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Community Adaptation Patterns to Tidal Flooding (Rob) In Penjaringan District, North Jakarta City

Rafa Elysia Leandra[(1)], Saptono Putro[(2)]

Universitas Negeri Semarang
Jl. Raya Banaran, Sekaran, Kec. Gn. Pati, Kota Semarang, Jawa Tengah, Indonesia

Email: [1]rafaelysia2@students.unnes.ac.id, [2]saptono_putro@mail.unnes.ac.id

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Abstract: Tidal flooding increasingly affects low-lying coastal areas in North Jakarta, particularly Penjaringan District, where recurrent inundation disrupts settlements, infrastructure, and livelihoods. This study analyzes the spatial distribution of tidal flood-prone areas, identifies key factors influencing community adaptation, and examines prevailing adaptation patterns. Employing a descriptive quantitative approach integrated with spatial analysis, primary data were gathered through field observations, structured interviews, and questionnaire surveys in Pluit and Penjaringan subdistricts, supplemented by secondary data for mapping and hazard assessment. Descriptive analysis evaluated internal factors like socio-economic characteristics, residence duration, and risk awareness, alongside external factors such as environmental conditions and infrastructure. Highest flood exposure in low-elevation, high-density areas near the coast. Communities adapt via physical, economic strategies for livelihood continuity, and social responses like collective action. These enhance short-term resilience but face constraints from limited resources and environmental pressures. Community-based adaptation reduces vulnerability, yet requires stronger integration with spatial planning and coastal policies for sustainable risk reduction.

Kata Kunci:
Adaptasi Masyarakat; Banjir Rob; Kerentanan Pesisir

***Corresponding Author*:**
Name:
Rafa Elysia Leandra
Email:
rafaelysia@students.unnes.ac.id

Abstrak: *Banjir pasang surut semakin sering memengaruhi daerah pesisir dataran rendah di Jakarta Utara, khususnya Kecamatan Penjaringan, di mana genangan berulang mengganggu permukiman, infrastruktur, dan mata pencaharian. Studi ini menganalisis distribusi spasial daerah rawan banjir pasang surut, mengidentifikasi faktor-faktor kunci yang memengaruhi adaptasi masyarakat, dan meneliti pola adaptasi yang berlaku. Dengan menggunakan pendekatan kuantitatif deskriptif yang terintegrasi dengan analisis spasial, data primer dikumpulkan melalui observasi lapangan, wawancara terstruktur, dan survei kuesioner di Kecamatan Pluit dan Penjaringan, dilengkapi dengan data sekunder untuk pemetaan dan penilaian bahaya. Analisis deskriptif mengevaluasi faktor internal seperti karakteristik sosial ekonomi, lama tinggal, dan kesadaran risiko, bersama dengan faktor eksternal seperti kondisi lingkungan dan infrastruktur. Paparan banjir tertinggi terjadi di daerah dataran rendah dan padat penduduk di dekat pantai. Masyarakat beradaptasi melalui tindakan fisik (misalnya, meninggikan rumah, penghalang), strategi ekonomi untuk keberlanjutan mata pencaharian, dan respons sosial seperti tindakan kolektif. Hal ini meningkatkan ketahanan jangka pendek tetapi menghadapi kendala dari keterbatasan sumber daya dan tekanan lingkungan. Adaptasi berbasis komunitas mengurangi kerentanan, namun membutuhkan integrasi yang lebih kuat dengan perencanaan tata ruang dan kebijakan pesisir untuk pengurangan risiko yang berkelanjutan.*

INTRODUCTION

Global climate change intensifies pressures on coastal areas through sea-level rise, shifts in extreme weather patterns, and coastal environmental degradation. Indonesia's northern Java coastal regions, in particular, face high vulnerability due to low-lying topography, dense populations, and rapid urbanization (Marfai & Mada, 2019).

North Jakarta stands out as one of Indonesia's most flood prone coastal areas. The core problem of North Jakarta, particularly Penjaringan Subdistrict, is the rising frequency and depth of tidal flooding (rob) triggered by the combined effects of sea-level rise and significant land subsidence rates. This situation is exacerbated by land use changes, limited green open spaces, and suboptimal drainage systems. Climate projections indicate global sea-level rise could reach 0.6–1.1 meters by the end of the 21st century, potentially expanding inundated areas in North Jakarta significantly (IPCC, 2021). Research by (Salsabillah et al., 2024) identifies Muara Angke, Pluit, and Penjaringan as high risk zones for tidal flooding due to flat terrain, subsidence rates, and rising sea levels. Land use in Penjaringan Subdistrict, marked by industrial and commercial expansion alongside reduced green spaces, amplify coastal flood risks (Fadilla et al., 2018).

Tidal flood impacts include physical damage such as structural erosion, infrastructure corrosion, and saltwater intrusion to socioeconomic realms, disrupting livelihoods, reducing incomes, and elevating health risks (Putiamini et al., 2022). Thus, community adaptation plays a pivotal role in bolstering coastal resilience. Adaptation refers to the process by which social systems adjust to environmental stressors to minimize vulnerability and increase coping capacity such as elevating structures, building local levees, shifting economic activities, and strengthening social networks (Nelson et al.,2007; Asrofi et al., 2017.)

Previous studies have observed physical and behavioral adaptations among Semarang's coastal residents to maintain economic and residential functions (Ikhsyan et al., 2017). (Septian et al., 2022) emphasized accommodative measures, including building modifications and domestic space adjustments. In North Jakarta, (Chairani, C., 2024) documented adaptations to subsidence and rob, though qualitatively and GIS mapping (Salsabillah et al., 2024), but has not integrated spatial mapping of tidal flood vulnerability with measurable analysis of influencing factors and adaptation patterns in Penjaringan.

The objectives of this research are to analyze the distribution of tidal flood-prone areas in Penjaringan District, identify factors shaping community adaptations to rob, and examine the adaptation patterns employed by residents to sustain social and economic activities. Findings are expected to inform evidence-based policies for adaptive, integrated, and sustainable coastal management.

METHOD

This study uses a descriptive quantitative approach supported by qualitative data, with spatial analysis to examine the distribution of tidal flood vulnerability and community adaptation patterns in Penjaringan District, North Jakarta. The sample was selected using purposive sampling techniques, and the number of respondents was determined using the Slovin formula.

$$n = \frac{\mathrm{N}}{1 + \mathrm{N} * \mathrm{e}^2}$$

Explanation:

n : sample size

N : number of samples

e : margin of error

The research design combined field surveys, questionnaire-based socio-economic assessment, and Geographic Information System (GIS) analysis. The overlay technique was used to perform spatial analysis with ArcGIS software, which involved combining thematic maps of the three primary variables. Primary instruments consisted of structured questionnaires, interview guidelines, and field documentation tools to record physical environmental conditions and community adaptive practices.

Data validity was strengthened through source triangulation by cross-verifying information from field observations, interviews, and secondary datasets. Data analysis comprised spatial analysis to map vulnerability zones and descriptive statistical analysis to identify internal and external factors influencing community adaptation patterns, employing a *Likert* scale approach that assigned scores to each adaptation-forming indicator within a 1–4 range. The analytical approach that allows identifying the level of relationship between the most influential factors and the type of community adaptation patterns is carried out using Spearman correlation analysis.

$$r_s = 1 - \frac{6\sum d^2}{n(n^2 - 1)}$$

Explanation:

n : number of samples

d : difference between 2 variables

r_s : Spearman correlation coefficient.

RESULTS AND DISCUSSION

Distribution of Areas by Tidal Flooding (Rob)

1) Flood Risk Parameters

a. Land Elevation

Land elevation parameters were processed using 2018 DEM data from the Geospatial Information Agency (BIG). This DEM data was processed using ArcGIS version 10.8, reclassifying the data to reflect elevation conditions in North Jakarta, specifically Penjaringan District.

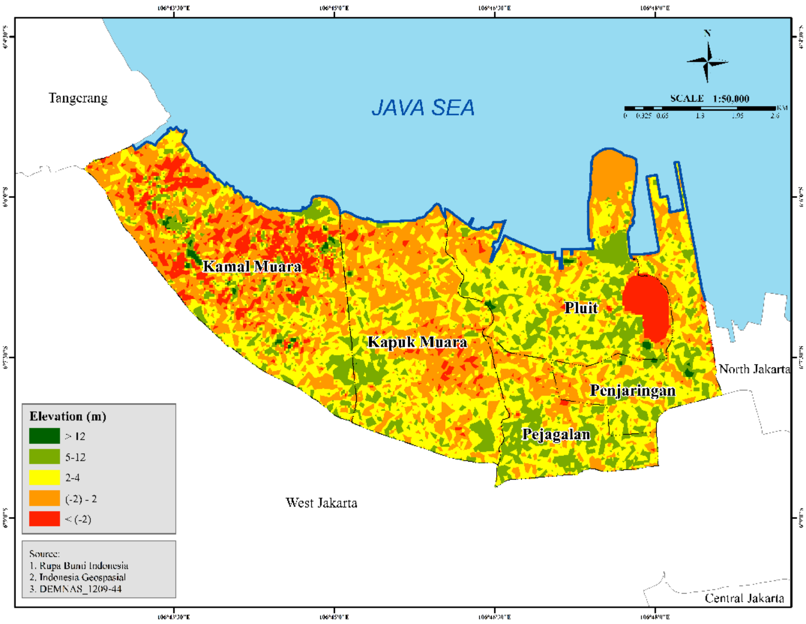

Figure 1. Land Elevation Parameter Map

Table 1. Land Elevation in Penjaringan District

Land Elevation (m)	Area (Ha)	Area (%)
>12	0,101871	0,90%
5 – 12	1,999528	17,61%
3 – 4	4,459607	39,28%
(-2) – 2	3,790651	33,39%

< (-2)	1,001001	8,82%
Total	**11,352658**	**100%**

Source: Analysis Results

The land elevation map above shows that Penjaringan District is dominated by low-elevation areas. The 3-4 meter elevation class is the largest, covering 4.46 Ha, or 39.28% of the total area. This indicates that the majority of Penjaringan District is located in a lowland zone, which is relatively flat morphologically and has a high potential for tidal inundation if sea levels rise

Altitude class (-2) – 2 with an area of 3.79 Ha or 33.39%, where this area is topographically very close to or lower than the average sea level. Parts of Penjaringan District are at or even below sea level, making them highly susceptible to tidal flooding. This reinforces the finding that tidal flooding in Penjaringan District is influenced not only by tidal factors, but also by the area's flat morphology, low elevation, and coastal urbanization pressures (Salsabillah et al., 2024). These conditions result in tidal water overflowing more easily and remaining longer on the surface, making it difficult for it to drain back into the sea, thus increasing the duration and extent of inundation. The Pluit and Penjaringan subdistricts, which directly border the Java Sea, are characterized by low-lying coastal alluvial plains. This makes them the most vulnerable to tidal flooding.

b. Land Use

Land use parameters are processed using a supervised classification method, which assigns class values to groups of grid cells in raster or raw data based on the same grid cell values that have previously been defined as representing a classification. In this case, the classifications defined are vegetation, industry, open land, rice fields, mangroves, settlements, and water bodies.

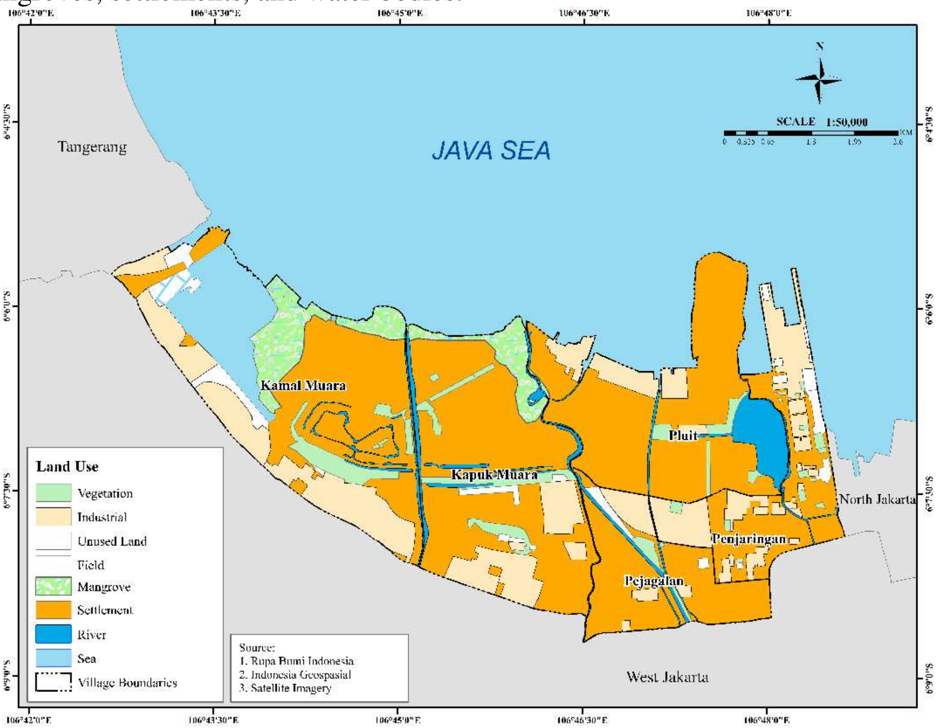

Figure 2. Land Use Parameter Map

Table 2. Land Use in Penjaringan District

Classification	Area (Ha)	Area (%)
Vegetation	37.823,62	9,94%
Industrial	66.874,65	17,57%

Unused Land	21.096,71	5,54%
Field	2.368,56	0,62%
Mangrove	15.785,9	4,15%
Settlement	163.676,51	42,99%
River	73.073,64	19,19%
Total	**380.699,59**	**100%**

Source: Analysis Result

Residential areas dominate, covering 163,676.51 Ha, or 42.99% of the total area. This reflects the high level of urbanization and population density in the coastal areas of North Jakarta, which significantly impacts the region's increased vulnerability to tidal flooding due to impermeable surfaces such as concrete and asphalt, which prevent tidal water and runoff from infiltrating the ground. The second largest land use is rivers, with an area of 73,073.64 Ha, or 19.19%. The extensive river network serves as the main drainage route, but it has the potential to become a channel for tidal water runoff into inland areas, especially during peak tides accompanied by high river discharge or suboptimal drainage capacity.

The vegetation class covers an area of 37,823.62 Ha, or 9.94%, with mangrove forests covering only 15,785.90 Ha, or 4.15%. This relatively small percentage of vegetation cover indicates its limited ecological function as an abrasion breaker, wave damper, and flood control before water overflows into residential areas.

The dominance of residential areas that have developed close to the coastline in almost all of the central to eastern parts of Penjaringan District, particularly in Pluit and Penjaringan Villages, has reduced water catchment space and increased the potential for flooding during high tides. This situation is further exacerbated by the fact that these settlements are located at low elevations and are experiencing land subsidence (Chairani, C., 2024)

Furthermore, the presence of water bodies and waterways that drain directly into the Java Sea in the Kapuk Muara and Penjaringan areas also significantly contributes to the tidal flooding problem in North Jakarta. During high tides, seawater enters the water bodies (a backwater effect), impeding the flow of water from the land to the sea, causing flooding to spread to surrounding settlements.

Land use patterns in Penjaringan District tend to be inconsistent with the characteristics of coastal areas prone to tidal flooding. Land use for dense residential areas with limited mangrove vegetation and the intensity of industrial activity in coastal areas exacerbate the vulnerability to tidal flooding. The results of this analysis align with research by (Abidin et al., 2015) which states that changes in land use in coastal areas of North Jakarta contribute significantly to the increasing frequency of tidal flooding.

c. Distance from Coastline

The method used for analysis is buffering analysis with the multiple-ring buffer feature in the ArcGIS 10.8 application. This buffering analysis examines the relationship between a main object and other objects around a certain distance. The parameters are classified into five distance classifications: 0-500m, 500-1000m, 1000-1500m, 1500-3000m, and >3000m.

Table 3. Distance Parameters of Penjaringan District from the Coast

Distance (m)	Area (Ha)	Area (%)
0 – 500 m	2.389,61	17,05%
500 – 1000 m	1.677,25	11,96%
1000 – 1500 m	1.498,92	10,96%
1500 – 3000 m	3.668,71	26,17%
>3000 m	4.783,66	34,13%

Total	**14.018,15**	**100%**

Source: Analysis Results

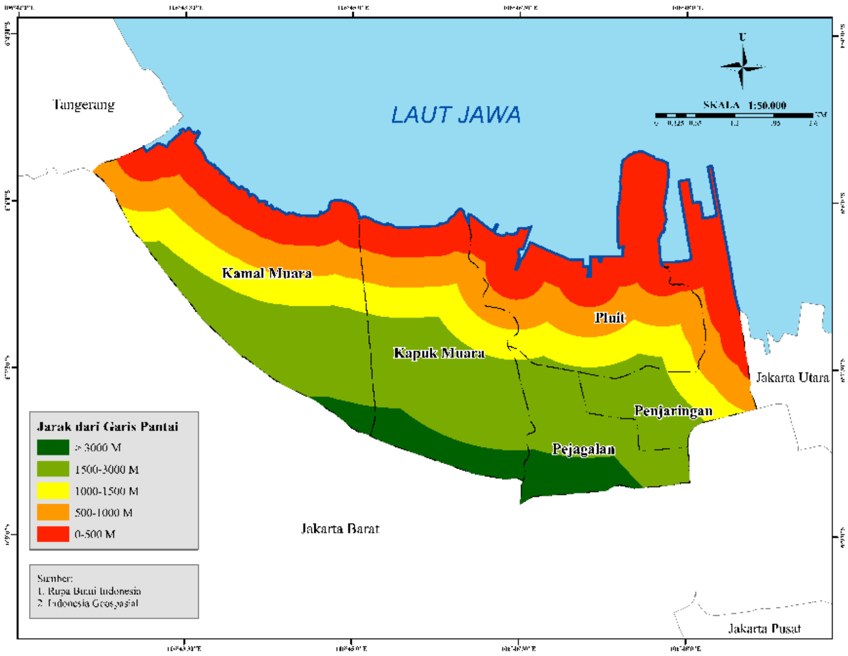

Figure 3. Distance Parameter Map from the Coastline

Penjaringan District has a relatively varied distribution of distances from the coastline. The most dominant distance classes are 1,500-3,000 m and >3,000 m, accounting for 26.17% and 34.13% of the area, respectively. This zone has a lower level of direct exposure to tidal flooding, as it is far from the influence of sea tides. However, this area still has the potential to be indirectly impacted through the drainage system, river flow, and land subsidence, which can accelerate waterlogging.

The 0-500m distance class from the coastline covers an area of 2,389.61 Ha, or 17.05%. Although not a dominant region, this zone is highly vulnerable to tidal flooding due to its direct border with the Java Sea. High tides can easily overflow onto land, especially during a combination of maximum tides, high waves, and significant land subsidence. This area includes coastal areas such as Pluit, Muara Angke, and parts of Kamal Muara, which are frequently reported to experience tidal inundation.

The closer an area is to the coastline, the more vulnerable it is to tidal flooding, especially in areas with dense residential land use and developed infrastructure. This situation aligns with the frequently reported tidal flooding incidents in Pluit, Muara Angke, Kamal Muara, and Kapuk Muara. The results of this analysis align with the concept of coastal vulnerability, which states that low elevation and proximity to the coastline are the primary factors in tidal flooding (Nicholls & Cazenave, 2010; BNPB, 2020).

2) Analysis of Tidal Flooding Events in Penjaringan District

Tidal flooding is a sea tide phenomenon that occurs due to fluctuations in sea level influenced by the gravitational pull of celestial bodies on the density of seawater on Earth (Ikhsyan et al., 2017). The IPCC also predicts that increasing coastal flooding in lowland areas is caused by rising global temperatures and sea levels. Tidal flooding generally occurs in areas lower than sea level during high tides. Tidal flooding in North Jakarta, particularly in Penjaringan District, is quite common. The following summarizes tidal flooding incidents in Penjaringan District over the past five years.

Table 4. Flood Incidents in Penjaringan District, North Jakarta past 5 years

Date of Incident	Location	Source	Notes
7 Juni 2020	Pantai Mutiara Pluit	Wartakota.com	80-120 cm
9 November 2020	Penjaringan	SindoNews.com	50 cm
2 Desember 2021	Muara Baru, Kaliadem	Liputan6.com	-
9 Desember 2021	Muara Angke Pluit, Muara Baru, Kamal Muara	TribunNews	-
14 Desember 2024	Penjaringan	Antaranews.com	10 cm
16 Desember 2024	Penjaringan	Detiknews.com	15-20 cm
16 Desember 2024	Muara Angke	metroTV	30-90 cm
26 Desember 2024	Pluit	DetikNews.com	55 cm
13 Januari 2025	Kapuk Muara	Antaranews.com	10 cm
28 April 2025	Muara Karang, Pluit	Fakta.com	60 cm
8 Juli 2025	Kapuk Muara	News.detik.com	65 cm
2 Desember 2025	Penjaringan	Jakarta.terkini	-
5 Desember 2025	Muara Angke, Pluit	Ntvnews.id	10-30 cm
6 Desember 2025	Penjaringan	News.republika.com	40-50 m

Source: Online News Media 2025

Based on a recapitulation, it is known that Penjaringan District is an area that is consistently affected by tidal flooding from year to year. The recorded recapitulation was taken over the past five years, and it was noted that the locations affected by tidal flooding were relatively the same: Pluit, Muara Angke, and Penjaringan Village. This series of recurring tidal events has a very strong correlation with the physical conditions of the Penjaringan District area, which is dominated by low elevations (<2 meters above sea level) and is exacerbated by land subsidence. These conditions cause seawater to easily overflow onto land and take a long time to recede. As a result, the community in this area is encouraged to undertake various forms of adaptation.

This flood data was obtained from various news media sources and validated through field observations, which were then analyzed descriptively and spatially. This analysis provides a snapshot of the dynamics of tidal flooding in Penjaringan District, enabling us to understand the region's vulnerability and its relationship to local community adaptation patterns.

Table 5. Distribution of Flood Points in Penjaringan District

Subdistrict	Flood Points	Presentase
Kamal Muara	-	0,00%
Kapuk Muara	2	14,29%
Pluit	7	50,00%
Penjaringan	5	35,71%
Penjagalan	-	0,00%
Total	**14**	**100%**

Source: Analysis Results

The distribution of tidal flood points concentrated in the northern Pluit area and the Muara Angke area with a percentage of 50.00% or with 7 flood distribution points of the total incidents indicating that this area is the main point of tidal events in Penjaringan District. The area is in the 0-500 meter distance zone from the coastline and is dominated by low-elevation plains, which causes vulnerability to seawater runoff during high tides. In addition, the Pluit area is also dominated by dense residential activities, ports and reclamation infrastructure that can affect the dynamics of seawater flow and drainage systems.

Penjaringan Village has a flood prevalence of 35.71%, with 5 flood points. Although this area does not entirely border the coastline, it has a network of rivers and drainage channels that directly connect to the coastal area. High tides can easily enter through the river channels (backwater effect), allowing tidal flooding to spread to residential areas. Furthermore, population density and limited drainage capacity also contribute to the high intensity of tidal flooding in Penjaringan Village.

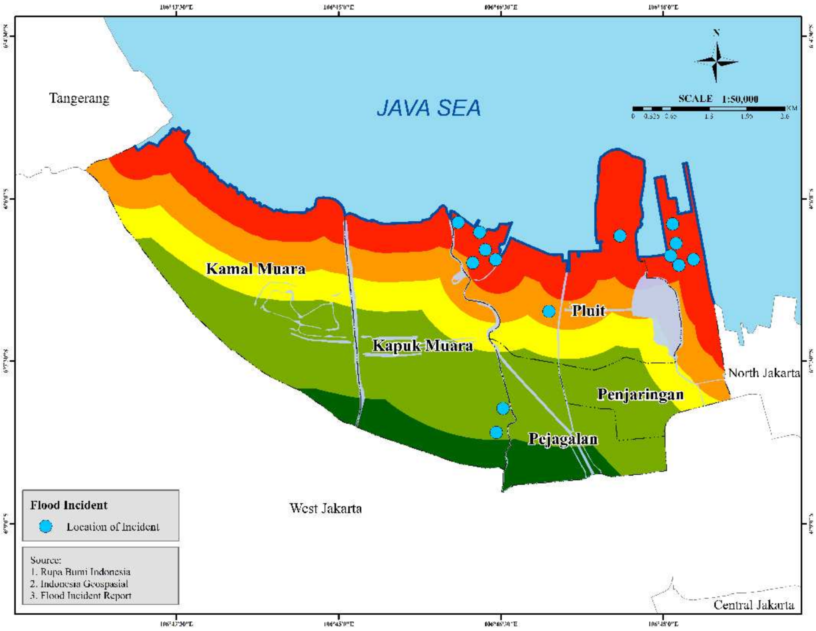

Figure 4. Map of Tidal Flood Distribution in Penjaringan District

The distribution pattern of tidal flooding events on this map aligns with the analysis of land elevation maps and distance from the coastline, indicating that areas with lower elevations and closer proximity to the coastline have a higher concentration of tidal flooding. This indicates a strong link between topography, geographic location, and tidal flooding. In conclusion, the areas most physically vulnerable are those most frequently experiencing recurring tidal flooding.

Forming Factors to Community Adaption to Tidal Flooding (Rob)

The concept of human adaptation is a reciprocal relationship between humans and ecosystems, or can be interpreted as human activity that takes over the role of the environment to maintain life (Ritohardoyo, 2005 in Sutigno, 2015). Adaptation to climate change is characterized by the ability of communities to adjust to climate change as a form of response to climate change conditions so that they can survive (Syah, 2012). In other words, adaptation can be interpreted as a method used by communities, either spontaneously or planned, to adjust to something. Community adaptation can vary in each region because it is influenced by physical, social, and economic aspects.

Internal factors in this case include demographics, economics, adaptation knowledge, and mobilization capacity. Demographic factors such as age, length of residence, and education level influence the community's level of experience and understanding of the risks of tidal flooding. Economic factors relate to the community's financial capacity to undertake adaptation efforts, particularly physical adaptations, which require relatively large costs. Adaptation knowledge plays a role in determining community awareness of the impacts of tidal flooding, and mobilization knowledge reflects the community's capacity to mobilize, evacuate, or organize daily activities during tidal flooding.

External factors forming adaptation relate to residential environmental conditions, social interactions, and accessibility. These environmental factors reflect the physical conditions of settlements, such as building quality, drainage systems, and the distance between settlements and coastal areas, which determine an area's level of exposure to tidal flooding. Social interactions and accessibility play a role in strengthening adaptive capacity through support between residents, communication during tidal flooding, and ease of access to public facilities such as evacuation routes and emergency services, which significantly determine the effectiveness of community response during tidal flooding.

Asummary of questionnaire responses from 100 respondents reveals that both internal and external factors equally contribute to shaping adaptation patterns among Penjaringan District communities facing tidal flooding (rob). External factors achieved a median score of 33, while internal factors scored 31, indicating that most respondents experience relatively high environmental exposure, accessibility, and social interaction, supported by individual conditions such as experience, knowledge, and adequate economic capacity. This demonstrates that communities are influenced not only by physical coastal conditions but also by individual capacities to respond to tidal flood risks.

Analysis results indicate that external factors primarily serve as triggers for adaptation, while internal factors determine the capability and quality of community adaptive responses. Areas with environmentally vulnerable conditions prone to rob compel communities to adapt, yet the success level also depends on individual and household capacities to manage those risks.

Community Adaptation Patterns to Tidal Flooding (Rob)

Community adaptation capacity in facing tidal flooding (rob) phenomena relates to several formative factors underlying the development of adaptation patterns. Based on questionnaire response analysis, adaptation patterns among Penjaringan Subdistrict communities when confronting rob are significantly influenced by both internal and external formative factors.

Internal factors, including economic conditions, knowledge of tidal flooding, experience with tidal flooding, and resource mobilization capabilities, tend to be associated with increased community capacity for protective and accommodative adaptation. Respondents with a higher level of risk awareness and more frequent experience of being affected tend to take physical measures to protect their homes, such as raising floors, repairing water pipes, preparing safety equipment, and storing valuables in safe places. Furthermore, communities also adjust their social and economic activities, for example by adjusting work hours, moving vehicles to safe locations, and preparing reserves for daily needs in the event of a tidal flood.

External factors also reinforce protective and accommodative adaptation patterns among the Penjaringan District community. These include residential conditions, infrastructure, social interactions, and accessibility. Frequent tidal flooding, proximity of settlements to the coastline, and limited drainage systems encourage communities to adopt protective and accommodative adaptations as survival strategies. Meanwhile, the retreat adaptation pattern is lower than other adaptations, indicating that most residents still prefer to remain in their homes and adapt to environmental conditions rather than undertake permanent relocation.

The correlation between these two factors was tested to determine their relationship with community adaptation patterns. The Spearman correlation test yielded positive and significant correlation coefficients, indicating a unidirectional relationship between adaptation-forming factors and community adaptation patterns. Internal factors had a strong correlation with protective adaptation patterns ($r_s = 0.679$; $p < 0.001$) and accommodative adaptation patterns ($r_s = 0.578$; $p < 0.001$). The results of this correlation test illustrate that individual community capacity, such as economic factors, level of knowledge about tidal flooding, and resource mobilization capabilities, play a significant role in encouraging communities to undertake physical protection measures and adapt to environmental conditions affected by tidal flooding. The adaptations that have been implemented by the community in Penjaringan District are:

1) Building small retaining walls in front of the house
2) Raising house floors or yards
3) Routinely cleaning drainage
4) Securing electrical installations to prevent flooding

5) Cordinating with neighbors when tidal floods
6) Postponing certain activities during tidal floods

(a) (b) (c)

Figure 5. (a)small retaining walls in front of the house, (b) raising house floors or yards, (c) a clean drainage
Source: Observation, 2025

The result of the respondent data analysis indicates that community adaptation patterns to tidal flooding in Penjaringan District are dominated by protective and accommodative adaptations, influenced by a combination of internal and external factors. This analysis also indicates that community adaptability is determined not only by individual capabilities but also by environmental characteristics and surrounding social support. This indicates that communities tend to persist and adapt to their homes, utilizing both individual internal capacities and existing external support, despite the region's high vulnerability to tidal flooding. These analysis findings align with the vulnerability characteristics of densely populated urban coastal areas, where social and economic ties, and limited housing are key factors in determining community adaptation patterns.

CONCLUSION

Penjaringan District is highly vulnerable to tidal flooding, particularly in coastal areas such as Pluit, Muara Angke, Kapuk Muara, and parts of Penjaringan Village. This vulnerability is influenced by the physical conditions of the region, which are dominated by low elevations, proximity to the coastline, dense settlements, and a suboptimal drainage system. Community adaptation patterns are influenced by internal and external factors. In general, community adaptation patterns in Penjaringan District are dominated by protective and accommodative adaptations, such as raising house floors, cleaning drainage channels, storing valuables in safe places, adjusting daily activities, and strengthening coordination between residents. Retreat adaptation is still relatively low due to economic limitations, social ties, and limited relocation options. This analysis confirms that strengthening community knowledge capacity and improving infrastructure are crucial to increasing regional resilience to tidal flooding in Penjaringan District.

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