An urban flood inundation and damage assessment for disaster risk reduction in Johan Pahlawan Sub-district, West Aceh Regency

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Abstract. Residential areas with the high rainfall intensity, flow pattern, and channel condition caused recurrent inundation flood in West Aceh Regency, Aceh Province, Indonesia. The inundation results in the physical damages to the housing components and the number of losses. This study aimed to devise the flood inundation map. The method was field survey to identifying the location, the inundation depth, and the conditions of the exposed residential in 20-24 September 2018. The results showed that the pattern of land flow and drainage conformed with the topography of the area. However, the channel condition, such as bushes, narrowing of the channel, and certain stations with low contoured, caused the vulnerability of inundation. The results showed that the area of the inundation was 26.66 Ha when the flood reached a maximum water level. The inundation varied in the study area, with a duration of 4 to 5 days. Forty housing units in different areas were exposed to the inundation flood, with varying damage conditions depending on the flood depth. It depended on the water depth of the flood. This approach can be a guideline for designing flood disaster mitigation strategies, especially for the elements of residential areas.

1. Introduction

Climate change has currently revealed a significant impact on water resources. Natural disasters due to weather system variability, climate change, and environmental degradation have often affected humans; and the impacts have rapidly increased in the last few decades [1]. Flood is one of the major natural disasters affecting many countries or regions around the world for years [2]. It is a natural event, defined as an overflow of water exceeding the carrying capacity of river channels, lakes, ponds, reservoirs, drainage systems, other bodies of water; and the inundation outside the body of water [3][4]. Flood is indicated by an unusual increase in the water level of river or channel, causing overtopping to the usually dry land or it receives more water than usual. Among the factors contributing to flood is heavy rain, melting snow, land subsidence, rising groundwater, dam damage [5].

Floods pose a substantial environmental threat, either natural or man-made [6]. We have to realize that there is no absolute protection against flood. Thus, it is crucial to discover a complex and integrated approach for flood protection [7][8]. In minimizing flood damage, the conventional flood protection measures remain important to implement [9]. On the other hand, it is necessary to increase the roles of flood prevention and risk management.

Generally, a flood risk assessment aims to determine a very high-risk location that requires mitigation measures. Risk mitigation means proposing, evaluating, and selecting the steps to reduce the risks in these areas. Therefore, a comprehensive analysis and assessment of flood risk is an integral part of the overall risk management concept [10]. One of which is by flood hazard assessment and flood hazard mapping.

The flood hazard assessment should be presented in the most straightforward classification, such as very high, high, medium, low, or very low hazards [11][12]. Inundation mapping or hazard assessment describes flood hazard areas by integrating the local knowledge, hydrological data, and
geomorphology using different approaches. The final flood hazard feature needs a broad inclusion of local or field knowledge in the model. For example, ranking the flood hazard indicators requires local knowledge, and it can vary depending on the circumstances [13]. Inundation or hazard mapping is an essential component of an emergency action plan; it benefits the officials in establishing policy and decision concerning how to plan meaningful land use in flood-prone areas [14].

The flood inundation mapping presents the spatial flood level quantitatively and qualitatively. Flood hazard assessment identifies the likelihood of the hazards, the specific times, as well as the intensity and impacted areas. The hazard is a potentially damaging physical event, a phenomenon that can lead to death or injury, property damage, environmental degradation, social and economic disruption [11].

In risk management, three main aspects are contributing to the flood risk in the urban system, namely hazard exposure, vulnerability and resilience. Hazard is an extreme natural event (including its frequency); exposure refers to the community, environment and property affected by the flood; and vulnerability refers to the vulnerability of the communities and property towards flood [15]. Meanwhile, the resilience of the region reflects the recovery condition from the impacts of the flood [16][17]. Vulnerability evaluation is an important element of flood management in decreasing the impacts of flooding, and reducing vulnerability is a more significant aspect for this type of management [18]. Thus, the development vulnerability assessment method is highly appropriate for further investigating to achieve this goal [19].

Flood hazard mapping can be undertaken by employing hydrological data, geomorphology, or a combination of both. Geomorphology is a geomorphological analysis of the landform and fluvial system and is supported by information concerning historical flood occurrence and detailed topographic information. This approach originates from two facts: 1) the microrelief of floodplains that regulates the flood water flow, and 2) the landform configuration and the pattern of fluvial sediment distribution have been formed by channels or rivers causing future floods [20].

The flood magnitude and damage are increasing worldwide. Therefore, geospatial technology has been utilized to reduce the damaging effects of flooding and to plan floodplains for the floodplain resident improvement [21]. Flood has repeatedly occurred in several residential areas in West Aceh Regency, Johan Pahlawan sub-district. The data of the Regional Disaster Management Agency of West Aceh Regency, Leuhan and Blang Beurandang villages experienced a repeated flood. The flood occurred in 2016, affecting nine districts, and Johan Pahlawan sub-district was the most severe. It led to thousands of residents in West Aceh to evacuate, and thousands of houses were submerged. The flood damaged the structural components of houses and caused significant losses. The recurring flood experiences and the casualties show that adequate information is necessary to reduce the level of flood threat in this location. It is paramount to recognize the threats in the area and include them in decision making, including implementing measures to reduce the impacts of the threats [22][23]. Therefore, this study aimed to devise the flood inundation map for the local spatial scale. Overall, this study was conducted by identifying the location, the inundation depth, and the conditions of the exposed residential areas using the survey method.

2. Materials and Methods

The study was conducted in the Johan Pahlawan sub-district, specifically in two villages inundated, namely Leuhan and Blang Beurandang villages. Of the 12 hamlets in the two villages, nine were affected by the flood. These included Raja Aceh and Cot Seumatang hamlets in Leuhan village as well as Raja, Manggis, Paya Seulimeng, Paya Simpo, Lam Ayon, Tiang Kapai and Blang Poroh hamlets in Blang Beurandang village.

2.1 Data Collection Process

The last flood event occurred in January 2017, and the survey was conducted in September 2018. The flood areas identification was conducted by field surveys employing Google Earth satellite imagery to determine the starting point. The key informants, the village headman, the staff of the village and the surrounding community, also supported the identification by providing information concerning the
location of the observation station along with the height, area and cause of the inundation. Data collection related to the flood condition is illustrated in Figure 1.

- Interviewing the key informants (1 and 2)
- Field survey (3 and 4)

**Figure 1.** Interview and field survey on the condition of the flood areas (taken on 20-24 September 2018)

### 2.2 Research Design

The technique used for determining the flow pattern was as follows. First, mapping the existing drainage network and its topographic condition assisted by Google Earth satellite imagery, the Global Mapper program version 18, to determine the condition of the region contour, GPS and total station. Second, documenting the condition of the drainage channel.

### 2.3 Tools and Data Processing

Data processing to identify the direction of the land flow, the drainage network mapping, and the initial flood area mapping was carried out based on the results of google earth satellite imagery. The data was analyzed using the Global Mapper program version 18 to determine the condition of regional contours. This study also involved GPS and total station. The ArcGIS program was also employed to process the data producing a map of the land flow direction. The channel flow direction was identified by analyzing the measurement results of the height differences to create a map of the existing drainage network and drainage condition. This map consisted of information on the direction of the drainage flow. Field documentation (photographs) explained the data on the drainage channel condition.

### 3. Results and Discussions

#### 3.1 Flood Inundation Condition

##### 3.1.1 Flood Area Identification

The high rainfall contributed to the flood in Leuhan and Blang Beurandang villages, Johan Pahlawan sub-district, West Aceh Regency, causing the flood inundation three to four times a year (BPBD
Of the 12 hamlets in the two villages, nine were affected by the flood. These included Raja Aceh and Cot Seumatang hamlets in Leuhan village as well as Raja, Manggis, Paya Seulimeng, Paya Simpo, Lam Ayon, Tiang Kapai and Blang Poroh hamlets in Blang Beurandang village. The inundation depth was varying. Figure 2 displays the photographs of the flood events.

- The flood event in Paya Simpo hamlet (1 and 2)
- The flood event in Paya Seulimeng hamlet (3 and 4)

Figure 2. The flood events (occurs on 20 October 2016)
Source: The community documentation

The flood inundation in Leuhan and Blang Beurandang village was generally due to the contour of the land. It was lower at several stations, causing the inundation during the flood events. Topographically, it conformed with the flow direction to the drainage channel. However, it required some improvements by adding new drainage networks. The capacity of the existing network was inadequate as a water catchment area, the distance to the outlet of the channel was far, requiring a certain amount of time. The channel that was full of shrubs disrupted the water flow. The sewer drainage channel did not function properly due to the considerable sedimentation and the road elevation without taking into account the water flow function.

3.1.2 The Analysis of Flood Inundation Stations
The location of flood monitoring was informed by the key informants, and it was analyzed using a contour map and processed by the ArcGIS program. To verify the map, field observation was conducted to document the height or traces of the inundation at residents houses and other public facilities affected by the flood, and to record the coordinates of the inundation stations for each hamlet (Figures 3 and 4).
• The water level of 2 m in the villager’s house at Raja hamlet (1 and 2)
• The water level of 1.5 m in the school building at Manggis hamlet (3 and 4)

**Figure 3.** Map verification by field measurement (1) (taken on 20-24 September 2018)

• The water level of 1 m in the villager’s house at Lam Ayon hamlet (1 and 2)
• The water level of 0.5 m in the villager’s house at Blang Poroh hamlet (3 and 4)

**Figure 4.** Map verification by field measurement (2) (taken on 20-24 September 2018)
The verification results showed that the inundation during the flood in the hamlets in Blang Beurandang village reached a maximum water level of 26.66 Ha (4.20% of the total area of Blang Beurandang village). Whereas, it was 9.70 Ha in some parts of Leuhan village (3.20% of the total area of Leuhan village). Based on the village staff interviews, it was revealed that when the heavy rain poured for several consecutive days, the flood inundation occurred for 4 to 5 days (started from 0.50 to 2 m). The most vulnerable village of inundation was Raja Aceh hamlet in Leuhan village and Raja hamlet in Blang Beurandang village.

The data verification output created the flood inundation map (Figure 5). Next, the area of inundation was identified by measuring the flood area using the ArcGIS program.

Figure 5. The flood inundation map

The water flowing in the drainage system discovers its way through the natural channel, ultimately accumulated in the Meureubo River. Sometimes, the water discharge flowing in a river exceeds its capacity and holds water in the drainage. Besides, the floodwater finds its way through natural inundation in low land. The water accumulated in the lowland and river floodplain does not necessarily return to the river. The only method to enable water to return to the river is by pumping or allowing the inundation to dry through evaporation.

3.2 The Damage Conditions of Residential Buildings

The flood inundation occurred in Leuhan, and Blang Beurandang village submerged not only the public and social facilities but also the residents’ houses. Forty units of houses were exposed to the flood inundation. Of the 40 houses, 17 houses were in Leuhan village, including nine houses in Raja Aceh Hamlet and eight houses in Cot Seumatang Hamlet. Twenty-three houses were also affected in Blang Beurandang village, including three in Raja hamlet, four houses in Paya Simpo Hamlet, five houses in Paya Seulimeng hamlet, two houses in Manggis hamlet and nine houses in Lam Ayon hamlet.

The residential houses exposed to the inundation flood had varying damage condition, such as the decreased foundation, the damage of the column and sloof structures, the cracked floors, the peeling
paint, tiles, the cracked of wall plaster, and the damage of the doors and windows. The damage identification was conducted by reviewing the affected houses to record the damages in the working table and then documented them.

4. Conclusion
The flood inundation in the study area has occasioned physical damages to the housing components and the number of losses. The channel conditions, such as the shrubs, the narrow channel, and the low contoured of certain parts of the area lead to the vulnerability to inundation. The water accumulated as inundation does not necessarily flow back to the river because the river exceeds its water capacity and holds water in the drainage. This study has been successful in devising a flood inundation hazard map by identifying the location, height and area of the inundation as well as the conditions of the exposed residential area, employing survey and verification methods. These approaches can be beneficial as the guideline in designing flood disaster mitigation strategies, especially for elements of residential areas.

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