Disaster Management : Selections of Evacuation Route due to Flood Disaster

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Disaster management: selections of evacuation routes due to flood disaster

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1. Introduction

1.1. Background

A flood is one of natural events that is difficult to avoid. In an urban area where populations always grow and residential areas become more expensive, settlements started developing in a flood risk area. The losses due to flooding

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can be in the forms of materials, damaged infrastructure, job opportunities and even can cause fatalities. These losses are even worse in dense populated areas [1]. This can be minimized by a better land-use planning, regulations, law enforcement, and non-physical mitigation management such as establishment of evacuation routes for casualties during flood event and proper socialization. Several selections of appropriate evacuation routes and eligible evacuation shelter locations are extremely helpful to reduce losses, especially lifesaving.

Data of rainfall, river morphology, administrative boundaries, population density and concentration, topography, are used to analyze the potential risks and the extent of flooding. In addition, based on analysis of roads condition and other infrastructure, it can be determined several alternatives of evacuation routes for casualties that are effective and safe.

It is not easy to determine correct evacuation routes and shelter locations. It needs a tool which has spatial detection ability. The use of Geographic Information Systems (GIS) is one tool that can be used, because GIS has an excellent capability in the mapping process [2]. By using GIS, the results of selection and determination of the evacuation routes due to flooding can be used directly in the research area. This also can be used as an evacuation model due to flood event in other places, as well as in the downstream area of a dam when the dam fails.

1.2. Research location

This research was conducted in the West Semarang District, Central Java, Indonesia (Fig. 1), with an area of 21.74 km^2 and 158,668 populations [3]. West Semarang area is passed by three rivers, i.e. Siangker, Silandak and West Banjir Kanal. This district is chosen as a study case because floods are frequently occurred. It also has a high population and represents an urban area.

2. Research implementation phase

2.1. Research flowchart

Stages of research can be seen in Fig. 2. The required data includes: rainfall data, topographic maps (Catchment Area, inundation areas), longitudinal and cross section of the rivers, road network maps, settlement areas and population concentration, and temporary shelter locations. The next step is to determine flood discharge, hydraulics analysis, areas of inundation, and analysis of effective and safe evacuation routes to shelter locations.

2.2. Design flood

The HEC-HMS software was used to analyze Q_{100} design flood. There are 4 rainfall stations influence the catchment areas, i.e. Tugu, Mijen, Simongan and Ungaran, which cover three catchment areas of Silandak (14.35 km^2), Siangker (7.16 km^2) and Garang (205.77 km^2). Thiessen polygon method was used to measure the rainfall areas.

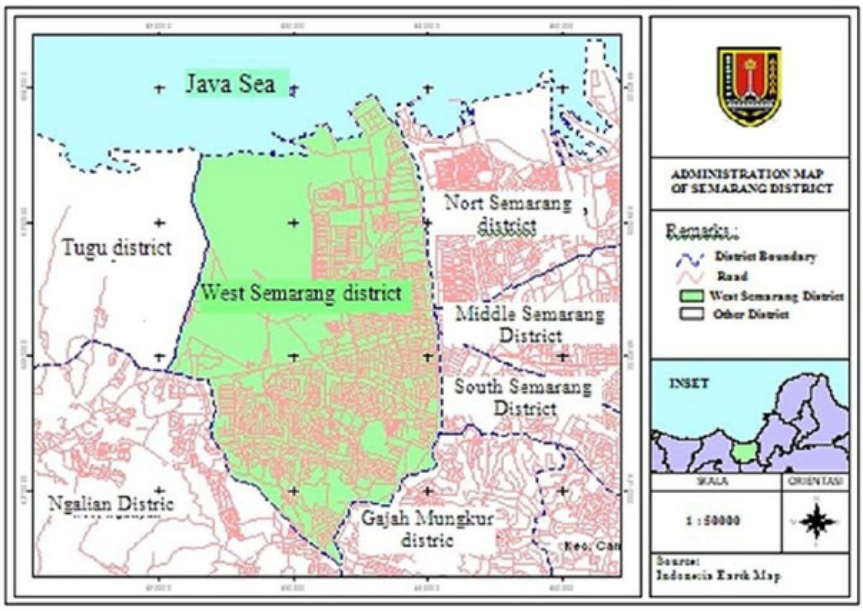

Fig. 1. The Research Location

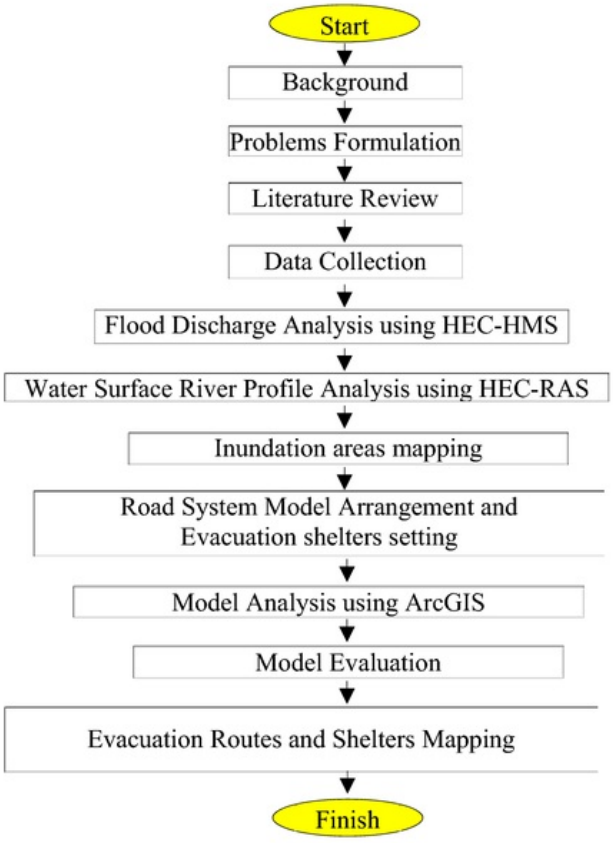

Fig. 2. Flowchart of Research

2.3. Water surface elevation and inundation area

A hydraulics analysis was carried out using HEC-RAS to find out the water surface elevation during flood events. RAS Mapper was then applied to detect the inundation area. Google Earth was used to find the flooded area and administrative boundaries accurately. The map showing potential flooded areas is a map that identifies the risk level of flood in an area at a certain period of time [4].

2.4. Evacuation routes

Based on the existing road systems, settlement location, and temporary shelter locations for the casualties, ArcGIS can identify the shortest and safe routes to the shelter locations [5]. The evacuation point is a temporary place for the casualties where they can stay, either in the shelters or in a family and/ or individual houses [6].

3. Results and discussions

3.1. Hydrology analysis

The regional design rainfall was analyzed based on rainfall data taken from four influencial stations for 23 year period. Thiessen Polygon method was used to calculate design rainfall, i.e. R100 = 322 mm (Silandak CA), 560 mm (Siangker CA) and 401 mm (Garang CA) respectively. The flood discharge was analyzed using HEC-HMS [7]. The amount of flood discharge for 100 year return period, Q100, are 258.50 m^3/s for Silandak CA, 285.20 m^3/s for Siangker CA and 3591.90 m^3/s for Garang CA. Fig.s 3(a), 3(b) and 3(c) show the Basin Model for each Catchment Area.

3.2. Hydraulics analysis

The river water surface was analyzed using the HEC-RAS software [8]. By using both HEC-RAS and RAS Mapper, it can be identified inundation areas that came from each river. Fig.s 4(a), 4(b), and 4(c) show the inundation areas. With the help of Google Earth, we can see accurately the inundation boundaries. It spread partly over the settlement areas and other areas for 10.80 km2.

3.3. Inundation map

The results of analysis using the HEC-RAS and RAS Mapper have produced two types of flood depth and velocity. Fig.s 5(a) and 5(b) are scenarios when the three rivers flood at the same time. This was done by overlaying inundation map on the administration map.

3.4. *Evacuation scenario*

The best and/ or the nearest evacuation route can be analyzed using ArcGIS [9]. Road capacity data was needed in order to select the nearest and safest route [10]. This research introduced four scenarios to evacuate people when flood event occurred. The scenarios are as follows:

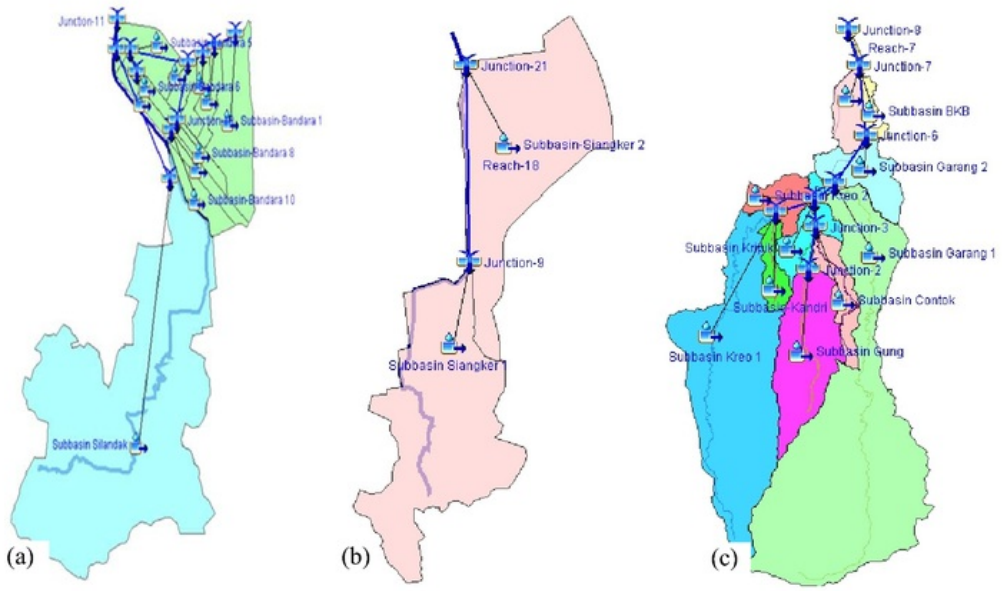

Fig. 3 (a) Basin Model Silandak CA, (b) Basin Model Siangker CA, (c) Basin Model Garang CA(West Banjir Kanal)

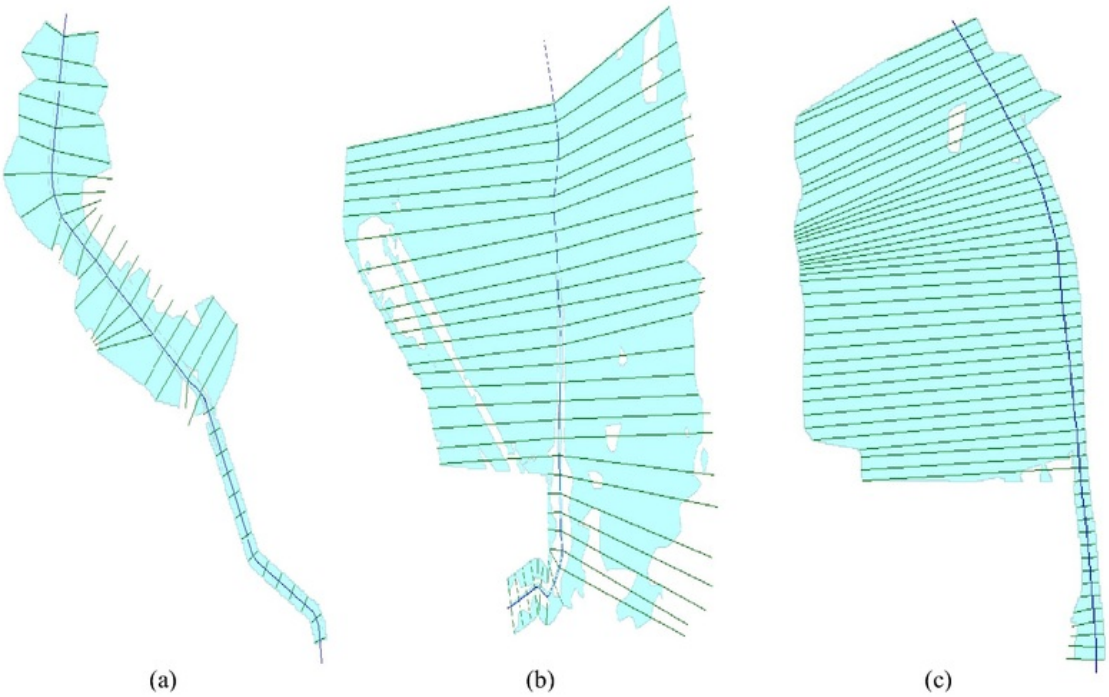

Fig. 4(a) The inundation spread of Silandak River; (b) Siangker River; (c) West Banjir Kanal

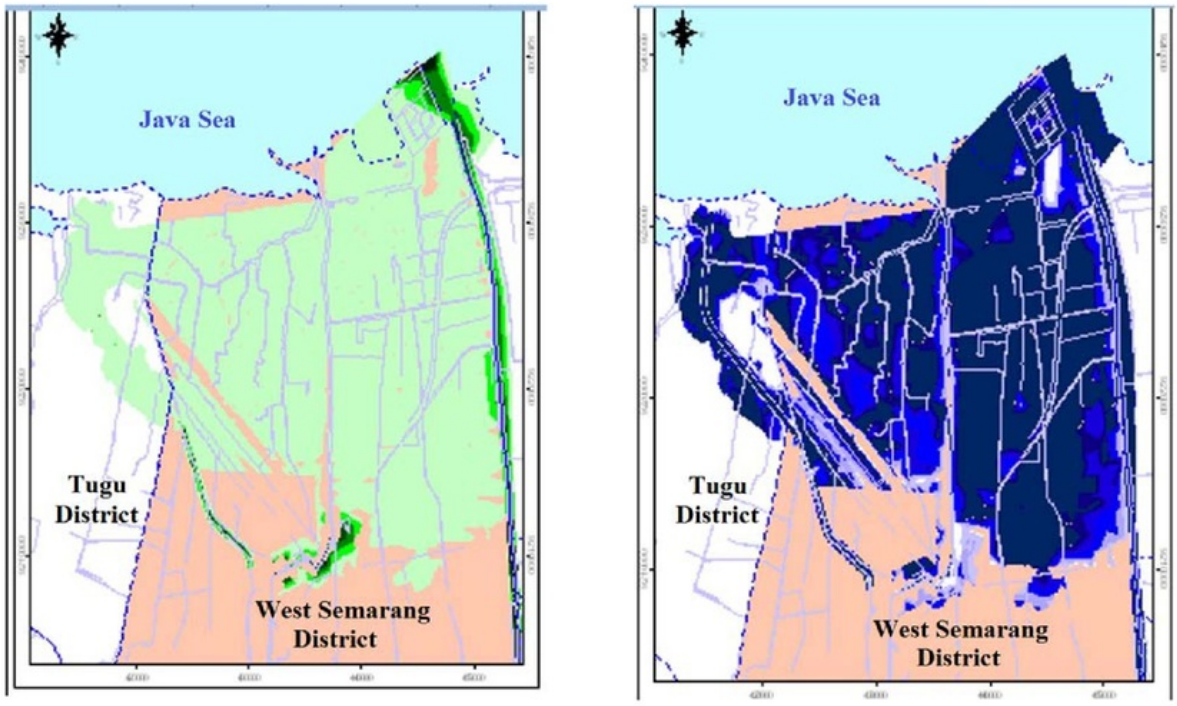

Fig. 5(a) Flood velocity Map; (b) Depth flood Map

1. Scenario A (Flooding in Silandak CA)

   In A-scenario, it was determined that there are 3 evacuation points. All evacuation points had been surveyed and evaluated their infrastructure and facilities availability, and ensured that they met the criteria required for evacuation shelters [11]. Then, a road network analysis was conducted to identify the evacuation routes as shown in Fig. 6(a). It was followed by evacuation time calculation.

   Evacuation time is the length of time required to evacuate the casualties from the collecting point to the evacuation point. The evacuation time was calculated from the beginning, i.e. when the flood reached the settlement and its vicinity until the flood reached the peak discharge (Q100).

   The flood began when the river water overflew Silandak river bank at 209 m3/sec discharge. It occurred at 03:26. By running HEC-RAS, it was found that the maximum discharge of 258.50 m^3/sec occurred at 04:00. The evacuation time was the difference between 04:00 and 03:26, i.e. 34 minutes. The evacuation process from the collecting point to the evacuation point consists of preparation time, travel time and safety coefficient. Analysis from three locations showed that the maximum travel time was 36 minutes by walk, and 13 minutes by motorcycle. This 36 minute walk has exceeded two minutes from the time limit. Yet, this 2 minutes is still tolerable because the safety factor is 80%.

2. Scenario B (Flooding in of Siangker CA).

   Based on the field survey, it was determined that there were 9 evacuation points, then road network analysis was conducted and followed by evacuation time calculation. See Fig. 6(b).

   The flood began at 01:49 when the discharge reached 170 m3/sec, while the maximum discharge of 285.20 m3/s occurred at 03:00. Thus, the evacuation time was 71 minutes. Research analysis showed that the longest evacuation time (from PRPP) was 70.21 minutes, reached by walk, and 20.04 minutes by motorcycle. Specifically, evacuation from PRPP area is obligated to use the motorcycle and/ or other vehicles. It is not safe by walk because it will exceed the maximum time limit.

3. Scenario C (Flooding in West Banjir Kanal).

   In scenario C, it was determined six evacuation points as seen in Fig. 7. Then road network analysis and evacuation time calculation were conducted.

The flood began at 07:15 when the discharge reached 3000 m^3/sec, while the maximum discharge reached 3717.60 m^3/sec and occurred at 08:00. Therefore, the evacuation time is 45 minutes. From the travel time analysis it was found that the maximum evacuation time by walk from the farthest location, Krobokan, was 39.03 minutes, and it took 14.84 minutes by motorcycle. From the Krobokan location, both by walk and/ or by motorcycle to the evacuation point are considerably safe.

4. Scenario D (Flooding in Silandak, Siangker and West Banjir Kanal).

In scenario D, there are 12 evacuation points. All evacuation points are a combination of the previous three scenarios. Evacuation time for the area around Silandak River CA was 34 minutes referred to Scenario A result. Evacuation time for the area around Siangker River CA was 71 minutes, resulted from Scenario B (Siangker River flood). Evacuation time for the area around the West Banjir Kanal based on Scenario C was 45 minutes.

4. Conclusions and recommendations

4.1. Conclusions

1 The capacity of the three rivers is not capable to hold the design flood (Q_{100}).
   a. Silandak River capacity = 209 m^3/sec, its design flood = 258.50 m^3/sec.
   b. Siangker River capacity = 170 m^3/sec, its design flood = 285.20 m^3/sec.
   c. West Banjir Kanal River capacity = 3000 m^3/sec, its design flood of 3717.60 m^3/sec.

2 The inundation covers the settlement and other areas of 10,80 km^2 (49.68%).

3 Based on the evacuation criteria and the field surveys results, there are 12 shelter points i.e. the State Elementary School of Tambakharjo, Tambakharjo Sub District Office, Nurul Falah Mosque, Kulon Kalibanteng Office, The RE Martadinata Military Police Office, Ronggowarsito Museum, Police Office in the West District Semarang, The West Semarang District Office, Salaman Mulyo Sub District Office, Karangayu Market, Baitul Atiq Mosque, and Yunior High School 30.

4 There are 18 evacuation routes identified, i.e.:
   a. From Gisikdrono Road to Tambakboyo Elementary School, Tambakboyo Sub District Office, and Nurul Fatah Mosque.
   b. From Ahmad Yani Airport to RE Martadinata PM Office, Ronggowarsito Museum, and the West Semarang District Office.
   c. From PRPP to the West Semarang Distict Office, the West Semarang Police Office, RE Martadinata PM Office.
   d. Tanjung Mas District to Yunior High School 30, West Semarang District Office, Karang Ayu Market.
   e. Anjasmoro Gas Station to the West Semarang District Office, the West Semarang Police Office, RE Martadinata PM Office.
   f. Krobokan Sub District Office to Yunior High School 30, Karangayu Market, Baitul Atiq Mosque.

5 Overall, the evacuation time by motorcycle is safe and does not exceed the time limit, i.e, the time required when the inundation reaches its peak. In several routes, the required evacuation time by walk has exceeded the inundation time (45 minutes):
from PRPP to The West Semarang District Office, to RE Martadinata PM Office and to the West Semarang Police Office. On average, it takes 70 minutes.

4.2. Suggestions

1. Some improvement is still required to apply this model to the research area and/ or other places by conducting some additional activities, i.e.:
   a. To validate the field condition that may affect upon the evacuation rate.
   b. To calibrate the real motor cycle speed to calculate the evacuation time.

2. Especially for PRPP, it is not permitted to evacuate people by walk because it will exceed the inundation time. It is obliged to evacuate people by motorcycle and/ or other vehicles.

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