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Risk Management Analysis for Flood and Inundation Mitigation in Pasuruan City

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Abstract

Flooding and inundation are recurring disasters in Pasuruan City due to its low-lying topography, high rainfall, tidal influences, and the overflow of the Welang, Petung, and Gembong Rivers. This study aims to analyze flood risks, evaluate mitigation measures, and formulate strategies to minimize flood impacts using the AS/NZS 4360:2004 Risk Management framework. The research employed a quantitative descriptive approach by collecting primary data through questionnaires distributed to 50 respondents representing local communities, government agencies, and technical stakeholders, complemented by secondary data from relevant institutions. Risk assessment was conducted by evaluating the Probability and Consequence of identified flood-related hazards and calculating the risk index using the formula Risk = Probability × Consequence. The results indicate that all identified risk factors fall within the High Risk category. The highest-priority risks include inadequate river normalization, insufficient drainage capacity, drainage blockage by waste, low topography, and river sedimentation. The study recommends integrated flood mitigation through regular river normalization, drainage system improvement, land-use control, infrastructure maintenance, inter-agency coordination, and enhanced community participation to reduce flood risks in Pasuruan City.

Keywords: Flood risk management, AS/NZS 4360:2004, Flood mitigation, Risk assessment, Probability, Consequence, Pasuruan City.

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INTRODUCTION

Flooding is one of the most destructive hydrometeorological disasters worldwide, causing significant social, economic, environmental, and infrastructure losses each year. The increasing frequency and intensity of flood events are associated with climate change, rapid urbanization, land-use transformation, and inadequate urban drainage systems (Intergovernmental Panel on Climate Change [IPCC], 2022; United Nations Office for Disaster Risk Reduction [UNDRR], 2015). In developing countries, flood disasters have become a major concern because they not only threaten human safety but also disrupt transportation networks, economic activities, and public services. Therefore, effective flood management requires not only structural measures but also systematic risk management that considers both the likelihood of flood occurrence and its potential impacts.

Indonesia is among the countries frequently affected by hydrometeorological disasters, with floods accounting for the largest proportion of annual disaster events. The vulnerability of many Indonesian cities is strongly influenced by their geographical characteristics, rapid urban development, and decreasing water infiltration capacity. Urban expansion has significantly reduced permeable land surfaces, while increasing runoff and pressure on existing drainage systems (Kodoatie, 2013; Suripin, 2004). Consequently, flood mitigation has become one of the primary priorities in urban infrastructure and disaster risk management.

Pasuruan City, East Java Province, is one of the urban areas experiencing recurrent flooding and inundation. The city covers approximately 76.79 km², has an average elevation of approximately 4 meters above sea level, and is characterized by relatively flat topography. In addition, Pasuruan City is located downstream of the Welang River, Petung River, and Gembong River, which discharge into the Madura Strait. These geographical characteristics make the city highly susceptible to flooding, particularly during the rainy season when high river discharge coincides with tidal backwater from the sea. Flood events frequently affect several urban villages, including Blandongan, Bakalan, Kepel, and Karangketug, resulting in disruption of transportation, residential areas, public facilities, and local economic activities.

The occurrence of flooding in Pasuruan City is caused by a combination of natural and anthropogenic factors. Natural factors include high rainfall intensity, low topography, upstream river discharge, tidal influence, and river sedimentation. Human-induced factors involve land-use change, reduction of infiltration areas, inadequate drainage capacity, poor maintenance of drainage infrastructure, and improper waste disposal into rivers and drainage channels. These conditions reduce the hydraulic capacity of both rivers and drainage systems, thereby increasing

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the probability and severity of flooding. Similar flood-generating mechanisms have been reported in previous studies on urban flood management (Kodoatie, 2013; Suripin, 2004).

Risk management has become an important approach in disaster mitigation because it provides a systematic framework for identifying hazards, evaluating risk levels, and determining appropriate mitigation priorities. According to AS/NZS 4360:2004, risk is defined as the combination of the probability of an event occurring and the consequences resulting from that event. The standard outlines a structured process consisting of communication and consultation, context establishment, risk identification, risk analysis, risk evaluation, and risk treatment. Risk assessment is performed by combining Probability and Consequence values using the equation:
Risk=Probability×Consequence

This framework enables decision-makers to prioritize mitigation measures based on quantified risk levels rather than relying solely on subjective judgment (Standards Australia & Standards New Zealand, 2004).

Several previous studies have demonstrated the application of risk management in flood mitigation. Purwanti and Pontiawaty (2013) emphasized that identifying major flood risks is essential for determining appropriate mitigation strategies, including river normalization, reservoir rehabilitation, floodgate construction, pumping stations, watershed conservation, and infiltration wells. Meanwhile, Purbawijaya (2011) concluded that flood mitigation should prioritize dominant risks identified through systematic risk assessment so that responsibilities can be allocated effectively among relevant stakeholders. Furthermore, Mundra et al. (2023) reported that inadequate drainage capacity, increasing rainfall, sedimentation, and poor maintenance significantly contribute to urban flooding, indicating that technical infrastructure and maintenance remain key components of flood mitigation.

Although several studies have investigated flood management in Indonesia, most focus on hydraulic design, drainage capacity, or structural mitigation measures. Studies specifically applying the AS/NZS 4360:2004 Risk Management framework to evaluate flood risk and establish mitigation priorities at the municipal level remain limited, particularly in Pasuruan City. Moreover, previous flood management efforts in Pasuruan have primarily emphasized infrastructure improvement without integrating systematic risk assessment involving technical experts, government institutions, and affected communities. Consequently, a comprehensive risk-based assessment is required to identify dominant flood risks and establish appropriate mitigation priorities.

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This study addresses this research gap by applying the AS/NZS 4360:2004 Risk Management framework to analyze flood and inundation risks in Pasuruan City. Primary data were collected through questionnaires distributed to 50 respondents representing local communities, government agencies, and technical stakeholders, while secondary data were obtained from relevant institutions and literature. Risk levels were determined by evaluating the Probability and Consequence of each identified risk factor, followed by risk ranking to determine mitigation priorities.

Therefore, the objectives of this study are (1) to analyze flood risks in Pasuruan City, (2) to evaluate flood mitigation efforts, and (3) to formulate priority strategies for minimizing flood risks based on the identified dominant risk factors. The findings are expected to support evidence-based decision-making and provide practical recommendations for local governments in developing integrated and sustainable flood risk management policies.

METHODOLOGY

This study was conducted in Pasuruan City, East Java Province, Indonesia, which is located on the northern coast of Java Island. The city covers an area of approximately 76.79 km² and has relatively flat topography with an average elevation of about 4 m above mean sea level. Pasuruan City is crossed by the Welang, Petung, and Gembong Rivers, making it highly vulnerable to flooding and urban inundation, particularly during periods of heavy rainfall and tidal backwater. The research focused on four flood-prone urban villages, namely Blandongan, Bakalan, Kepel, and Karangketug, where flooding frequently disrupts residential areas, transportation, and public infrastructure.

This research employed a quantitative descriptive approach using the AS/NZS 4360:2004 Risk Management framework to identify, analyze, and evaluate flood risks. The study adopted the stages of risk management, including risk identification, risk analysis, risk evaluation, and risk treatment. This framework was selected because it provides a systematic approach for assessing risks based on the likelihood of occurrence and the severity of their impacts, thereby supporting decision-making in flood mitigation planning.

Primary data were collected through structured questionnaires distributed to 50 respondents selected using purposive sampling. The respondents consisted of flood-affected residents, village and district officials, technical staff from the Regional Disaster Management Agency (BPBD), the Public Works and Spatial Planning Agency (DPUPR), the Regional Development Planning Agency (Bappelitbangda), the Water Resources Agency (PU SDA), and environmental

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experts. Secondary data included flood records, rainfall data, drainage network information, river characteristics, maps, government reports, and relevant scientific literature. These data were used to support the identification and evaluation of flood risk factors in Pasuruan City.

Flood risk assessment was carried out by evaluating each identified risk factor using two parameters: Probability (P) and Consequence (C). Respondents assessed the likelihood of occurrence and the magnitude of impacts using a five-point Likert scale based on the AS/NZS 4360:2004 standard, where Probability ranged from Rare (1) to Almost Certain (5) and Consequence ranged from Insignificant (1) to Catastrophic (5). The mean values of Probability and Consequence were calculated for each risk variable, and the flood risk index was determined using the equation Risk = Probability × Consequence. The resulting risk values were classified into Low, Moderate, High, and Very High according to the AS/NZS 4360 risk matrix.

The collected data were analyzed using descriptive statistical analysis to determine the mean Probability and Consequence values for each identified flood risk factor. Subsequently, the calculated risk indices were ranked to identify the dominant risks requiring priority mitigation. The findings were interpreted by considering the physical characteristics of Pasuruan City, previous flood events, and existing flood management practices. Finally, the study formulated mitigation strategies based on the identified priority risks to support sustainable flood risk management and provide practical recommendations for local government decision-making.

RESULTS AND DISCUSSION

Pasuruan City is characterized by a low-lying topography with an average elevation of approximately 4 m above sea level and is traversed by the Welang, Petung, and Gembong Rivers. These geographical conditions, combined with high rainfall intensity and tidal influence from the Madura Strait, make the city highly vulnerable to recurrent flooding and urban inundation. The study involved 50 respondents representing flood-affected communities, local government agencies, technical institutions, and environmental experts to evaluate the probability and consequences of flood-related risks using the AS/NZS 4360:2004 Risk Management framework.

The analysis of Probability (P) indicated that respondents perceived flood occurrence in Pasuruan City as highly likely. The mean probability values ranged from 3.60 to 4.22, corresponding to the Likely category in the AS/NZS 4360 classification. The highest probability values were identified for insufficient river normalization (4.22), low topography (4.16), inadequate drainage capacity (4.15), high rainfall (4.12), and river sedimentation (3.88). These findings indicate that respondents considered both natural conditions and infrastructure

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deficiencies as the primary contributors to flood occurrence. The city's geographical position as a downstream area receiving runoff from upstream watersheds further increases the likelihood of flooding, particularly during periods of intense rainfall coinciding with high sea tides.

The Consequence (C) assessment revealed that flooding causes considerable impacts on residential areas, transportation networks, public infrastructure, and local economic activities. The mean consequence values ranged from 3.54 to 4.04, indicating a Major level of impact. River sedimentation obtained the highest consequence score (4.04), followed by tidal backwater (3.96), low topography (3.94), high rainfall (3.82), and upstream river discharge (3.74). These results demonstrate that flood impacts in Pasuruan City extend beyond physical damage and include disruption of transportation, deterioration of drainage performance, and reduced public services. Flood risk values were calculated using the equation Risk = Probability × Consequence, producing risk indices ranging from 12.50 to 16.88. According to the AS/NZS 4360 risk matrix, all identified variables were classified as High Risk. The highest-ranked risk was insufficient river normalization, with a risk value of 16.88, followed by inadequate drainage capacity (16.52), drainage blockage caused by solid waste (16.52), low topography (16.39), and sedimentation in the Petung River (15.99). These findings indicate that inadequate river maintenance and drainage performance remain the dominant contributors to flood risk in Pasuruan City. Consequently, river normalization, sediment removal, drainage rehabilitation, and regular infrastructure maintenance should become priority mitigation measures.

The findings support previous studies emphasizing that flood risk management should prioritize dominant risk factors identified through systematic assessment. Purwanti and Pontiawaty (2013) reported that river normalization, reservoir rehabilitation, and watershed conservation are fundamental strategies for reducing flood impacts, while Purbawijaya (2011) highlighted the importance of prioritizing mitigation measures according to quantified risk levels. Similarly, the present study demonstrates that flood management in Pasuruan City cannot rely solely on structural measures but requires integrated risk management involving infrastructure improvement, land-use control, institutional coordination, and community participation. Therefore, the implementation of the AS/NZS 4360:2004 framework provides an effective basis for identifying priority risks and supporting evidence-based decision-making for sustainable flood mitigation in Pasuruan City.

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CONCLUSION

This study applied the AS/NZS 4360:2004 Risk Management framework to evaluate flood and inundation risks in Pasuruan City by assessing the Probability and Consequence of identified risk factors. The results indicate that all evaluated variables fall within the High Risk category, demonstrating that flooding in Pasuruan City is influenced by the combined effects of natural conditions, inadequate drainage infrastructure, river sedimentation, land-use changes, and institutional management. The highest-ranked risks were identified as insufficient river normalization, inadequate drainage capacity, drainage blockage caused by solid waste, low topography, and river sedimentation, indicating that both hydraulic and environmental factors play dominant roles in increasing flood vulnerability.

The findings suggest that flood mitigation in Pasuruan City should prioritize regular river normalization, drainage system rehabilitation, sediment removal, infrastructure maintenance, and improved land-use management. In addition, strengthening coordination among government agencies and increasing community participation in maintaining drainage systems and river cleanliness are essential for reducing flood risks. The application of the AS/NZS 4360:2004 framework proved effective in identifying priority risks and supporting evidence-based decision-making for flood management. Therefore, the proposed risk-based approach can serve as a practical reference for local governments in developing integrated and sustainable flood mitigation strategies in Pasuruan City and in other urban areas with similar hydrological and geographical characteristics.

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