Case Study: Significant factors in hazard and vulnerability assessments in flood mitigation in Padang City

A Ikhvan\(^1\,\,^2\) and M Mera\(^3\)

\(^1\)Doctor Student in Civil Engineering, University of Andalas, Indonesia.
\(^2\)Water Resources Development Agency of West Sumatra, Indonesia
\(^3\)Associate Professor in Civil Engineering, University of Andalas, Indonesia.

Corresponding author: mas_mera@eng.unand.ac.id

Abstract. Flood disasters often occur in Padang City due to rainfalls with high intensity and frequency, and are exacerbated by the city located on a flatter coast up to the steep Bukit Barisan. The mountain of Bukit Barisan is parallel to the Padang shoreline, and the distance between them is relatively close, it's just about 20 km. The present research focuses on the determination of the significant factors in the assessments of both hazard and vulnerability in flood mitigation in Padang City. The hazard assessment in the present study uses indicators of hydro-meteorological, elevation, slope, land use, and flood-frequency data. Whereas the vulnerability assessment uses indicators of Population density, Settlement density, sex ratio and age group ratio data. The results of the present study show that the most significant factors in flood-hazard assessment in Padang City are the land elevation factor from the sea level and the slope factor especially in the upper reaches of the river. Meanwhile, the factors of density levels of both the settlement and population are crucial in the assessment of flood vulnerability in Padang City.

1. Introduction
Change in land use due to population growth resulting in deforestation for residential areas, agriculture, mining and the use of wood as human needs, and also natural phenomena such as climate change are triggering the occurrence of floods, landslides and debris flows.

Previous researchers [1-7] revealed a lot of things related to damage to the river environment due to changes in river morphology concerning the stability of the riverbed, especially in rivers in mountainous areas since those have a steep slope. Furthermore, for rivers that are generally located on flatter areas the discussion is more focused on the problem of flood management on flood plains and sediment transport as conducted by researchers [8-13]

To reduce the damage caused by disasters arising from changes in natural conditions, researchers, practitioners and decision makers seek to learn from all disciplines to make updates on river management, and disaster risk reduction [14], as well as the management of risks that will occur [15].

Some practitioners consider that increasing resilience by building infrastructure is an important goal in managing flood risk. That is because infrastructure resilience is often described as the most decisive factor for reducing disaster risk in a city [16]. Meanwhile, according to [17], a resilient city is a city with a community resilience system or the ability of the community to withstand disasters, and is able to recover in effective and efficient time period from disaster events, as well as in terms of preserving and restoring buildings and other vital facilities. However, there are still challenges to make
resilience concept as an effective operational tool to achieve objectives in making disaster management policies [18].

The implementation of different strategies in managing flood risk will result in different impacts on the river system. Then other people with different backgrounds should review these impacts differently [19]. Natural phenomena that cause changes in river morphology can be considered different due to differences in time. Because what is acceptable now is not necessarily acceptable in the future. [20].

Flooding in cities due to river overflows is not a phenomenon that occurs by itself, but is the result of activities, policies related to the characteristics of human life in watersheds [18]. A flood-risk management with comprehensive and well-coordinated approach can reduces flood risk. Certainly, the same understanding among stakeholders at various administrative levels on the issue of flood risk is a must, and the flood process should not be considered a one-time task but it is an ongoing learning process [21].

![Map of West Sumatra Province with Padang City highlighted](image)

**Figure 1.** Padang City (located in West Sumatra Province) as research site. This city is located [24, 25]

The first step in flood-risk assessment is making a hazard map. This map can be a reference for managing risk and making a decision for disaster-mitigation operations. However, risk assessment should not stop at reviewing existing risks only, but the assessment process must be repeated in every
decision making in determining either structure or non-structure alternatives to reduce damage due to flood [19].

Effective flood-disaster mitigation must have three main elements, namely: (1) hazard assessment to identify populations and assets that are threatened, and determine the level of threat that will occur; (2) warning the public about disasters that will threaten; and (3) preparation, namely knowledge about disaster-prone areas and knowledge of early warning systems to know when to evacuate and when to return when the situation is safe [22]. Therefore, this paper focuses on determining the significant factors in the assessments of both hazard and vulnerability in flood mitigation in Padang City, West Sumatra Province (Figure 1). Factors in the assessments of hazard and vulnerability are as in the study of Bubeck et al. [23].

2. Methodology
Flood-risk assessments are based on two parameters, i.e. hazard and vulnerability. Factors used to determine the flood hazard in Padang City are rainfall, elevation, slope, landform, land use, and frequency of flooding. These hazard factors are determined based on natural factors that always cause flooding in urban areas from several previous research results, especially studies regarding floods in Padang City. Meanwhile, the factors used to determine the level of flood vulnerability are related to the human condition in the vulnerable location, namely: population density, settlement density, sex ratio, and age group ratio.

Data used in this study are obtained from related agencies such as BNPB, BPBD, BMKG, West Sumatra PSDA, BWS S5 and BPS of Padang City. The assessments are made of the factors that determine damage and losses arising from flooding, as well as a discussion of the significant factors within each of these parameters.

3. Results and discussion
Floods in Padang City are caused by: high rainfall; the many rivers flowing through the city; and high tides (rob). The floods due to high rainfall locally are exacerbated by an inadequate drainage system or unable to accommodate surface runoff, because the area of the forest is significantly reduced (Figure 2-4).
The development of urban-community settlements in water-catchment areas and in conservation areas has reduced the areas of water-catchment areas and temporary water catchment areas. This is in turn to be widespread flood-prone areas.

3.1. Flood-hazard assessment

Flood-hazard assessment must be carried out in an integrated way by identifying all factors causing hazards associated with water [18]. Therefore hazard quantification must begin by relating flood-hazard parameters to factors of hydro-meteorological, elevation, slope, land use, and frequency of flood-events data.

All rivers in Padang City flow into the Sumatra west coast. The headwaters of the river are generally located on the western slopes of Bukit Barisan [26]. There are 21 rivers with widths between 5 and 60 m and lengths between 0.4 and 20 km (Figure 5).

Rainfall is a very important climate element in flood-hazard assessment. Rainfall data are collected from five rainfall stations in Padang City, namely Batu Busuk, Gunung Sarik, Gunung Nago, Ladang Padi and Simpang Alai. The data showed that the highest average monthly rainfall was always in November and the lowest average monthly rainfall almost always occurred in February within 44 years (1975 to 2018) (Figure 6). The Station of Gunung Nago recorded the highest average monthly rainfall, which was 578 mm, while the Simpang Alai Station recorded the lowest average monthly rainfall, which was 205 mm. From the Figure 6, it can be seen that the monthly rainfall in average was above 400 mm which was the peak of rain in November and October. Rainfall in Padang City was high with an average monthly height above 200 mm.

From topographical conditions (Figure 7), 60% of Padang City is an area with hilly morphology and very steep slopes. Only 30% is suitable to be used as residential areas. Padang City land cover is divided into six types, namely: (a) residential land (16.5%); (b) rice fields (9%); (c) mixed agriculture (3.4%); (d) bush (0.6%); (e) vacant land (0.6%); and (f) forests (70%).

While from the availability of 12,509 ha of land in the city of Padang, only 18% of the land is very suitable for residential areas. However, based on data on the distribution of land use for settlements in 2014, there are still 0.2% of the area not suitable for residential land. Map of land suitability of Padang City is shown in Figure 8.
According to Iswandi [28], flood-hazard levels in Padang City consist of three categories: (1) an area of 9,531 ha is high prone-areas, (2) an area of 10,220 ha is medium prone-areas, and (3) an area of 49,745 ha is low prone-areas. In this study area, flood-prone areas in Padang city are distributed and are presented based on the level of flood hazard as shown in Figure 9.

Meanwhile, flood-frequency factors consist of four categories: (1) 3.3% of the study area is always flooded (more than 6 times a year), (2) 2.6% of that is often flooded (4 to 6 times a year) whereas (3) 1.4% of that is rarely flooded (less than 4 times a year), and (4) 92.7% of that is never flooded as seen in Figure 10.

Furthermore, based on Iswandi [28] there are six types of land use including housing (16.5%), rice fields (9.3%), mixed agricultures (3.8%), bushes (0.6%), empty lands (0.6%), and forests (69.3%). The distribution of land elevation and land use in Padang city is shown in Figure 11.

Overlaying the maps above the flood-hazard areas give as follows: (1) an area of 8,351.6 ha is in high hazard-zones; (2) an area of 11,378.7 ha is in medium hazard-zones, and (3) an area of 49,738.8 ha is in low hazard-zones [28]. Distribution area with flood-hazard levels in Padang city is shown in Figure 12 as the flood-hazard map.
3.2. Flood vulnerability assessment

Vulnerability is a condition of a community that leads to or causes an inability to deal with disasters [29]. In this case, the parameters used to determine the level of vulnerability in this study are: (1) the level of population density; (2) sex ratio; (3) age group ratio; and (4) settlement density.

The population density parameter in the flood-vulnerability assessment is a picture of community conditions related to the population per square km. This means that the more the number of inhabitants per square km, the higher the level of vulnerability in dealing with disasters. Based on BNPB [29] the population density level has a weight of 30%. Whereas from population density data obtained from BPS [30], population density levels in 2015 are divided into three categories, namely: (1) low (< 500
people per square km); (2) moderate (500 to 1,000 people in km$^2$); and (3) high (> 1,000 people in square kilometer). There are two subdistricts with low density, namely: Pauh and Bungus Teluk Kabung; two subdistricts with moderate density, namely Koto Tangah and Lubuk Kilangan; Seven sub-districts with high levels of density, namely North Padang, East Padang; West Padang; South Padang; Nanggalo; Kuranji; and Bungus Teluk Kabung as shown in Figure 13.

The sex ratio parameters in the flood-vulnerability assessment are determined based on the percentage comparison between the sexes of men and women. This means that in terms of vulnerability the greater the number of female sex from male sex, the more vulnerable a community is in the face of flooding (Figure 14).
The age group ratio parameters in the flood-vulnerability assessment are determined based on the age group that is vulnerable to face the threat of flooding. This means that the greater the non-productive age, the higher the level of vulnerability in dealing with floods. While the ratio of the age group is the percentage of the ratio of productive to non-productive age. Productive age categories are those in the age range between 15 and 64 years, other than that age range (ie 0 to 14 years and > 64 years) categorized as non-productive ages (Figure 15).

Whereas settlement densities are divided into four categories, namely densely populated, rather densely populated, sparsely populated, and no residents. Based on BNPB [29], the density of settlements to flood vulnerability is 25%. Data on distribution of settlements in 2015 according to BPS Padang (2016) are as follows: 9.03% of the area is densely populated; 0.7% of the area is rather densely populated; 22.7% of the area is sparsely populated; and 67.5% of the area is no residents (Figure 16).

While the parameters of flood disaster events that occur, based on data from Padang City BPBD [31] show the frequency and extent of affected floods in residential areas from time to time significantly increased. Therefore flood-vulnerability assessment on this parameter is very influential in flood-disaster mitigation. Figure 17 shows that land use in Padang City of 16.5% is a residential area, where around 53.5% is located in a very dangerous zone for flooding, and 31.5% has a high level of vulnerability that is spread over three sub-districts namely West Padang, Nanggalo and Padang South.

![Figure 17. Map of flood-hazard settlements (left) and of flood-vulnerability settlements (right) [28]](image)

4. Conclusions
The most determining factor in the flood-hazard assessment in Padang City is the land elevation from the sea level. The lower the land elevation, the greater the danger of flooding. The second significant factor in assessing the flood hazard is the river slope factor, especially in the upper reaches. The higher the land slope, the higher the level of flood hazard that may occur.
Meanwhile, the most significant factors in the flood-vulnerability assessment in Padang City are the density level of both settlement and population. The higher the density level of both the settlements and population in an area, the higher the level vulnerability of the area against the flood.

5. Recommendations

A further study of this research is an investigation of the capacity assessment to reduce disaster risk in flood-mitigation efforts in Padang City.

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