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RESILIENCE AGAINST TIDAL FLOODING: A HISTORICAL PERSPECTIVE FROM SEMARANG CITY'S COASTAL DISTRICTS

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ABSTRACT

Semarang's coastal areas face significant threats from tidal flooding (Rob), exacerbated by natural and human factors. As an economic hub on Java's north coast, Semarang is particularly vulnerable to coastal hazards. This study examines historical perspectives on tidal flooding, focusing on the adaptive responses of districts such as Genuk, Semarang Utara, Semarang Barat, and Tugu. The analysis reveals the interplay between urbanisation, environmental degradation, and community vulnerability. While improvements in flood control infrastructure have reduced flood intensity, challenges such as land subsidence and rising sea levels remain. The findings highlight the importance of adaptive strategies, including restoring natural barriers like mangroves and promoting community conservation efforts. Since 2010, government initiatives have emphasised large-scale flood mitigation, but these should be integrated with socio-economic and environmental considerations. Sustainable urban planning and community engagement are vital for enhancing resilience against future flooding. Semarang can work towards a sustainable future that addresses climate change and coastal vulnerability by aligning flood control strategies with national development goals.

Introduction

Indonesia, an archipelagic nation comprising over 81,000 km of coastline and 17,000 islands, is particularly vulnerable to tidal flooding (I. Rudiarto *et al*., 2020; Aksa & Afrian, 2022; A. Salim & Nadya, 2022). The National Disaster Management Agency of Indonesia, or *Badan Nasional Penanggulangan Bencana* (BNPB), documented a 46% rise in tidal flooding incidents between 2020 and 2022 (Adillah *et al*., 2024). While primarily driven by astronomical tides, tidal flooding becomes hazardous when intensified by environmental factors such as sea-level rise, storm surges, and land subsidence, which are increasingly observed in Indonesian coastal regions (Pratama, 2019; Rudiarto *et al*., 2020; Triana & Wahyudi, 2020; Aksa & Afrian, 2022; Jabbar *et al*., 2023; Adillah *et al*., 2024; Arhatin *et al*., 2024; Febrianti *et al*., 2024; Hadini *et al*., 2024; Okvitasari *et al*., 2024).

These natural drivers are further compounded by human-induced factors, including rapid population growth, land use changes, excessive exploitation of river basins leading to sedimentation, inadequate drainage and hydrological infrastructure, and poor coastal and river management (Kausarian *et al*., 2018; Rudiarto *et al*., 2018; Triana & Wahyudi, 2020; Rudiarto *et al*., 2020; Handayani *et al*., 2020; Sulistiyono *et al*., 2024; Febrianti *et al*., 2024; Hadini *et al*., 2024), significantly affecting infrastructure, economic systems, environmental health, and local communities (Kartika *et*

al., 2019; Rudiarto *et al*., 2020; Setiawan *et al*., 2022; Aksa & Afrian, 2022; Okvitasari *et al*., 2024; Sulistiyono *et al*., 2024). This underscores the urgent need for comprehensive and integrated flood management strategies to effectively address and mitigate the impacts of tidal flooding.

Over the past 30 years, the northern coast of Central Java has experienced the highest rate of economic growth in the region (Wahyudi *et al*., 2012). This period has been marked by significant development and industrial expansion, driven by increased investment, infrastructure improvements, and a burgeoning local economy. This growth has been facilitated by strategic initiatives to enhance the region's connectivity and competitiveness such as upgrading transportation networks and supporting industrial zones. However, over the past two decades, this growth has been periodically interrupted by instances of tidal flooding, locally known as "*Rob*"' (Kartika *et al*., 2019). These occurrences have been intermittent but notable, reflecting recurring inundation events that have affected the region's coastal areas. The rising frequency of these tidal floods poses significant challenges to the region's infrastructure and economic stability.

Semarang City, located on this coast, is particularly affected by severe tidal flooding. This issue has worsened due to rising sea levels from climate change (Suhelmi, 2013; Buchori *et al*., 2018; Findayani *et al*., 2024; Salim & Wibowo, 2024), land subsidence (Marfai & King, 2008b; Suhelmi *et al*., 2009; Ismanto *et al*., 2009; Nugroho, 2013; Salim & Wibowo, 2024), and rapid urban expansion (Rudiarto *et al*., 2018; Khoirunisa, 2023). As the capital of Central Java Province, Semarang is crucial to regional commerce, industry, and culture. Urban development, including land reclamation and infrastructure growth, has disrupted natural drainage and increased flooding risks. The city's key infrastructure such as the airport, rail station, and port, is situated in flood-prone areas, highlighting the gravity of the issue. The juxtaposition of rapid economic development with the recurring threat of tidal flooding emphasises the need for comprehensive strategies to mitigate flood risks while sustaining economic progress.

Recent research shows that both natural factors such as tidal movements and coastal erosion, and human actions, like urban development and land-use changes, interact in complex ways to influence the coastal hazards experienced by Semarang (Rudiarto *et al*., 2018; Handayani *et al*., 2020). Studies highlight how these factors have contributed to the city's exposure to tidal flooding. These interactions demonstrate that Semarang remains highly vulnerable to coastal hazards over time, reflecting its ongoing risks from flooding and related issues. To develop effective disaster management strategies, it is crucial to understand historical patterns of coastal hazards (Marfai *et al*., 2008).

Analysing past occurrences and their impacts on the city provides valuable insights into how hazards have evolved and influenced Semarang's urban environment. Addressing current flooding challenges requires a multidisciplinary approach that integrates historical data with environmental science and urban planning. Such an integrated approach helps create sustainable solutions and enhances the city's resilience to future flooding events.

Several approaches have been utilised to advance understanding of disaster phenomena, particularly tidal flooding in Semarang City. One approach integrates historical hazard data with contemporary technologies to enhance flood management. This involves analysing past flood events and combining this data with advanced modelling techniques to simulate various flood scenarios (Marfai, 2003; Sejati & Buchori, 2010; Pratama, 2019).

These simulations and early warning systems that use real-time data improve prediction accuracy and inform the development of adaptive infrastructure. Analysing historical trends in conjunction with urban development and climate change facilitates the creation of

long-term strategies, thereby enhancing the city's resilience and stability. Meanwhile, another approach emphasises a thorough analysis of disaster phenomena from community adaptation perspectives (Sariffuddin & Wijaya, 2014; Buchori *et al*., 2018; Bott *et al*., 2021; Fajrin *et al*., 2021; Jabbar *et al*., 2023).

This method illuminates how disasters influence community development and societal evolution. Historically, such events have driven technological advancements, governance, and urban planning. By examining historical responses and community adaptations, valuable insights into effective disaster management can be gained. Integrating these insights into current practices aids in developing resilient infrastructure, refining emergency response strategies, and enhancing public preparedness. This approach strengthens immediate response capabilities and supports long-term recovery and adaptation, better equipping communities to handle future disasters.

Incorporating a historical perspective into disaster studies is fundamental to adopting a comprehensive approach to disaster management. Socio-economic and environmental factors influence natural hazards and human vulnerabilities; therefore, emphasising historical and contextual analysis is crucial for gaining a thorough understanding and enhancing the effectiveness of disaster management strategies (Paul, 2011; Blaikie *et al*., 2014; Aguilar *et al*., 2016; Sandoval *et al*., 2023). Exploring the interplay between historical events and global climate change reveals how historical perspectives can deepen our understanding of contemporary climate issues and sustainability challenges (McIntosh *et al*., 2012).

By examining past human actions and their environmental impacts, this analysis underscores the importance of incorporating historical insights into modern climate change strategies and sustainability efforts. This approach highlights the significance of historical context in crafting adequate responses to global environmental changes. In essence, a historical perspective enriches our understanding, informs current strategies, and guides future developments in sustainable building.

The resilience to tidal flooding in Semarang City, particularly in its coastal districts, has evolved significantly, reflecting historical challenges and adaptive responses. This study aims to investigate the tidal flood phenomenon along the coast of Semarang City by engaging local stakeholders to provide a comprehensive and nuanced understanding of tidal flood occurrences across various coastal districts.

Since systematic evidence and data management concerning tidal flood events were only established post-2010, this research fills a critical gap in the historical record by examining how these events evolved into significant disasters. By integrating historical data with contemporary observations, the study enhances our understanding of the long-term impacts of tidal flooding and contributes to the broader discourse on disaster evolution and management. This approach sheds light on the historical progression of tidal flood events and informs current and future strategies for mitigating and responding to such environmental challenges.

Materials and Methods

Study Area

This research was conducted in the coastal districts of Semarang City, the capital of Central Java province, and a significant metropolitan area in Indonesia. Semarang City is bordered by the sea along four distinct districts: Genuk, Semarang Utara, Semarang Barat, and Tugu, as illustrated in Figure 1. The study employed a qualitative methodology, focusing on case studies selected according to specific criteria. To be included in the study, a neighbourhood had to meet several conditions: (1) It needed to be located within one of the coastal districts, (2) Demonstrate vulnerability to tidal flooding based on data provided by the Regional Disaster Management Agency, and (3) Have a documented history of flood events, as indicated by preliminary information from key informants

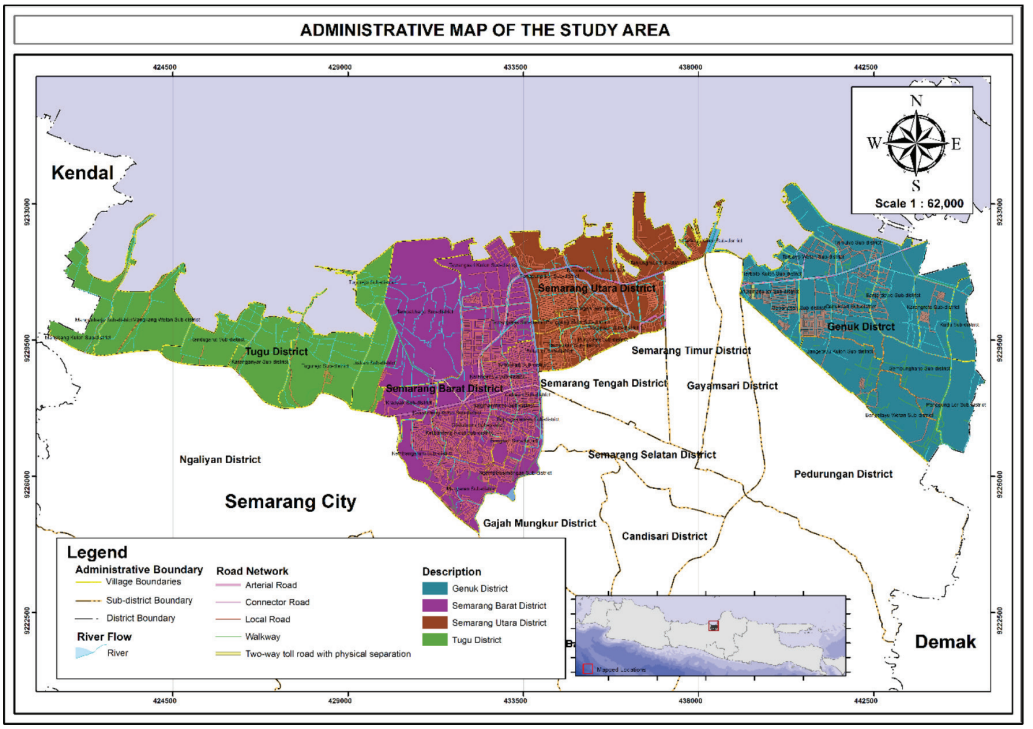


Figure 1: Study area
Source: Analysis (2023)

within the districts or sub-district offices. This approach ensured that the selected case studies represented areas most affected by tidal flooding, providing a comprehensive understanding of the challenges and responses related to coastal flood risks in Semarang City.

Methods

Data collection for this study involved a multifaceted approach, including in-depth interviews, field observations, and internet surveys. In-depth interviews were conducted with selected individuals using purposive and snowball sampling techniques. Initially, researchers, guided by information from the district office, examined each coastal sub-district to identify neighbourhoods at risk of tidal flooding. This process led to the identification of neighbourhoods and stakeholders designated as resource persons. A total of 12 key informants, including sub-district officials with expertise in coastal village development and tidal flood management, participated in the study. Interviews with residents followed. Field observations were conducted at various locations identified by these sources to document current conditions in areas frequently affected by tidal flooding. Additionally, an internet survey was conducted to collect data from relevant agencies and news sources concerning tidal flood disasters in Semarang City.

Results

Tidal Flood in Coastal Semarang City: Overview

The Semarang City area, located along the northern coast of Java Island, is highly susceptible to coastal disasters. These disasters primarily arise from natural factors and developmental influences. Semarang's coastal threats are mainly meteorological or hydrometeorological, with coastal flooding being a significant concern. According to

Semarang City Regional Regulation Number 13 of 2010, which addresses Disaster Management Implementation, certain parts of the city are in low-lying areas characterised by various soil formations, including weathered, shallow, and deep soils. These inherent physical characteristics make these areas prone to frequent flooding, particularly along riverbanks and in the northern coastal plains.

Coastal flooding in Semarang City encompasses three primary types: (a) Local floods, (b) River floods (also known as fluvial floods), and (c) Tidal floods (Marfai & King, 2008a). Tidal flooding, referred to as *Rob* by locals, is a coastal or tidal inundation event that exhibits distinct characteristics. *Rob* occurs in predictable patterns following lunar and solar cycles, primarily due to high tides inundating areas that are lower than sea level, especially during peak tide periods (L. Kurniawan, 2003).

The Java Sea has a monsoon climate, with wind directions shifting every six months: Easterly winds create "*gelombang Timuran*" (eastern waves) during the dry season, while westerly winds produce "*gelombang baratan*" (western waves) during the rainy season (Wahyudi *et al*., 2012). Interviews indicate that *Rob* events typically intensify during the peak tide season from June to August due to the eastern waves, with waves reaching heights of 2 meters and tides around 1.20 meters (Wahyudi *et al*., 2012).

Rob is a common coastal flood affecting almost all regencies and cities along the North Coast (Pantai Utara, abbreviated as Pantura) of Central Java. Recent data from the National Disaster Management Agency (*Badan Nasional Penanggulangan Bencana*, BNPB) indicates that the severe *Rob* event in 2022 impacted several areas, including 12 regencies and/or cities (Table 1). The extent of *Rob*'s impact varies across regions. Data from the Tanjung Emas Maritime Meteorological Station (*Stasiun Meteorologi Maritim*) and tidal predictions from the Indonesian Navy's Hydro-Oceanographic Center (*Pusat Hidro-Oseanografi TNI Angkatan Laut-Pushidrosal*) indicate that weather conditions in the Java Sea during the perigee season of 2022 posed a risk of tidal flooding along the northern coast of Central Java.

This was driven by strong winds reaching up to 36 km/h and maximum wave heights of up to 2.0 meters. Satellite altimetry data revealed a positive anomaly in sea surface height, further intensified by the Super Full Moon phenomenon. Consequently, tidal flooding was forecasted, with peak tide levels expected to reach up to 1.1 meters. Areas at risk included the coastal regions of Pekalongan, Kendal, Semarang, Demak, Jepara, Pati, and Rembang.

Rukayah and Abdullah (2019) describe how Semarang City has been recognized as a key seaport on Java since the 14th century, evolving into a central trading hub in the archipelago. The city's diverse multi-ethnic settlement laid the groundwork for urban development. During the Dutch colonial era, Semarang City played a crucial role in the VOC's trading strategy. The city was designed with canals similar to those in the Netherlands, earning it the nickname "Venetia van Java". Since then, Semarang City has undergone rapid expansion, transforming from a minor trading post into a major port city (Setioko, 2010). Following the independence era, urban population growth surged significantly, leading to the development of modern infrastructure such as airports, regional roads, and other transportation facilities (Setioko, 2010). Today, Semarang has evolved into a metropolitan city.

Historical records reveal that coastal dynamics have intensified with the city's development. Evidence shows that since the 8th century, coastal hazards, such as sedimentation and land subsidence, have resulted in the submersion of portions of the cultural heritage and historical development of coastal culture along the north coast of Java (Rukayah & Abdullah, 2019). Studies indicate that, in Semarang City specifically, the site of the old seaport has shifted from coastal waters to the city center, reflecting significant alterations in the coastline (Rukayah *et al*., 2018). The Semarang River estuary has faced persistent siltation issues

Table 1: Areas affected by Rob during the perigee phenomenon in 2022

No.	Regency/City	Sub-District/Village	*Rob*'s Inundation
1	Kab. Brebes	Randusanga Wetan, Randusanga Kulon, Prapag Lor, Prapag Kidul	0.1 – 0.2 metres
2	Kota Tegal	Muarareja, Tegal Sari, Panggung, Mintaragen	up to 0.45 metres
2	Kab. Tegal	Dampuak	0.4 – 1 metres
3	Kota Pekalongan	N/A	0.1 – 0.9 metres
4	Kab. Pekalongan	Tegaldowo, Karangjompo, Mulyorejo, Depok	0.05 – 0.4 metres
5	Kab. Pemalang	Pesantren, Mojo, Ketapang, Kaliprau, Tasikrejo, Blendung, Kertosari and Limbangan	0.3 – 1 metres
6	Kab. Batang	Klidang Lor, Karangasem Lor	up to 0.4 metres
7	Kab. Kendal	Mororejo, Wonorejo, Kartikajaya, Wonosari, Pidodokulon, Karangsari, Bandengan .	N/A
8	Kota Semarang	Bandarharjo, Tanjungmas	≥ 1 metres
9	Kab. Demak	Sriwulan, Purworejo, Morodenak, Margolinduk	0.25 – 1 metres
10	Kab. Jepara	Kedungmalang, Surodadi, Panggung	10-20 cm 0.1 – 0.2 metres
11	Kab. Pati	Puncel, Banyutowo, Dukuhseti, Alasdowo, Tegalombo, Kinanti, Dororejo, Sambiroto, Tunggulsari, Jepatlor, Margotuhu, Keborama, Margomulyo, Bulumanis, Pangkalan, Pohijo, Tunjungrejo, Margotuhu, Kertomulyo, Sambilawang, Tlutub, Khadilangu, Guyangan, Bendar, Kudukeras, Bakaran.	N/A
12	Kab. Rembang	Gegunung Kulon, Pandean, Tasikagung, Pantiharjo, Pasar Banggi, Pandangan, Karangharjo, Kalipang, Banyudono	N/A

Source: *Pusat Data, Informasi, dan Komunikasi Kebencanaan BNPB* (2022)

that have greatly affected its usability (Rukayah & Abdullah, 2019). In response to these challenges, the Dutch authorities constructed the modern seaport known as Tanjung Emas, necessitated by the need to address the ongoing accumulation of sediment that had compromised the functionality of the older port facilities.

The historical overview indicates that coastal hazards in Semarang City have a long-standing presence rather than being a recent issue. The region'ss coastal dynamics are marked by various threats, including phenomena such as *Rob*, which exemplify the persistent and complex nature of coastal hazards in the area. The expansion and urbanisation of Semarang have increasingly interacted with natural tidal systems, leading to a heightened frequency and severity of *Rob* events. This interaction underscores how human activities have exacerbated natural processes. The active and multifaceted nature of these coastal processes reveals Semarang's enduring and evolving challenges in effectively managing its coastal environment.

Rob, a recurring natural phenomenon, is not uniformly categorised as a disaster due to its regularity. However, understanding *Rob* incidents requires reference to flood data from Semarang City as one form of flooding. Empowered with disaster management responsibilities, the Semarang City Regional Disaster Management Agency, or *Badan Penanggulangan Bencana Daerah* (BPBD), has diligently collected data on hazardous events,

particularly those resulting in losses. Data from 2012 to 2020 identified by the BPBD reveal concentrated *Rob* incidents in coastal districts such as Semarang Utara, Tugu, and Genuk, indicating higher occurrence rates than in Semarang Barat (Table 2).

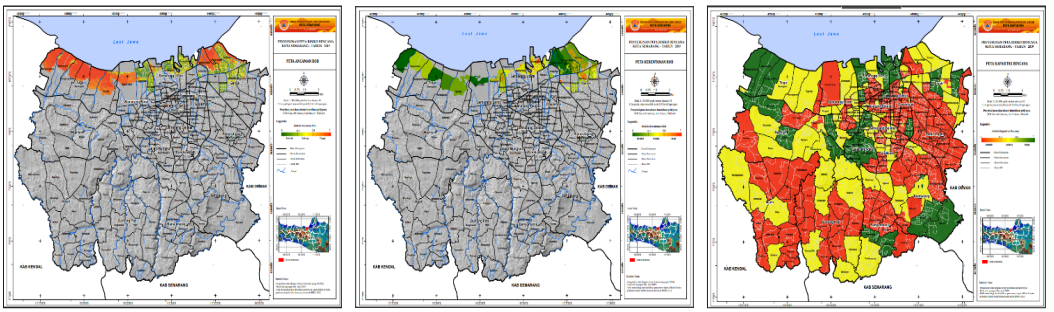
BPBD conducts disaster risk assessments by identifying potential adverse effects, such as threats to human life, property, and the environment, arising from potential disasters. In line with the National Disaster Risk Assessment Guidelines (BNPB, 2012), this assessment utilises three main analytical factors: The risk posed by *Rob*, vulnerabilities to *Rob*, and the community's ability to handle disasters (Figure 2). These factors form the basis for evaluating the risks linked to *Rob*-related disasters. According to the *Rob* hazard map, the potential for *Rob* inundation extends to all coastal sub-districts and certain inland areas, such as the Genuk District. Tugu and Genuk Districts face a high threat from *Rob*, whereas Semarang Barat and Semarang Utara Districts experience moderate to low threats. The vulnerability assessment considered various aspects, including social, economic, and physical vulnerabilities. These assessments indicate that most coastal sub-districts with the potential to be affected by *Rob* have low vulnerability levels. Regarding capacity, Semarang Barat and Genuk Districts still exhibit areas with low capacity levels.

The 2019 *Rob* disaster risk assessment identifies several districts with potential risks, including Genuk, Gayamsari, Semarang Timur, Semarang Utara, Semarang Barat, and Tugu. According to Table 3 and Figure 3, approximately 10% of these districts are classified as high risk based on the *Rob*' assessment, with Genuk and Tugu experiencing the greatest exposure and highest levels of

Table 2: Rob's events in coastal districts of Semarang City, 2012-2020

District	Sub-District	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Semarang Utara	Tanjunmas	√	√	√	√	√				√	6
	Panggung Kidul				√				√		2
	Bandarharjo		√	√	√	√					4
	Panggung lor		√		√				√		3
	Total	**1**	**3**	**2**	**4**	**2**	**0**	**0**	**2**	**1**	**15**
Tugu	Mangunharjo	√	√	√			√	√	√	√	8
	Mangkang Wetan	√	√		√	√	√	√	√	√	9
	Mangkang Kulon					√	√	√			4
	Total	**2**	**2**	**1**	**1**	**2**	**3**	**3**	**2**	**2**	**21**
Genuk	Banjardowo		√					√			2
	Gebangsari		√		√			√			4
	Trimulyo		√		√	√	√	√			6
	Genuksari							√			2
	Muktiharjo lor		√	√	√	√		√			6
	Terboyo Kulon		√	√	√	√		√	√		7
	Total	**0**	**5**	**2**	**4**	**3**	**1**	**6**	**1**	**0**	**27**
Semarang Barat	Krobokan		√		√						3
	Tawang Mas			√							1
	Total	**0**	**1**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**4**

Source: *BPBD Kota Semarang*, 2012-2020, analysis (2023)



(a) (b) (c)

Figure 2: Map of: (a) Threats, (b) Vulnerabilities, and (c) Disaster capacity in Semarang City in 2019
Source: BPBD Kota Semarang (2019)

Table 3: Disaster Risk Level Per District in Semarang City in 2019

Districts	Risk Level					
	Low		Medium		High	
	Ha	%	Ha	%	Ha	%
Gayamsari	19	0.87%	0	0.00%	1	0.41%
Genuk	851	39.48%	55	6.44%	143	40.98%
Semarang Barat	203	9.41%	191	22.26%	52	15.01%
Semarang Timur	5	0.23%	0	0.00%	0	0.00%
Semarang Utara	338	15.68%	76	8.89%	4	1.16%
Tugu	740	34.33%	536	62.40%	148	42.44%
Total	**2155**	**100.00%**	**859**	**100.00%**	**349**	**100.00%**

Source: *BPBD Kota Semarang* (2019)

risk. In contrast, medium-risk and low-risk areas account for 26% and 64% of all regions susceptible to *Rob* floods, respectively

Information on the *Rob* disaster is scarce. Although *Rob* events occur frequently on a daily basis, their destructive impact is not catastrophic. However, the coastal regions of Semarang City occasionally face severe *Rob*-related incidents, leading to temporary disruptions in community life. Some of these incidents have gained national attention due to the involvement of both regional and national government institutions in their management. The most recent extreme *Rob* events occurred in May 2022 during high tide. The surge of seawater, accompanied by high waves, breached the sea embankment in the Tanjung Mas Port area, allowing seawater to inundate the land. Reports suggest that *Rob* waters rose to a height of 1.5 metres. The inundation reached an area of more than 400 hectares, including the sub-districts of Tanjung Mas, Bandarharjo, and Kemijen (Figure 4). Consequently, economic activities at the port and several nearby factories came to a halt.

According to BPBD data, the occurrences of *Rob* in every district somewhat align with the findings from the interviews. Officials at the sub-district level and residents in areas susceptible to *Rob* hazards describe it as a recurring coastal threat. Nevertheless, exposure to these hazards seems to be escalating annually, as indicated by widespread inundation, more frequent inundations, rising inundation levels, and longer durations for inundations to subside.

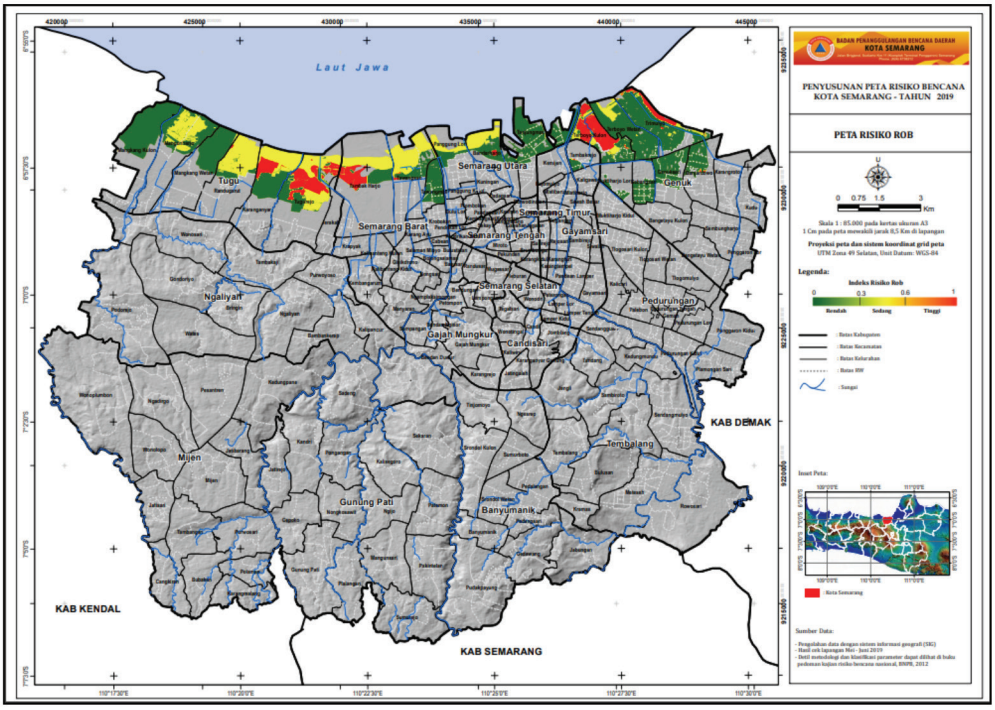


Figure 3: Disaster risk map in Semarang City 2019
Source: BPBD Kota Semarang (2019)

Figure 4: Documentation of *Rob* disaster (Left) and the infographic (Right)
Source: BPBD Kota Semarang, 2022

Examining the diverse viewpoints expressed by the sources, the progression of *Rob* incidents along the coast of Semarang City is discerned, evolving from mere coastal hazards to being classified as coastal disasters.

The transformation of Semarang City's coastal area post-1970 notably amplified susceptibility to *Rob* inundation. During that time, long-term development policies and spatial plans began to be prepared and established as guidelines for the development of Semarang City, including its coastal areas (Nugraha & Mardiansjah, 2017). Significant initiatives included the establishment of industrial zones in Genuk and Semarang Utara, alongside residential and recreational areas in Semarang Utara and Semarang Barat, involving land reclamation processes. During that period, certain coastal areas of Semarang City encountered tidal inundation, particularly in Genuk and Semarang Utara Districts. However, the inundation from *Rob* during that time was perceived as normal, as it did not cause damage to residential areas. At that time, the distance between the coastline and settlements remained considerable, leading to floods primarily affecting the coast, ponds, and green open spaces like bushes.

The growing importance of Semarang City as a significant metropolitan centre in Indonesia has led to more intense development along its coast (Nugraha & Mardiansjah, 2017). This emphasis on strategic functions along Semarang City's coastline in policy decisions pressures these coastal areas to expand. The changes have significantly increased vulnerability to *Rob* hazards by reducing the natural protective barriers of coastal ecosystems and modifying land use, thus diminishing the overall resilience of coastal areas against these hazards. According to interviews, besides industrial and residential zones, coastal regions are also closely associated with the establishment of pond areas, which serve as vital support for economic growth within coastal communities. In the 1990s, there was a surge in fish farming activities, primarily due to market demand for tiger prawn products. Expanding pond areas within mangrove ecosystems has led to extensive deforestation of mangrove plants in pursuit of higher productivity. Additionally, there was a trend among the community to convert agricultural land or marshlands into pond areas. This progressive alteration of Semarang City's natural coastal ecosystem contributes to the exacerbation of *Rob* events over the long term.

The evolving physical landscape of coastal regions is resulting in an increasing frequency of flooding triggered by *Rob*, affecting both residential and industrial zones. Nonetheless, the rapid receding of *Rob* floodwaters is believed to have minimal impact on people's livelihoods. The heightened risk of *Rob* flooding is not being addressed by the community or the Semarang City government, which lacks awareness of other coastal hazards, thereby exacerbating the future impact of *Rob* flooding. Changes in land use, reclamation efforts, and the decline of mangrove ecosystems are reshaping coastal environments. These factors are accelerating various coastal hazards, including erosion and land subsidence. Furthermore, global concerns such as rising sea levels and extreme weather patterns are affecting the height of sea waves, particularly during peak tidal periods.

Since 2000, the heightened frequency and severity of Rob occurrences have raised awareness of it as a prevalent disaster in Semarang City's coastal regions. Various studies on the *Rob* disaster have commenced, including modelling *Rob* inundation to comprehend potential exposure to *Rob* hazards in the city. During this period, sustainable development and disaster risk reduction became global priorities, leading to several national and regional policies promoting actions to mitigate *Rob* and other disaster risks. Among these initiatives is the formation of the BPBD in 2010, which replaced the Disaster Management Implementation Unit, or *Satuan Pelaksana Penanganan Bencana* (Satlak PB), at the Regency/City level. The BPBD Semarang City began recording disaster events in 2012 and evaluating disaster risks in 2019.

As urban resilience-building policies gain momentum, the authorities in Semarang City are increasingly focusing on the potential impacts of the *Rob* disaster. They are taking various actions to enhance community capacity and adapt to the growing severity of *Rob* inundation. Since 2010, in addition to empowering the BPBD as the primary authority for disaster management, various other policies in Semarang City have contributed to reshaping perspectives on disaster risk reduction. Notably, updates to development and spatial planning policies underscore the importance of integrating disaster awareness into sectoral development initiatives. Both regional and central governments are involved in implementing these programmes, given the strategic infrastructure along Semarang City's coastal areas, which is vital for metropolitan economic growth. Furthermore, Semarang is situated within a river basin, necessitating ecosystem preservation and infrastructure development to effectively manage water resources.

The development initiatives for water resource management infrastructure also significantly contribute to mitigating the impact of *Rob* inundation exposure. This is crucial since *Rob* occurrences in Semarang City manifest in both direct and indirect manners (Figure 5). Direct incidents occur in coastal areas where high tides breach inland barriers such as land or structures, while indirect incidents affect inland regions with poorly maintained drainage systems (L. Kurniawan, 2003). In Semarang City, *Rob* infiltrates indirectly through primary river channels, leading to the most severe flooding around the river basin. For instance, a notable tidal flooding event in the city centre, bordered by the West Canal and East Canal, occurs via the Semarang River, Kali Baru, and Kali Banger (Ramadhany *et* al., 2012). Additionally, urban drainage networks facilitate Rob's indirect infiltration. Semarang City requires integrated management for its river and drainage areas, which are segmented into three parts. This is necessary due to the numerous river estuaries in the city that could potentially serve as entry points for water onto land.

Rob's direct incidents occur in industrial and residential zones that directly abut the coastline. Erosion and rising sea levels have led to coastal retreat, bringing the coastline closer to land, where it serves various urban purposes. Additionally, certain sections of the developed region are directly adjacent to pond waters. Consequently, *Rob* easily penetrates inland due to the absence of buffer zones along Semarang City's coastline. As for the indirect incidents of Rob, seawater infiltrates inland through river mouths. The elevation of river water caused by tidal fluctuations results in the inundation of land adjacent to the river, either directly or via the interconnected drainage system. *Rob* inundation can also occur through water seepage into the soil. The land's lower elevation, due to subsidence, exacerbates this situation.

Figure 5: Direct Rob flood at Marina beach (Left) and indirect Rob flood around the Sringin River (Right)
Source: BBWS Pemali-Juana (2017)

Characteristics of Tidal Flood Phenomena in Coastal Districts

The identification of the history and characteristics of *Rob* in each coastal district provides a holistic view of how tidal flooding affects different areas (Figure 6). This comprehensive analysis is critical for developing targeted strategies to mitigate the impacts of *Rob* and enhance resilience in affected communities. It includes a detailed examination of the history and characteristics of *Rob* (tidal flooding) in each coastal district. First, along the coast of Genuk District, two predominant land uses are evident: Industrial and residential. The Genuk coastal area developed alongside the growth of industries. Initially, the Small Industrial Environment (LIK) attracted local workers from nearby villages, but subsequent industrial expansion in Terboyo Wetan and Trimulyo Sub-Districts significantly increased immigration, drawing workers from other regions seeking industrial employment (Sariffuddin & Wijaya, 2014). The industrial sector is experiencing rapid expansion on the north side of Kaligawe's main road, while residential areas are situated to the south.

Genuk faces a significant threat of tidal flooding and is identified as one of the districts with the largest inundation areas (Ramadhany *et al*., 2012). Based on interviews, since before 1990, both the industrial zones and adjacent coastal communities have faced flooding, although these events were typically of short duration. Historically, marshlands and ponds in the area served as effective natural floodwater reservoirs, preventing overflow onto developed land.

However, recent industrial expansion, involving the reclamation of marshlands and ponds, has significantly altered the local landscape and modified the dynamics of *Rob* along the Genuk coast. Genuk's geographical configuration, resembling a small basin and situated at a lower elevation than the surrounding areas, increases its susceptibility to flooding as a natural water collection point. Several rivers traverse the district—the Babon River to the east, the Sringin River centrally, and the Tenggang River to the west—each contributing to the ingress of tidal floodwaters.

The increasing severity of *Rob* in Genuk is driven by both direct and indirect factors, including geographical layout, industrial expansion, and river systems. Since 2000, the intensity of tidal flooding has markedly increased in Genuk, particularly affecting industrial zones. Due to Rob's frequent and severe impacts, the Terboyo Industrial Area has experienced significant setbacks, including reduced investment and disrupted industrial operations. Similarly, coastal communities in Genuk have faced challenges, with varying degrees of impact from *Rob*.

Settlements in the Terboyo Kulon Sub-district, located at the periphery of pond areas, are directly affected by *Rob*. Here, roads serve as barriers between water bodies and residential areas, yet proximity to these water sources results in frequent inundation, particularly during the morning. Residents in this sub-district experience daily disruptions from *Rob*, highlighting the urgent need for effective flood management strategies. Coastal villages in Terboyo Wetan and Trimulyo Districts, as well as Muktiharjo Lor District, are indirectly affected by *Rob*. The rivers traversing these areas, including the Babon, Sringin, and Tenggang Rivers, contribute to the inundation by facilitating the inland intrusion of seawater. This intrusion leads to runoff around residential areas along the riverbanks, exacerbating the flood risk. The interplay between river dynamics and tidal surges underscores the complex nature of *Rob's* impacts in these regions.

Since 2017, the threat posed by tidal flooding, or *Rob*, has significantly diminished due to several key interventions. The successful completion and operation of the Tenggang and Sringin River pumps have been instrumental in mitigating flood risks. These pumps are designed to enhance the capacity for water removal, reducing the incidence of flooding

during peak tidal events. Comprehensive river revitalisation projects have improved flood management, including widening, dredging, and reinforcing riverbanks. These efforts have increased the rivers' capacity to handle water flow and mitigated the risks associated with riverbank overflow. Improvements in local drainage infrastructure have further bolstered flood resilience. Upgrades to drainage systems within residential areas and along Kaligawe's main roads have been implemented to better manage water flow during high tide and heavy rainfall. These enhancements facilitate the swift removal of excess water, reducing the likelihood and severity of flooding.

As a result of these combined efforts, flood intensity has noticeably decreased. Some residents have reported a significant reduction in flood-related threats, leading to a revival of economic activities in industrial areas and a resurgence in the vitality of coastal villages. This positive trend underscores the effectiveness of targeted flood management interventions and the importance of continued investment in infrastructure improvements to sustain and enhance flood resilience.

Second, Semarang Utara District holds significant historical importance in the development of Semarang City and remains a pivotal area in its urban evolution. Central to this district is Tanjung Mas Port, a major logistical and economic hub that has played a crucial role in driving industrial growth in the surrounding region. The port's strategic location and operational capacity make it a critical element in the district's economic framework. Geographically, Semarang Utara is positioned between two canals that originate from Semarang City, contributing to its unique urban and cultural landscape. The district has developed a robust cultural identity rooted in fishing and agriculture, with Tambalorok Village serving as a prime example of the vibrant fishing communities that characterise the coastal regions of Semarang Utara. These communities have historically relied on the area's rich aquatic resources, shaping local livelihoods and cultural practices.

However, the extensive utilisation of coastal land in Semarang Utara for industrial and residential purposes has heightened its vulnerability to flooding. The tidal flood inundation model indicates that tidal flooding has the potential to affect approximately 50% to 70% of Semarang Utara District (Handoyo *et al*., 2016; Jabbar *et al*., 2023). Based on interviews, before 1990, Rob's impact on residential areas was both direct and indirect. Some settlements faced daily inundation cycles, particularly during peak tide periods, with brief flooding events occurring regularly. In contrast, other areas experienced flooding primarily during high tides and severe weather conditions. Coastal villages in the Tanjung Mas and Bandarharjo Sub-districts, such as Tambaklorok and Tambakrejo, which are highly susceptible (Jabbar *et al*., 2023), face direct flooding from both sea incursions and overflow from nearby ponds. Being close to the coast and low-lying, these areas are particularly vulnerable to tidal surges and pond water overflow. Meanwhile, Bandarharjo, situated among several river flows (Monica & Mardwi, 2014), experiences indirect flooding in certain areas, intensifying the effects of high tides and increasing the overall flood risk.

Additionally, the Tanah Mas real estate development in the Panggung Lor Sub-district began experiencing indirect flooding from its early stages of development. This situation was compounded by land reclamation activities carried out to the west of the Semarang River, which altered natural drainage patterns and increased the area's susceptibility to floodwaters. Since approximately 2010, Semarang Utara, located in the core of Semarang City, has implemented several measures to address and mitigate flooding risks. These initiatives include the establishment of the Semarang River Pump, revitalising the Baru and Bringin Rivers, and developing both east and west flood canals. These flood management interventions have substantially reduced the risk of flooding in many settlements within Semarang Utara, including the city's central areas.

Despite these improvements, the region faces challenges due to ongoing coastal erosion, rising sea levels, and accelerated land subsidence. These factors undermine flood prevention efforts and contribute to persistent vulnerabilities. As a result, villages such as Tambalorok and Tambakrejo remain particularly susceptible to flooding. To address these ongoing issues, the construction of seawalls is planned and is expected to play a crucial role in mitigating flood risks in the future. These seawalls are intended to provide a critical defence against tidal surges and sea level rise, thereby enhancing the resilience of vulnerable areas and supporting long-term flood management strategies in Semarang Utara.

Third, in contrast to Genuk and Semarang Utara, Semarang Barat District has predominantly focused on residential and tourism development. Although industrial activities have begun to emerge in select locations within this district, they are not as pronounced or extensive as those observed in other coastal regions of Semarang. Based on the interview, prior to 1990, the coastal zone of Semarang Barat was designated for real estate and tourism development under the policy framework of Central Java Province. This area was originally a pond that underwent reclamation to facilitate urban expansion and development.

The implementation of this policy is exemplified by the creation of the Pearl of Java (PoJ) City and the Beach Recreation and Promotion Centre (Pusat Rekreasi dan Promosi Pantai - PRPP) areas. These developments reflect a strategic shift towards leveraging coastal zones for economic growth through residential and tourism-oriented projects rather than industrial uses. The reclamation and subsequent development of the area have transformed the former pond landscape into a hub for residential living and tourism, contributing to the district's economic and cultural evolution. Despite the relatively lower incidence of *Rob* in Semarang Barat compared to other regions, the risk remains considerable, particularly during severe weather events. The area benefits from a low-density layout, extensive green spaces, efficient drainage systems, and wide roadways, all of which have contributed to mitigating the impact of *Rob* and flooding. However, these physical attributes do not render the area immune to flooding risks.

Specific regions within Semarang Barat, especially those at lower elevations relative to their surroundings, remain vulnerable to *Rob*. For instance, the Marina Beach area, located directly along the coast, experiences direct impacts from *Rob* events. In contrast, the Taman Marina housing cluster, situated farther from the shoreline, is still susceptible due to its lower elevation and interconnected drainage systems. These systems facilitate *Rob's* intrusion into surrounding water bodies, exacerbating flood risks.

Fourth, the coastal landscape of Tugu presents a distinct contrast to the other districts within Semarang. Characterised predominantly by agricultural activities and the presence of ponds, Tugu exhibits a pronounced urban-rural transitional ambiance. This area maintains a relatively open and less developed land use pattern compared to more urbanised districts. Based on interviews, *Rob's* impact in Tugu was minimal until after 2015. Before this period, *Rob's* effects were mainly confined to inundating the pond areas without significant encroachment into residential zones. Areas such as Mangkang Wetan, Mangunharjo, and Mangkang Kulon experienced relatively negligible impacts from *Rob*, as the flooding primarily affected agricultural and pond areas rather than residential communities.

However, following 2015, the situation began to change, with *Rob* increasingly affecting residential areas. This shift underscores a growing vulnerability in Tugu, highlighting the need for enhanced flood management and adaptation strategies to address the emerging risks associated with tidal flooding in this region. The transition from minimal to more pronounced impacts of *Rob* in Tugu necessitates reassessing flood risk management approaches

to protect agricultural and residential areas from future inundation events. The rising incidence of *Rob* in residential areas of Tugu can be attributed to several interrelated factors. Coastal abrasion has significantly damaged the pond areas previously serving as natural buffers, thus facilitating *Rob's* encroachment into residential zones. This increased vulnerability is further compounded by extreme coastal abrasion, which has been exacerbated by the transformation of surrounding coastal landscapes into industrial zones.

Additionally, the degradation of mangrove ecosystems in Tugu during the 1990s has significantly contributed to the acceleration of coastal abrasion. Based on image analysis, a substantial portion of the mangrove forest area is severely damaged, with Landsat data indicating over 92% and ALOS data showing 78% in the Tugu District (Ardiansyah & Buchori, 2014). Mangroves, which once acted as crucial natural barriers against tidal surges, have been largely destroyed, diminishing their protective role and increasing the exposure of coastal and agricultural areas to *Rob*. The combined effects of pond area damage accelerated coastal abrasion, and ecosystem degradation have not only heightened the threat of *Rob* but also contributed to the deterioration of agricultural lands and overall environmental quality in Tugu.

In response to rising coastal abrasion and tidal flooding, the Tugu community is increasingly prioritising conservation efforts. There is a strong focus on natural mitigation strategies such as restoring mangrove forests and protecting buffer zones, to effectively reduce flood risks. Recognising the link between environmental degradation and increased vulnerability, local initiatives emphasise sustainable practices and coordinated efforts to address these challenges and enhance resilience.

Key conservation strategies being promoted include the restoration of mangrove habitats, which play a crucial role in buffering coastal areas against tidal surges and reducing the impact of coastal erosion. Reestablishing these vital ecosystems enhances natural resilience and protects local livelihoods and environmental health. Additionally, coastal protection measures, such as constructing artificial barriers and rehabilitating natural buffers, are being pursued to fortify the region against ongoing and future flood risks.

Collaborative efforts involving local authorities, stakeholders, and residents are central to these conservation initiatives. These efforts aim to build resilience and adaptability to Tugu's evolving coastal dynamics by fostering partnerships and community engagement. This inclusive approach ensures that conservation strategies are effectively tailored to local needs and conditions, supporting the region's long-term sustainability and enhancing its capacity to manage and mitigate the impacts of coastal challenges.

Factors Influencing Tidal Flooding Dynamics in Semarang City

The analysis of tidal flood characteristics across districts reveals the complexity of coastal hazards shaped by multiple factors. This study highlights how urbanisation significantly increases community vulnerability in Semarang's coastal areas. On the northern coast of Java, around 50% of the population resides in urbanised zones, intensifying the risk of climate-related disasters (Rudiarto *et al*., 2018; Handayani *et al*., 2020). Coastal development has heightened flood risks (Igigabel *et al*., 2022), driven by population growth, uncontrolled land use, and limited infrastructure capacity. While socioeconomic progress is expected to improve adaptive capacity, it also presents new challenges. Additionally, environmental degradation, including the loss of natural coastal ecosystems, has weakened the region's ability to absorb tidal impacts and mitigate disaster risks.

In Semarang City, urbanisation has significantly reshaped natural landscapes into built environments, particularly through industrial and residential development (Sejati *et al*., 2018). This growth is concentrated along coastal zones that are highly vulnerable to hazards such as flooding, erosion, and land

subsidence (Khoirunisa, 2023). Industrial expansion in the Semarang Metropolitan Area, especially along the eastern and western coasts, illustrates how urban development continues to encroach upon high-risk areas (Fariha *et al*., 2021). These dynamics intensify disaster risks in already fragile coastal environments.

Natural areas that absorb and mitigate tidal impacts are vital in managing flood risks. In Semarang City, land-use changes favouring industrial and residential development have significantly reduced these transition zones. Located at the intersection of marine and terrestrial systems, these areas provide diverse ecosystem services, support biodiversity, and help regulate water flow to minimise flood severity (Semlitsch & Jensen, 2001; Ewel *et al*., 2001; Levin *et al*., 2001; P. Baye, E. Beller, R. Leventhal, 2015; Elliott *et al*., 2019). However, despite their importance, these zones are often overlooked in regulatory planning, creating ongoing conservation challenges (Semlitsch & Jensen, 2001).

In Semarang City, the conversion of coastal and estuarine transition zones into built environments has reduced water absorption capacity, disrupted tidal flows, and increased surface runoff. This transformation elevates both the frequency and severity of tidal flooding, as natural flood-regulating mechanisms have been lost. Moreover, the interaction between human-induced changes and natural coastal dynamics—such as tidal movements, sediment transport, and erosion—has made tidal processes more complex and less predictable. These altered dynamics introduce new uncertainties, complicating efforts to manage and mitigate flood hazards and their environmental impacts.

Disruptions in the energy exchange between land and sea have degraded coastal ecosystems in Semarang (Sunaryo *et al*., 2018). Mangrove areas, in particular, are declining due to both natural and anthropogenic pressures. These ecosystems act as green belts that buffer wave energy, support biodiversity, and supply essential nutrients (Ahmad & Fuad, 2018). Oceanographic factors such as abrasion and accretion (Ahmad & Fuad, 2018; Irsadi *et al*., 2019), along with sea-level rise-induced flooding (Marfai, 2014), have significantly affected mangrove sustainability on Java's north coast. Abrasion removes substrate and habitat, while accretion may help stabilise new mangrove areas. However, increasing coastal inundation continues to intensify damage to these critical ecosystems.

Beyond oceanographic factors, the uncontrolled expansion of aquaculture along Java's north coast, including in Semarang, has contributed to mangrove degradation (Wahyudi *et al*., 2012; Rahmila & Halim, 2018; Utami *et al*., 2021). Traditionally reliant on fisheries, coastal communities have increasingly shifted towards aquaculture to support economic growth. This transition from fixed-catch fisheries to fishpond-based aquaculture has become widespread across the region. However, this development has come at an environmental cost, particularly the conversion of mangrove forests into aquaculture zones, which reduces natural coastal buffers and compromises ecosystem resilience.

Urban development, including industrial, residential, and recreational activities, has further degraded mangrove ecosystems in Semarang (Fithor *et al*., 2019; Utami *et al*., 2021). Recently, the conversion of mangrove areas into recreational spaces has been promoted as a conservation compromise (Rahmila & Halim, 2018). However, such uses often disrupt ecosystem rehabilitation. Negative impacts include reduced shoreline protection, diminished resistance to wind abrasion, declining environmental quality, fewer visitors, and lower fish production (Fithor *et al*., 2019). These changes have increased community vulnerability to coastal hazards, particularly tidal flooding and erosion.

Land reclamation projects in Semarang City, driven by urban development, involve filling wetlands, estuaries, and shallow waters to create new land, significantly altering coastal tidal patterns (Chen *et al*., 2020; Hamdani *et al*., 2021). Due to its strategic location and

strong infrastructure, Semarang is a prime site for industrial expansion in Central Java. The coastal zone near major transport routes and ports, especially around Tanjung Mas Port, has been prioritised for growth. These reclamation projects aim to provide space for manufacturing, port operations, and related infrastructure to support regional economic development.

Land reclamation in Semarang City is also aimed at enhancing its status as a major waterfront urban area on Java's northern coast. These projects focus on expanding the coastal boundary to develop new residential areas near Ahmad Yani Airport, boosting housing capacity and urban appeal. This effort supports urban goals such as modern housing, economic growth, and improved infrastructure. By integrating residential, commercial, and recreational spaces along the coast, Semarang seeks to create a vibrant waterfront city that leverages both aesthetic and economic advantages.

Discussion

Urbanisation, land use changes, and reclamation projects have reduced coastal areas' natural ability to handle dynamic conditions. The increasing frequency and severity of tidal flooding, exacerbated by human activities, are compounded by land subsidence, coastal erosion, and rising sea levels. Climate change further intensifies these hazards by altering weather patterns and increasing extreme events, making flood management in Semarang's coastal districts increasingly complex and challenging.

Recent government policies at national and regional levels increasingly emphasise disaster risk reduction strategies to mitigate tidal flooding. In Semarang, rising awareness of multi-hazard coastal risks has prompted responses from various stakeholders and the implementation of comprehensive government policies. Effective disaster management requires both structural and non-structural approaches, though this study finds that structural measures have had a more immediate impact on tidal flood mitigation. However, long-term planning aspects, such as development and spatial planning, remain under-discussed despite their crucial role in shaping coastal resilience.

Key structural measures in Semarang include advanced flood control systems that integrate natural drainage through two major canals and several rivers. The government has implemented river normalisation (dredging and reinforcing banks), pumping stations to remove excess water, and coastal embankments to protect against tidal surges and erosion (Marfai & King, 2008a; M. A. Salim & Wibowo, 2024). These efforts aim to improve water flow management and strengthen the city's resilience to flooding, addressing both immediate risks and long-term sustainability.

Several flood control projects in Semarang are part of national initiatives that consider city and regional development, Semarang's role as an economic hub, and the high investment costs involved. These infrastructures address immediate flood risks while supporting long-term urban growth and regional economic stability. The significant costs reflect the scale and complexity needed to protect the city's vital economic functions and align with national development goals, contributing to both local resilience and broader economic growth.

Since 2010, national projects have focused on the river normalisation of the East and West Flood Canals and the development of the Semarang River pumping station. Informal settlements along the rivers were cleared to widen the riverbanks, and regular dredging addresses rapid sedimentation. The Semarang River pumping station, once the largest in Southeast Asia, was a major milestone. Additional normalisation and pumping stations at the Sringin and Tenggan Rivers further support flood control and enhance the city's resilience.

The Semarang City Government oversees regional infrastructure development, focusing on flood-prone areas. Key strategies include building pumping stations in residential zones and improving local drainage as part of a broader flood control programme. Complementing these efforts, local communities contribute by

creating simple water pumps for emergency flood response, underscoring the vital role of grassroots participation in enhancing urban resilience.

Tidal flooding in Semarang City, driven by both natural forces and human activities, demands a multifaceted disaster risk management approach. The city government's focus on structural measures, river normalisation, pumping stations, and coastal embankments has effectively mitigated immediate flood risks. However, long-term resilience requires integrating flood risk into urban development and spatial planning. Strategic land use, environmental conservation, and public participation are essential to reduce vulnerability and promote sustainable coastal development (Wu *et al*., 2024).

Local communities play a vital role in flood management through grassroots efforts, such as building self-reliant water pumps in high-risk areas, demonstrating the value of local engagement in disaster response. These initiatives complement government actions and emphasise the importance of collaboration, harnessing local knowledge and resources to enhance resilience. A holistic, risk-based approach that integrates both physical and social sciences is essential for effective disaster risk reduction (Eslamian & Eslamian, 2022). Incorporating socio-economic and cultural factors alongside urban development provides a more comprehensive understanding of building community resilience (Warsilah, 2023).

The persistent challenge of tidal flooding in Semarang calls for ongoing investment in infrastructure and environmental protection. Both national and local governments must adopt integrated disaster risk management strategies that balance immediate flood mitigation with long-term sustainability. Building resilience requires advanced engineering, ecosystem preservation, and community-driven adaptive approaches. By aligning flood control with national development goals, Semarang can create a sustainable and resilient future amid increasing coastal hazards and climate change.

Conclusions

Semarang's coastal districts have long faced environmental threats, particularly from tidal flooding (known locally as Rob). This persistent issue poses socio-economic and ecological challenges influenced by both natural and human-induced factors. This study investigates the historical progression of coastal hazards in Semarang, illustrating how urbanisation, land subsidence, rising sea levels, and environmental degradation have increased community vulnerabilities across districts such as Genuk, Semarang Utara, Semarang Barat, and Tugu. Although engineering interventions, such as improved drainage systems and pumping stations, have mitigated flood impacts in some areas, others continue to face significant risks due to a lack of natural buffers and uncontrolled development. By combining historical data with contemporary urban planning, this study emphasises the importance of adopting long-term strategies for more adaptive and sustainable flood management.

Furthermore, it highlights the necessity of integrating structural solutions with community-based initiatives and ecosystem restoration efforts, such as mangrove rehabilitation, to enhance resilience. The findings underscore the need for a comprehensive, multi-level approach to disaster risk reduction that harmonises environmental sustainability with urban development. This research encourages further exploration into ways to strengthen local knowledge, policy integration, and community participation to support resilient coastal cities amidst climate change and ongoing environmental pressures.

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TIMELINE			1990	2000	2010	2020
Tugu	Tidal Flood	Exposure to tidal inundation enter the ponds	Exposure to tidal inundation enter the ponds and agriculture areas			There is increased exposure to tidal inundation further inland, particularly in residential areas, as well as damage to aquaculture ponds and agricultural land due to persistent flooding
	Land Use Dynamic	Land use directly adjacent to coastal waters consists of mangrove forests and aquaculture ponds. Moving inland, the area transitions into coastal settlements and agricultural land. Industrial and commercial/service clusters have developed in higher coastal plains, particularly in areas close to major roads		The expansion of ponds has reduced the extent of mangrove forests and converted agricultural land		Communities have begun replanting mangroves in coastal areas, while aquaculture ponds and agricultural activities persist despite declining productivity
	Factors of Tidal Flood Inundation		• Land use change from agriculture to ponds • Reduced mangrove areas due to ponds development			• Land subsidence • Coastal erosion • High waves
	Adaptation Strategies	Raising embankments in ponds and agriculture area to prevent tidal flooding from entering				Mangrove forest rehabilitation, development of area drainage networks, road elevation, and raising of house foundations
Semarang Barat	Tidal Flood	Exposure to tidal inundation started to enter residential area		Increased exposure to tidal inundation in residential areas		Reducing exposure to tidal inundation
	Land Use Dynamic	The original land use along the coastline, close to the sea, was primarily ponds, while further inland, the land is used for an airport area, residential zones, industry, and commercial/services	The ponds have been converted into a mixed-use integrated waterfront area through a reclamation process, with functions including residential, commercial, and service sectors, education, and recreation			
	Factors of Tidal Flood Inundation	• Reclamation and land use change from ponds to residential areas		• Land subsidence • High waves • Interconnected drainage system		
	Adaptation Strategies	Road elevation and raising of house foundations			The construction of urban and neighboorhood flood control infrastructure	
Semarang Utara	Tidal Flood	Increased exposure to tidal inundation is becoming daily in residential and industrial areas				Reducing exposure to tidal inundation
	Land Use Dynamic	Based on its historical and strategic aspects, this area has developed as a hub for port and industrial activities, residential settlements, and commercial/services				
	Factors of Tidal Flood Inundation	• Reclamation for settlements and industries • Reduced green open space • Reduced mangrove areas		• Land subsidence • Coastal erosion • High waves		
	Adaptation Strategies	Road elevation and raising of house foundations			The construction of urban and neighboorhood flood control infrastructure	
Genuk	Tidal Flood	Exposure to tidal inundation started to enter residential and developing industrial areas	Increased exposure to tidal inundation is becoming daily in residential and industrial areas			Reducing exposure to tidal inundation after the construction of flood control infrastructure
	Land Use Dynamic	Land use directly adjacent to coastal waters consists of dryland farming, shrubland, and ponds	Most of the land use has been converted into industrial areas			
	Factors of Tidal Flood	• Reclamation and land use change from agriculture and ponds to industry • Reduced green open space		• Land subsidence		
	Adaptation Strategies	Road elevation and raising of house foundations			The construction of urban and neighboorhood flood control infrastructure	

Figure 6: The history and characteristics of tidal floods in coastal districts of Semarang City
Source: Analysis, 2024

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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