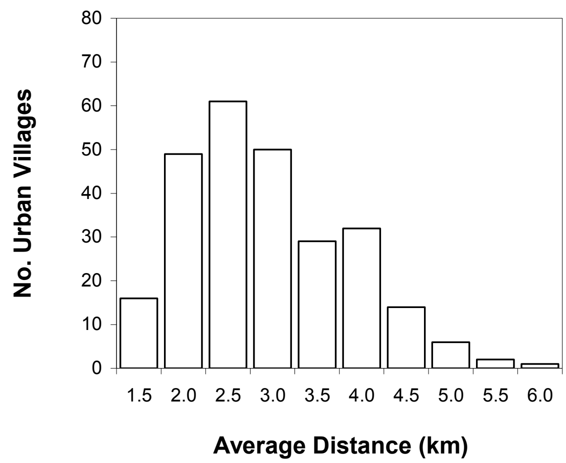

Figure 8. Average distance of 5 closest fire stations.

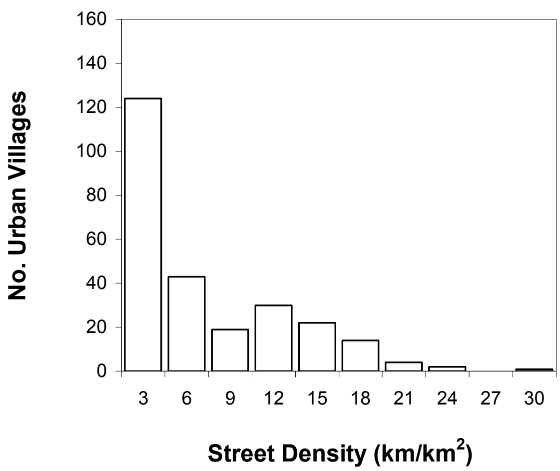

Figure 9. Accessible street density.

The GESI Pilot Project (GHI & UNCRD 2000) approach to assess the general emergency preparedness is adopted in this study. One of main references in determining the preparedness is the Governor Decree on Disaster Management (GoJ 2008). The Emergency Management Score (EMS) for Jakarta is 1.46.

Fire-Following Earthquake Risk

The fire-following earthquake (FFE) risk, represented by FFE Risk Index, is analyzed using Eq. 1 based on three indices (Fire Ignition Index, Fire Spread Index, and Fire Suppression Index). The first index is shown as Fig. 4, while the second and third indices are shown as Figs. 10 and 11. The resulting FFE Risk Index is shown as Fig. 12; higher index values suggest higher risk. The index appears to be higher for urban villages in the northern part of Jakarta, and decreases for those in the southern part.

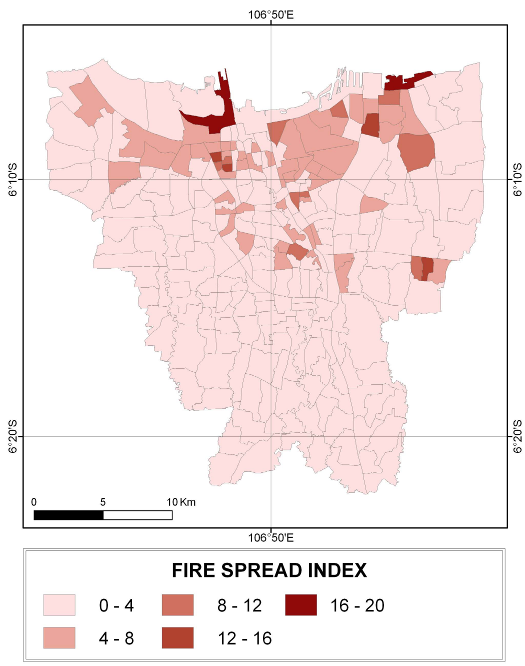

Figure 10. Fire Spread Index spatial distribution.

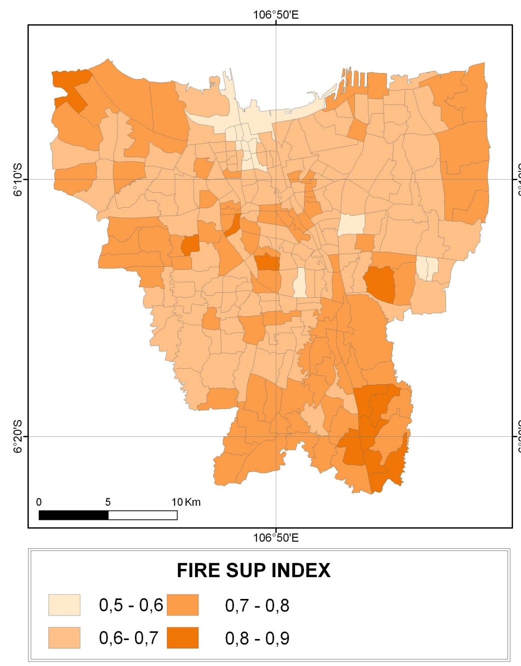

Figure 11. Fire Suppression Index spatial distribution.

Conclusions

This paper discusses the fire-following earthquake (FFE) phenomenon in Indonesia, and is an attempt to address the FFE risk for Jakarta. The score-based risk analysis was conducted at the lowest administration level, using readily available and easy-to-update data. The risk analysis algorithm is described in detail. The resulting FFE Risk Index is given for each urban village. The FFE risk appears to be the higher for urban villages in the northern part of Jakarta, and decreases for those in the southern part.

Acknowledgments

The research on FFE risk of Jakarta was supported by Post-Disaster Rehabilitation Research Grant – University of Indonesia 2008.

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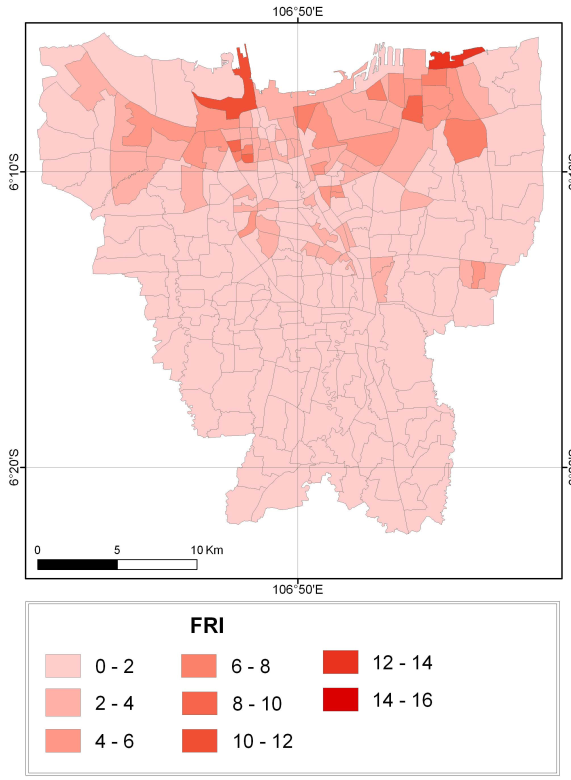

Figure 12. Fire-Following Earthquake Risk Index spatial distribution.

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