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Original Article

Flood Resilience and Community Adaptation in Bengkulu City, Indonesia

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ABSTRACT
Flooding has become a recurrent hazard in Bengkulu City due to high rainfall intensity, inadequate drainage systems, and rapid urban development in flood-prone areas, which increasingly exposes communities to social, economic, and environmental losses. However, empirical assessments of community resilience and adaptive capacity remain limited, particularly from a community-based perspective. This study aims to assess the level of resilience and adaptive capacity of communities in Bengkulu City in responding to flood disasters using the Climate and Disaster Resilience Initiative (CDRI) framework combined with a scoring technique. Primary data were collected through questionnaires administered to residents living in flood-prone zones, while secondary data were obtained from the Central Statistics Agency and the Regional Disaster Management Agency of Bengkulu City. The results indicate that Bengkulu City covers approximately 15,600 hectares, of which 4,950 hectares (31.7%) are classified as flood-prone areas, consisting of high-hazard (2,130 ha), moderate-hazard (1,970 ha), and low-hazard zones (850 ha). The most affected districts include Muara Bangkahulu, Sungai Serut, and Ratu Samban. The overall adaptive resilience score of 62.4 falls within the moderate category, indicating that communities possess basic adaptive capacity but remain weak in institutional coordination and disaster preparedness. These findings imply the need for strengthening early warning systems, enhancing disaster education, improving flood-resilient infrastructure, and promoting community-based empowerment to improve adaptive resilience. The study provides practical insights for local governments to formulate evidence-based and community-oriented flood risk reduction policies aimed at building long-term urban resilience.

KEYWORDS
Resilience, Adaptation, Flood, Bengkulu City.

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INTRODUCTION

Floods are hydrometeorological disasters that repeatedly threaten the lives and livelihoods of communities, particularly in Indonesia's coastal urban areas (Lassa, 2018). In Bengkulu City, flooding is triggered by a combination of natural and anthropogenic factors, such as heavy rainfall, degradation of river basin buffer zones, inadequate drainage systems, and land-use pressures in residential areas (Hermon, 2014). The impacts of flooding are not limited to physical and environmental damage but also result in significant social, economic, and psychological losses, particularly for vulnerable groups such as women, children, and the elderly (BPS Bengkulu City, 2024).

Spatially, Bengkulu City is classified as an area with a high flood risk level. Data from the Provincial Disaster Management Agency (BPBD) and the Ministry of Health's Crisis Center indicate that between 2019 and 2024, floods occurred nearly every year and affected eight major districts: Muara Bangkahulu, Ratu Agung, Sungai Serut, Selebar, Kampung Melayu, Singaran Pati, Gading Cempaka, and Ratu Samban (Bengkulu Provincial BPBD, 2024). In the context of global climate change, the intensity and frequency of extreme rainfall are projected to continue increasing, meaning that flooding in Bengkulu City is no longer episodic but has become a recurring, long-term structural risk.

Most flood studies in urban areas still focus on physical hazards and infrastructure damage, while the dimensions of community adaptive capacity and resilience are often treated in a narrative-descriptive and normative manner (Hermon, 2014). In fact, the level of flood impact is determined not only by the magnitude of the hazard but also by the community's ability to anticipate, respond to, and recover from disaster events. The scarcity of studies integrating spatial flood hazard analysis with measurements of community adaptive capacity indicates a research gap, particularly at the scale of coastal cities like Bengkulu.

In this study, the concepts of adaptation and resilience are distinguished both conceptually and operationally. Adaptation is understood as the capacity of communities to adjust to flood risks through improved disaster knowledge, preparedness, social capital, and local institutional support. Meanwhile, resilience is defined as the ability of a social system to maintain its functions, minimize losses, and recover post-disaster as a result of the accumulation of such adaptive capacities (BNPB, 2021). Thus, resilience is not treated as a normative term but rather as a measurable construct that can be empirically analyzed.

A community-based approach is relevant in the context of Bengkulu City, given that top-down approaches to disaster management often fail to adequately accommodate the social conditions and real needs of communities on the ground (Hermon, 2024). Various studies indicate that communities with strong social capital, high citizen participation, and effective institutional coordination tend to have better levels of preparedness and resilience in the face of disasters (BNPB, 2021). Participatory adaptation approaches have also proven more effective as they can accommodate the cultural, social, and economic contexts of local communities (Mercer, 2010).

This study proposes an analytical framework that models the relationship between flood hazards, adaptive capacity, and community resilience. Flood hazards are analyzed spatially to represent the level of physical threat, while community adaptive capacity is analyzed through social, institutional, and environmental indicators using the Climate and Disaster Resilience Initiative (CDRI) framework. The integration of these two approaches enables an evaluation of community resilience that is not only perception-based but is also directly linked to the level of flood hazards faced.

The objective of this study is to analyze the level of resilience and adaptation of the community in Bengkulu City to flood disasters through the integration of flood hazard analysis and the measurement of community adaptive capacity. Scientifically, this study contributes to the development of an integrative approach between spatial hazard analysis and social adaptation indicators. Methodologically, this study offers a community resilience evaluation model that can be replicated in other urban areas with coastal characteristics and limited hydrological data.

The novelty of this study lies in the integration of geomorphology-based flood hazard analysis with the measurement of community adaptive capacity using the CDRI framework at the city level, as well as in the modeling of explicit relationships between hazards, adaptation, and resilience. The results of this study are expected to serve as a reference for local governments in formulating evidence-based flood mitigation policies that are responsive to local conditions and aligned with sustainable development goals, particularly Goals 11 and 13.

METHOD

Research Location

This study was conducted in Bengkulu City, Bengkulu Province, which is geographically a coastal area characterized by low-lying terrain and traversed by several major rivers. The study area focused on subdistricts with high flood risk levels based on data from the Regional Disaster Management Agency, namely Muara Bangkahulu, Sungai Serut, Ratu Samban, Kampung Melayu, Selebar, Ratu Agung, Singaran Pati, and Gading Cempaka. Administratively and spatially, these locations were selected because they represent variations in flood hazard levels and different social conditions among the communities.

Research Design

This study employs a spatial–social integrated assessment design, which integrates spatially based flood hazard analysis with socially based analysis of community adaptive capacity. This approach allows for an understanding of community resilience not only in terms of the physical threat of flooding, but also in terms of the community's social, institutional, and environmental capabilities in coping with flood risks. Methodologically, this design combines the Geomorphic Flood Index (GFI) analysis for flood hazard mapping and the Climate and Disaster Resilience Initiative (CDRI) for measuring community adaptive resilience.

Research Procedures

The research procedure was conducted in several integrated stages. The first stage involved the collection and processing of spatial data for flood hazard analysis using the GFI method. The second stage involved the delineation of flood hazard zones based on the results of this spatial analysis. The third stage involves collecting social data through a questionnaire survey of residents living in flood-prone zones. The fourth stage involves calculating the community's adaptive resilience using the CDRI method based on a scoring technique. The final stage involves integrating the results of the flood hazard analysis and the community's adaptive capacity to evaluate the level of resilience of the Bengkulu City community against flood disasters.

Data Collection

The data used in this study consist of spatial and social data. Spatial data include land surface elevation data (Digital Elevation Model), river networks, watershed boundaries, and administrative boundaries. Elevation data was obtained from medium-resolution DEM data sourced from the National Geospatial Information Agency, while river network and watershed boundary data were obtained from regional-scale hydrographic and geomorphological maps. All of this spatial data was processed using Quantum Geographic Information System (QGIS) software.

Social data was obtained through a questionnaire survey distributed to residents living in flood-prone zones. The number of respondents was determined based on a sample size estimate for the population of Bengkulu City of 394,190 people, with a 95 percent confidence level and a 5 percent margin of error, resulting in a sample size of 180–200 respondents selected through proportional random sampling in flood-prone areas.

Data Analysis

A flood hazard analysis was conducted using the Geomorphic Flood Index (GFI) method to estimate the potential for flooding in areas with limited hydrological data. This method takes into account the geomorphological relationships between land elevation, river depth, and catchment area. The GFI calculation is based on the following equation:

$$WD = Jam - H$$

$$HR = b\,(Ar)^{n}$$

where WD is the flood depth, HR is the potential river water level or water depth, H is the elevation difference between the land surface and the riverbed, Ar is the area of the watershed connected to the observation site, n is a hydrological and hydraulic exponent representing the flow response to the watershed area, and b is a scaling factor used to account for local geomorphological conditions. These parameters were extracted from elevation and river network data using the hydrological analysis plugin in QGIS. The GFI calculation results were then classified into three flood hazard zones: low, moderate, and high.

Community adaptive capacity analysis was conducted using the Climate and Disaster Resilience Initiative (CDRI) method with a scoring technique. Each indicator and sub-indicator was assessed based on respondents' answers, then normalized on a scale of 0–100. The indicators analyzed include aspects of population and demographics, health, education and disaster awareness, social capital, social cohesion and local institutions, as well as infrastructure and the

physical environment. The final value of community adaptive resilience is determined based on predefined category intervals, ranging from very low to very high.
This study employs a quantitative approach, with data collected via a questionnaire distributed to respondents living in flood-prone areas. For further details, see Table 1 below. Table 1. Community adaptive resilience in coping with flood hazards

Table 1. Community resilience and adaptability in coping with flood hazards

Interval	Criteria	Description:
> 88.4	Very high	The community already has good resilience and adaptability.
67.7 – 88.4	High	The community already has good resilience and adaptability but is not yet well-organized in addressing the impacts of flood disasters.
46.9 – 67.6	Moderate	The community does not yet have good resilience and adaptability, so flood disasters adversely affect the community's social and economic life within a period of <1 year
26.1 – 46.8	Low	The community does not yet have good resilience and adaptability, so flood disasters have a negative impact on the community's social and economic life within a period of 1–5 years.
< 26	Very low	The community does not yet have good resilience and adaptability, so flood disasters adversely affect the community's social and economic life within a period of >5 years

Source: Analysis Results, 2025

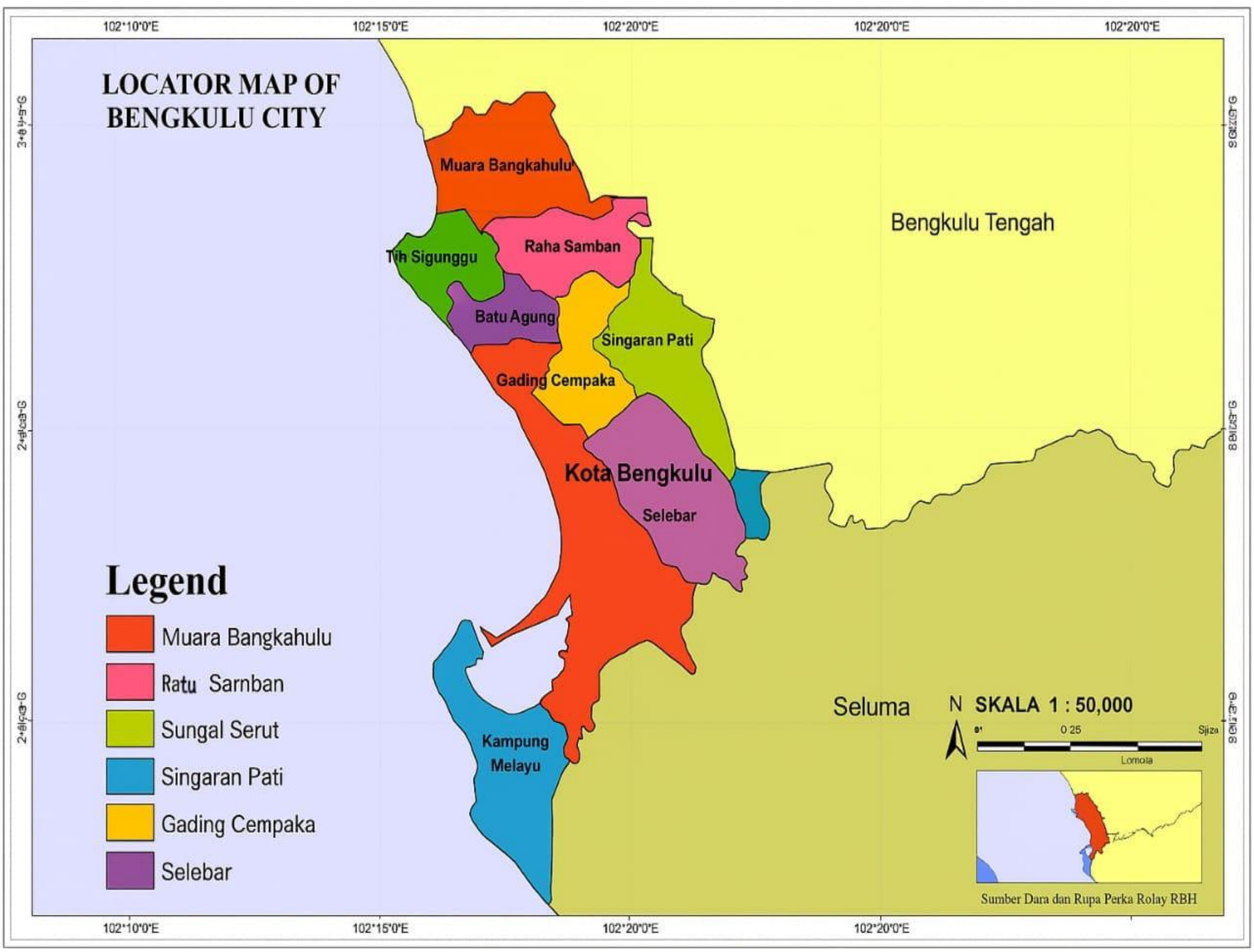

Figure 1. Research Location Map
Source: Data Analysis, 2025

RESULTS AND DISCUSSION

The results of the Geomorphic Flood Index (GFI) analysis indicate that flood hazard levels in Bengkulu City are divided into several zones with distinct characteristics. Low-hazard zones have a relatively low frequency of flooding—approximately once a year—and are generally located in areas with higher elevations and at a relatively greater distance from the main river channel. The moderate-risk zone indicates a potential for flooding with a frequency of about one to three times in five years, which is commonly found in transitional areas between lowlands and developing residential areas near rivers.

High-risk flood zones are areas with the highest potential for flooding—occurring nearly every year—which are generally located in low-lying areas with gentle slopes and in close proximity to major river systems. Additionally, there are non-risk zones dominated by hilly and highland areas, which geomorphologically have a low risk of flooding. The spatial distribution of these flood hazard zones illustrates an uneven pattern of vulnerability across the entire Bengkulu City area and serves as a crucial foundation for analyzing community adaptive resilience. A visualization of the distribution of flood hazard zones in Bengkulu City is presented in Figure 3.

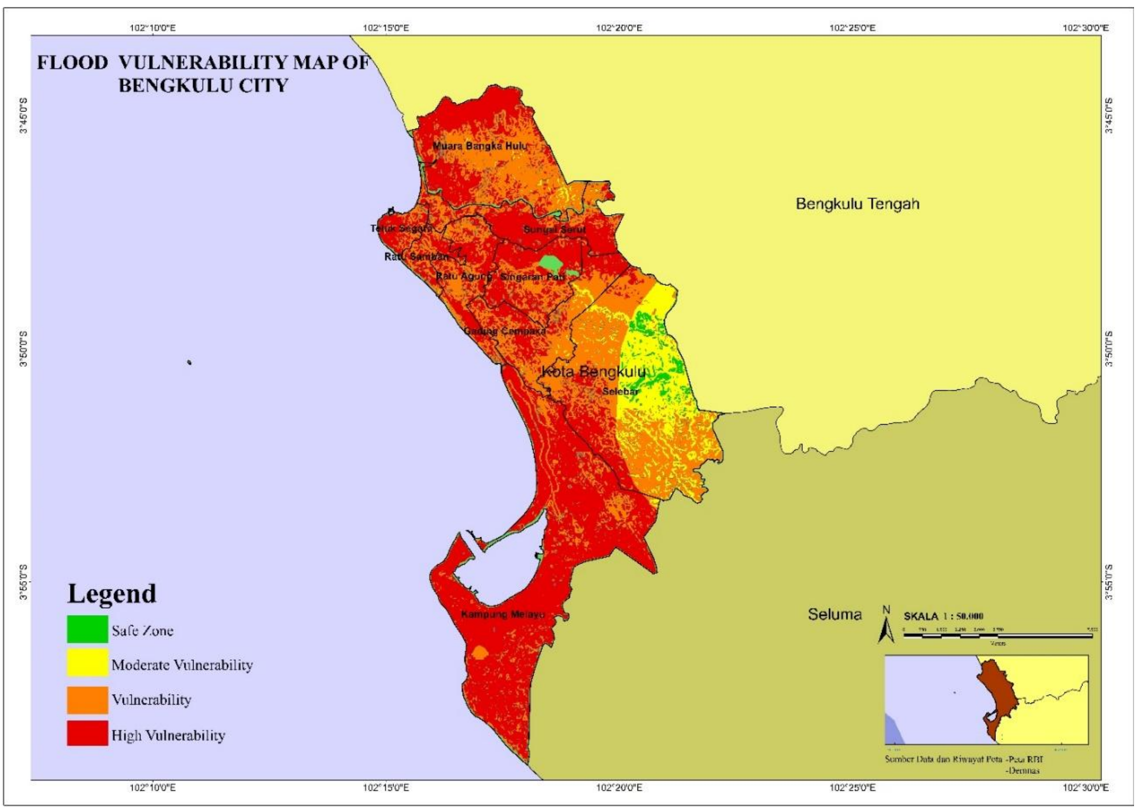

Figure 3. Flood-Prone Areas Map of Bengkulu City
Source: Data Analysis Results, 2025

The flood risk map of Bengkulu City shows that flood hazards are unevenly distributed and form distinct spatial patterns across different zones. Of the total area of approximately 15,400 hectares, the area classified as flood-prone covers roughly 10,200 hectares. The low-risk zone covers about 2,500 hectares and is generally located in areas with relatively higher elevations or farther distances from the main river channels. The moderate-risk zone, spanning 3,800 hectares, is predominantly found in developing residential areas within transitional lowlands, while the high-risk zone, covering 3,900 hectares, is concentrated in lowland areas with gentle slopes and direct proximity to river networks.

Meanwhile, areas classified as non-flood-prone cover approximately 5,200 hectares and are dominated by hilly and highland areas. The dominance of moderate- to high-risk zones indicates that the majority of urban activities in Bengkulu City are located in areas at risk of flooding, which has direct implications for sustainability economic activity, infrastructure resilience, and social stability. These conditions underscore that flood risks in Bengkulu City are not merely local in nature but have become a structural urban issue requiring a spatially-based mitigation and adaptation approach. The distribution of these flood-prone zones is shown in Figure 3.

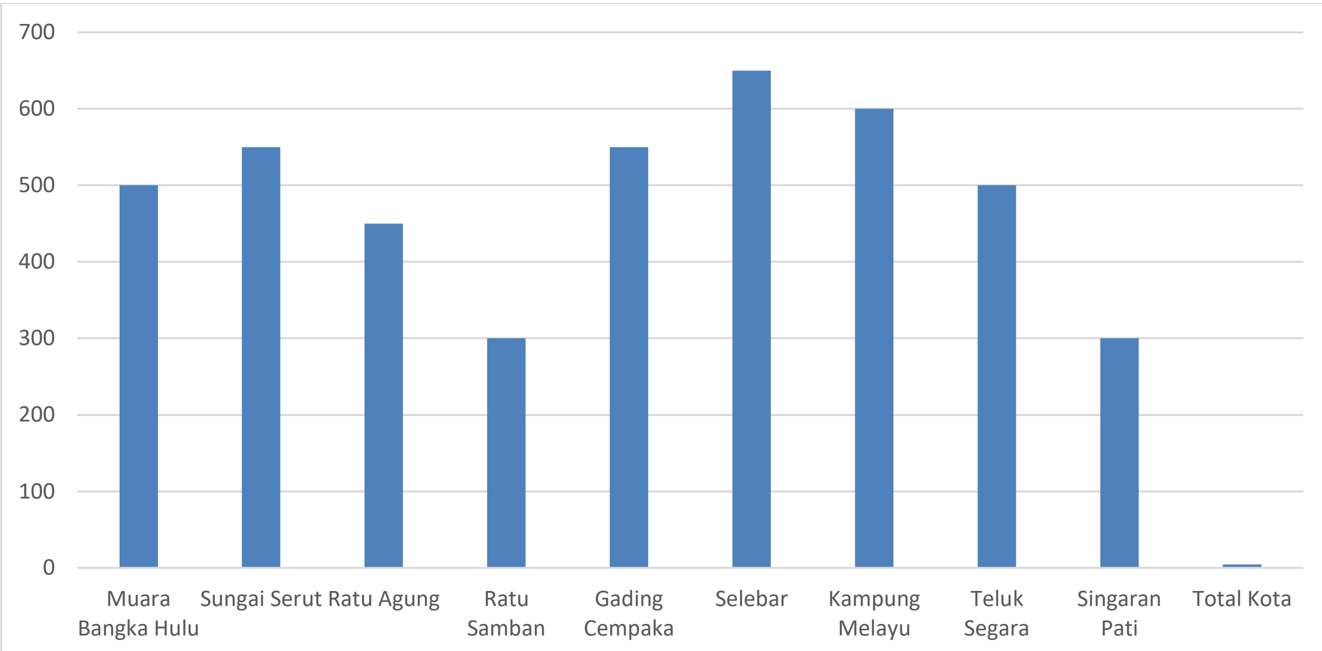

Figure 4. Map of high flood risk areas (ha)

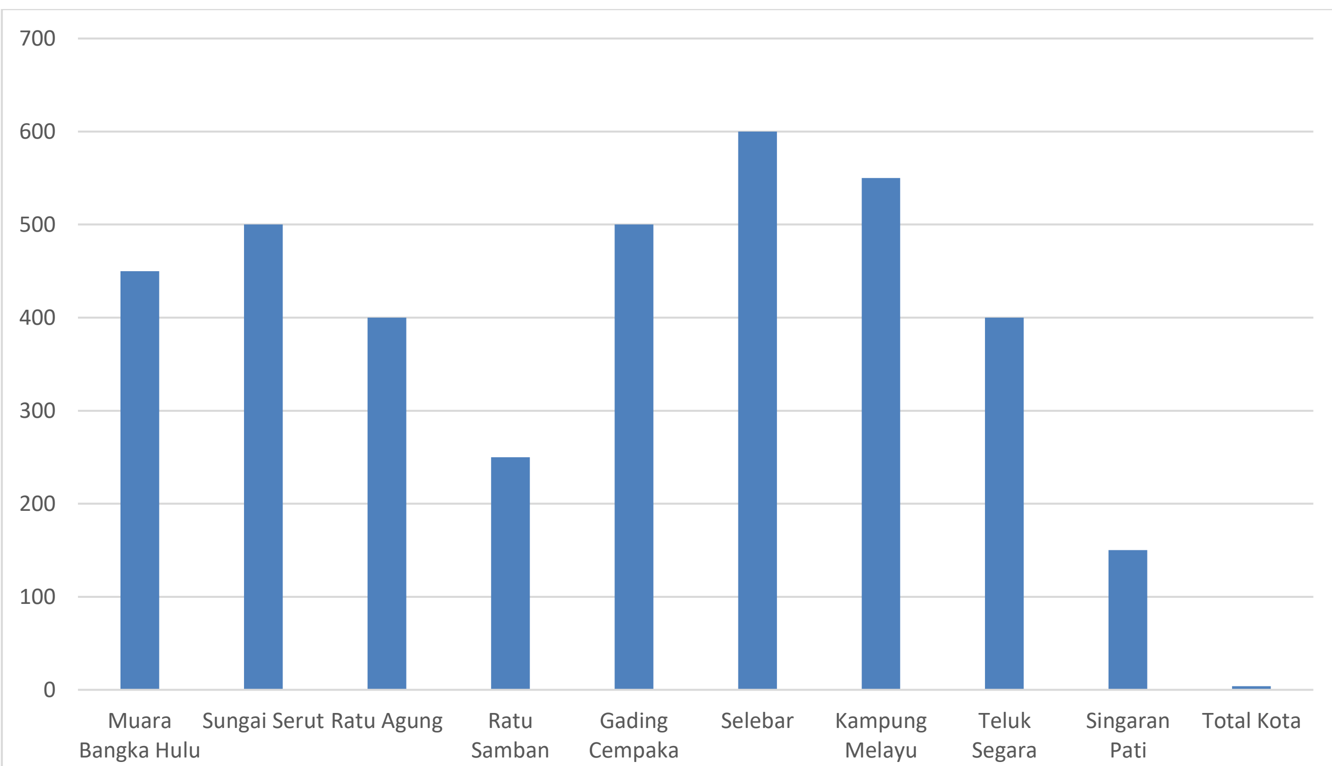

Figure 5. Graph of moderate flood risk levels (ha)

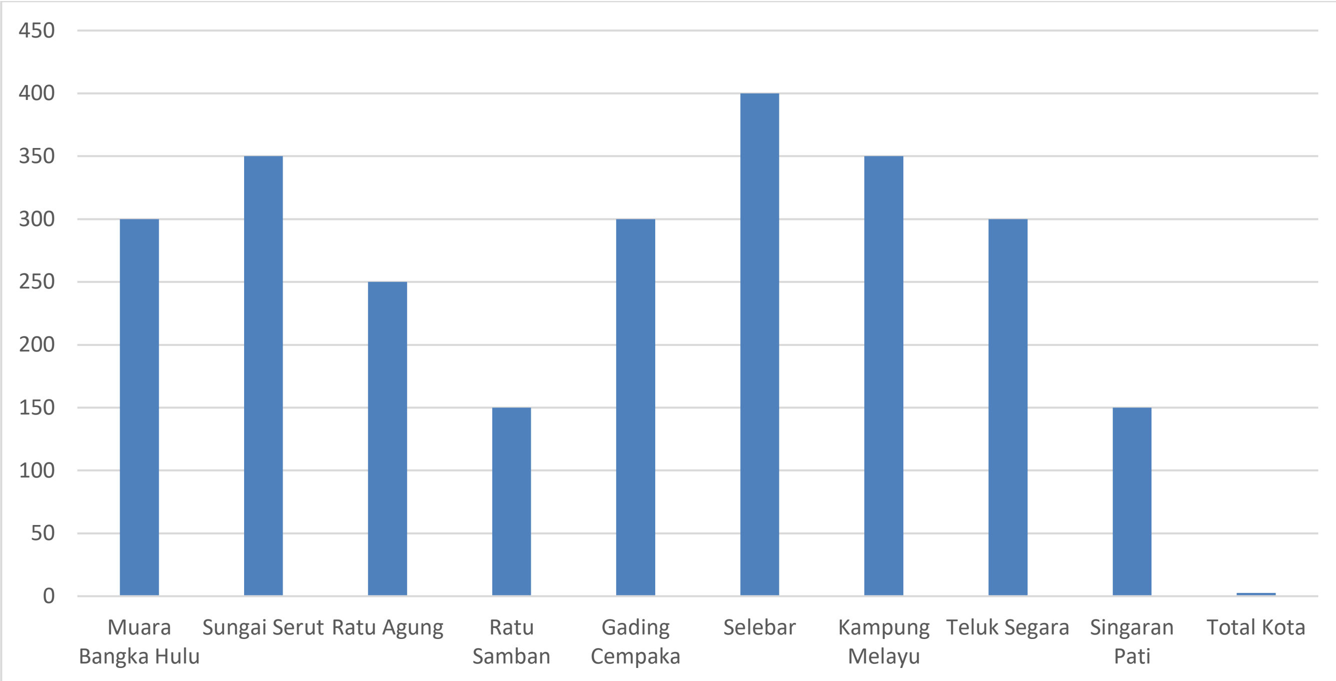

Figure 6. Map of areas with a low flood risk (ha)

Therefore, flood mitigation efforts in Bengkulu City should prioritize areas with a high level of vulnerability, given that these areas pose the greatest risk of damage physical, social, and economic losses. High-risk areas are generally located in nearby low-lying areas with a plot river primarily due to suboptimal drainage systems and intense residential development pressure. These conditions limit the environment's capacity to absorb stormwater runoff, making recurrent flooding a phenomenon that is difficult to avoid without integrated structural and non-structural interventions. Therefore, the construction and improvement of drainage systems, river channelization, and flood-risk-based spatial planning are strategic steps that cannot be delayed to reduce the vulnerability of urban areas.

From a demographic perspective, the City of Bengkulu had a population of 394,190 in 2023, with a density of approximately 2,538 people per square kilometer. This relatively high population density indicates that the potential impacts of flooding are not limited to physical damage but also have direct implications for public safety and well-being. In the six subdistricts included in the study sample, population density ranges from 2,400 to 3,000 people per square kilometer, reflecting varying levels of urbanization as well as differences in flood vulnerability. Subdistricts with higher density tend to face greater settlement pressure in flood-prone areas, thereby increasing the risk of damage to residential infrastructure and disruptions to community economic activities.

Another relevant social aspect is the availability of educational facilities. Approximately 150 elementary, middle, and high schools are distributed across the six sub-districts in the study area. The presence of these educational facilities has the potential to serve as a vital asset in building community awareness and disaster literacy. However, the existence of educational infrastructure does not automatically correlate with the level of community preparedness for floods. The recurring threat of flooding still has the potential to cause significant losses in social, economic, and cultural dimensions, especially if disaster knowledge has not been widely internalized in the daily lives of the community.

The vulnerability of residential areas in flood-prone regions is further exacerbated by low adaptive capacity in certain aspects, such as environmental infrastructure and disaster preparedness. Without adequate improvements in adaptive capacity, residential areas will remain vulnerable to the impacts of flooding, including building damage, disrupted mobility and economic activities, and the disruption of community social networks. This situation indicates that community resilience is not only determined by the strength of social capital but also heavily depends on the quality of available infrastructure and support systems.
Therefore, strengthening communities' adaptive resilience requires a more comprehensive approach. The

development of early warning systems, enhanced disaster preparedness training that actively involves the community, and environmental management based on local empowerment are key components of medium- and long-term adaptation strategies. Furthermore, improvements in the quality of residential infrastructure in flood-prone areas must be accompanied by strengthened institutional capacity and cross-sectoral coordination. Synergy between local governments and communities is key to ensuring that adaptation efforts are not piecemeal but rather sustainable and capable of addressing the challenges of flood risk disparities in Bengkulu City. The results of community adaptive resilience measurements summarized in Table 3 provide an empirical basis for formulating more targeted adaptation policy priorities.

Table 3. Community adaptive resilience in coping with flood hazards

No	Indicators	Sub-Indicators / Assessment Description	Criteria Description	Criteria Description	Criteria	Notes:
1	Population and Demographics	Population density, distribution of the working-age population, sex ratio, and population mobility in flood-prone areas	High High concentration of vulnerable areas	High High concentration of vulnerable areas	High	Population density in vulnerable areas:
2	Health	Access to health services, environmental health, and medical facility preparedness	High Uneven access	High Uneven access	High	Access is not yet equitable:
3	Education and Disaster Preparedness	Disaster literacy, mitigation education, and training participation	Moderate Uneven literacy rates	Moderate Uneven literacy rates	Moderate	Literacy rates are not yet equitable:
4	Social Capital	Social networks, mutual aid, solidarity, and community participation	High Strong community solidarity	High Strong community solidarity	High	Strong community solidarity:
5	Social Cohesion and Local Institutions	The role of neighborhood associations (RT/RW), community organizations, and local coordination	High Cross-sectoral coordination	High Cross-sectoral coordination	High	Cross-sectoral coordination:
6	Infrastructure and Physical Environment	Drainage, levees, evacuation routes, and mitigation-oriented land use planning	Moderate Infrastructure not yet optimal	Moderate Infrastructure not yet optimal	Moderate	Infrastructure is not yet optimal
	Average Total Adaptive Resilience		71.7	67.7 – 88.4	High Aggregate resilience	High Aggregate resilience

Based on the results of an analysis using the Climate and Disaster Resilience Initiative (CDRI) methodology, the weighted total score for the adaptive resilience of the community in Bengkulu City was 71.7, which falls into the high category. This score indicates that, overall, the community possesses relatively strong adaptive capacity in coping with flood risks. Social aspects such as social capital, community solidarity, and the functionality of local institutions are the dominant factors driving this high adaptive resilience score. However, this achievement does not necessarily reflect a uniformly strong resilience across the entire city, as there are still structural weaknesses in the areas of mitigation infrastructure and disaster education.

Spatial analysis reveals that the level of community adaptive resilience in Bengkulu City is uneven across districts. Districts with high flood risk levels, such as Muara Bangkahulu, Sungai Serut, and Kampung Melayu, exhibit more vulnerable adaptive capacities compared to districts with higher topography, such as Teluk Segara and Ratu Agung. This disparity underscores that high aggregate adaptive resilience scores do not always align with the level of hazard exposure faced by communities in high-risk areas. High population density, limited drainage capacity, and settlement pressures in riverbank zones result in significant physical and social vulnerabilities in high-risk areas, even though the community's social capital is relatively strong.

The Muara Bangkahulu subdistrict serves as a prime example of this situation. Geomorphologically, this area is located in a low-lying plain and is traversed by the Bengkulu River, making it highly susceptible to flooding nearly every year. Field survey results indicate that the community in this area has strong social bonds and active mutual aid mechanisms, particularly in activities such as cleaning waterways and providing emergency assistance when floods occur. This social capital plays a crucial role in accelerating emergency responses and mitigating the direct impacts of flooding. However, institutionally, coordination between the community and the government remains suboptimal, particularly regarding long-term mitigation planning and the management of environmental infrastructure. This situation results in flood responses that remain largely reactive and have not yet been fully integrated into a disaster risk reduction framework.

A similar situation is also found in Kampung Melayu, which is one of the coastal areas with a high risk of flooding. The main issues in this area stem from poor local drainage conditions and increasing residential development along the riverbanks. This development pressure narrows water flow channels and reduces infiltration capacity, making annual flooding increasingly difficult to manage. In this context, community adaptive resilience is significantly influenced by the quality of available physical infrastructure. Although the community has experience dealing with floods and a fairly strong social network, the limitations of physical mitigation measures keep the risk of infrastructure damage and disruption to economic activities high.

These findings indicate that community adaptive resilience cannot be understood solely as a result of social strength, but must also be viewed as an interaction between social capacity and physical environmental conditions. Disaster education and infrastructure, which remain in the moderate category, are the primary weaknesses in the adaptive resilience system of Bengkulu City. The low level of internalization of disaster knowledge in daily life means that community preparedness still relies on empirical experience and emergency responses, rather than systematic preventive planning.

In this context, efforts to enhance community adaptive resilience must be undertaken through a more integrated approach. Structural measures are crucial for reducing physical hazard levels through river normalization, improved drainage capacity, the construction of flood control infrastructure, and the provision of green open spaces that function as water absorption areas. These efforts must be prioritized in high-risk areas to reduce the level of physical vulnerability, which has long been a limiting factor for community adaptive resilience.

Additionally, social and institutional approaches must be strengthened to ensure that community adaptive capacity does not rely solely on informal solidarity but is also supported by effective institutional systems. Strengthening coordination among communities, village governments, and disaster management agencies is key to building a more planned and sustainable response system. Establishing emergency communication mechanisms and enhancing the role of local institutions in mitigation planning can help bridge the gap between policy and on-the-ground practices.

CONCLUSSION

Based on the results of an analysis using the Climate and Disaster Resilience Initiative (CDRI) methodology, the adaptive resilience of the community in Bengkulu City falls into the high category overall, with an average score of 71.7. However, these results indicate significant spatial disparities, where subdistricts with high flood risk levels—such as Muara Bangkahulu, Sungai Serut, and Kampung Melayu—still have relatively weaker adaptive capacity compared to areas with higher topography. These findings underscore that a high adaptive resilience category should not be interpreted as a uniform, risk-free condition, but rather as an average achievement that masks local vulnerabilities in flood-prone areas.

Theoretically, this study reinforces the understanding that community resilience is a contextual and spatial construct, shaped by the interaction between hazard levels, social adaptive capacity, and physical environmental conditions. High social capital has proven capable of supporting community emergency responses, but it is insufficient to offset infrastructure limitations and the low level of internalization of disaster education. Thus, resilience is not linear with respect to hazards but is strongly influenced by disparities in adaptive capacity across regions.

The policy implications of these findings underscore the need for a risk-area-based approach, rather than a one-size-fits-all policy at the city level. Local governments should prioritize improving mitigation infrastructure and disaster literacy in subdistricts with high-risk hazards, as well as strengthen institutional coordination so that community social capital can be integrated into long-term mitigation planning.

For future research, we recommend the development of a spatially-based resilience model that integrates hazard data, social indicators, and the dynamics of land-use change, as well as longitudinal analysis to capture changes in community adaptive capacity over time. This approach is essential for deepening our understanding of urban resilience in the context of increasingly complex flood risks.

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Conflict of interest The author has no competing interests to declare that are relevant to the content of this article.

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