Multi-hazard assessment and shelter allocation in DKI Jakarta: an initial study

F H Sihombing

Calvin Institute of Technology

Corresponding author: fritz.sihombing@calvin.ac.id

Abstract. Multi-hazard assessment extends the traditional disaster hazard assessment. It provides an exhaustive view of disaster hazard management where all possible disasters are observed. More importantly, the interaction and compounding impact of the concurrent disasters event should be understood thoroughly. Up until now, hazard assessments of all possible disaster events in DKI Jakarta are estimated separately. This study aimed to initiate a multi-hazard assessment of earthquake and flood for urban areas in DKI Jakarta. A scenario-based of a concurrent disaster event is created, that is the sequence of earthquake and flood occurrence, and its impact are studied using multi criteria analysis. The evacuation shelters are proposed within the affected area and the shortest path for disaster reliefs are estimated using the shortest path algorithm. The area with high level multi-hazard should carefully plan their disaster mitigation and recovery management to prepare the society for the concurrent disaster event and ensure their resiliency.

1. Introduction

Hazard is a condition or situation that causes a damaging effect. It can be generated from a natural event or human activity. The damaging effect itself may include the loss of life, infrastructure and property damages, economic disruption, and environmental degradation. Natural disaster hazard assessment is an analysis of destructive natural events, such as the earthquake, tsunami, thunderstorm, landslide, and flood. It is followed by a risk assessment, where the likelihood of such hazard is quantified. Hazard and risk assessment are important, especially for urban development planning and management, because the impact of a natural disaster is instantaneously and can be catastrophic.

A comprehensive disaster risk mitigation, disaster relief management, and post-disaster recovery planning helps the society prepare for a disaster, a resilient society. This can be done within the scope of nationwide and globally. For example, The Sendai Framework for Action is a document for a global multilateral network aimed to reduce the risk and impact of natural disaster. It outlines the necessity to implement and encourage the multi-hazard early warning system [1]. Multi-hazard assessment, can be defined as an observation of a defined location subjected to all possible and relevant hazards [2].
Urban settlement is subject to multi-hazard toll because it has multiple hazard sources, such as earthquake fault, precipitation rate, electrical grid, urban sewage and river, housing grid, and highway network. Moreover, infrastructure networks such as highways, bridges, electric and communication grids, are exposed to multiple hazards in their service life. Quantification of hazards and risk are required to manage their serviceability and mitigate its impact. Nevertheless, a single focus of hazard assessment may lead to misunderstanding of the nature of the risk embodied in the urban settlement. Therefore, the approach to assess the hazard should be on multiple sources considering all possible events and, if possible, the interaction between hazards [3].

DKI Jakarta is a capital city of Indonesia, it has political importance as well as economic influence. It is a massive urban settlement that accommodates 10.57 million people [4] inside of 661.5 kilometer square of the land area. The government agency and scientist assessed the earthquake and flood hazard of DKI Jakarta separately [5,6]. However, up until now, a multi-hazard assessment has not been conducted yet in DKI Jakarta. In this study, we aimed to initiate a multi-hazard assessment of earthquake and flood for urban areas in DKI Jakarta, providing additional knowledge of how such areas will possess different threat intensity because of the variability of hazard sources and its interaction. A scenario-based of a concurrent disaster event is created, that is the earthquake and flood, and its impact are studied. The evacuation shelters are proposed within the affected area and the shortest path for disaster reliefs are estimated. The earthquake and flood are selected because both disasters occur frequently in DKI Jakarta. The remainder of this paper is organized as follows: Section 2 describes the brief literature review. A classification of problem types, along with dataset and solution methods is presented in Section 3. Section 4 describes findings and the discussion. Section 5 describes several potential further research directions and concludes the paper.

2. Multi-hazard assessment

2.1. Earthquake hazard

Earthquake is the result of a sudden activity on the earth’s fault that propagates seismic waves. The seismic waves consisted of P-wave and S-wave. The P-waves are compressional waves, propagate longitudinally, and shake lightly or no shake at all. The S-waves are the shear waves, propagate transversely, and the effect is destructive. The occurrence of an earthquake may trigger another disaster, such as liquefaction, landslides, tsunami, or fire.

Earthquake hazard assessment aims to understand the intensity of its shakes from such earthquake occurrences at a particular location within a certain period in the future. This framework requires a good knowledge of geological formation and seismic properties of the study area. Scientific approach provides both analytical and numerical models of earthquake generation and propagation. The parameters that are used in the model represents physical properties of geological formation and seismic properties in the real world [7].

Irsyam, Hutabarat [6] conducted seismic risk microzonation study of DKI Jakarta which consisted of seismic hazard assessment, site characterization, site specific response analysis, and risk assessment. This exhaustive study has provided comprehensive knowledge for earthquake hazard and risk management in DKI Jakarta. They delineated an active seismic source within radius 250 km from DKI Jakarta consisting of fault (Cimandiri, Lembang, Semangko, Sunda, and Kumering) and subduction zone (South Sumatra Megathrust and Java Megathrust). They estimated the seismic hazard deterministically and probabilistically. The deterministic approach has used a combination of magnitude
and source distance within 250 km from DKI Jakarta to simulate the appropriate ground motion. In a probabilistic approach, the variability of the earthquake occurrence at certain magnitude is considered. Therefore, instead of a single value it returns the distribution of earthquake magnitude given the fault properties (source type, distance, and return period). Furthermore, the estimated hazard is extended to calculate the seismic risk in DKI Jakarta, and the damage of the building is defined FEMA 154 guidelines. Figure 1a shows the earthquake hazard map of DKI Jakarta.

2.2. Flood hazard assessment

In the rainy season, heavy rainfall in a long duration may occur frequently. These occurrences lead to the exceedance of the soil infiltration capacity and flow capacity of river and municipal sewages which generate flooding from riverbank or sewages onto adjacent lands. These areas, that are adjacent to the riverbank, are called floodplains and have flood hazard levels higher than the area that is far from the riverbank or in the upland hill.

Flood hazard assessment estimates the probability of a certain size of the flood appearing in any given year. This work requires hydrologic data from the river and stream, and meteorological data of area of interest. These works are a time-consuming effort, because they need at least historical data of twenty years to be able to infer the statistic of the flood-generating event. If the apparatus to collect these data are not available, then the assessment can be substituted using remote sensing data, damage reports, and field observations. However, these models of approximation may have some limitations that can lead to error in the judgement of defining flood hazard of the area of interest.

DKI Jakarta suffered from major floods in 2002, 2007, 2013, 2015, and 2020 [8, 9]. Budiyono, Aerts [10] studied the river flood risk in DKI Jakarta and found the increasing flood impact socially and economically. They have also listed active agents that encourage this increase physically (land subsidence, river and sewage flow capacity, and climate change) and socio-economically (urbanism and massive land misuse). The government itself is trying to reduce the flood risk and adapting from a deterministic-technical-protection toward a flood-risk-management-based approach. Therefore, estimation of flood hazard is an important part to manage the flood risk in DKI Jakarta and scientific studies have already been conducted regarding this subject. Figure 1b shows the flood hazard map of DKI Jakarta.

2.3. Multi-hazard assessment

Previously, earthquake and flood hazard assessment have been conducted in DKI Jakarta. These assessments are used to manage their risk, mitigate their impact, and ensure the recovery phase following the disaster occurrence. Moreover, the approach is rather distinctive and separated where the disaster occurs independently and separately. Multi-hazard assessment, however, offers an extended perspective of traditional disaster hazard assessment. One disaster event can trigger another disaster event, or multi-disaster events are independent and occurred at the same time. The multi-hazard assessment provides an exhaustive view of disaster hazard management where all possible disasters are included and their interactions and compounding impact are observed thoroughly [11].

This study conducted two parts of the work. The first part was generating a simple multi-hazard map using GIS and the second part was allocating potential evacuation shelters considering the shortest available for the disaster relief team to reach it rapidly. All GIS works are performed in QGIS [12].

2.4. Multi-hazard map
In this part, the work was to generate a simple multi-hazard map by applying GIS tools including, projecting, buffering, overlaying, and rasterizing, and then performing multi criteria analysis. Multi criteria analysis is a framework to generate information for decision making which combines geographical information and value judgement spatially [13]. To obtain multi-hazard map the following spatial layer are used:

1. Earthquake hazard map (figure 1a)
2. Flood hazard area map (figure 1b)
3. DKI Jakarta administrative area map

Earthquake and flood hazard maps are obtained from BNPB [8], flood affected area map is obtained from InaSAFE [14], and DKI Jakarta administrative area map is obtained from Ina Geoportal [15]. These spatial layers were pre-processed and transformed to raster format. The multi criteria analysis was performed by overlaying all raster layers, that is the disaster hazard maps and administrative area map. Every pixel in the disaster hazard raster layers defines the disaster impact severity. The highest pixel value, obtained from the combination of two disaster hazard raster layers, shows the most hazardous area. We used QGIS to process and manipulate the vector layer operation. A hypothetical scenario of earthquake impact is carried out. From figure 1a, we understand that the southern part of DKI Jakarta possesses the higher earthquake hazard than the northern part of DKI Jakarta. Figure 2 shows the framework of this process.

Figure 1. (a) Earthquake hazard map. (b) Flood hazard map
3. **Case study: shelter allocation for concurrent disaster event**

Following the simple multi-hazard map of DKI Jakarta, the second part of the work was conducting a hypothetical case study with its specific feature. This case is based on the shelter allocation plan in the earthquake prone and flood affected area in DKI Jakarta. The earthquake and flood events are concurrent, where the earthquake occurred first and followed by the flood event. The damage impact of this concurrent event to homes and buildings is, assumed, significant and therefore it requires evacuation of people to the shelter place and waiting for the disaster relief team to arrive. We used the road networks map from OpenStreetMap [16] (Figure 3) and estimated the shortest path available for the disaster relief team to reach the shelter place. Figure 4 shows the framework of this process.
3.1. Multi-hazard map

Using the map of earthquake and flood affected areas, the buffer areas are calculated. We randomly select the earthquake affected area (Figure 5a) from the higher earthquake hazard area. The flood impact is calculated based on the 2013 flood occurrence that is available in the Inasafe database. The 2013 Jakarta flood affected mostly the northern part of DKI Jakarta. However, there were several floodplains developed in the middle part to the southern part of DKI Jakarta (Figure 5b). The buffer area is defined 500 meters around the affected area (Figure 5c).

The multi criteria analysis requires the raster layer for its calculation, therefore, all layers were converted into the raster layers. These layers were overlaid to find which location possessed the highest value of hazard. The hazard in this context is the multi-hazard that is the sequence of the earthquake and flood. Figure 6 shows the result of multi criteria analysis for multi hazard assessment. The index shows numeral level from 1 to 5, where 1 is the least hazardous area and 5 is the most hazardous area. As we can see, the high multi-hazard level in such areas is because of the occurrence of both the earthquake and flood in that area. The concentration of this phenomenon has appeared in the southern part of DKI Jakarta, however not all areas in the southern part possessed the high multi-hazard level. This is because, in the beginning we defined the earthquake affected area randomly, so not all areas in the southern part suffered the earthquake impact. We assumed the impact of the earthquake in the affected area causes buildings and infrastructures damages, and the worst is collapse. Moreover, if such areas in the southern part of DKI Jakarta have the earthquake mitigation and recovery plan, the risk of earthquake hazard can be reduced. Flooding in the southern part of DKI Jakarta occurred in the floodplain, that is near the riverbank.

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**Figure 4.** The framework to estimate the shortest path for shelter location and disaster rescue team
Figure 5. Maps that are used for multi criteria analysis.

(a) Earthquake affected areas, (b) Flood affected areas, and (c) affected areas and its buffer area of both earthquake and flood

Figure 6. Multi-hazard index map for earthquake and flood

4. Case study: shelter allocation for concurrent disaster event

We conducted a hypothetical case study where the earthquake and flood events are concurrent, that the earthquake occurred first and followed by the flood event. Figure 7 shows the affected area, shelter points (destination), disaster rescue team points (origin), and the possible paths from origin to destination. It also shows the optimum path, that is the shortest distance between origin and destination. We calculated the optimum path using QGIS Network Analysis Toolbox 3 (QNEAT3), that applies Dijkstra's Shortest Path First algorithm [17]. The sub-optimum paths are the path that is not included in the optimum path, that is the distance between origin and destination points are considered too far away compared with the other possible combination in the shortest path result. The sub-optimum paths are calculated manually, by setting the destination and origin point manually. The affected area means that the earthquake and flood impact causes disruption in the society and needs immediate response from the disaster relief team. Using the optimum path, the disaster relief team can provide a rapid response to
help peoples in the affected area. Table 1 and 2 show the combination of origin and destination points and its total cost.

**Table 1. Shortest path available for rapid response of disaster relief team**

| Origin Points | Destination Points | Total Cost     |
|---------------|--------------------|---------------|
| 1             | 7                  | 1916.38427    |
| 2             | 2                  | 943.521361    |
| 2             | 6                  | 2150.00222    |
| 2             | 11                 | 2024.14697    |
| 4             | 4                  | 2148.56572    |
| 5             | 4                  | 2009.38484    |
| 5             | 9                  | 1236.94542    |
| 7             | 7                  | 1370.98996    |
| 8             | 3                  | 1736.76142    |
| 9             | 9                  | 1463.60639    |

**Table 2. Estimation of travel cost of in the sub-optimum path**

| Origin Points | Destination Points | Total Cost |
|---------------|--------------------|-----------|
| 1             | 1                  | 3206.581  |
| 3             | 10                 | 2327.141  |
| 8             | 8                  | 2421.933  |
| 8             | 5                  | 2437.446  |
Figure 7. Shelter allocation and shortest path

5. Conclusion

The first work in this study, a multi-hazard assessment, was performed, considering the earthquake and flood concurrent event. Multi-criteria analysis shows the multi-hazard level of a particular area. The second work, a hypothetical case study of earthquake and flood, was conducted. The affected area was delineated and shelter locations for evacuation were proposed. To help the disaster relief team provide a rapid response, the shortest path between origin points (disaster rescue team checkpoint) and destination points (shelter location) was calculated. The area with high level multi-hazard should carefully plan their disaster mitigation and recovery management to prepare the society for the concurrent disaster event and ensure their resiliency. These works in this study are the initial study of multi-hazard assessment and management; the scope of observation and analysis are simple and rather hypothetical. Following this dissemination, we will extend the multi-hazard analysis study using real dataset, coherent scenarios, and extensive numerical methods.
References

[1] Nations U 2015. Sendai framework for disaster risk reduction 2015–2030. United Nations New York
[2] Garcia-Aristizabal A, Gasparini P, Ulinga G 2015. Multi-risk assessment as a tool for decision-making. Urban vulnerability and climate change in Africa: Springer; p. 229-58.
[3] Bell R, Glade T. Multi-hazard analysis in natural risk assessments. Landslides safety & security engineering series. 2012:1-10.
[4] Jakarta BPSPD 2020. Population. DKI Jakarta: Central bureau of statistics of DKI Jakarta Province (In Bahasa)
[5] Garschagen M, Surtiari G, Harb M 2018. Is Jakarta’s new flood risk reduction strategy transformational? sustainability.10(8):2934.
[6] Irsyam M, Hutabarat D, Asrurifak M, Imran I, Widiyantoro S, Hendriyawan D 2015, et al. Development of seismic risk microzonation maps of Jakarta city. CRC Press p. 35-47.
[7] Boore DM, Atkinson GM 2019. Ground-motion prediction equations for the average horizontal component of PGA, PGV, and 5%-Damped PSA at spectral periods between 0.01 s and 10.0 s. Earthquake spectra. 24(1):99-138.
[8] Flood disaster information [Internet]. BNPB. 2020 [cited 2020 May 1]. (In Bahasa)
[9] Jakarta floods [Internet]. BMKG. 2020 [cited 2020 May 1].
[10] Budiyono Y, Aerts JCJH, Tollenaar D, Ward PJ. River flood risk in Jakarta under scenarios of future change. Natural hazards and earth system sciences. 2016;16(3):757-74.
[11] Gallina V, Torresan S, Critto A, Sperotto A, Glade T, Marcomini A 2016. A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. Journal of environmental management. 168:123-32.
[12] Quantum GIS. 3.10 ed: Open source geospatial foundation project.
[13] Malezewski J 1999. GIS and multicriteria decision analysis: John Wiley & Sons
[14] Flood Affected Area in DKI Jakarta. In: InaSAFE, editor.: InaSAFE.
[15] DKI Jakarta Administrative Area. Ina Geoportal.
[16] DKI Jakarta - Road Networks [Internet]. OpenStreetMap. 2020 [cited 2020 May 1]. Available from: https://openstreetmap.id/en/data-dki-jakarta/
[17] Dijkstra EW 1959. A note on two problems in connexion with graphs. Numerische Mathematik. 1(1):269-71.