Settlement Patterns and Availability of Environmental Infrastructure in Flood-Prone Areas along the Bingai Riverbanks: A Study on Community Risk and Resilience

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ABSTRACT
Flooding is a recurring disaster in the riverbank areas of the Bingai River, Binjai, North Sumatra, largely influenced by settlement patterns and inadequate environmental infrastructure. This study aims to analyze the relationship between settlement patterns and the availability of environmental infrastructure with the level of risk and community resilience in facing flood disasters. Using a qualitative descriptive method with a SWOT analysis approach, the research involved 100 respondents, consisting of 80 residents and 20 business actors affected by flooding. The findings indicate a relatively strong sense of community, with 85% of residents actively participating in communal work (gotong royong), and 78% having developed survival strategies. However, 90% of residents face challenges related to micro-infrastructure, such as poor drainage systems and a lack of evacuation routes. Additionally, 73% of resident experience limited access to disaster mitigation information, resulting in low community preparedness for flood events. In terms of opportunities, 50% of the community has begun utilizing local technology, while 60% of business actors have adapted more resilient business models in response to flooding. Key challenges include changes in river flow patterns caused by human activity (88%) and increased migration to riverbank areas (60%), both of which could elevate future flood risks. Based on these findings, several strategic recommendations are proposed, including the enhancement of flood-adaptive micro-infrastructure, community education on disaster mitigation, the development of environmentally based economic models, and more sustainable settlement management. Through the implementation of these strategies, it is expected that communities along the Bingai Riverbanks will be better prepared to face floods and build stronger resilience systems against environmental changes.

Keywords: *Settlement Patterns, Community Resilience, Floods*

Introduction

The riverbank area of the Bingai River in Binjai, North Sumatra, is a region frequently affected by flooding due to high rainfall and increasingly unpredictable river flow patterns. The development of settlements in this area often overlooks disaster mitigation considerations, thereby increasing community vulnerability to floods. One of the main contributing factors to this risk is the informal and poorly planned nature of settlement patterns (Nuraini, 2017; Sugiarto & Kustiah Ramadania, 2024). Furthermore, the availability of environmental infrastructure—such as drainage systems, roads, and clean water facilities—is often inadequate, which exacerbates the impact of flooding on residents' daily lives.

This condition has led to a variety of social and economic problems, ranging from damaged infrastructure to disruptions in local economic and social activities (Nuraini, 2017, 2021). The increasing frequency and intensity of flooding in recent years indicate the urgent need for an in-depth study on the relationship between settlement patterns and the availability of environmental infrastructure with community risk levels and resilience in the face of flooding (Aini et al., 2023; Linda et al., 2024; Nuraini et al., 2023).

Previous studies have highlighted the importance of proper settlement planning in flood-prone areas as part of broader disaster mitigation strategies. Research by Sebastian (2008) revealed that communities living along riverbanks are at high risk of flood impacts if no proper spatial planning and environmental adaptation measures are in place. Similarly, Sagala (2014) emphasized the need for planning strategies that accommodate the characteristics of disaster-prone areas to reduce potential impacts. Putra (2015) stressed the importance of disaster preparedness in mitigating the negative effects of flooding, as well as the critical role of rescue efforts.

At the national level, Dritasto and Astuti (2016) found that socio-economic factors often hinder communities from transforming settlement patterns in disaster-prone areas, such as in Dayeuhkolot Sub-district, Bandung Regency. Thoyibah and Pamungkas (2020) formulated design principles for buildings in flood-prone areas that can be implemented to reduce disaster impacts, as seen in their case study of Centini Village, Lamongan. Setiawan (2014) examined the infrastructure needs of fishing communities who also face similar challenges in disaster-prone areas. Akhmad (2019), in his study on land welfare for communities in flood-prone zones of Tembalang District, Semarang City, found that suboptimal spatial planning significantly contributes to increased disaster risk.

This study aims to analyze how settlement patterns and the availability of environmental infrastructure influence the level of risk and community resilience against flooding in the riverbank area of the Bingai River. By understanding the relationship between these factors, the study intends to contribute to the formulation of more effective policy recommendations for local governments and relevant stakeholders in planning and managing settlements in flood-prone areas. The findings are expected to be not only academically valuable but also practically useful in supporting disaster mitigation efforts and enhancing community resilience. Through a comprehensive approach, this research seeks to provide deeper insights into adaptive strategies and improved environmental planning to reduce the impacts of flooding in the Bingai Riverbank area.

Literature Review

This study employs a theoretical framework that explains the interrelationships among settlement patterns, the availability of environmental infrastructure, risk levels, and

community resilience to flood disasters. To achieve this, the study integrates three levels of theory: Grand Theory, Middle Theory, and Applied Theory—which collectively link overarching concepts to specific field-level applications.

A. Grand Theory: Urban Ecology Theory

Teori perkotaan menjelaskan bagaimana manusia dan lingkungan hidupnya saling berinteraksi Urban Ecology Theory explains how humans and their living environments interact within a dynamic ecological system. According to this theory, settlement patterns in a particular area evolve based on environmental, social, and economic factors that shape the spatial structure and patterns of community activities (Park & Burgess, 1925 in Nuraini, 2019). In the context of this study, Urban Ecology Theory helps to understand how settlements along the Bingai River have formed and evolved under high flood risk conditions. This theoretical perspective allows the research to explore how interactions between the community and the natural environment influence their flood resilience and how the availability of environmental infrastructure serves as a determining factor in creating more adaptive settlement systems.

B. Middle Theory: Community Disaster Resilience Theory

The Community Disaster Resilience Theory focuses on a community's capacity to cope with, adapt to, and recover from disaster threats (Norris et al., 2008 in (Purba et al., 2024; Sugiarto et al., 2023)). Community resilience is influenced not only by physical aspects such as environmental infrastructure but also by social and economic dimensions, including disaster preparedness and mitigation systems. In this study, the theory is used to explain how the availability of environmental infrastructure in flood-prone areas can either enhance or hinder community resilience. It also provides a framework to analyze whether the existing settlement patterns contribute to increased flood risks or have the potential to be developed into more resilient forms.

C. Applied Theory: Risk-Based Spatial Planning Theory

This theory emphasizes that spatial planning must integrate disaster risk considerations in order to create safer and more sustainable environments (Burby et al., 2000 in (Nuraini, 2024)). In this study, the theory is applied to assess whether the development of settlements along the Bingai River has considered disaster mitigation aspects or instead has increased community vulnerability to floods. By using this theory, the study can formulate risk-based policy recommendations for adaptive spatial planning, including the provision of environmental infrastructure that supports community resilience. These three theories are interrelated in supporting the objectives of the research, which is to analyze the relationship between settlement patterns and the availability of environmental infrastructure with the levels of risk and resilience of communities in flood-prone areas (Nuraini, 2021, 2024). Urban Ecology Theory facilitates understanding of the ecological and social dynamics of riverbank settlement formation. Community Disaster Resilience Theory provides a framework for measuring the extent to which communities can withstand and recover from flooding based on existing settlement and infrastructure conditions. Meanwhile, Risk-Based Spatial Planning Theory guides the research in identifying solutions and policies that can reduce flood risks and enhance community resilience through improved planning. Together, these theories form a strong conceptual foundation to address the research questions and

propose scientifically grounded solutions to improve environmental quality in the Bingai Riverbank area.

Conceptual Framework of the Study

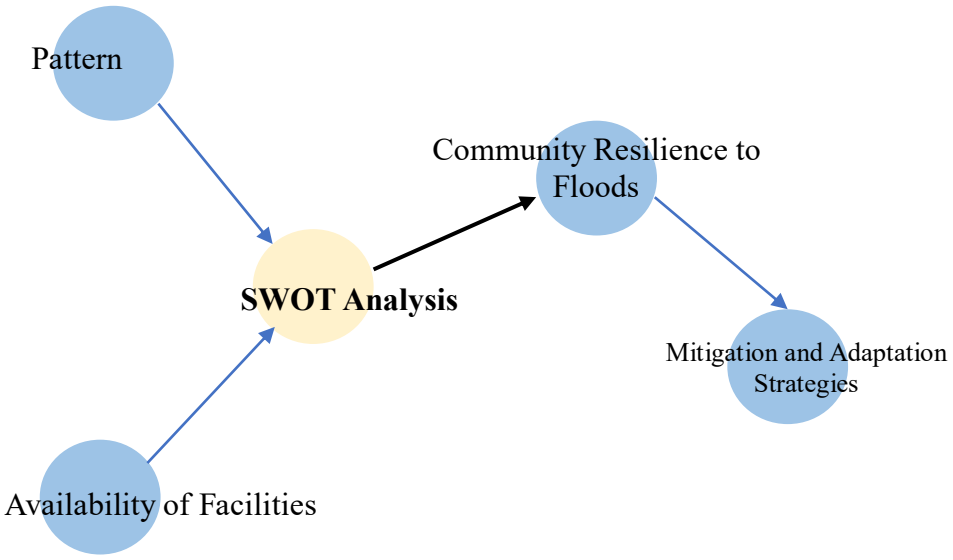

Figure 1. Conceptual Framework of the Study
Source: Author's Design, 2025

The figure above illustrates the conceptual framework of the research, depicting the relationships among settlement patterns, the availability of environmental infrastructure, SWOT analysis, community flood resilience, and strategies for mitigation and adaptation.

Results and Discussion

This study aims to analyze settlement patterns and the availability of environmental infrastructure in the flood-prone areas along the Bingai Riverbanks, as well as to assess community risk and resilience in the face of disasters. Data were collected from 100 respondents, consisting of 80 residents and 20 business actors, and analyzed using the SWOT approach to identify strengths, weaknesses, opportunities, and threats affecting settlement conditions and community resilience in the area.
The table below presents the tabulation of key variables and responses from both residents and local business actors:

Table 1. Tabulation of Research Variables Based on Resident and Business Actor Responses

Variable	Indicator	Resident Response (%)	Business Actor Response (%)
	Community Social Sustainability	85	65

Community Resilience to Flooding	**Survival Strategies**	78	70
	Use of Local Technology	50	55
Availability of Environmental Infrastructure	**Micro-Infrastructure Vulnerability**	90	75
	Limited Access to Flood Risk Information	73	68
Mitigation and Adaptation	**Development of Environment-Based Economy**	45	60
Settlement Patterns	**Changes in River Flow Patterns Due to Human Activity**	88	80
	Migration to Riverbank Areas	60	50

Source: Processed by the Author, 2025

The table above illustrates the percentage responses from residents and business actors concerning the investigated variables. The following bar chart provides a visual representation of these findings:

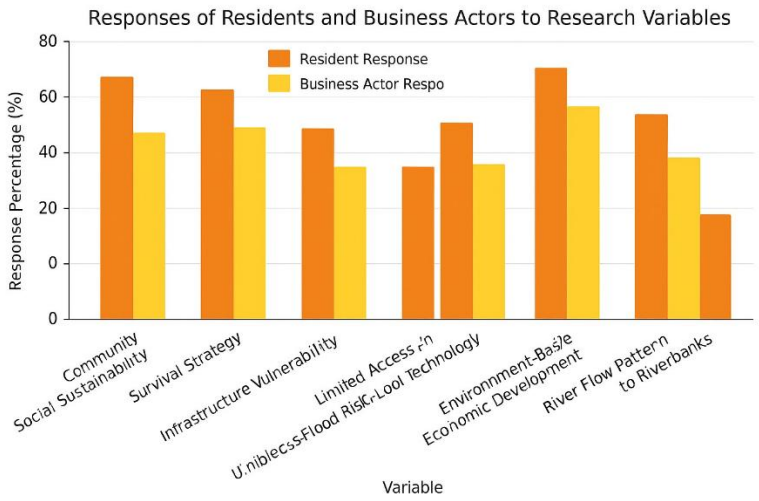

Figure 2. Bar Chart of Research Findings
Source: Processed by the Author, 2025

The bar chart presented above visually illustrates the percentage distribution of responses. Further interpretation of the results is provided below:

A. Community Social Sustainability

According to the data, 85% of residents stated that mutual cooperation (gotong royong) remains an essential factor in enhancing flood resilience, whereas only 65% of business actors perceived its benefits. This suggests that social engagement is stronger among long-term residents of the riverbank area. In contrast, business actors tend to have lower levels of social involvement, as many operate in the area without significant community integration.

This social solidarity can be a valuable asset in community-based disaster mitigation programs. Local governments or organizations can leverage this aspect to encourage the formation of more effective community-level disaster response teams.

B. Survival Strategies

Approximately 78% of residents and 70% of business actors have developed survival strategies during floods, including raising the floor level of houses, preparing emergency supplies, and identifying alternative exit routes. The difference in these figures indicates that although many have adapted, 22% of residents and 30% of business actors still lack clear strategies.

This lack of preparedness highlights the need for improved education on disaster mitigation. Community outreach and emergency response training could help bridge this gap.

C. Vulnerability of Micro-Infrastructure

This category refers to the level of damage and limitations of environmental infrastructure in the riverbank area. A total of 90% of residents and 75% of business actors reported major issues such as poor drainage, inaccessible roads during floods, and a lack of emergency support facilities.

These findings emphasize that community resilience is not solely dependent on social factors but also on infrastructure quality. Improving drainage systems and developing better evacuation routes should be prioritized in spatial planning and flood mitigation policies.

D. Limited Access to Flood Risk Information

About 73% of residents and 68% of business actors indicated they have limited access to information related to flood risks and early warning systems. This indicates that a significant portion of the population is still underserved in terms of flood mitigation awareness.

Limited access to information amplifies the impact of flooding, especially for those without adequate survival strategies. Community-based educational initiatives and public information boards at strategic points can improve readiness.

E. Utilization of Local Technology for Flood Adaptation

Fifty percent of residents and 55% of business actors have started using simple technologies such as infiltration wells, biopores, and flood-resistant construction materials to reduce flood impacts. While these are encouraging figures, half of the respondents have yet to adopt such strategies.

The relatively low adoption rate of flood adaptation technologies indicates a need for intervention. Extension programs or subsidies for households to implement these technologies could help boost resilience.

F. Development of Environment-Based Economy

Forty-five percent of residents and 60% of business actors identified opportunities for developing more flood-resilient businesses, such as vertical farming and digital-based enterprises. The higher percentage among business actors suggests they are more adaptive in seizing business opportunities despite flood risks. This potential could be further supported by training and assistance to empower local communities to develop disaster-resilient livelihoods.

G. Changes in River Flow Patterns Due to Human Activity

Eighty-eight percent of residents and 80% of business actors acknowledged that changes in river flow caused by human activities have worsened flood impacts. Deforestation in upstream areas, sand mining, and unregulated construction are cited as the main drivers of increased flood intensity. This problem illustrates that flood mitigation efforts must extend beyond local communities and include broader spatial planning policies, including upstream land-use regulation.

H. Migration to Riverbank Areas

Sixty percent of residents and 50% of business actors reported increasing migration to the riverbank areas due to low land prices and easy access to natural resources. However, this migration has worsened flood conditions by increasing settlement density in high-risk areas. This situation shows that without regulations governing settlement development in flood-prone zones, flood risks will continue to rise. More strategic policies are needed to control land use in disaster-prone areas.

The following section presents the results of the SWOT analysis in table format:

Table 2. SWOT Analysis Results

Factor	Description
Strengths	High community social sustainability (85% of residents actively participate in gotong royong). Strong survival strategies (78% have adaptation methods).
Weaknesses	High vulnerability of micro-infrastructure (90% of residents face poor drainage conditions). Limited access to flood risk information (73% lack mitigation education).
Opportunities	Increased utilization of local technologies for flood adaptation (50% of residents use simple technologies). Development of environment-based economy (60% of business actors have adjusted their businesses to flood conditions).
Threats	Changes in river flow patterns due to human activities (88% of residents report negative impacts). Increasing migration to riverbanks (60% of residents note growing settlement density).

Source: Compiled by the Author, 2025

This table highlights the strengths, weaknesses, opportunities, and threats relevant to settlement conditions and community resilience in the Bingai Riverbank area.

Discussion

This study aims to analyze settlement patterns and the availability of environmental infrastructure in the flood-prone areas along the Bingai Riverbanks, while also assessing community risk and resilience in the face of disasters. Based on the findings presented earlier, the following discussion interprets the results in relation to the study's objectives.

A. Community Social Sustainability

The findings indicate that 85% of residents actively participate in gotong royong (mutual cooperation), reflecting a high level of community social capital. This aligns with the study's objective to identify factors that support flood resilience. Strong social solidarity plays a critical role in disaster mitigation efforts, as highlighted by Norris et al. (2008), who argue that strong social bonds enhance a community's capacity to face disasters.

B. Survival Strategies

Approximately 78% of residents have developed adaptive strategies for dealing with floods, such as elevating houses and preparing emergency kits. This demonstrates awareness and preparedness among residents, which aligns with the objective of identifying community adaptation efforts. Burby et al. (2000) emphasize the importance of incorporating disaster risk considerations into spatial planning to strengthen community resilience.

C. Vulnerability of Micro-Infrastructure

Conversely, 90% of residents reported challenges related to inadequate infrastructure, particularly poor drainage systems, which increase their vulnerability to flooding. This finding is consistent with the study's goal of evaluating the availability of environmental infrastructure. Wisner et al. (2004) emphasize that physical vulnerabilities, such as insufficient infrastructure, can significantly magnify disaster impacts.

D. Limited Access to Flood Risk Information

About 73% of residents indicated limited access to information regarding flood risks and early warning systems, highlighting the need for improved public education and communication systems. This finding aligns with the objective of identifying factors influencing community resilience. Norris et al. (2008) state that access to information and education is a critical component of community resilience building.

E. Utilization of Local Technology for Flood Adaptation

Only 50% of residents have adopted simple local technologies such as infiltration wells and biopores for flood adaptation. This reflects an opportunity to promote greater use of low-cost technologies for disaster mitigation, supporting the study's objective to identify opportunities for enhancing resilience. Park and Burgess (1925) underscored the role of technological adaptation in supporting community resilience in urban ecological systems.

F. Development of Environment-Based Economy

A total of 45% of respondents recognized opportunities to develop flood-resilient businesses, such as vertical farming. This indicates potential for economic activities that support resilience, aligning with the objective of identifying opportunities to strengthen community capacity. Saaty (1980) emphasized the role of sustainable economic development in enhancing community resilience.

G. Changes in River Flow Patterns Due to Human Activity

Approximately 88% of residents reported negative impacts from changes in river flow patterns caused by human activities, which contribute to the increased risk of flooding. This supports the objective of identifying threats to community resilience. Wisner et al. (2004) noted that unregulated human activities can intensify vulnerability to disasters.

H. Migration to Riverbank Areas

Sixty percent of residents stated that migration to the riverbanks is increasing, contributing to higher settlement density and greater flood risk. This finding is relevant to the study's objective of understanding settlement dynamics in disaster-prone areas. Park and Burgess (1925) highlighted that population migration into high-risk zones can increase community vulnerability.

Conclusion

This study aimed to analyze the settlement patterns and the availability of environmental infrastructure in the flood-prone areas along the Bingai Riverbanks, as well as to examine the risks and resilience of the local community in dealing with disasters. Based on the findings, it was revealed that the community possesses a high level of social cohesion, characterized by strong solidarity and active mutual cooperation; however, they still face numerous challenges, particularly concerning flood-prone infrastructure, limited access to disaster mitigation information, and the negative impacts of altered river flow patterns caused by human activities in upstream areas. In addition, while the majority of residents have developed survival strategies in response to flooding—demonstrating a general awareness of flood risks—these strategies are not evenly distributed across the population, leaving certain vulnerable groups without adequate adaptive mechanisms. In terms of opportunities, the adoption of local technologies and the development of environmentally-based economic activities have started to emerge, though they remain limited due to a lack of technical support and access to capital. Meanwhile, migration to the riverbanks continues to increase, further degrading environmental conditions and raising future flood risks.

Based on these findings, several strategic measures are recommended to enhance community flood resilience. First, regarding infrastructure improvements, there is a need to upgrade drainage systems using sustainable approaches such as the construction of infiltration wells, biopore-based rainwater management, and regular maintenance of drainage channels through community cooperation. Strengthening micro-infrastructure, such as developing structured evacuation routes and providing temporary shelters for affected residents, would also serve as effective flood mitigation actions. Second, in terms of increasing public awareness and education, it is essential to implement regular training programs involving disaster simulations, disseminate information more effectively through flood warning boards, mobile-based early warning applications, and engage community leaders in educating residents about disaster mitigation. Improved access to such information is expected to better prepare the community in responding to flood risks and to encourage more appropriate preventive actions.

Third, in terms of local technology use, broader outreach is needed to promote the application of simple flood-resistant construction techniques that communities can adopt independently, including the use of water-resistant building materials, stilt house designs, and community-based protective systems that enhance safety during the rainy season. Community-driven innovations, such as utilizing green spaces around settlements, can also help improve water absorption and reduce flood impacts. Fourth, in the economic domain, support programs should be developed for small business actors to adapt to frequently flooded environments, for example by promoting digital business models that are not reliant on physical locations and encouraging flood-resilient sectors such as vertical farming and aquaponics that can operate in limited spaces without direct exposure to floodwaters.

Fifth, in terms of settlement management, a stricter policy approach is needed to regulate migration patterns to the riverbanks by offering incentives for those willing to relocate to safer areas and enforcing stricter building regulations in disaster-prone zones. Safer spatial planning alternatives must be provided to prevent the spread of informal settlements in high-risk areas. Sixth, to address changes in river flow patterns caused by human activities, stricter regulations are required to limit the exploitation of natural resources in upstream regions, including bans on illegal logging and controls on industrial activities that disrupt the river's ecological balance. By implementing these strategies, the settlement patterns along the Bingai Riverbanks can be managed more effectively, enabling the community not only to survive floods but also to develop more adaptive systems in response to environmental change. Structured and community-based mitigation efforts are essential to ensure that community resilience continues to improve in line with future environmental conditions and challenges. This study also lays the groundwork for further research into developing more effective community-based disaster mitigation models in other flood-prone areas of Indonesia.

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