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Flood Hazard Analysis and Adaptive Mitigation in Coastal Semarang Using a Geographic Information System Approach

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Abstract: The coastal area of Semarang City is divided administratively based on sub-districts of Tugu, West Semarang, East Semarang, North Semarang, and Genuk. The area is highly vulnerable to inundation and wide-ranging flooding due to excess rainfall, low elevation, and hydrological impacts caused by reclamation activities in the city of Semarang. The aim of this study was to spatially identify this hazard and suggest appropriate mitigation strategies, based on a four-factor quantitative GIS model. The factors used were slope, average annual rainfall, land use and soil type. The four were combined using overlay and weighting. The resulting model revealed that 5,364.45 hectares (66.40%) of the study area is Highly Vulnerable. Another 33.26% (2,687.42 hectares) was determined to be Moderately Vulnerable and 0.33% (27.07 hectares) Slightly Vulnerable. No land was determined to be completely safe. In light of this distribution, the recommendations made here are weighted towards structural measures (where risk is highest), such as hardening the seawalls and normalizing the polder system. It will lower the risk of future disasters in the long run.

Keyword: Flood, Coastal Semarang, Geographic Information System (GIS), Disaster Mitigation, Spatial Mapping.

INTRODUCTION

A natural disaster is defined by Law No. 24 of 2007 as any event or series of events, whether caused by human activity or nature, that results in casualties, material loss, ecological damage, or social misery. The Indonesian Dictionary (KBBI) defines flooding more narrowly as "water surging through in large, fast-moving volumes" or "dry land suddenly submerged by rising water." According to Haris Setiawan et al. (2020), standing water of varied sizes that spills out when a river's channel can no longer contain it is essentially the same thing. The source of the surplus water varies; sometimes it is a natural surge, and other times human activity causes the discharge to be higher than it should be. In either case, once the water hits the ground, daily life comes to a complete stop. Directly in that path is the shore of Semarang, which passes through Genuk, Tugu, East Semarang, North Semarang, and West Semarang. According to Arifin et al. (2016), a large portion of the city's flooding is caused by its terrain, which is mountainous in the south and flat and low in the north. Separate from rainfall, varying distributions of land use, slope, and soil type can affect the flow and concentration of water, which can in turn increase the risk.

Similar to Findayani Aprilia (2018), many have said that the Northern Semarang area is more prone to tidal flooding than the rest of the city because the land is below mean sea level. Water over developed land or productive agriculture is a true loss; water over vacant, underutilized land hardly makes an impression. The range seen along this coast is represented by three hazard levels: mildly vulnerable, moderately vulnerable, and severely vulnerable. Depending on whether escalation is the best course of action, each level requires a unique reaction. This study operates under the following premise: map areas where flooding has already occurred, determine which zones are most at danger, and then develop flood management measures that are appropriate for the actual coastal area.

METHOD

Study Area

Northern Semarang is especially susceptible to tidal flood intrusion, which is brought on by terrain that is below mean sea level, according to Findayani Aprilia (2018). The research area was depicted in Figure 1.

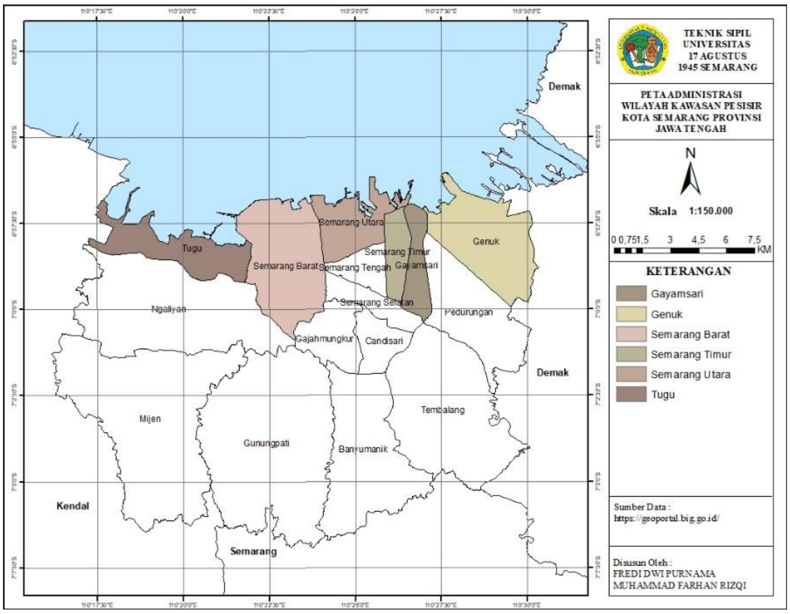

Figure 1. Study Area

Research Method

The three-stage, quantitative approach is structured in accordance with Azra (2024). Pre-analysis is the first step, which involves assembling tools and supplies and reading pertinent GIS literature. After then, the operational stage takes over, which includes gathering information, modifying digital map layers and their characteristics, and combining spatial and non-spatial databases into a single working set. In the third stage, all parameters are combined into a single composite map, which is then scored and weighted to provide the flood danger classes. The vulnerability zoning map serves as the foundation for all subsequent processes, including the delineation of flood-prone areas.

Data Collection

All of the datasets utilized here are listed in Table 1, and none of them were collected directly in the field; instead, they were all obtained from secondary sources, including official institutional records and literature reviews. This is consistent with the definition of secondary data collection given by Arif Rachman, Yochanan, and Andi Ilham Samanlangi (2024), which is information that has previously been gathered, processed, and published by someone else as opposed to unprocessed field observation. Every parameter in this study may be traced back to a database or publication kept up to date by the appropriate government body.

Table 1. Data Collection

No.	Required Data	Source
1	Coastal Administrative Boundary Map of Semarang City	https://geoportal.big.go.id/
2	Slope	https://tanahair.indonesia.go.id/portal-web/unduh/demnas
3	Land Use	https://www.indonesia-geospasial.com/2020/09/download-shp-tutupan-lahan-tahun-2019.html
4	Soil Type	https://www.indonesia-geospasial.com/2021/03/download-shapefile-jenis-tanah-seluruh.html
5	Rainfall	https://dataonline.bmkg.go.id/dataonline-home

Flood Hazard Classification

Putri et al. (2023) construct a flood hazard assessment based on four superimposed spatial variables: slope, rainfall, land use, and soil type. They then utilize the Sturges rule to classify the combined map. Table 2 outlines the scoring system that results from entering n = 5 into K = 1 + 3.3 log(n), which yields a class count that rounds up to 4.

Table 2. Flood Hazard Classification

Flood Hazard Level	Flood Hazard Score	Description
I	4 – 8	Not Vulnerable
II	8 – 12	Slightly Vulnerable
III	13 – 16	Moderate
IV	17 – 20	Highly Vulnerable

In actuality, this scheme has four levels: not vulnerable, slightly vulnerable, moderate, and severely vulnerable. Each score range and class count can be directly linked to the formula below.

$$K = 1 + 3.3\log n \quad (1)$$

$$K_i = \frac{X_t - X_r}{k} \quad (2)$$

Where:
K = Number of classes formed
N = Map units overlaid
Ki = Class interval
Xt = Highest data value
Xr = Lowest data value
k = Desired class interval

RESULT AND DISCUSSION

Flood Events in Coastal Semarang

This is not an isolated occurrence. In total, BPBD Semarang, the city's disaster management agency, has documented a yearly inundation in this area, tallying 110 total incidents between 2019 and 2025 across six coastal sub-districts, as indicated in Table 3.

However, such a large exposure presumably has something to do with the exposure in this area.

Table 3. Flood Event History

No	Year	Events
1	2025	30
2	2024	34
3	2021	19
4	2020	10
5	2019	17

Slope

The second most important parameter of Semarang's flood hazard is slope gradient, which is calculated on the basis of the DEM that has been clipped to the study area. It is geometrically corrected and classified in five classes: class 0-8% flat, class 8-15% gently slope, class 15-25% fairly steep class 25-45% steep and class >45% very steep, as shown in Table 4.

Table 4. Slope of Coastal Semarang

No	Slope (%)	Description	Area (Ha)	Percentage (%)	Score
1	0 - 8%	Flat	7199.581	85.072	1
2	8 - 15%	Gently sloping	889.683	10.513	2
3	15 - 25%	Fairly steep	286.733	3.388	3
4	25 - 45%	Steep	82.84	0.979	4
5	>45%	Very steep	4.047	0.048	5
	Total		8462.884	100	

There are 889.683 ha (10.513%) gently sloped (8 to 15%). 7,199.581 ha (85.072%) are flat, 286.733 ha (3.388%) are pretty steep (15 to 25%), 82.84 ha (0.979%) are severe (25 to 45%), and 4.047 ha (0.048%) are extremely steep (more than 45%).

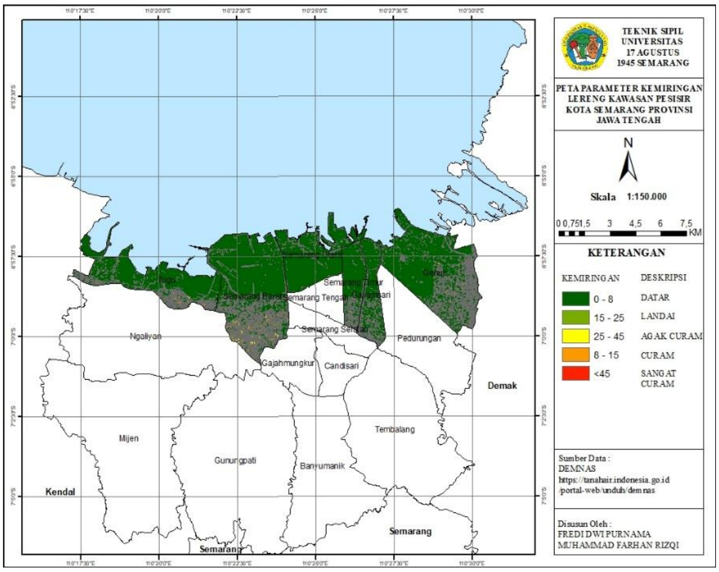

Figure 2. Slope Map

There are ramifications because the majority of the research area is made up of flat to moderately sloping land, especially around the shore. Low gradients make it more difficult for water to travel across the surface, so whatever reaches the land—tidal surge or runoff alike—tends to sit rather than drain. Geomorphologically speaking, gentler topography just moves water more slowly than steep terrain, which means that standing water is more likely to occur during that time and that it will take longer for the water to return to the sea (Paendre et al., 2025).

Rainfall

Here, the rainfall pattern is nearly perfect. The entire 8,563.64 ha of the research area falls into the 200–300 mm/month class, with the highest parameter score of 4. Neither the 50–100 mm/month range nor the 100–200 mm/month range fall into the lower categories. Every area along the Semarang coast experiences significant rainfall at nearly the same intensity every month, thus when a storm hits, all of the area's drainage systems are under stress from peak flow at the same time.

Table 5. Rainfall in Coastal Semarang

No	Rainfall Classification (mm/month)	Area (Ha)	Percentage (%)	Score
1	50 - 100	-	-	2
2	100 - 200	-	-	3
3	200 - 300	8563.64	100	4

The main factor causing this coastline to flood is the severity of the rainfall. There is a clear correlation between increased rain and increased susceptibility. Runoff surges above the capacity of the local drainage network, which is a simple hydrological phenomenon. The area breakdown is shown in Table 5 and Figure 3.

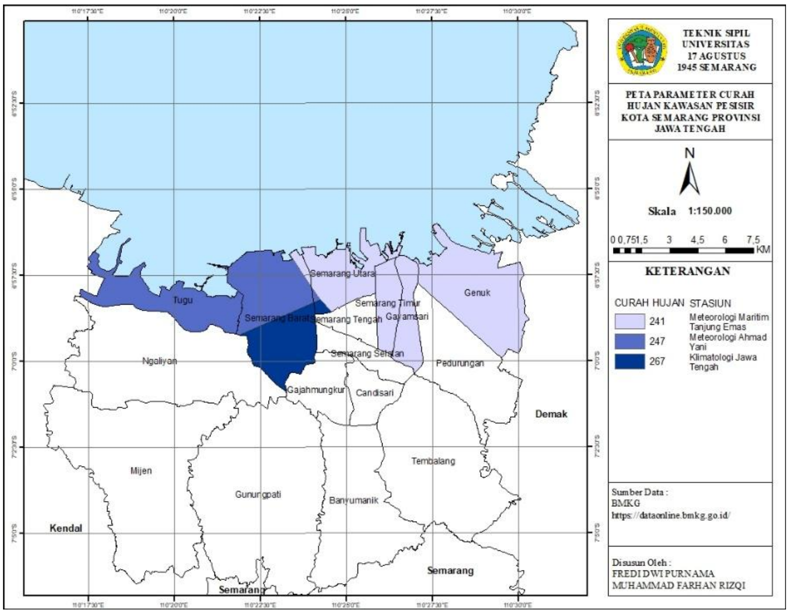

Figure 3. Rainfall Map

Land Use

Lakes, fishponds, built-up buildings, forests, grasslands, tourist areas, plantations, villages, paddy fields, shrubland, dryland farming, and uncultivated vegetation are among the twelve land-use types that comprise the coastal area (Table 6, Figure 4). The largest area is occupied by settlements (2,310.435 hectares, or 28.355% of the total), followed by built-up buildings (1,193.816 ha, or 14.651%). Both have the highest criteria score of five and are considered built-up land.

Table 6. Land Use in Coastal Semarang

No	Land Use	Area (Ha)	Percentage (%)	Score
1	Lake	50.204	0.616	4
2	Fishpond	980.542	12.034	4
3	Built-up structures	1193.816	14.651	5
4	Forest	6.505	0.080	1
5	Grassland	1067.116	13.096	2
6	Tourism area	150.103	1.842	4
7	Plantation	887.984	10.898	3
8	Settlement	2310.435	28.355	5
9	Paddy field	991.279	12.166	2
10	Shrubland	16.007	0.196	2
11	Dryland farming	468.884	5.754	3
12	Non-cultivated vegetation	25.301	0.311	2
	Total	8148.176	100	

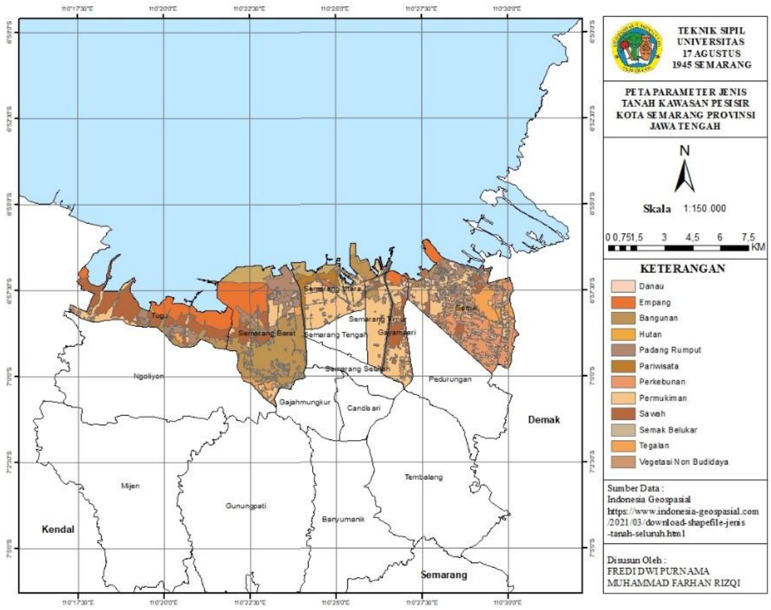

Figure 4. Land Use Map

When built-up land and settlement are combined, they make up about 43% of the coastal area. They are primarily concentrated near the city center and the waterfront, which is precisely where urban activity and people density are highest. By altering soil structure, reducing infiltration capacity, and forcing more water into surface runoff, building and land clearing increase the risk of flooding on their own (Ridwan & Sarjito, 2024). The same pattern is seen elsewhere, according to Nurwaty et al. (2023), where land-use change in coastal zones reduces the area available for water collection and increases the burden on natural drainage.

Soil Type

The unique character of the soil in coastal Semarang is important for the planning of infrastructure and space. Located where land, sea, and multiple river outlets converge, the majority of its composition's change can be attributed to natural processes. According to the most recent mapping, there are only two varieties of soil, and they all react differently to erosion.

Table 7. Soil Type in Coastal Semarang

No	Soil Type	Description	Area (Ha)	Percentage (%)	Score
1	Alluvial	Not sensitive	4020.721	46.949	5
2	Latosol	Slightly sensitive	4543.309	53.051	4
3	Mediterranean soil	Moderately sensitive	-	-	3
4	Podzolic	Moderately sensitive	-	-	2
5	Organosol	Highly sensitive	-	-	1
	Total		8564.03	100	

Latosol and alluvial soil are the only two types found in the 8,564.03 ha total research area, according to Table 7. Soils that are organosolic, podzolic, or Mediterranean are just not found here. According to Iis Kurniati and Igede Sugiyanta (2015), latosol has a red to brown color, a loose, clayey texture, and a structure that readily disintegrates into crumbs or weak blocks. Because its clay mineral phase is the 1:1 kind, it resists erosion better than others, drains effectively, and supports a lot of organism activity. With a base saturation of more than 35% and low to moderate quantities of nutrients and organic materials, it has a somewhat acidic chemical makeup. At 4,543.31 ha, or around 53.05% of the studied area, this is the predominant soil along the coast.

Alluvial soil is characterized by its activity and covers an area of 4,020.72 ha, representing 46.96% of the study area. It can also retain standing water longer than organosol if the sea rises or there is more rainfall. According to Putri et al. (2023), the type of soil is also very important, because this is what regulates the infiltration capability, the water retention of the soil and also the drainage inside the soil. In addition, the soil characteristics of Semarang's coastal areas consist of latosol and alluvial soil.

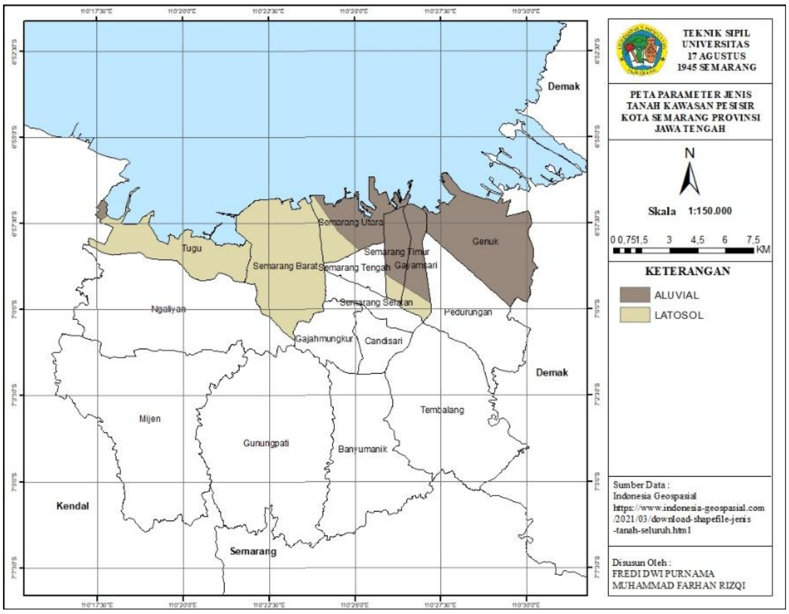

Figure 5. Soil Type Map

Flood-Prone Areas

By combining the four criteria as above, the final flood hazard map of the coastal area of Semarang was obtained with criteria composite scores ranging from 11 to 19. The zones include moderately vulnerable, severely vulnerable and somewhat vulnerable. The zone of High Vulnerable covers the largest area of 5,364.451 acres or 66.4% of the study area. As seen in Table 8, there was 2,687.421 ha (33.265%) coverage in the Moderate category, with only 27.071 ha coverage (0.335%) in the Slightly Vulnerable category, the smallest area.

Table 8. Flood Potential Classification in Coastal Semarang

No	Score Range	Flood Potential Classification	Area (Ha)	Percentage (%)
1	4 – 8	Not Vulnerable	-	-
2	9 - 12	Slightly Vulnerable	27.071	0.335
3	13 - 16	Moderate	2687.421	33.265
4	17 - 20	Highly Vulnerable	5364.451	66.400
	Total		8078.943	100

Following the trend in Figure 6, the enormous majority of Semarang's coastal areas are expected to have moderate to very high vulnerability. However, this level of concentration of vulnerability is not trivial, and requires that risk reduction and disaster management plans be implemented accordingly.

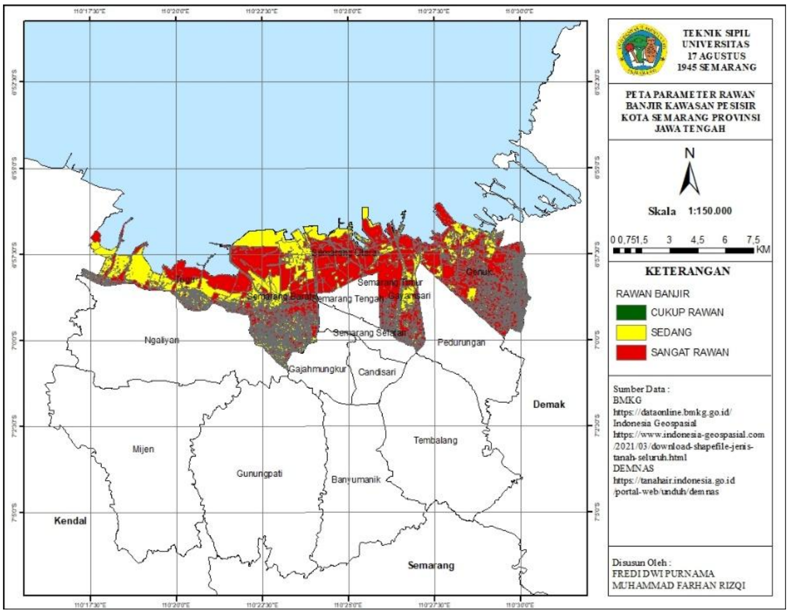

Figure 6. Flood Hazard Map

Disaster Mitigation

Alamsyah et al. (2022) classify disaster mitigation methods into structural (designed or natural solutions) and non-structural (community capacity, planning, regulations). Watora et al. (2024) classify disaster relief strategies further into emergency response, post-disaster and preparation & mitigation. The coastal Semarang area was divided by a spatial risk assessment into three: extremely vulnerable, moderate, and mildly vulnerable. Actual risks for each zone govern the effectiveness of the respective hazard mitigation strategy.

The severely susceptible zone (5,364.451 hectares or 66.4%) is the most affected and should be prioritized for structural mitigation measures. This could be achieved by building coastal embankments to prevent seawater intrusion, implementing drainage improvements, and planting coastal mangrove forests to act as a living barrier against the encroaching sea. The mangroves protect against the invasion of the sea through their natural hydrodynamic property which attenuates the waves velocity, as well as through the construction of a tidal monitoring station that issues an alert signal in case of floods.

The moderate zone (2,687.421 ha, 33.265%) require a more moderated approach of improved local drainage, no more intrusive development in exposed areas, and spatial structure based on risk. Non-structural measures with equally high impact include stakeholder communication, increasing public awareness of flood risk, and disaster response plans, which will keep communities prepared when anything goes wrong.

Only 27.071 hectares, or 0.335%, make up the slightly vulnerable zone. In this situation, preventive is crucial, including protected water catchment areas, ongoing environmental monitoring, and land-use control to stop susceptibility from spreading upstream. The non-structural component is completed by risk-based spatial planning and public education.

Priorities immediately change when a flood actually occurs: evacuate and rescue impacted residents; swiftly deliver emergency supplies to the necessary locations. When the water eventually subsides, the emphasis shifts to repairing infrastructure, repairing any damaged areas, and honestly assessing the effectiveness of the mitigation strategies. When taken as a whole, none of this is about completely preventing floods; rather, it is about minimizing the damage each time and strengthening the coast's resilience for future events.

CONCLUSION

The majority of coastal Semarang (7,199.581 ha) is covered by flat topography (0–8%), and rainfall in the area consistently falls between 200 and 300 mm/month. Alluvial soil (4,020.72 ha, 46.96%) and latosol soil (4,543.31 ha, 53.05%) make up the soil underlying settlement and built-up land, which combined occupy around 43% of the total area. According to the hazard model, 27.071 ha are mildly vulnerable (scoring 9–12), 2,687.421 ha are moderate (score 13–16), and 5,364.451 ha are highly vulnerable (score 17–20) with composite scores of 11–19. A three-phase plan for mitigation, prevention, emergency response, and post-disaster recovery results from this. Prevention combines non-structural measures like catastrophe risk mapping, public education, and risk-informed spatial planning with structural measures like embankments, broader drainage channels, mangrove planting, and tidal gauge stations. Evacuation, rescue, and providing relief to impacted residents are the first priorities when a flood actually occurs; infrastructure recovery, environmental cleanup, and an honest assessment of the mitigation system's effectiveness come next. While none of these completely removes the risk of flooding, taken as a whole, it should lessen the risk and its effects while strengthening these coastal communities' ability to withstand future floods.

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