Formulating Disaster Mitigation Strategies for Surakarta City, Indonesia by Using Risk Matrix and House of Risk Phase 2

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Abstract. Surakarta is a city in Central Java, Indonesia that has the potential to be affected by any type of disaster. This study aims to identify hazards that may cause disasters in the city; to measure the level of damage produced by the disasters; and to provide disaster mitigation strategies for the city over the 2023-2027 period of time. To achieve these aims, this study uses the risk matrix method to determine the level of risk imposed by each of the potential disasters and implements the house of risk (HoR) phase 2 to formulate disaster mitigation strategies. The study reveals that there are 7 potential disasters taking place in the city during the time period of 2023-2027. The use of HoR phase 2 results in 10 mitigation strategies, namely "Carrying out disaster outreach and education"; "Collaborating with other parties in disaster management", "Strengthening the legal framework for disaster management", "Mapping disaster-prone areas", "Providing early warning of disasters to communities", "Forming disaster-resilient villages", "Cleaning and developing water drainage channel", "Controlling illegal settlements", "Adding water catchment areas"; and "Conducting reforestation".

1 Introduction

Natural disasters cause significant losses, both directly and indirectly, such as loss of life, infrastructure damage, financial losses, environmental degradation, and trauma for survivors (1)(2)(3). The causes of natural disasters can be categorized into two types (4): natural disasters caused by natural phenomena, such as earthquakes, volcanic eruptions, tsunamis, and windstorms, and human-induced natural disasters, such as slope cutting, deforestation, forest fires, improper waste disposal, oil drilling.

Indonesia is located in an area where three tectonic plates converge: the Eurasian Plate, the Pacific Plate, and the India-Australia Plate, each moving westward and northward relative to Eurasia (5). Consequently, Indonesia is tectonically unstable and is one of the most active continental margins on Earth, leading to a high susceptibility to disasters (6).

Surakarta is a city located in Central Java Province of Indonesia. It lies between 70' 36" – 70' 56" South Latitude and 45'15" – 70' 56" East Longitude, covering an area of 44.03 km2. Surakarta is divided into 5 sub-districts, 54 urban villages, and rural villages. The city's elevation ranges from 93 meters to 98 meters above sea level, and it has a tropical monsoon climate with daily temperatures ranging from 21°C to 32.5°C and an average annual rainfall of 2,200 mm.

According the United Nations (7), a disaster is a serious distraction of the operative of a community or a society at a particular level of scale caused by harmful occurrences interrelating with circumstances of exposure, capacity and vulnerability which subsequently culminate in one or more of human, material, economic and environmental losses and effects. Disaster risk, as defined by the United Nations (8), is the likelihood of an outcome having an undesirable impact on persons, systems or properties. Meanwhile, according to Law Number 24 of 2007 (9), disaster risk refers to the potential losses caused by a disaster in a specific area over a certain period, including deaths, injuries, illnesses, threatened lives, loss of security, displacement, damage or loss of property, and disruption of community activities. Hazard, according to the United Nations General Assembly, refers to "a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation" (10). According to the BNPB Regulation Number 4 of 2008 (11), potential disasters in Indonesia can be grouped into two main categories: main hazard potential and collateral hazard potential. Main hazard potential can be seen in maps indicating earthquake-prone zones in Indonesia, illustrating Indonesia as a region with earthquake-prone zones, landslide vulnerability maps, volcanic eruption hazard maps, tsunami hazard maps, flood hazard maps, and others. Consequences refer to the impact resulting from an event (disaster) that has occurred. The consequences depend on the severity level of a disaster. For example, high-severity disasters like earthquakes, tornadoes, and floods can cause significant human casualties and economic losses (12).

In this study, hazard identification was conducted to identify potential natural disasters and assess the level of damage caused by a disaster. Therefore, the researchers conducted research using risk matrix method (see, for example, (13)) and the method of house of risk (HoR) phase 2 (14) to assess the potential risks and provide

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alternative solutions or mitigation efforts to reduce the impact of disaster risks in Surakarta City over a period of 5 years, from 2023 to 2027. The use of the risk matrix along with the HoR phase 2 can be seen, for example, in (2).

2 Method

2.1 Research Object

The research was conducted in the Surakarta City area, focusing on studying natural disasters occurring within the city. This study involved the Surakarta City Regional Disaster Management Agency (BPBD) as the official government organization responsible for disaster-related issues within the administrative area of Surakarta City.

2.2 Data Collection Method

The data used in this research can be categorized into two types: primary data, collected directly by the researcher to address the research questions through observation, direct interviews, and documentation, including hazard types, hazard frequency data, and disaster risk data. Secondary data includes historical data on variables collected and compiled by other parties, obtained from laws, journals, theses, and information available on the internet. The data collection methods in this study are as follows:

2.2.1 Interviews

Interviews involve collecting data or information by directly meeting with relevant parties. Through interviews, interviewers can gain a complete understanding, expressions, feelings, experiences, and opinions on the topic being researched. Data collected through interviews in this research include risk event data, risk agent data, and disaster mitigation data.

2.2.1 Literature Review

Literature review is a technique used to obtain data or information related to the research problem from relevant books, research findings, journals, and theses related to the object of study.

2.2 Data Analysis Method

Risk assessment aims to identify and outline all potential risks arising from both internal and external factors. It ranks the risks that require immediate attention and those that do not need further intervention, providing input or recommendations to ensure that the highest priority risks are effectively managed (15).

The data analysis in this study employs the risk matrix method. The risk matrix is an identification stage that prioritizes risks for preventive action by mapping the probability of risk events and the impact of these events. The risk matrix is divided into three areas: green indicates no corrective action is needed, orange indicates corrective action should be considered, and red indicates corrective action is urgently needed. Additionally, the study also utilizes the HoR phase 2 method, which focuses on risk management through prevention measures. Identified risk agents causing risk events can be managed to reduce the likelihood of these risks occurring.

The first step in this research is to identify potential natural disasters in Surakarta City, based on Law No. 24 of 2007. This is done through interviews with the Surakarta City's BPBD. The second step is to determine the aggregate risk potential (ARP) value by determining the frequency of disaster events over a specific period and establishing probability scores based on BNPB guidelines, using a scale from 1-5 where 1 indicates highly unlikely and 5 indicates highly likely. Then, determining the level of consequence (risk impact) of a disaster and assigning consequence scores on a scale from 1-5, where 1 indicates no effect and 5 indicates a serious effect (12). The probability and consequence values for each disaster risk are then plotted on the risk matrix. The risk matrix is divided into three areas: green indicates low risk, orange indicates moderate risk, and red indicates high risk. To further consider each aspect, modeling and evaluation can be performed using the multiplication modeling of disaster event probability with consequence estimates (16).

The next step involves applying the HoR phase 2 with the Surakarta City BPBD to generate appropriate mitigation strategies. Then, determining the correlation value between disaster risks and mitigation strategies, where 0 indicates no relationship, 1 indicates low correlation, 3 indicates moderate correlation, and 9 indicates high correlation. Subsequently, calculating the total effectiveness of mitigation (TEk); determining the level of mitigation difficulty (Dk), where 3 indicates easy mitigation strategy, 4 indicates moderately difficult mitigation strategy, and 5 indicates challenging mitigation strategy; and then determining the effectiveness of mitigation strategies in relation to the difficulty of their implementation (ETDk). The higher the score obtained, the more effective the strategy can be implemented. The results of the HoR phase 2 method are the sequence of natural disaster mitigation strategies in Surakarta City from 2023 to 2027.

3 Results and Discussion

Data on disaster occurrences taking place in Surakarta City from 2018 to 2022 are presented in Table 1. Several potential disasters that could strike Surakarta City, causing significant losses to the surrounding communities, are listed in Table 2. The assessment results of the probability and consequence of each disaster risk are presented in Table 3 as the Aggregate risk potential (ARP) values. These ARP values were subsequently plotted into a risk matrix to identify disaster priorities, as shown in Figure 1.

Table 1. Disaster occurrences in Surakarta

Years	Number of Occurrences				
	Flood	Fire	Landslide	Extreme Weather	Drought
2018	10	3	1	42	0
2019	8	0	1	74	65
2020	4	0	2	27	0
2021	14	8	3	46	0
2022	31	3	4	24	0
Amount	67	14	11	213	65

(Source: Surakarta City Disaster Management Agency)

Table 1 shows that there were five types of disaster incidents from 2018 to 2022. Extreme weather had the highest number of occurrences, followed by floods, drought, fires, and landslides. Based on discussions held, there are seven potential disaster types that could occur in Surakarta City, as shown in Table 2.

Table 2. Potential Disasters in Surakarta City

No	Disaster Potential	No	Disaster potential
1	Flood	5	Extreme Weather
2	Fire	6	Earthquakes
3	Landslide	7	Drought
4	Volcanic Eruptions		

Floods can occur due to water exceeding the drainage system's capacity, damaged river conditions, violations of spatial planning, less integrated development planning, low soil infiltration capacity, and above-normal rainfall, leading to waterlogging (17). Fires have negative impacts on the physical environment, including decreased air quality due to dense smoke reducing visibility and disrupting transportation, altering the physical-chemical and biological properties of the soil, changing the microclimate due to plant loss, and contributing to the greenhouse effect globally (18). Landslides cause human casualties, property and asset losses, environmental damage, and psychological impacts (19). Volcanic eruptions pose hazards such as pyroclastic flows, lava, lahars, ashfall, and tsunamis (20)(21)(22)(23)(24). Extreme weather events, typically sudden strong winds with a specific center and movement (25), can cause damage to areas in their path. Earthquakes may disrupt human life (26), leading to casualties (27), damage to infrastructure (28) and/ or cultural assets (29), and financial losses (30). According to (31), drought results in communities struggling for clean water and insufficient irrigation.

Table 3. Aggregate risk potential (ARP) values

Hazard	Number	Probability (P)	Consequences (C)	ARP
Flood	67	4	4	16
Fire	14	2	4	8
Landslide	11	2	3	6
Volcanic eruption	0	1	2	2
Extreme weather	213	5	2	10
Earthquake	0	1	2	2
Drought	65	2	3	6

Based on the ARP values presented in Table 3, the most frequent disaster events causing significant damaging impacts are floods, which have the highest ARP value. Floods occur frequently, leading to severe consequences such as financial losses and damage to government and public infrastructure. Extreme weather events also occur annually, causing minor damages like fallen trees or billboards, resulting in financial losses. Fires happen almost every year, causing moderately severe consequences, particularly in environmental damage. Landslides occur annually, with moderate consequences, often resulting in injuries. Droughts occur occasionally, causing moderate consequences, especially in environmental losses. Volcanic eruptions are almost impossible to occur, and earthquakes have a very low probability, both with low consequences.

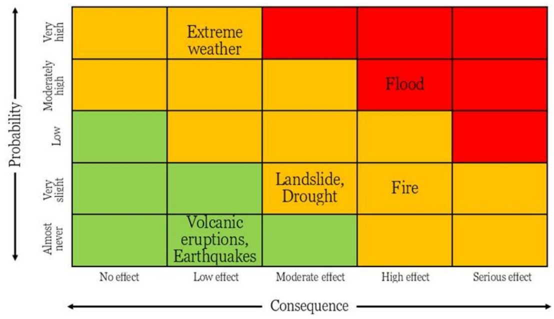

Figure 1. Risk matrix

According to Figure 1, floods have a high occurrence frequency annually and pose a high risk, making them the top priority for disaster mitigation (ARP value 16). Extreme weather events have a very high annual frequency, necessitating disaster risk management (ARP value 10). Fires pose a high risk (ARP value 8), while landslides and droughts have moderate risk levels with occasional occurrences (ARP value 6). Volcanic eruptions and earthquakes have low-risk levels and almost impossible occurrence frequencies (ARP value 2).

The HoR phase 2 is employed to manage risks, where identified risk factors can be managed to reduce the likelihood of their occurrence. In the HoR phase 2, mitigation strategies are sought, and the total effectiveness of mitigation (TEk), the mitigation difficulty level (Dk), and the mitigation strategy effectiveness in addressing implementation difficulty (ETDk) are calculated.

Table 4 presents the sequence of disaster risks from the highest based on ARP values. The resulting sequence of disaster risks serves as a reference for determining mitigation strategies aimed at minimizing the sources of risk, as presented in Table 5.

Table 4. Potential disasters

Code	Potential disaster	Code	Potential disaster
R1	Flood	R5	Drought
R2	Extreme Weather	R6	Volcanic Eruptions
R3	Fire	R7	Earthquakes
R4	Landslide		

Table 5. Mitigation strategies for disaster risks

Code	Mitigation strategy	Code	Mitigation strategy
P1	Carrying out disaster outreach and education	P6	Controlling illegal settlements
P2	Providing early warning of disasters to communities	P7	Adding water catchment areas
P3	Forming disaster-resilient villages	P8	Cleaning and developing water drainage channel
P4	Collaborating with other parties in disaster management	P9	Conducting reforestation
P5	Mapping disaster-prone areas	P10	Strengthening the legal framework for disaster management

With reference to the interviews and discussions with the Surakarta City Regional Disaster Management Agency, there are 10 mitigation strategies in addressing disaster risks in Surakarta City for the period from 2023 to 2027. Subsequently, the TEk values, the Dk values, and the ETDk values were calculated using the HoR phase 2, as presented in Table 6. In this sense, the larger the ETDk value generated for a mitigation strategy, the more effective the measures are in minimizing the risks caused by disasters.

Referring to the results in Table 6, each mitigation strategy P1, P4, and P10 have the highest TEk value, all equal to 450; followed by P5 with a TEk value of 306; then P2 with a TEk value of 288; next, P6 with a TEk value of 254, P3 with a TEk value of 240; P8 with a TEk value of 202; then P7 with a TEk value of 190; and finally, relatively lower, P9 with a TEk value of 144. Based on discussions with the Regional Disaster Management Agency, difficulty levels for each mitigation strategy were determined as presented in Table 6. Furthermore, the effectiveness of mitigation strategies in relation to their implementation difficulty (ETDk) yielded the highest values for P1 and P4, both with an ETDk value of 150.00; followed by P10 with an ETDk value of 112.50; then P5 with an ETDk value of 102.00; P2 with an ETDk value of 96.00; P3 with an ETDk value of 80.00; P8 with an ETDk value of 67.33; P6 with an ETDk value of 50.80; P7 with an ETDk value of 38.00; and lastly, P9 with an ETDk value of 36.00.

Table 6. The ETDk calculation by using the HoR phase 2

Disaster risk	Mitigation strategy										ARP
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	
R1	9	9	9	9	9	9	9	9	3	9	16
R2	9	9	9	9	9	9	0	3	9	9	10
R3	9	0	1	9	1	3	1	1	0	9	8
R4	9	3	3	9	9	3	3	3	3	9	6
R5	9	3	3	9	9	1	3	3	9	9	6
R6	9	9	0	9	1	0	1	0	0	9	2
R7	9	3	1	9	1	0	0	0	0	9	2
Tek	450	288	240	450	306	254	190	202	144	450	
Dk	3	3	3	3	3	5	5	3	4	4	
ETDk	150.00	96.00	80.00	150.00	102.00	50.80	38.00	67.33	36.00	112.50	
Priority	1	5	6	1	4	8	9	7	10	3	

Table 7 presents the mitigation strategies with their order of priority that should be carried out by the Surakarta City Regional Disaster Management Agency from 2023 to 2027.

Detailed explanations of the mitigation strategies by the Surakarta City Regional Disaster Management Agency can be found in the Surakarta City Disaster Risk Study (32), as follows:

1. Carrying out disaster outreach and education

In its implementation, the Regional Disaster Management Agency conducts campaigns introducing disasters and emphasizes the importance of adhering to disaster-prone zone regulations from the district level down to the neighborhood level. This includes conducting education and training (training programs), periodic technical guidance supported by a systematic and certified curriculum.

2. Collaborating with other parties in disaster management

In its execution, the Regional Disaster Management Agency conducts comprehensive socialization in various government agencies (OPD), the Regional People's Representative Council (DPRD), civil society organizations, private sectors, universities, media, and strategic partners at both central and regional levels. This builds networks and communication links among parties interested in and concerned about disaster risk reduction efforts in Surakarta City.

In industrial activities, it is not allowed to release air pollutants in the form of smoke. Proper wastewater treatment facilities must be established to prevent soil and water ecosystems from being damaged by hazardous chemicals. Industrial zones are not allowed near water sources, and excessive use of hazardous chemicals and pesticides is prohibited.

Table 7. The rank of the mitigation strategies

No	Mitigation strategy	Code	ETDk	Rank
1	Carrying out disaster outreach and education	P1	150.00	1
2	Collaborating with other parties in disaster management	P4	150.00	2
3	Strengthening the legal framework for disaster management	P10	112.50	3
4	Mapping disaster-prone areas	P5	102.00	4
5	Providing early warning of disasters to communities	P2	96.00	5
6	Forming disaster-resilient villages	P3	80.00	6
7	Cleaning and developing water drainage channel	P8	67.33	7
8	Controlling illegal settlements	P6	50.80	8
9	Adding water catchment areas	P7	38.00	9
10	Conducting reforestation	P9	36.00	10

3. Strengthening the legal framework for disaster management
The strengthening of the disaster management legal framework by the Surakarta City Regional Disaster Management Agency involves the formulation of regulations, Standard Operating Procedures (SOPs), strengthening of local regulations related to disaster management, strengthening policies and institutions for disaster management that accommodate all potential resources (government, society, business, academia, and media), strengthening disaster risk reduction forums at the Surakarta City level down to the village level, and strengthening regulations related to disaster information dissemination to maintain information validity.
4. Mapping Disaster-Prone Areas
In its implementation, the Surakarta City Disaster Management Agency maps disaster-prone areas based on risk analysis calculations performed using several parameters: threat level (Hazard), vulnerability level (Vulnerability), and capacity level (Capacity), which are layered to determine the risk level.
The hazard component is determined through probability analysis and the intensity of events. The vulnerability component is calculated based on four parameters: social vulnerability (exposed population), economic vulnerability (loss of productive land), physical vulnerability (losses due to house and building damage), and environmental vulnerability (environmental damage). Finally, the capacity component is determined using two parameters: regional resilience (government sector) and community readiness (community sector). The results of all risk calculations, risk mapping, and their spatial distribution are presented on a disaster risk map, with analysis units ranging from village level to district and municipal levels.

5. Providing early warning of disasters to communities
In its implementation, the Regional Disaster Management Agency establishes a reliable early warning information system for various disaster threats in Surakarta City, which is connected to the national disaster early warning system, reaching directly to the community.
6. Forming disaster-resilient villages
In its execution, the Regional Disaster Management Agency promotes disaster awareness culture in the community, integrated into programs such as Disaster-Prepared Schools. This includes preparing evacuation guidelines and self-rescue from disaster threats, as well as installing evacuation signs at vital facilities such as hospitals, laboratories, industries, offices, places of worship, schools, public infrastructure, tourist areas, and cultural heritage sites
7. Cleaning and developing water drainage channel
In its implementation, the Regional Disaster Management Agency develops drainage network systems based on integrated primary and secondary water management systems, including primary networks comprising main and tributary rivers, secondary networks consisting of ditches or channels along roadsides, and tertiary networks comprising small channels within residential areas. The development of an integrated drainage network system follows the existing network and rainwater catchment areas, allowing rainwater runoff to be controlled through the existing drainage system.
8. Controlling illegal settlements
In its implementation, the Regional Disaster Management Agency regulates land use and conducts socialization in disaster-prone areas, including policy preparation for relocating residents threatened by disasters.
9. Adding water catchment areas
In its implementation, the Regional Disaster Management Agency increases the capacity and urban drainage network through potential surface runoff volume calculations. Integration of runoff outlets into the macro drainage system, as well as the construction of new structures such as retaining walls and sediment basins, is carried out.
10. Conducting reforestation
In its implementation, the Regional Disaster Management Agency controls and regulates the periodic pruning of large tree branches and the felling of fragile trees in densely populated areas and main roads.

4 Conclusion

Based on the results and discussion on proposed disaster mitigation strategies in Surakarta City using the risk matrix and the HoR phase 2 methods, the following conclusions can be drawn. **First**, potential disasters that may occur in Surakarta City over the time period of 2023-2027 are floods, extreme weather, fires, landslides, droughts, volcanic eruptions, and earthquakes. **Second**, based on the ARP values, it can be concluded that the most significant potential risks are floods (ARP value 16), extreme weather (ARP value 10), fires (ARP value 8), landslides (ARP value 6), droughts (ARP value 6), volcanic eruptions (ARP value 2), and earthquakes (ARP value 2). **Third**, 10 mitigation strategies have been identified as alternatives for disaster management in Surakarta City. **Fourth**, the mitigation strategies with the highest priority to carry out are "Carrying out disaster outreach and education" and "Collaborating with other parties in disaster management", both with the identical ETDk value of 150, respectively.

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