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Climate–stressed coastal: Reconfiguring marine fisheries port management

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Abstract

Climate change has increased the frequency and intensity of tidal flooding in Pekalongan City, Central Java, severely affecting the Nusantara Fishery Port (PPN) Pekalongan. As a central hub for marine and fisheries activities, the port has experienced functional deterioration due to repeated inundation, resulting in infrastructure damage, reduced fishery production and declining welfare among local fishers. This study applies a qualitative single-case study approach to examine the impacts of tidal flooding and to assess adaptation measures using the Permanent International Association of Navigation Congresses (PIANC), United Nations Development Programme (UNDP) and Sustainable Development Goals (SDGs) frameworks. The findings show that tidal flooding has significantly reduced capture fisheries productivity, with output decreasing from approximately 103,000 tons in 1995 to under 20,000 tons in 2023. Recurrent inundation also damages port infrastructure and fishing gear, disrupts loading and unloading activities and thereby further undermines overall fishing activity. The adaptation policy assessment at Pekalongan PPN indicates that 50% of the 10 sub-indicators have been achieved, particularly those related to technical interventions and local coordination, while funding mechanisms and participation in international policy forums remain limited. The main long-term strategy involves developing inland ports through the Integrated Fisheries Port and International Fish Market program, which is supported by the Japan International Cooperation Agency. Strengthening the regulatory framework, fiscal incentives and global engagement is recommended to advance comprehensive and sustainable port adaptation governance.

Keywords: Fishery, fishing port, Pekalongan, policy evaluation, tidal flood

Introduction

Climate change poses systemic risks to human settlements and infrastructure, with coastal regions among the most threatened due to sea-level rise and intensifying tidal floods. Rising global temperatures, polar ice melt and hydrological shifts have disrupted urban planning, economic

activity and vital infrastructure, particularly seaports that serve as gateways of trade and fisheries (Ledda et al., 2021; Loza & Veloso-Gomes, 2023; Sharaan et al., 2024). In response, several major ports worldwide have advanced adaptation strategies encompassing spatial data integration, infrastructure reinforcement and risk management systems to safeguard operational continuity under climate uncertainty (Asariotis et al., 2024; Ng et al., 2019; Santos et al., 2024).

Empirical evidence underscores the urgency of port adaptation in various parts of the world due to the threat of rising sea levels (Alfredini et al., 2024; Chinago Budnukaeku, 2024; Mazuze, 2024; Oerlemans et al., 2025; Van den Berg & De Langen, 2011). Indonesia's low-lying coastal cities face similar climate-related risks and Pekalongan City in Central Java is among the most vulnerable, situated on a coastal plain only 0-6 meters above sea level (Wahyuddin et al., 2023). The city's exposure is intensified by land subsidence, rapid urbanisation and sea-level rise, contributing to frequent tidal floods 14 events were recorded in 2024, with North Pekalongan most affected (Statistical Office of Pekalongan City, 2025; Yulianto et al., 2024). A critical asset at risk is the Nusantara Fishery Port (PPN) in Pekalongan, a strategic hub that supports the livelihoods of over 1,400 fishers and serves as a key driver of the regional marine economy (Andira et al., 2019). Over recent decades, capture fisheries production has declined sharply, consistent with increasing tidal-flood disruptions to port operations, including loading and unloading, fish auctions, utility distribution and reduced investment in supporting facilities (Kusumaning & Puriningsih, 2019; Maurizka & Adiwibowo, 2021)

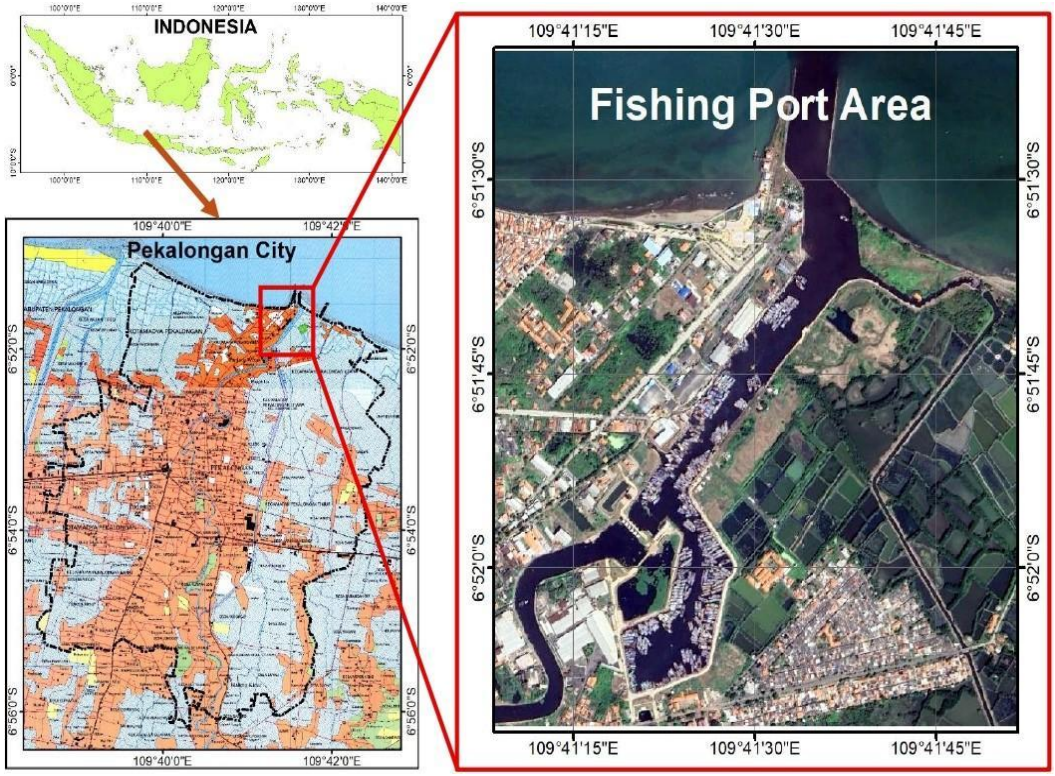
Another major consequence of tidal flooding is sedimentation in the port area, which, exacerbated by such conditions, obstructs shipping lanes and hinders large vessels from docking (Craghan, 2005; Ji et al., 2023; Pellegrini et al., 2024). This condition has prompted a shift in fish landings to other ports outside Pekalongan, such as Klidanglor Port and Muara Angke. Additionally, infrastructure damage from tidal floods not only disrupts port services but also imposes high costs on post-disaster recovery, as seen in the cases of Tanjung Emas Port in Semarang and various European ports (Rahili et al., 2023; Ribeiro et al., 2021). While local authorities have undertaken structural measures such as dike construction, pump installation and plans for a new onshore port, systematic evaluations of adaptation policy effectiveness in Pekalongan remain scarce (Ng et al., 2019; Sharaan et al., 2024).

This research addresses a critical gap by assessing tidal flood impacts and evaluating adaptation policies at PPN Pekalongan through a case study approach grounded in international frameworks (Ng et al., 2019) and indicators from PIANC, UNDP and the SDGs. The analysis contributes to climate adaptation governance literature by demonstrating how governance limitations, particularly in financing and international engagement, continue to constrain resilience despite advances in technical and spatial measures. It also advances debates in port geography and coastal management by illustrating how fisheries-dependent economies face distinct vulnerabilities that narrow adaptive pathways. Together, these insights offer a conceptual and empirical foundation for strengthening governance frameworks in climate-exposed coastal ports.

Method and study area

Study location

The research was conducted within the Nusantara Fishery Port (PPN) Pekalongan, located in North Pekalongan District, Pekalongan City, Central Java Province. The specific study location is depicted in Figure 1 below.



Source: Author's work, 2025

Figure 1. Location of Nusantara Fishery Port Pekalongan

Methodology

This study employed a qualitative single-case design centred on PPN Pekalongan to examine how climate-induced tidal flooding affects port operations and how adaptation is managed. The case-study approach provided analytical flexibility, allowing the use of multiple data collection and interpretive techniques suited to the port's specific institutional and environmental context, and enabling in-depth analysis within real-world conditions (Mortensen et al., 2020; Onghena et al., 2019). Conducted between April and October 2024, the research investigated the port's exposure to tidal-flood risks, assessed existing and planned managerial responses and reviewed the climate-adaptation policies implemented at PPN Pekalongan to understand their effectiveness and alignment with broader adaptation objectives.

Data collection methods and analysis

Semi-structured in-depth interviews formed the core data collection method, supplemented by field observations and secondary data analysis. Secondary data included planning and development documents for PPN Pekalongan and Pekalongan City, regulations on tidal flood mitigation, chronicles of tidal flood events and relevant scientific literature. This data was subsequently validated through further conversations.

Observation and document analysis

Primary data were collected through direct field observations and in-depth interviews with key informants who provided substantive insights into tidal flood disasters in the PPN Pekalongan area. Field observations were conducted in a semi-structured manner to capture as much detail and as many aspects as possible of the phenomena under investigation. The scope of observation encompassed port operations, the impacts and risks of past tidal flood events and the new port development project.

In-depth, semi-structured interviews

In-depth, semi-structured interviews are guided conversations in which the researcher probes respondents' understanding of tidal flood issues in the port area. This qualitative research method has been widely used for several decades and serves as a primary tool for conducting research in geography (Barrick, 2019). A total of 20 informants were interviewed during the research period (Table 1). A snowballing method was used to identify key informants representing the policy makers, port authorities, fishermen, academia and local communities. The collected data were then validated through data triangulation.

Table 1. List of Informants

Sector	Stakeholder	Number of informants
Policy maker	- Development Planning Agency (Bappeda), Pekalongan City	2
	- Regional Disaster Management Agency, Pekalongan City	3
	- Department of Marine Affairs and Fisheries	2
	- Department of Public Works and Spatial Planning	2
	- Head of Bandengan Sub District	1
	- Head of Degayu Sub District	1
Port authorities	Pekalongan Fishing Port	2
Academia	Pekalongan University	2
Fisherman	Fisherman group	2

Environmmental protection and sustainability community group	-	Bintari	1
	-	Kemitraan	1
	-	Mercy Corps	1

To investigate policies influencing climate change adaptation at PPN Pekalongan, a desk study and regulatory review were conducted with relevant PPN Pekalongan stakeholders. These included the Ministry of Marine Affairs and Fisheries (KKP), the Ministry of Public Works and Housing (PUPR), the National Development Planning Agency (Bappenas), the Central Java Provincial Government, the River Basin Organisation (BBWS) and the Pekalongan City Government. Additionally, in-depth interviews were conducted with PPN Pekalongan management. All findings were summarised into a comprehensive table of indicators for evaluating climate change adaptation policies against tidal floods in ports (Table 2). The key indicators used to assess Climate Change Adaptation Policies against Tidal Floods in Ports were synthesised from previous research, combined with regulatory documents related to port operations, such as those from the PIANC and UNDP and aligned with the principles of SDGs. Indicators were evaluated in a binary manner (achieved/not achieved) and assessments were based on document analysis, expert judgment, triangulation or consensus-building.

Table 2. Indicators for evaluating climate change adaptation policies against tidal flooding in ports

Policy category	Indicator	Sub-indicator	Description	Evaluation criteria	Sources
A. Infrastructure and Spatial Planning Policy	Strengthening Adaptive Infrastructure	Integration of flood-resilient port development policies	Policies must regulate the elevation of quays, the use of corrosion-resistant materials, and adaptive drainage systems, to cope with sea level rise and tidal flooding	- Availability of specific regulations on flood-resilient infrastructure - Compliance with climate change adaptation standards - Implementation of adaptive drainage systems in port areas	Brooke et al., 2020; Ng et al., 2016
		Flood risk-based zoning and spatial planning	Port spatial planning must consider flood risk zones, regional elevation, and ecosystem-based buffer zones to mitigate the impact of tidal flooding	- Availability of adaptive spatial planning policy documents - Implementation of buffer zones or natural protection systems - Assessment of the impact on spatial planning changes on port resilience	Brooke et al., 2020; Huntjens et al., 2012
B. Operational and Risk Management Policy	Crisis Management and Operational	Implementation of early warning systems and flood mitigation	Ports must have tide sensors, extreme weather forecasts, and risk mitigation	- Availability and effectiveness of early warning systems	Brooke et al., 2020; Yang et al., 2018

Policy category	Indicator	Sub-indicator	Description	Evaluation criteria	Sources
	Resilience System		procedures to reduce the impact of operational disruptions from flooding	- Tested risk mitigation protocols - Coordination with relevant stakeholders for the implementation	
		Standard Operational Regulations for Post-Disaster Recovery	Policies must establish infrastructure recovery plans, evacuation procedures, and backup systems to ensure the continuity of port operations after disasters	- Availability of standard post-disaster recovery documents - Level of contingency infrastructure readiness - Level of operational recovery speed after flooding	Huntjens et al., 2012; Ng et al., 2019
C. Financial and Investment Policy	Adaptation Funding Support	Fiscal incentives for green infrastructure investment	Governments should provide tax incentives, subsidies, or green financing schemes for ports investing in environmentally friendly and flood-resilient technologies	- Availability of incentive schemes for port authorities - Total amount of green investments implemented - Effectiveness of incentives in enhancing port resilience	Ng et al., 2016; UNDP, 2004
		Integration of flood insurance policies for port infrastructure	Policy should establish a flood-risk insurance scheme to support rapid post-disaster economic recovery at the port	- Availability of mandatory insurance schemes - The percentage of ports with insurance coverage - Post-disaster economic recovery time	Brooke et al., 2020; Yang et al., 2018
D. Regulatory and Standardization Policy	Implementation of Climate Change Adaptation Standards	Regulations for flood-resilient port infrastructure construction	National regulations must enforce port design standards that accommodate future sea level rise and extreme weather changes	- Availability of national regulations on flood-resilient construction - Compliance with construction standards - Implementation of regulations on new infrastructure development	Brooke et al., 2020; Ng et al., 2019
		Alignment of climate adaptation policy with	Climate adaptation policies in ports must be aligned with maritime regulations related licensing,	- Policy coordination between climate and maritime ministries	Brooke et al., 2020; Huntjens et al., 2012

Policy category	Indicator	Sub-indicator	Description	Evaluation criteria	Sources
		national maritime policy	marine spatial planning, and coastal protection	- Level of inter-sectoral policy alignment - Implementation of adopted policies at the port	
E. Stakeholder Engagement Policy	Multi-Stakeholder Collaboration and Participation	Consultation and coordination mechanisms among government, ports, and coastal communities	The drafting of adaptation policies must involve a range of stakeholders, including port operators, local governments, academics, and coastal communities	- Availability of regular consultation forums - Stakeholder participation in decision-making - Implementation of consultation outcomes in adaptation policies	Kane et al., 2016; Ng et al., 2019; UNDP, 2004
F. International Cooperation Policy	Global Collaboration for Climate Change Adaptation	Participation in international forums and initiatives related to port adaptation	Ports should engage in international alliances focusing on climate change, such as the International Association of Ports and Harbors (IAPH)	- Availability of policies on participation in global forums - The number of forums/ alliances participated in - Implementation of international discussions in local policies	Brooke et al., 2020; Ng et al., 2019

Source: Author's work, 2025

Table 1, "Indicators for Assessing Climate Change Adaptation Policies Against Tidal Floods in Ports," outlines the policy categories, indicators, sub-indicators and assessment criteria. This framework demonstrates a comprehensive approach aligned with principles of effective climate governance (Brooke et al., 2020; Huntjens et al., 2012; UNDP, 2004) and corresponds with the Sustainable Development Goals (SDGs). It is intended to address a research gap concerning climate change vulnerability within port areas.

Results and discussion

Overview of PPN Pekalongan

PPN Pekalongan operates as a Technical Implementation Unit (UPT) under the Directorate General of Capture Fisheries, Ministry of Marine Affairs and Fisheries (KKP), led by a Port Head appointed by the Minister of Marine Affairs and Fisheries. PPN Pekalongan serves as a central hub for fisheries in Pekalongan City, fostering the city's economic development. Its core infrastructure includes docks, navigation channels, breakwaters, navigation facilities, fish auction sites, office buildings and tourism facilities (Figure 2).

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Source: Author's work, 2025

Figure 2. Core Facilities at PPN Pekalongan

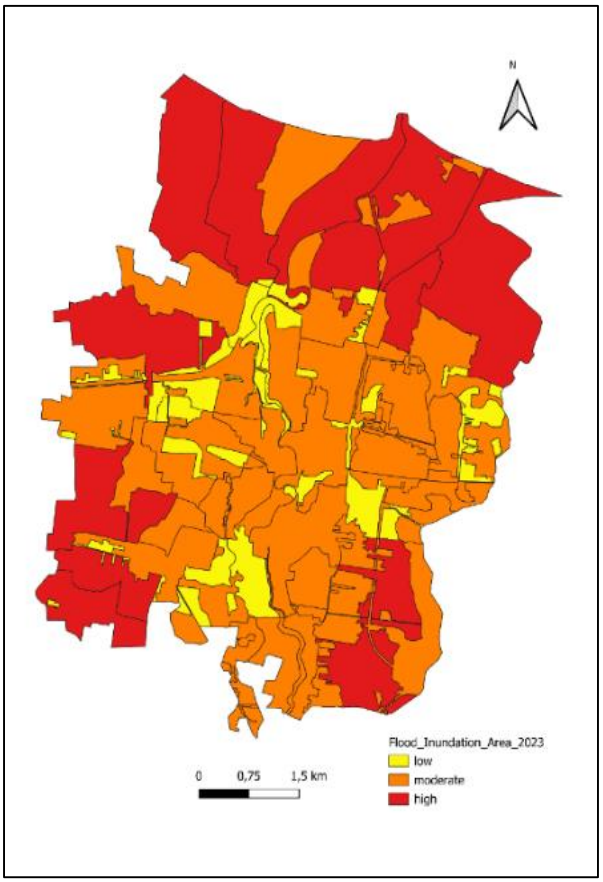
In 2023, PPN Pekalongan recorded activity from 161 vessels, owned by individuals or companies, that conducted fishing operations and landed their catch at the port. These vessels employed various fishing gears, such as single-boat pelagic purse seines, cast nets and drift gill nets and were predominantly small to medium in Gross Tonnage (GT). Approximately 1,400 fishermen are affiliated with the port, originating from three sub-districts: Krapyak, Panjang Wetan, and Panjang Baru. The 2023 landings consisted of diverse pelagic and demersal species, including skipjack tuna, shortfin scad, redtail scad and squid, with skipjack tuna being the most abundant at 1,125 tons. Most of the fish caught were sold through the Fish Auction Site (TPI) at PPN Pekalongan. Due to its low-lying topography, the port area remains highly susceptible to tidal flooding.

Identification of tidal flood risk due to climate change

The coastal zone and overall topography of Pekalongan City lie on low-elevation plains, ranging from 0 to 6 meters above sea level (Wahyuddin et al., 2023). The city is also surrounded by several major rivers, including the Pekalongan and Loji Rivers, which further heighten flood exposure. This low-lying terrain makes the region highly susceptible to sea-level rise driven by global warming. Furthermore, land subsidence in Pekalongan City exacerbates the effects of tidal floods driven by climate change. This subsidence primarily occurs in residential areas on young alluvial

soils, which are unconsolidated sediments prone to sinking. Approximately 80.43% of the city's area consists of alluvial deposits (Hakim et al., 2023).

In 2024, Pekalongan City experienced 14 tidal flood events, comprising 5 occurrences in West Pekalongan District, 2 in East Pekalongan District, none in South Pekalongan District and 6 in North Pekalongan District (Statistical Office of Pekalongan City, 2025). PPN Pekalongan is in North Pekalongan, the district with the largest flood-prone area due to its direct exposure to the Java Sea. This aligns with data from the Regional Disaster Management Agency (BPBD) in 2023, which identified North Pekalongan District as having the highest inundation extent among regions (Figure 3).



Source: BPBD Pekalongan City

Figure 3. Map of Tidal Flood Inundation Area in Pekalongan City

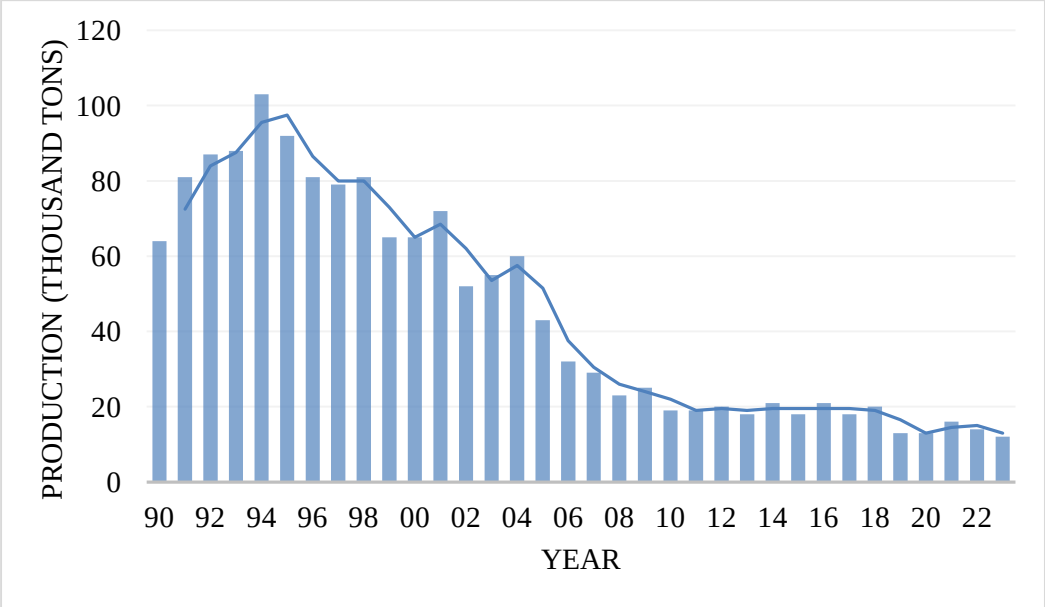
The extensive tidal flood inundation area in Pekalongan City is categorized into three groups: low (2–51 ha), moderate (52–133 ha) and high (134–293 ha). Situated at the northernmost edge, PPN Pekalongan falls within the high-risk zone, where flood durations exceed 24 hours. This risk is particularly consequential given the port's role as a central economic hub for the city.

Impacts of tidal floods in the PPN Pekalongan area

Tidal floods inflict substantial adverse impacts on the PPN Pekalongan area. Prolonged inundation disrupts port operations and reduces (Rahili et al., 2023). Tidal floods also reduce fishing activities,

leading to declining fisheries productivity in Pekalongan City. The primary cause of reduced capture fisheries output is the long-term decrease in the number of vessels landing their catch in the city, a trend that began in the 2000s and aligns with community perceptions of when tidal flooding intensified (Maurizka & Adiwibowo, 2021). These declines directly affect the income and welfare of households dependent on the capture fisheries sector.

Figure 4 illustrates the long-term trajectory of capture fisheries production in Pekalongan City over more than three decades. The period of growth began from 1990 to 1995, during which capture fisheries production increased significantly from approximately 65 thousand tons in 1990 to a peak of about 103 thousand tons in 1995. Subsequently, a gradual decline occurred from 1996 to 2005. A period of sharp decline, accompanied by low production stability, has been observed from 2006 to the present. In 2023, production was recorded below 20 thousand tons. Overall, capture fisheries production shows a long-term decline, presumed to be a consequence of tidal flood impacts.



Source: Author's work, 2025

Figure 4. Capture Fisheries Production of Pekalongan City

Flood events also damage port infrastructure, increasing repair and maintenance costs, particularly for roads and other critical facilities (Messner et al., 2013; Shen & Kim, 2020). Several infrastructures, such as drainage systems, breakwaters, revetments and embankments, often become dysfunctional when submerged. In response, PPN Pekalongan has constructed parapets around the dock and Fish Auction Site (TPI) to limit seawater intrusion, although these structures hinder loading and unloading, requiring fishers to use planks to move catch to the auction area. Beyond infrastructure disruption, fishers face broader climate-related risks that alter fishing patterns and reduce productivity. Intensifying sea storms threaten fishing operations and damage vessels and gear, generating economic losses for communities dependent on capture fisheries (Fiorella et al., 2021; Suh & Pomeroy, 2020; Townhill et al., 2019).

Climate change adaptation policies against tidal floods at PPN Pekalongan

The tidal flooding caused by climate change in the Pekalongan PPN area and around Pekalongan City requires cross-sector support and cooperation. For this reason, Pekalongan PPN management needs to establish cooperation with a number of stakeholders from the local government and private sector to create a flood-safe port area, as outlined in Table 3 below.

Table 3. Institutional hierarchy of climate change control in Indonesia

Hierarchy	Institution	Action
National	Central Government of the Republic of Indonesia through ministries and agencies such as the Ministry of Environment and Forestry (KLHK), the Ministry of Marine Affairs and Fisheries (KKP), and the National Disaster Management Agency (BNPB)	Optimizing budgets to prevent and address climate change impacts and formulate policies for preventing climate change disasters
Provincial	Provincial Government of Central Java	Adjusting climate disaster prevention policies and coordinating actions using an ecoregion-based approach
Regional	Government of Pekalongan City	Implementing climate change prevention measures in urban development plans
Port Authority	Pekalongan Fishery Port (PPN Pekalongan)	Implementing prevention actions within the port area

Source: Author's work, 2025

Evaluating climate adaptation policies for tidal flood management is essential to ensure that adopted measures remain effective, efficient and sustainable. This study assesses key dimensions of adaptation, including infrastructure, spatial planning, port operations, finance, investment, regulation and stakeholder roles (Table 4). These indicators are synthesised from previous studies, combined with regulatory documents pertinent to port operations, including those from the Permanent International Association of Navigation Congresses (PIANC) and the United Nations Development Programme (UNDP) and are aligned with the principles of the Sustainable Development Goals (SDGs).

Table 4. Implementation of climate change adaptation policies to tidal flooding at ports

Policy category	Indicator	Sub-indicator	Implementation
A. Infrastructure and Spatial Planning Policy	Strengthening Adaptive Infrastructure	Integration of flood-resilient port development policies	PPN Pekalongan applies building maintenance guidelines based on Minister of Public Works Regulation No. 24/PRT/M/2008. Port drainage is regulated under Pekalongan City Regulation No. 7 of 2021. Drainage operations are also carried out in

Policy category	Indicator	Sub-indicator	Implementation
			collaboration with the Pekalongan City Government through the construction of a weir system, which redirects port drainage southward using pumps operated by the tidal flood response team of BBWS.
		Flood risk-based zoning and spatial planning	Zoning regulations for the land area of PPN Pekalongan are outlined in the Pekalongan City Spatial Plan (RTRW), while zoning for the marine area is governed by the Coastal Zone and Small Islands Zoning Plan (RZWP3K) issued by the Central Java Provincial Government. Both the RTRW and RZWP3K incorporate disaster-mitigation considerations for flooding in Pekalongan City, including within the port area.
B. Operational and Risk Management Policy	Crisis Management and Operational Resilience System	Implementation of early warning systems and flood mitigation	An early warning system for flood disasters is implemented via a WhatsApp group initiated by the Central Java Maritime Station of BMKG, which issues alerts regarding potential flood risks. PPN Pekalongan also undertakes flood-mitigation measures by preparing evacuation routes and designated safe assembly points.
		Standard Operational Regulations for Post-Disaster Recovery	Post-disaster recovery operations remain situational, as no detailed regulations currently govern these procedures. Existing recovery measures include securing and safeguarding port facilities, installing pumps to reduce flood impacts, and conducting post-flood cleaning /normalisation.
C. Financial and Investment Policy	Adaptation Funding Support	Fiscal incentives for green infrastructure investment	No incentives are available for green-infrastructure investment, and existing funding is limited to post-flood repair costs.
		Integration of flood insurance policies for port infrastructure	Not available
D. Regulatory and Standardization Policy	Implementation of Climate Change Adaptation Standards	Regulations for flood-resilient port infrastructure construction	Design standards for fishery ports follow the Minister of Marine Affairs and Fisheries Regulation No. PER.08/MEN/2012 on Fishery Port Management, while structural and construction models are outlined in detailed port design documents.

Policy category	Indicator	Sub-indicator	Implementation
			However, these documents have not yet incorporated flood-risk considerations.
		Alignment of climate adaptation policy with national maritime policy	Coordination between PPN Pekalongan and relevant stakeholders—particularly the local government—runs effectively, with annual meetings facilitated by the Pekalongan City Development Planning Agency (Bappeda).
E. Stakeholder Engagement Policy	Multi-Stakeholder Collaboration and Participation	Consultation and coordination mechanisms among government, ports, and coastal communities	Outcomes from these coordination and evaluation processes involving local government, PPN Pekalongan, and coastal communities are translated into action plans that guide policy implementation. One implemented action is the construction of parapets around the port's dock area to prevent tidal flooding from entering the port.
F. International Cooperation Policy	Global Collaboration for Climate Change Adaptation	Participation in international forums and initiatives related to port adaptation	Not available

Source: Author's work, 2025

Climate-related pressures at PPN Pekalongan demonstrate how tidal flooding has evolved from an environmental disturbance into a governance challenge shaped by institutional fragmentation and uneven capacity. Although the port collaborates with agencies such as the Central Java Maritime BMKG for early warning and the Pekalongan City Government for flood response, these arrangements remain largely operational rather than strategic. Measures such as pump installation and post-flood clean-up address immediate disruptions but do not alter the structural drivers of vulnerability, including land subsidence, inadequate spatial control and limited fiscal autonomy. This pattern reflects a wider tendency in Indonesian coastal governance to rely on ad hoc, multi-agency cooperation without a clear institutional lead, resulting in dispersed responsibilities and inconsistent implementation.

The evaluation of adaptation indicators shows that only half of the assessed sub-indicators are being met, with the strongest performance in infrastructure and spatial planning. The prominence of engineering-based interventions such as parapets and drainage adjustments reveals a 'protection-first' paradigm that prioritises visible physical works over governance reforms. This imbalance is rooted in the regulatory hierarchy governing PPN Pekalongan. As a Technical Implementation Unit under the Ministry of Marine Affairs and Fisheries, the port lacks the authority to independently mobilise adaptation finance or introduce innovative risk-management instruments. Instead, it depends on the Ministry of Public Works and Housing and municipal agencies for disaster-related infrastructure. Such institutional fragmentation limits the port's ability to pursue integrated, long-term adaptation strategies.

The weakest performance is observed in the financial and investment indicators, where no fiscal incentives or climate-risk insurance schemes exist. This absence reflects structural fiscal constraints rather than managerial shortcomings. Indonesia's port governance framework

centralises financial authority at the ministerial level, leaving local ports with limited discretion to develop green-financing mechanisms or insurance mandates. As a result, adaptation funding remains reactive, directed primarily towards post-disaster repairs rather than anticipatory risk reduction. This reliance on emergency expenditure reinforces a cycle in which climate impacts are repeatedly absorbed by local communities and port operators, rather than redistributed through formal risk-transfer systems.

International engagement indicators also lag significantly. Although PPN Pekalongan indirectly benefits from the JICA-supported Integrated Fisheries Port and International Fish Markets programme, this collaboration is mediated through national ministries and does not translate into active participation in global adaptation networks. The absence of bottom-up engagement limits opportunities for institutional learning, benchmarking and the adoption of international best practices. This pattern reflects a broader regulatory lag in Indonesian coastal governance, where national design standards do not yet incorporate flood-risk criteria, despite accelerating land subsidence and sea-level rise. Consequently, construction regulations remain compliant with national norms but misaligned with local environmental realities. Without a shift towards a governance framework that integrates fiscal mechanisms, regulatory standards, and multi-level coordination, the long-term resilience of PPN Pekalongan, and similar ports across Indonesia, will remain uncertain under accelerating sea-level rise.

Source: Author's work, 2025

Figure 5. Development in the on-shore port area

Comparative perspective with other indonesian ports

The climate-related pressures affecting PPN Pekalongan form part of a wider pattern of systemic vulnerability across Indonesia's northern coastal ports, where land subsidence, sea-level rise and fragmented governance interact to reinforce risk. Comparable impacts are evident in neighbouring ports along the north coast of Java (Figure 6). Tanjung Emas Port in Semarang provides a particularly relevant comparison, as it has long relied on polder systems, sea walls and dikes as its primary defence. Yet extreme subsidence reaching 100–120 mm per year due to groundwater extraction and sediment compaction has rendered these structures increasingly ineffective. The major tidal-flood and dike-failure event of May 2022 illustrates how engineering-led adaptation

becomes unsustainable when subsidence is not addressed through integrated groundwater and spatial-planning governance.

A contrasting pathway is seen in Muara Angke, Jakarta, where state-led redevelopment port elevation, coastal reinforcement and integration with public housing has been supported by stronger fiscal capacity. However, both Pekalongan and Muara Angke share persistent weaknesses in international engagement and fiscal-insurance mechanisms. Neither possesses formal climate-risk insurance for small-scale fishers, reflecting a national gap in maritime financial protection and a continued reliance on ad hoc disaster relief.

The operational shift of Pekalongan-based vessels to Klidanglor Port in Batang further demonstrates how institutional fragmentation produces maladaptive outcomes. Vessels increasingly favour Batang for its accessibility during tidal floods, while Pekalongan experiences declining landings and reduced economic activity. This redistribution does not reflect reduced fishing effort but rather cumulative land loss, chronic flooding and governance inertia. These dynamics highlight the need for a Regional Port Resilience Framework that synchronises adaptation across provincial and municipal boundaries. Without such coordination, adaptation efforts remain piecemeal and fail to prevent the emergence of a genuinely resilient coastal port system.

Beyond Pekalongan, findings suggest that climate adaptation in secondary and intermediate fishing ports in Indonesia and across Southeast Asia is primarily constrained by fragmented structural governance, limited fiscal capacity and regulatory hierarchies. This case reflects a broader regional pattern where institutional coordination is as important as physical infrastructure for resilience.

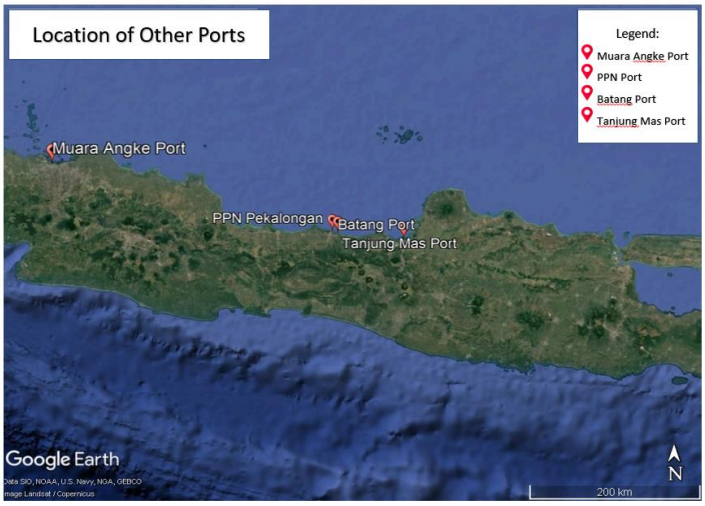


Figure 6. Location of Ports

List of policy recommendations

a) The management of PPN Pekalongan, under the Ministry of Marine Affairs and Fisheries, must formulate standardised guidelines for addressing climate-induced disasters in port environments. These guidelines should draw on the best international practices and align with frameworks developed by organisations such as the Permanent International Association of

Navigation Congresses (PIANC) and the International Association of Ports and Harbours (IAPH). Establishing such a reference would enable coherent adaptation planning across Indonesia's fishery ports and enhance institutional readiness in the face of escalating climate risks.

b) To enhance adaptive governance, it is essential to strengthen collaborative management capacity with key stakeholders. This can be achieved by leveraging inclusive platforms, such as the monthly Focus Group Discussions (FGDs), which facilitate multi-actor dialogue and the integration of land-use and climate adaptation strategies into the port's spatial planning framework.
c) Creating an integrated, real-time tidal risk information system platform to support operational decision-making during climate change disasters. This platform requires collaboration between the BMKG (Meteorology, Climatology, and Geophysics Agency), the Regional Disaster Management Agency (BPBD) and hydrological sensors.

Conclusion

This study demonstrates that climate-induced tidal flooding intensified by land subsidence and rapid urbanisation has severely undermined the operational capacity of the Nusantara Fishery Port (PPN) Pekalongan. The decline in capture fisheries production, from 103,000 tonnes in 1995 to under 20,000 tonnes in 2023, reflects deep socio-economic repercussions for fishing households and the wider regional maritime economy. Using PIANC, UNDP and SDG-aligned indicators, the assessment reveals a pronounced governance deficit: only half of the ten adaptation sub-indicators are met. While technical and spatial measures have been adopted, financial mechanisms and international engagement remain notably weak. The absence of fiscal incentives and climate-risk insurance forces reliance on post-disaster expenditure rather than proactive risk-transfer strategies.

The findings highlight the need for a shift from fragmented engineering responses towards an integrated governance framework. Priority actions include standardised climate-disaster guidelines, real-time tidal-risk information systems and innovative financing instruments such as green bonds or insurance schemes. The planned JICA-supported on-shore port represents a strategic opportunity to restore fisheries productivity, yet its effectiveness will depend on coherent multi-level coordination.

The findings indicate that fishing ports in Indonesia and across Southeast Asia are likely characterized by structural governance fragmentation and fiscal limitations that constrain the effectiveness of climate adaptation efforts.

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