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Risk Analysis of Flood Disasters in Junior High Schools of Surakarta, Indonesia

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Abstract

Purpose: Flood disasters are one of the most frequent hydrometeorological hazards in Indonesia, significantly affecting the education sector, particularly schools located in flood-prone areas.
Methodology: This study aims to analyze flood risk levels in junior high schools across Surakarta City by integrating hazard and vulnerability assessments using Geographic Information System (GIS) techniques. The hazard analysis employed parameters of slope, rainfall intensity, land use, and river proximity, which were weighted and overlaid to generate a flood hazard map. Vulnerability was assessed through physical (building structure, drainage, foundation, elevation, and materials) and social components (school community, teacher-staff gender ratio, and student gender ratio).
Results: The results indicated that 40% of Surakarta's area fell under a high flood hazard zone, and most schools exhibit moderate levels of social and physical vulnerability. The flood risk matrix revealed that 43 schools (70%) fell into the high-risk category, 22 (28%) were moderate, and only 1 (2%) was low. The high-risk concentration corresponded with low-lying areas near the Bengawan Solo River Basin.
Applications/Originality/Value: These findings emphasized the urgency of integrating Disaster Risk Reduction (DRR) into school-based programs such as Safe Schools from Disasters (SPAB) and improving physical infrastructure resilience. The outcomes of this study are expected to support local policy in flood mitigation planning for the education sector.

Introduction Section

Indonesia is a region traversed by 3 world plates, namely the Pacific Plate, the Eurasian Plate, and the Australian Plate. This condition causes the Indonesian region to have an increasing risk of disasters such as hydrometeorological disasters and geological disasters (Hafida et al., 2018). Hydrometeorological disasters are closely linked to climate change, which should motivate the audience to recognize their role in mitigation efforts and emphasize the importance of understanding how climate change influences floods, landslides, and other weather disturbances (UU No 24, 2007). Hydrometeorological disasters in Indonesia are caused by changes in environmental conditions, climate change, or weather disturbances such as La Niña, El Niño, monsoons, and tropical cyclones (Sidauruk et al., 2023). Frequent climate change has led to a high rate of hydrometeorological disasters, particularly floods, which are a significant problem in several regions of Indonesia (Rosyida et al., 2019). Hydrometeorological disasters, especially floods, are highly detrimental to communities, both materially and non-materially (Listiaji et al., 2019).
Flooding is a natural phenomenon in which water cannot be contained by drainage systems, causing inundation. Floods cause significant losses, especially in affected areas (Waiyasusri & Wetchayont, 2025). Flooding can also occur due to low soil infiltration capacity, resulting in the inability to absorb water (Balahanti et al., 2023). In Indonesia, flooding disasters often occur every year, especially major floods due to overflowing rivers almost certainly occur in Central Java Province (Wibowo et al., 2019). In 2024, Indonesia experienced 814 recorded floods, according to the National Disaster Management Agency (BNBP). These floods resulted in 363 deaths, 52 missing persons, 783 injuries, and extensive damage to infrastructure, including 45,371 homes and numerous educational, religious, and health facilities (BNBP, 2024). Detailing these impacts emphasizes the severity of flood events and their disruption to society (Husniawati et al., 2023).
Flooding is a natural phenomenon that can cause disasters and directly affect people's lives and communities (Lulang et al., 2024). Floods cause significant losses, including in education, and can profoundly impact community cohesion. Floods have a significant impact on the damage to and loss of educational facilities, as well as on the inaccessibility of schools for students. These floods significantly disrupt the continuity of the teaching and learning process in schools (Eny Junyanti, 2024).

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Understanding disaster risk is crucial for the audience, as it involves recognizing the interaction between regional vulnerability and hazards, which can lead to loss of life, injury, and community disruption (Permana, 2023). Risk is an event related to an uncertain future, namely the possibility or opportunity for loss, threat, or danger (Chou & Chiu, 2021). Disaster risk is defined as the estimated loss of life caused by a hazardous event. Disaster risk can take the form of death, injury, illness, loss of homes and property, and can disrupt community activities. Disaster risk is the interaction between regional vulnerability and the threat of danger (hazard). The cause of this danger is a natural event known as a disaster (Hapsoro & Buchori, 2015).

A hazard/threat is an environmental event, either caused by humans or by nature, that is detrimental and affects human activities or life (Imaduddinna & Widodo, 2017). Hazard assessment is a fundamental process of assessing the nature of human- or natural-caused hazards (WIjaya et al., 2023). A threat is a condition that could cause future harm or danger. It can disrupt individuals or community groups and occur continuously depending on the location, intensity, frequency, and probability of the event (Sarah et al., 2024). Vulnerability is the disruption of environmental conditions, communities, structures, and services caused by a particular hazard, resulting in losses (Sarapang et al., 2019). Vulnerability levels are categorized as social, economic, physical, and environmental (BNBP, 2012). Vulnerability is linked to human capacity to protect and cope with the impacts of natural hazards/disasters (Hapsoro & Buchori, 2015).

Vulnerability is the potential level of loss caused by the severity of a particular hazard. Geographical conditions are closely related to disaster vulnerability. The physical condition of the area and its social structure will influence whether or not the potential for disasters increases (Arif et al., 2017). However, there has never been a specific vulnerability study for school environments that specifically formulates the risk component elements within the vulnerability aspect of the school environment. School vulnerability is an important study because the school community is predominantly a vulnerable group. Therefore, this research is crucial. In conducting a vulnerability analysis in a region, there are four components of vulnerability: social, economic, physical, and environmental (Sauda et al., 2019). The city of Surakarta is located in the ancient Bengawan Solo river basin, which forms a winding valley, making the area prone to flooding (Mirahesti, 2016). Highlands, including Mount Lawu to the east, Mount Merapi to the west, and the Kendeng Hills to the north, surround Surakarta City. These factors contribute to its frequent flooding (Kholidah, 2022).

Surakarta City has experienced major floods in 1918 and again in 1966, causing significant losses. Several areas within the city were affected by the overflowing Bengawan Solo River (Maulana, 2015). Flooding in 2007 paralyzed several roads in Surakarta City, and it occurred again in 2015, caused by heavy rains that overwhelmed the city. It caused the Bengawan Solo River to overflow and the Cengklik Reservoir to burst, inundating parts of western Surakarta City (Muttaqin & Sibarani, 2015).

Few researchers have analyzed flood disaster risk in Surakarta City, particularly in junior high schools. These include (Sugianto, 2022) study, which examined flood risk in Jatinangor District, Sumedang Regency; (Rinaldi & Permana, 2019) Vocational High Schools in Bandung City; and (Septiningrum et al., 2022) study, which examined vulnerability in elementary schools in flood-prone areas of Sukoharjo. Previous studies on flood disaster risk have not yet analyzed flood risk within the school environment. School environments are among the most at-risk environments due to the presence of vulnerable groups, including school residents. Therefore, research on disaster risk within the school environment is essential. This study was conducted to analyze flood hazard levels at junior high schools and the flood disaster risk for affected schools. The results of this study can be used to recommend Safe Schools from Disasters (SPAB) policies in Surakarta City.

Methods

a. *Research Location*

This research was conducted in all junior high schools in Surakarta City, located between 110 45` 15″ – 110 45` 35″ East Longitude and 70` 36″ – 70` 56″ South Latitude. Surakarta is located in the lowlands at an altitude of ±95 meters above sea level, located between two volcanoes, namely Mount Lawu and Mount Merapi, with an area of 44.1 km² (Alfarizi et al., 2024). Surakarta City is classified as an area with relatively flat topography, and is located in the ancient Bengawan Solo River basin, which forms a winding valley, making the area prone to flooding (Mirahesti, 2016). Surrounded by highlands, namely Mount Lawu to the east, Mount Merapi to the west, and the Kendeng Hills to the north, these are factors contributing to Surakarta's frequent flooding (Kholidah, 2022).

b. *Data Collection Techniques*

The data collection techniques in this study consisted of primary and secondary data collection. Primary data was obtained through direct research relevant to the problem, which could be addressed through interviews. It was done to obtain accurate results and validate the flood hazard map. Secondary data were obtained from the Basic Education Data System (Dapodik) to determine flood vulnerability levels in junior high schools. Three processes were used in this data collection: literature review, field surveys, and interviews.

Table 1. List of Primary Data and Secondary Data for Hazard Variables

Data Type	Variable Hazard	Information	Source
Primary Data	*1. Interview Data*	*Contains information directly from the source.*	*Field Survey*
	2. Flood Validation Point	*Field locations used to check the accuracy of the flood hazard map analysis.*	
Secondary Data	*1. Flood hazard Map Data*	*To show the accuracy of flooding in an area*	*Inarisk* *https://inarisk.bnpb.go.id/* *& Ina-Geoportal* *https://tanahair.indonesia.go.id/portal-web/*
	2. Raster Data (DEM, Land Use, and Rainfall)	*Spatial data in raster form is used to analyze height, land use, and rainfall intensity in the Surakarta City area.*	

Table 2. List of Secondary Data and Primary Data of Vulnerability Variables

Data Type	Variable Vurnerability	Information	Source
Primary Data	*1. Structural Condition Data*	*To determine the level of strength, building materials and school construction against potential disasters.*	*Field Survey*
Secondary Data	*1. School Location Data*	*Information related to the geographical position of the scholl.*	*Google Earth* *https://earthengine.google.com/*
	2. Data On The Number Of School Students	*Information related to the number of school students.*	*Basic Education Data (Data Pokok Pendidikan)* *https://dapo.kemendikdasmen.go.id/*
	3. Data On Number Of Teachers And School Employees	*Information related to the number of teaching staff and school staff.*	
	4. Data On The Number Of School Rooms	*Information on the number of physical school facilities including classrooms, laboratories, mosques, etc.*	

c. Population, Sample/Sampling Technique

The population in this study was all 72 junior high schools in Surakarta City. The sample used in this study was 61 junior high schools in Surakarta City, drawn from the total population, calculated using the 5% Slovin formula. The sampling techniques used in this study were Cluster Random Sampling and Stratified Random Sampling. Cluster Random Sampling was used to randomly select samples/validate flood hazards in the field, while Stratified Random Sampling was used to determine the sample size in Junior High Schools in Surakarta City based on the flood hazard classification, which is divided into three classes: High, Medium, and Low. Cluster Random Sampling is a sampling technique in which groups are selected, and individual samples are then drawn from them (Fajrin & Leonardi, 2019). The Stratified Random Sampling method divides the population into smaller groups. Each member of the population has an equal opportunity to be selected as a sample (Arvyanda et al., 2023).

Table 3. Cluster Sampling Calculation Results

No	Cluster	Sample
1	High	15
2	Medium	9
3	Low	5
Amount		29

Table 4. Stratified Random Sampling Calculation Results

No	Starata	Sampel
1	High	39
2	Medium	16
3	Low	6
Amount		61

d. *Research Instruments*

An instrument is a tool that helps researchers collect data. Data collection requires more than one type of instrument. The instruments used in this study were:

1. *Flood Hazard Validation Sheet. This sheet was used to validate flood hazard assessments at junior high schools.*

Table 5. Flood Hazard Validation Sheet

No	**Indicator**
1.	*Drainage Conditions*
2.	*Topographic Slope Conditions*
3.	*Land Use Conditions*
4.	*History of flood events*

2. *School Vulnerability Sheet, this sheet is used to find out the structural conditions in Junior High Schools.*

Table 6. School Vulnerability Sheet

Variable	Parameter	weight	Units	Deskription	Source
Social Vulnerability (0,6)	1) *Gender Ratio Of Teachers and Education Staff*	*0,1*	*Soul*	*The number of teachers and educational staff who influence the process or strategy in mitigation.*	*Basic Education Data (Data Pokok Pendidikan)* *https://dapo.kemendikdasmen.go.id/*
	2) *Student gender Ratio*	*0,3*	*Soul*	*The comparative number of students that can be used for evacuation planning and emergency response.*	
	3) *School Community*	*0,6*	*Soul*	*The total number of school residents who could potentially be affected in an emergency or disaster situation.*	

Physical Vulnerability (0,4)	1) Drainage	0,4	Units	Drainage that does not function properly can cause air to overflow and increase the potential for pooling or flooding around the building.	Field Survey
	2) Building Materials		Units	Having a big influence on physical resistance to flooding, buildings dominated by concrete and brick will be stronger than buildings made of wood.	
	3) Building Age		Units	The older the building, the more the physical structure will tend to decline and can cause more severe damage when flooding occurs.	
	4) Floor Height Above Flood		Units	Taller buildings will have a lower level of vulnerability because they are not submerged by floods.	
	5) Buildings Above Flood Waters		Units	Buildings located in areas frequently flooded tend to have higher physical vulnerability, both due to location factors and the decline in material quality due to repeated exposure to air.	
	6) Foundation		Units	A strong foundation that is embedded deep enough will be able to withstand air pressure and maintain the stability of the building when flooding occurs.	
	7) Roofing Material		Units	Roofs made of lightweight materials will easily come loose due to wind pressure and heavy rain accompanied by	

flooding, while roofs made of clay or heavy materials will be more stable and resistant to any conditions.

3. *Interview Guidelines, These guidelines are used to obtain or collect information related to the research problems or topics used.*

Table 7. Interview Guidelines

No	Question
1	*History of flood disasters.*
2	*The duration of the height of the flood disaster.*
3	*The height of the water level during a flood.*
4	*The time when the flood occurred.*
5	*Causes of flooding.*

e. Data Analysis Techniques

The data analysis techniques used in this study are:

1. *Flood Hazard Analysis*

   The technique used to analyze flood hazard in Surakarta City is a Geographic Information System (GIS) approach using ArcGIS software. To determine flood hazard, the team processed Digital Elevation Model Raster Data (Seftiani et al., 2023). Digital Elevation Model (DEM) data is raster data used to determine the elevation of the Earth's surface at the studied location (Ardiansyah et al., 2024). The parameters used to determine the flood hazard map are rainfall derived from Rainfall Estimates from Rain Gauge and Satellite Observation (CHIRPS) data, land use derived from Ina-Geoportal data, slope, elevation, and distance from rivers (Buffer) (Widiyatmoko et al., 2015) . These five parameters, whose scores or weights were calculated, were overlaid using the Weight Sum method to create the Surakarta City flood hazard map.

2. *Vulnerability Analysis*

   Vulnerability analysis is conducted by grouping vulnerability parameters for each vulnerability variable by class. Each vulnerability parameter is classified into three classes: high, medium, and low. This classification is obtained based on calculations using the mean and standard deviation equations (Mukaroma et al., 2022). Each class has a score or value, which is assigned hierarchically:

Table 8. Vulnerability Level

Class	Score	Intervals
Low	1	<1,3
Medium	2	1,4-2,6
High	3	>2,7

The obtained scores are then multiplied by the weights for each risk component within the vulnerability variable. The results are then summed to obtain the total for each vulnerability variable, representing both physical and social vulnerability. This total reflects the contribution of each vulnerability variable. After obtaining the total for each vulnerability variable, the final vulnerability class can be determined. The final vulnerability class is calculated using a similar method, using the mean and standard deviation. This calculation yields a vulnerability map that can be used to analyze flood disaster risk comprehensively.

The vulnerability components used in this study are physical vulnerability and social vulnerability. Indicators for the physical vulnerability component include the number of classrooms, the number of school facilities, and structural conditions. Indicators for the social vulnerability component include the school community, the teacher-to-staff gender ratio, and the student gender ratio.

3. *Flood Risk Analysis*

   Risk analysis is used to determine the level of flood hazard and vulnerability in junior high schools. It can be done using a disaster risk analysis matrix. This matrix is a systematic approach to assessing and classifying flood risk levels in an area, particularly within the Surakarta City Junior High School environment. The risk analysis matrix represents the intersection of vulnerability and hazard levels. Using this matrix, the levels of hazard and vulnerability can be identified through colors that represent the level of disaster risk.

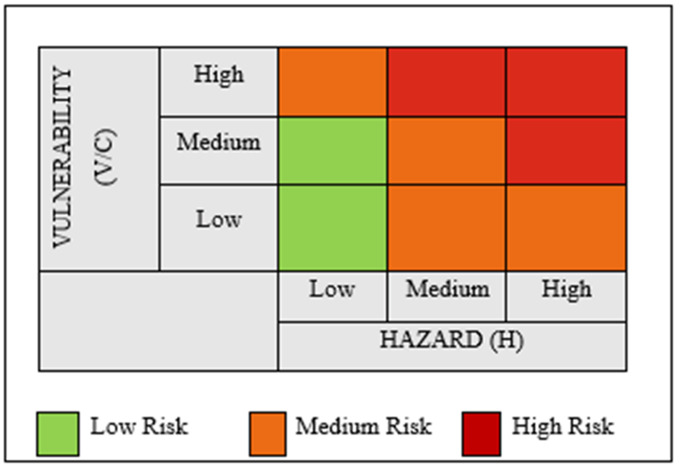

Figure 1. Risk Analysis Matrix

Result And Discussion

a. Result

1. Hazard

a) Hazard Class Area

A flood hazard class analysis was conducted to determine the level of potential hazard in each area, particularly in Surakarta City, based on a combination of parameters including slope gradient, rainfall, distance to rivers, and land use. The combined results produced a flood hazard map, categorized into three classes: low, medium, and high. The calculated area indicators for each hazard class are shown in Table 9.

Table 9. Flood Hazard Area Calculation

No	Hazard Class	Wide (Km)
1	Low	90,32679
2	Medium	20,60960
3	High	17,58270

b) Parameter Indicators

1) Slope Map

The map shows the slope gradient in the Surakarta region, with 3 classifications: gentle, moderately steep, and steep. In the gentle classification, it is spread across almost all parts of the Surakarta city area, which is marked in green because it is a lowland. In the moderately steep classification, it is only slightly spread across several areas of Surakarta, as shown in yellow. In the steep classification, it is spread across the Jebres area, which is marked in red, because the area tends to be higher.

2) Rainfall Map

This map shows rainfall data in the Surakarta City area, classified as Low, Medium, and High. Areas classified as Low have low rainfall intensity, indicated in green; areas classified as Medium have moderate rainfall intensity, indicated in light blue; and areas classified as High have high rainfall intensity, indicated in dark blue.

3) River Network Map

This map shows the river network in the Surakarta City area. The network pattern is spread out and branched. The numerous medium-sized branches and small streams indicate a high level of natural drainage, which helps drain rainwater and increases the potential for flooding.

4) Land Use Map

This map shows land use in the Surakarta City area. Land use is dominated by residential areas evenly distributed throughout the city, indicated in green. There is limited scrubland in a few locations (indicated in purple), and freshwater bodies are indicated in brown.

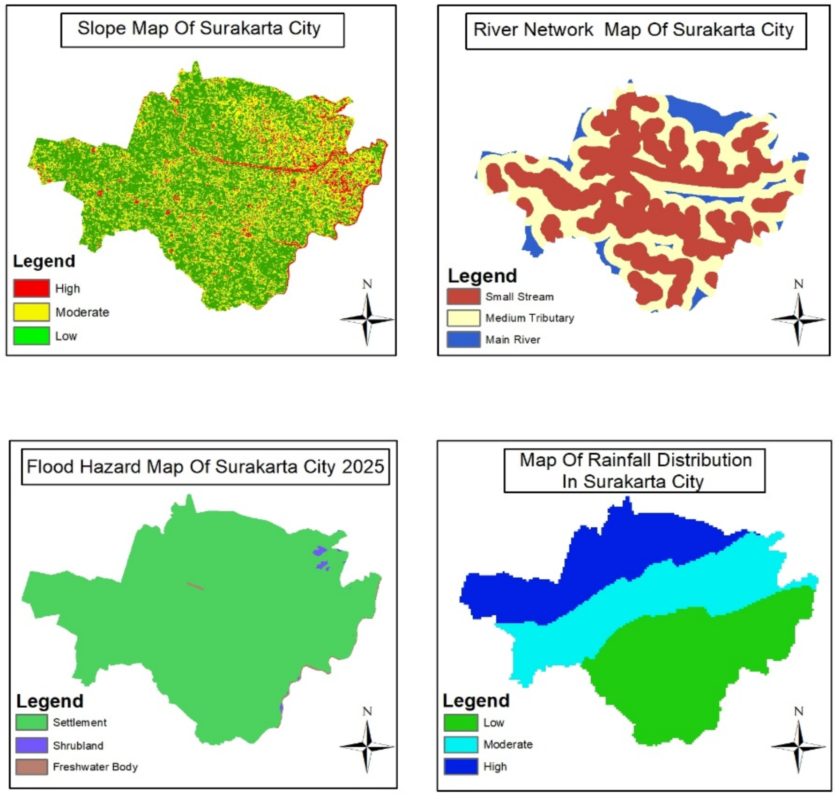

Figure 2. Flood model Parameter

5) *Flood Hazard Map*

This map depicts the majority of Surakarta's flood hazard areas. There are three levels of flood hazard distribution: high, moderate, and low. High-hazard areas are distributed across most of Surakarta's central and southern areas, with red dominating, indicating a high flood risk. Moderate-hazard areas are primarily visible on the outskirts of flood-prone areas, indicated in yellow. Low-hazard areas are distributed across the northern and western parts of Surakarta, indicated by green.

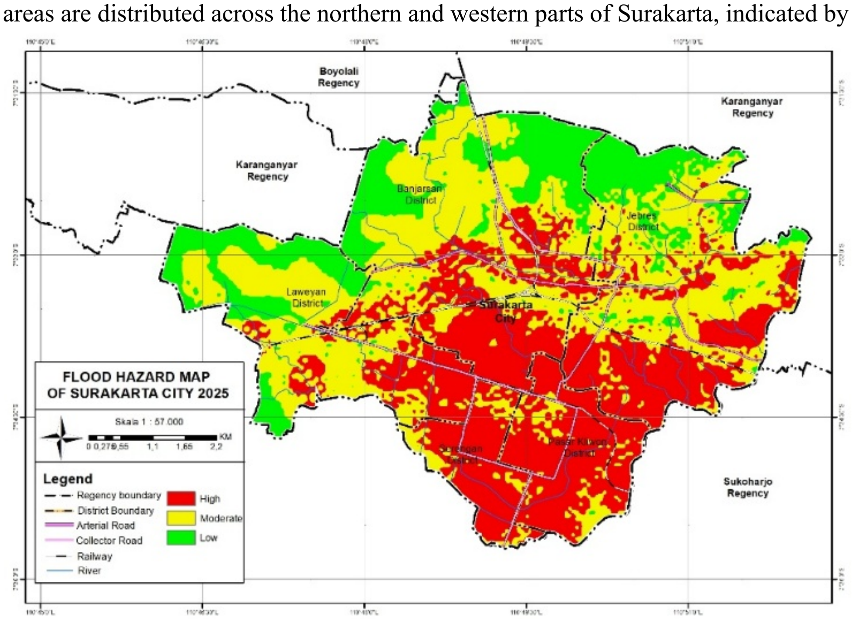

Figure 3. Flood Hazard Map Of Surakarta City

6) *Field Validation Result*

Field validation results are used to compare the spatial analysis of flood hazards with actual field conditions. The validation process was conducted across 29 points in Surakarta City, including the districts of Laweyan, Serengan, Pasar Kliwon, Banjarsari, and Jebres. Based on the validation results, three classifications were used to determine flood hazard: low, medium, and high. Due to the high flood hazard, 15 validation points were used. Of these, 13 were identified as flooding, representing 80% of the flood-affected area, while two were not identified as flooding, representing 20% of the unaffected area. In medium- and low-hazard flood areas, there were 14 validation points. Of these, four were identified as flooding, representing 29% of the affected area, and 10 were not identified as flooding, representing 60% of the unaffected area.

2. *School Vulnerability*

a) *Social Vulnerability*

This map shows the level of social vulnerability in junior high schools in Surakarta City, with three classifications: Low, Medium, and High. Schools with low vulnerability are distributed throughout Laweyan District and are marked in green; schools with moderate vulnerability are distributed throughout parts of Surakarta City and are marked in yellow; and schools with high vulnerability are predominantly located in Banjarsari, Pasar Kliwon, and Serengan.

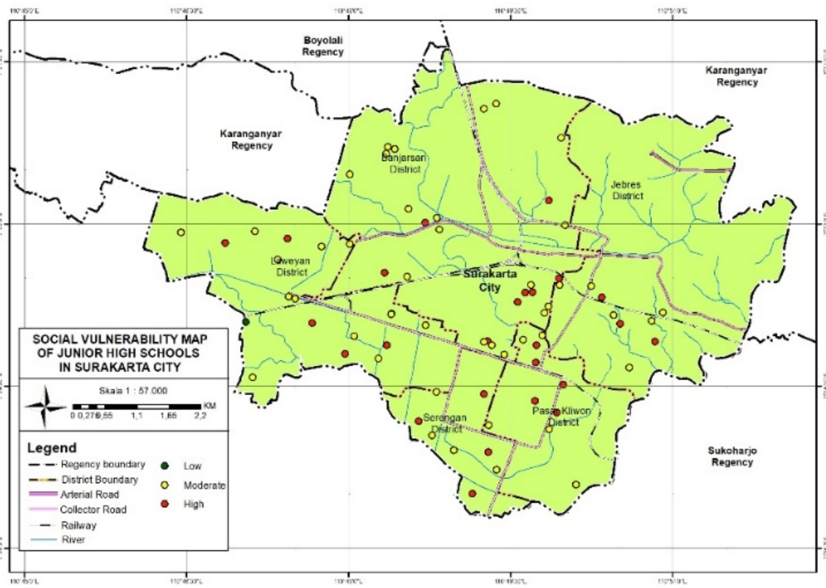

Figure 4. Social Vulnerability Map Of Junior High School In Surakarta City

b) *Physical Vulnerability*

This map shows the level of physical vulnerability in junior high schools in Surakarta City, with three classifications: Low, Medium, and High. Schools with low vulnerability are distributed throughout the city center and are marked in green; schools with moderate vulnerability are distributed throughout parts of Surakarta City and are marked in yellow; and schools with high vulnerability are predominantly located in the city center and the Serengan area.

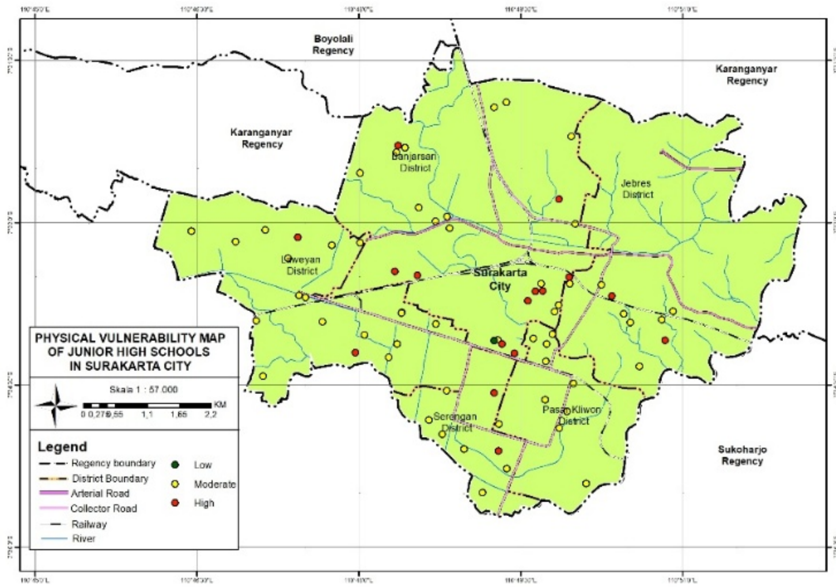

Figure 5. Physical Vulnerability Map Of Junior High School In Surakarta City

c) Total Vulnerability

This map shows the total level of vulnerability in junior high schools in Surakarta City, with three classifications: Low, Medium, and High. Schools with low vulnerability are scattered across several areas of Surakarta City and are marked in green. Schools with moderate vulnerability are scattered across several areas of Surakarta City and are marked in yellow. Schools with high vulnerability are scattered across several areas of Surakarta City, marked in red.

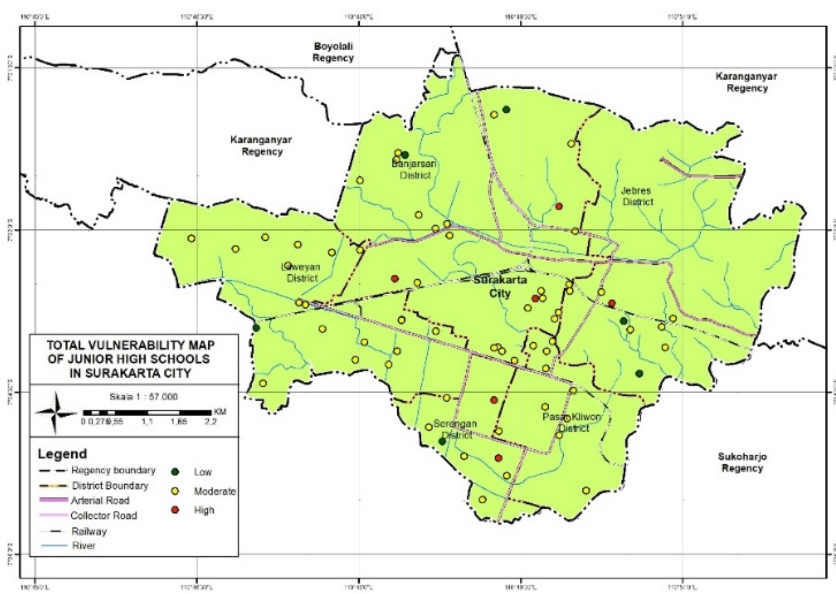

Figure 6. Total Vulnerability Map Of Junior High School In Surakarta City

3. Risk

This map shows the flood risk level for junior high schools in Surakarta City, with three classifications: low, medium, and high. Schools with low vulnerability are scattered across several areas of Surakarta City and are marked in green. Schools with moderate vulnerability are scattered across several areas of Surakarta City, marked in yellow. Schools with high vulnerability are scattered across several areas of Surakarta City.

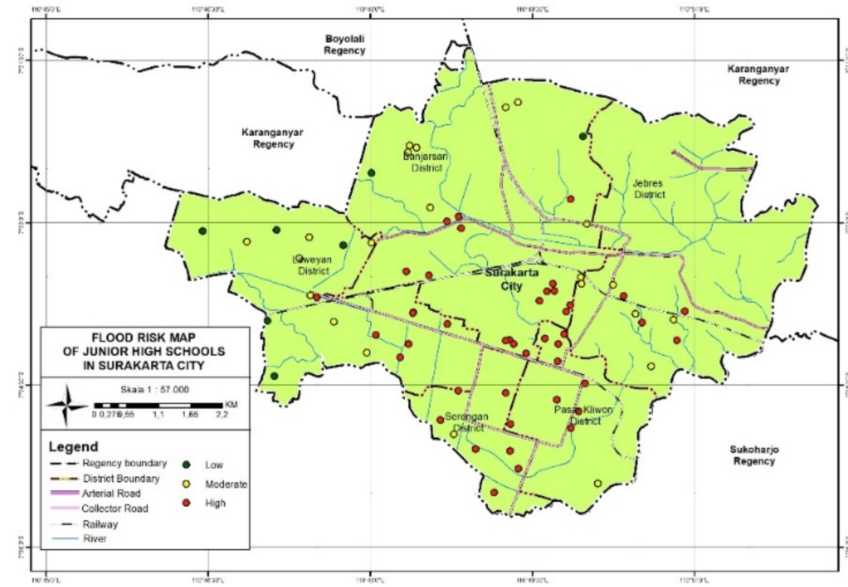

Figure 7. Flood Risk Map Of Junior High School In Surakarta City

b. Discussion

A hazard is a natural or artificial phenomenon that has the potential to threaten human life, cause property loss, and environmental damage. However, flood hazards are not only threats to property and life, but also disrupt socio-economic systems and community mobility (Andreasen et al., 2025). Flood hazards are not always caused by extreme rainfall but also by physiographic influences such as land slope and natural drainage capacity (Tamiru & Dinka, 2021).

This study examines flood hazard levels in the Surakarta City area using a Geographic Information System (GIS). Four main parameters are used to map flood hazard: slope gradient, land use, distance between rivers, and rainfall. The flood hazard map for the Surakarta City area uses three classification levels: Low, Medium, and High. Each classification has its own area: Low (90.32679 km), Medium (20.60960 km), and High (17.58270 km). Twenty-nine flood validation points were selected to determine ground conditions. After conducting validation or direct field surveys, 16 points were identified as experiencing flooding, and 13 points were not. However, based on the hazard classification, several points in the high-risk area did not experience flooding.

This research aligns with that of (Husein et al., 2025), which examined flood risk and hazard levels in the Lake Ziway Watershed (DAS) in Central Ethiopia. This study used Geographic Information System (GIS), remote sensing, and the Analytic Hierarchy Process (AHP). Eleven key parameters were used to map flood hazard: slope gradient, drainage density, rainfall, soil type, distance from the river to the road, Topographic Wetness Index (TW), Normalized Difference Vegetation Index (NDVI), Land Use Land Cover (LULC), and lithology. The results show that approximately 60% of the Ziway watershed falls into the high to very high hazard category, and 35% falls into the high to very high risk zone. It was achieved using high-resolution image validation (Google Earth).

This study also shares similarities with research conducted by (Mathe et al., 2025), which mapped and assessed flood vulnerability in the Mahi River Basin, India, using hybrid machine learning (ML) and geospatial analysis methods. The primary focus was to improve the accuracy of flood hazard mapping by combining ML models with physical, hydrological, and land use parameters. The main models in this study were RF, SVM, and LR. Twelve parameters were used to create the flood hazard map: slope, elevation, rainfall, distance to river, soil type, land use, Topographic Wetness Index (TWI), drainage density, (Normalized Difference Vegetation Index) NDVI, Aspect, Curvature, and SPI. The results of this approach, using three main models, were the most accurate, with validation achieving 90% accuracy. However, there are differences in the analysis methods and validation results: Mathe et al. (2025) used an adaptive machine learning (ML) approach and achieved high accuracy, while this study relied on a simple overlay-based GIS.

However, this study differs from that of (Taghizadeh et al., 2025), which examined how to improve the accuracy of flood risk mapping using machine learning (ML) and explainable AI (XAI) methods in the Pearl River Delta (PRD) region of China. This region is a densely populated urban area with frequent flooding and extreme rainfall. This application provided more accurate, transparent flood risk mapping than conventional GIS methods.

Flood vulnerability is the level of a region or community's vulnerability to flooding, including its capacity to respond to and recover from its impacts. Vulnerability is a key component of flood risk, related to hazards, and is used to determine the overall magnitude of the risk. Vulnerability depends not only on physical factors but is also significantly influenced by socioeconomic conditions and the community's adaptive capacity (Ozkutuk & Chirayath, 2025). The vulnerabilities used in this study are physical and social.

Social vulnerability to flooding in junior high schools depends on the school community, the teacher-to-staff gender ratio, and the student gender ratio. These data were obtained from the Basic Educator Data (DAPODIK). These parameters were used for vulnerability analysis in flood risk research at junior high schools. The school community served as the basis for the total number of school residents potentially affected in a disaster. The teacher-to-staff gender ratio was used to determine the ratio of teachers to educational staff, which influences mitigation processes or strategies. The student gender ratio was used as a comparison for evacuation planning and emergency response. These parameters are then calculated using a formula and classified in accordance with the provisions. Based on the calculation results, social vulnerability is divided into three classes using predetermined intervals. There are 42 schools with an interval of 1.01-1.99, which fall into the medium classification, and 25 schools with an interval >3.00, which fall into the high classification.

Based on this data, it is clear that the majority of junior high schools in Surakarta City have moderate social vulnerability to flooding. Physical vulnerability to flooding in junior high schools consists of building elevation, drainage, building materials, building age, floor height, foundations, and roofing materials. These data were obtained from direct field surveys. These parameters were used in the flood risk analysis study for junior high schools. Based on the results of the physical vulnerability calculations, the vulnerability was divided into three classifications based on adjusted intervals. There was one school with an interval <1.2, which fell into the low category, 55 schools with an interval of 1.3-2.00 fell into the medium category, and 16 schools with an interval of 2.1-3.00 fell into the high category. Based on this data, it is clear that the majority of junior high schools in Surakarta City are moderately vulnerable to flooding.

Total vulnerability can be obtained by combining all vulnerability parameters into a weighted Equation, providing a clear and transparent methodology for researchers and policymakers. Each parameter, including physical and social vulnerability, is summed to determine the total vulnerability class. The vulnerability level of junior high schools in Surakarta City is divided into three classifications with predetermined intervals and weights for each vulnerability parameter. Six schools with an interval <1.3 fall into the low classification, 60 schools with an interval of 1.4-2.6 fall into the medium classification, and 6 schools with an interval >2.7 fall into the high classification.

Based on this, the majority of junior high schools in Surakarta City have a moderate overall vulnerability to flooding. This study shares similarities with research conducted by (Akindejoye et al., 2025), which examined the identification of social vulnerability profiles to coastal flooding. This study similarly grouped vulnerability levels into three classifications and assessed the role of social factors in potential flood impacts. However, differences exist in the methodological approach and social context. In this study, Akindejoye et al. (2025) used a machine learning algorithm to identify non-linear patterns between social factors

Risk is the potential loss resulting from a flood event. It results from interactions among flood hazards, exposure, and vulnerability in urban areas. Risk does not depend on the magnitude or frequency of flooding, but rather on the preparedness of an area to prevent, mitigate, and respond to flooding (Lopes et al., 2025).

This study examines flood disaster risk in junior high schools in Surakarta City. To determine flood risk, a risk matrix based on hazard and vulnerability analysis was used. The analysis using the matrix yielded three risk-level classifications: 1 school was classified as low, 22 as medium, and 43 as high.

Based on this, it is clear that most junior high schools in Surakarta City are at high risk of flooding. It can be attributed to the area's lowland conditions. Surakarta City itself is located in the ancient Bengawan Solo River basin, a winding valley that makes it prone to flooding and densely populated. Therefore, these conditions indirectly impact the high flood risk in the area.

This research aligns with that of) (Muhammad et al., 2025), which determined the flood risk level in Bauchi City, Nigeria, using Machine Learning (ML) and Explainable AI (XAI) to improve prediction accuracy and identify the dominant factors driving flooding. The results of Muhammad et al.'s (2025) study confirmed that regional morphology and social density can be key determinants of increased flood risk in urban areas. However, there are differences in the approaches used. Muhammad et al. (2025) used an ML approach to improve the effectiveness of risk mapping and support urban resilience policies, achieving the highest accuracy. Furthermore, this research is in line with research (Shin et al., 2025), which examines the quantitative impact of flooding in urban areas caused by various sources of flooding (multi-source flooding), namely river flooding, inland flooding, and storm surge, using two flood risk indices, namely Flood Intensity (FI) and Flood Hazard Rating (FHR). The results of this study indicate that flood risk analysis incorporating multiple sources produces accurate flood hazard maps, with the risk area increasing by up to 22%. It shows the importance of considering hydrological and geographical conditions holistically. However, the approach used is different; Shin et al. (2025) used two-dimensional hydrodynamic simulations with quantitative indices.

This research aligns with (Rahma et al., 2019), which examined students' knowledge and preparedness for flood risks at Muhammadiyah Cawas Vocational School. This study aimed to determine how school preparedness is significantly influenced by students' knowledge and awareness of flood risks. Schools play a crucial role in serving as centers for disaster mitigation education, as many students still lack adequate knowledge of disaster risks, particularly flooding. However, students' awareness and social adaptation are relatively high, allowing for development through disaster education, which can be implemented through training, simulations, and curriculum integration.

Conclusion

This study successfully identified the level of flood hazard, vulnerability, and risk in Junior High Schools (SMP) in Surakarta City using a Geographic Information System (GIS) approach and a risk matrix. However, it is important to acknowledge that data limitations, such as outdated or incomplete information, may affect the precision of these assessments. Based on the analysis results, approximately 40% of Surakarta's area is included in the high flood hazard category, especially in the central and southern areas located in lowlands and close to the Bengawan Solo River. The vulnerability analysis shows that most schools have a moderate level of social and physical vulnerability, reflecting the condition of their buildings and drainage systems, as well as the social capacity of school residents, who are particularly vulnerable to flooding. The risk matrix indicates that 43 schools (70%) have a high flood risk, 22 schools (28%) have a moderate risk, and 1 school (2%) has a low risk. This condition shows that regional geomorphology and human activity density are the main determinants of increased flood risk. Thus, mitigation efforts should focus on improving flood-resistant school infrastructure, improving drainage systems, and strengthening preparedness capacity through the implementation of the Disaster Safe School (SPAB) program. The results of this study can serve as a basis for local governments and educational institutions in planning education-based flood-mitigation policies in Surakarta City.

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