

Integration of Infrastructure Asset Management in Disaster Mitigation and Sustainable Development Strategies in Densely Populated Coastal Areas: A Literature Review

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Abstract

Densely populated coastal areas face serious threats due to sea level rise and land subsidence, which accelerate the deterioration of mitigation infrastructure. This study aims to formulate the integration of Infrastructure Asset Management (IAM) into sustainable disaster mitigation strategies using the Systematic Literature Review (SLR) method with the PRISMA protocol. From 345 initial documents, 20 leading articles were selected for in-depth analysis. The results of the study show that coastal resilience requires a transformation from reactive maintenance to proactive risk-based management. Key findings identify three pillars of integration: (1) the use of digital technologies (BIM, GIS, Digital Twin) for real-time monitoring; (2) innovation in corrosion-resistant materials and hybrid (green-gray) infrastructure approaches; and (3) the application of Life Cycle Cost Analysis (LCCA) for long-term budget efficiency. The study concludes that synchronizing data governance across agencies is crucial to the success of mitigation efforts. The practical implication emphasizes that adopting an adaptive IAM framework can minimize the risk of structural failure and ensure public safety amid global climate uncertainty.

Keywords: Infrastructure Asset Management, Coastal Mitigation, SLR, PRISMA,



Sustainability.

INTRODUCTION

As an archipelagic country, Indonesia faces more complex vulnerabilities than other coastal regions in the world due to a combination of sea level rise and massive land subsidence. A study conducted by Heriandy et al. (2022) shows that large coastal cities in Indonesia, such as Jakarta and Semarang, are experiencing a much faster rate of land subsidence than global sea level rise, resulting in the permanent expansion of tidal flooding. This condition places civil infrastructure under extreme environmental stress, where building foundations and urban drainage systems often lose their operational function long before reaching their planned lifespan. This geological pressure forces civil engineering practitioners to rethink infrastructure protection strategies that are not only structurally sound but also capable of adapting to dynamic land elevation changes.

The high concentration of population in Indonesia's coastal areas adds another layer of complexity to infrastructure risk management. Coastal areas are often centers of economic growth and densely populated settlements that are difficult to relocate, so that failure of a single critical infrastructure element can trigger massive socio-economic impacts. According to Marfai et al. (2008)), building density in high-risk zones such as North Semarang causes economic losses that continue to increase every year due to tidal flooding that damages property and disrupts residents' mobility. In the context of civil engineering, this density limits the space for new mitigation infrastructure development, making the most feasible strategy the optimization and protection of existing assets in densely populated areas. Therefore, a more precise management approach is needed to maintain infrastructure service functions without resorting to large-scale, unsustainable evictions.

In addition to the physical threat of sea level rise, civil engineering infrastructure in coastal areas faces the challenge of more progressive material degradation due to aggressive chemical environments. Exposure to marine aerosols and saltwater intrusion brings high concentrations of chloride ions that trigger penetration into concrete pores, ultimately causing reinforcement corrosion (Mujib et al., 2024). Chidiac & Mahmoodzadeh (2009) emphasize that this corrosion phenomenon is the main cause of the decline in the structural capacity of bridges and buildings in coastal areas before they reach their designated design life. Without a systematic monitoring system, this internal damage often goes undetected until a fatal failure occurs. This underscores the urgency of continuous preventive maintenance to ensure that mitigation infrastructure



retains sufficient structural integrity to withstand disaster loads that may occur at any time.

Faced with increasing threats, disaster management in civil engineering must transform from a reactive approach to a more proactive mitigation strategy. A reactive approach that focuses only on post-event recovery measures has proven to be inadequate due to the high social and economic costs resulting from the sudden failure of critical infrastructure. According to Haigh and Haigh & Sutton (2012), the built environment sector must adopt strategies that minimize the impact of disasters from the planning stage and long-term maintenance. By prioritizing integrated structural mitigation, the risk of damage can be minimized, so that the sustainability of urban functions in coastal areas is maintained even under the pressure of repetitive disasters. This proactive strategy requires a robust database of infrastructure conditions so that technical interventions can be carried out in a timely manner before damage reaches a critical stage.

The urgency of mitigation in coastal areas must be in line with the principles of sustainable development so as not to cause further environmental degradation for future generations. Civil infrastructure development in marine areas should no longer rely solely on rigid, massive concrete structures, but should begin to integrate more adaptive and ecosystem-friendly approaches. UNDRR (2015), through the Sendai Framework for Disaster Risk Reduction, emphasizes that sustainable infrastructure development is key to reducing global disaster risk while maintaining ecological balance. In the coastal context, this includes the use of materials with a low carbon footprint and designs that allow natural sediment circulation to be maintained. By adopting sustainable principles, mitigation infrastructure not only functions as a physical protector but also as an element that improves the quality of coastal environmental carrying capacity in the long term.

Amid demands for resilient and sustainable infrastructure, infrastructure asset management has emerged as a strategic instrument that provides a systematic framework for managing physical structures throughout their life cycle. According to Too (2010), asset management is not merely an inventory process, but rather a multidisciplinary approach that aims to optimize asset performance and service life at the most efficient cost. In the context of coastal disaster mitigation, asset management enables managers to gain a deep understanding of the value, current condition, and risk level of each element of coastal protection structures and their supporting infrastructure. With structured asset data, technical decision-making is no longer based on estimates, but on empirical evidence that allows intervention priorities to be carried out at the points that are most crucial to public safety.

Digital transformation in asset management has opened up new opportunities for



improving the accuracy of disaster mitigation through the use of Building Information Modeling (BIM) technology and condition monitoring sensors. According to Love & Matthews (2019), the integration of digital technology into asset management enables the creation of a “digital twin” that can simulate the response of infrastructure to environmental loads dynamically. In coastal areas, the use of wireless sensors integrated with geographic information systems (GIS) can provide real-time data on structural degradation or imperceptible ground movement. The ability to digitally predict infrastructure weaknesses before physical failure occurs is a major leap forward in civil engineering, enabling preventive measures to be taken with a much higher degree of precision than conventional visual inspection methods.

Although digital technology offers great potential, the effectiveness of disaster mitigation in many developing countries, including Indonesia, is often hampered by data fragmentation and unintegrated asset management. There is often an information gap between agencies that manage disaster data and those responsible for the physical maintenance of infrastructure. Aritonang (2021) notes that the lack of integration of asset data between government agencies can lead to delays in identifying critical points that require immediate repair, thereby increasing the risk of losses when disasters occur. In densely populated coastal areas, inaccurate asset data is not only an administrative problem, but also a direct threat to public safety because mitigation decisions become misguided. Therefore, an integration framework is needed that can bring together various data sources into a coherent asset management system.

In addition to safety aspects, the integration of asset management into mitigation strategies is also based on the urgency of financial efficiency in infrastructure development. Economically, the costs incurred for preventive maintenance and asset strengthening are much lower than the total reconstruction costs resulting from post-disaster structural failure. A report from the World Bank (2019) reveals that investment in resilient and well-planned infrastructure can provide significant net economic benefits through reduced future damage costs. In coastal areas with a high risk of damage, asset management helps optimize the allocation of limited budgets so that they are targeted at infrastructure components that provide maximum protection for the community. Thus, the application of asset management is not only seen as an operational cost burden, but as a strategic investment to ensure fiscal sustainability and regional economic resilience.

Although studies on infrastructure asset management and disaster mitigation strategies have developed separately in civil engineering literature, there is still a significant gap in efforts to comprehensively integrate the two, especially for coastal areas with high population density. Most



previous studies tend to focus on individual structural resilience without considering the broader asset ecosystem within a long-term sustainability framework. According to Ayyub (2014), the integration of multi-hazard risk management and asset life cycle is still often overlooked in urban infrastructure planning. In Indonesia, the lack of literature specifically discussing asset management integration models as a basis for mitigation in coastal areas experiencing land subsidence is an obstacle to formulating adaptive policies. Therefore, there is an urgent need to synthesize various approaches from global literature to develop a new framework relevant to the unique characteristics of densely populated coastal areas.

Given the complexity of the issues described above, this study aims to conduct a comprehensive literature review to formulate a framework for infrastructure asset management integration as a sustainable disaster mitigation strategy in coastal areas. Given the rapid development of digital technology and the dynamics of climate change, a synthesis of various recent studies is crucial to identify best practices that can be adapted in the context of densely populated coastal areas in Indonesia. This study is expected to not only contribute theoretically to the literature on civil engineering and disaster management, but also serve as a practical reference for policymakers in planning infrastructure investments that are more resilient, efficient, and in line with the principles of sustainable development. Thus, this article serves as an effort to bridge the gap between asset management theory and mitigation implementation in the field to ensure the sustainability of coastal infrastructure for future generations.

METHODOLOGY

This study was conducted by applying the Systematic Literature Review (SLR) method to comprehensively map the framework for asset management integration in coastal disaster mitigation. The literature review procedure was carried out by adopting the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, which ensures that the article collection and selection process is transparent, systematic, and replicable. The initial stage of the research began with the Identification phase, in which a search of digital bibliographic databases such as Scopus, ScienceDirect, and Google Scholar yielded a total of 345 documents through specific keyword queries. From this number, an initial validation was carried out, resulting in 312 articles that were successfully identified for further review, while several other documents were excluded because they were duplicates or did not conform to the scientific document format.

Entering the Screening stage, the 312 articles were screened based on the relevance of



their titles and abstracts to the focus on civil engineering and asset management in coastal areas. In this phase, strict filtering was carried out to separate studies that were general in nature from those that had technical applications in physical coastal infrastructure such as embankments, bridges, and urban drainage systems. This screening process resulted in the exclusion of 258 articles that were deemed to not meet the criteria for technical depth or focus on disaster mitigation in densely populated areas. In the final stage, Eligibility, 54 articles remained to undergo a full-text review. Based on an evaluation of the methodology and novelty of the data presented, 20 outstanding articles were selected to enter the final article review stage. Data from these 20 articles was then extracted in depth to synthesize adaptive infrastructure asset management strategies for land subsidence and sea level rise phenomena, in order to support sustainable coastal development. Figure 1 explains how this research was conducted.

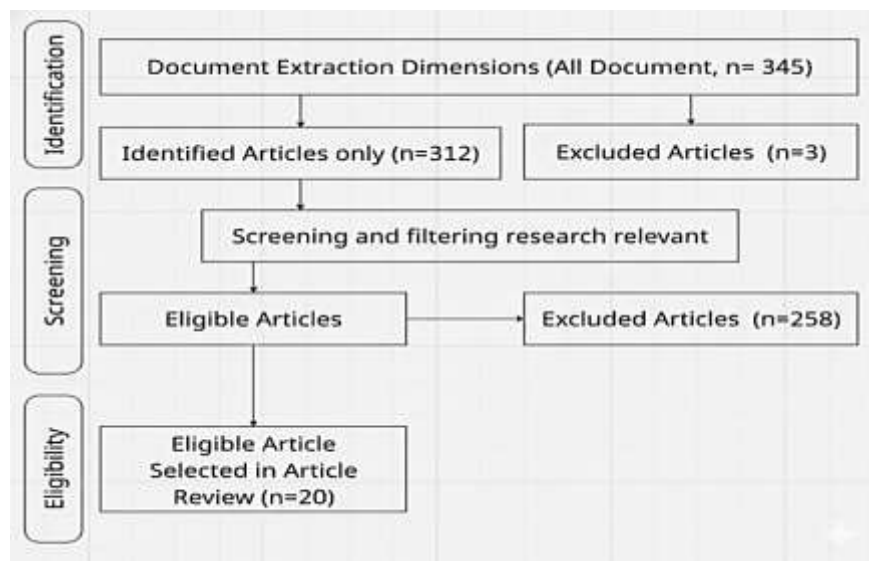


Figure 1. PRISMA Diagram Workflow

RESULT AND DISCUSSION

Characteristics and Trends in Coastal Asset Management Literature

Research trends in the first cluster show that studies on coastal asset management are concentrated in areas with high geological vulnerability. Heriandy et al. (2022) and Marfai et al. (2008) specifically highlight Indonesia as a critical location due to the rate of land subsidence on the north coast of Java, which far exceeds the global average. Meanwhile, Takagi et al. (2016) compare adaptation approaches in Southeast Asian regions facing similar flood risks, and Nurse

734

et al. (2014) explore how island nations are beginning to adopt international asset management standards to protect their vital infrastructure. These four studies confirm that geographical location and physical characteristics of a region greatly determine the complexity of mitigation strategies that must be taken.

Regarding the types of assets managed, the literature focuses heavily on hard protection infrastructure as the front line. Linham & Nicholls (2010) review the long-term effectiveness of seawalls, while Burcharth et al. (2014) emphasize the importance of life cycle management in wave breakers in deep marine environments. On the other hand, Arnell and Gosling (2016) expand the discussion to underground assets such as urban drainage systems, which are crucial for preventing tidal flooding, and Chidiac & Mahmoodzadeh (2009) highlight coastal bridges as transportation assets that are most vulnerable to material degradation due to chloride exposure. Collectively, this literature concludes that diversifying the types of assets monitored is key to regional resilience.

The dynamic aspects of disaster risk are a major concern due to the uncertainty of climate change. Oppenheimer et al. (2019) and Hinkel et al. (2014) argue that conventional asset management is no longer adequate without the integration of accurate sea level rise projections. Ayyub (2014) introduced a mathematical model to predict the remaining service life of assets under extreme environmental stress, while Sayers (2015) discussed how climate uncertainty variables should be incorporated into the calculation of coastal protection infrastructure maintenance costs. These four studies demonstrate a strong transition from historical management approaches to predictive approaches based on future modeling.

Social complexity and space limitations in densely populated areas pose significant technical obstacles to asset management. Hallegatte et al. (2013) and Neumann et al. (2015) highlight the difficulty of expanding infrastructure in areas that are already densely populated, requiring the optimization of existing assets through retrofitting technology. Abhas et al. (2012) review the conflict of interest between residential settlements and the need for land for mitigation infrastructure, while Haigh & Sutton (2012) offer asset management solutions that involve community participation to improve the resilience of built-up areas. This literature emphasizes that in densely populated areas, civil engineering decisions must always be in synergy with social realities and land availability.

The concluding section reviews the shift in values in the assessment of construction asset conditions. Too (2010) and Love & Matthews (2019) promote asset condition assessments that look not only at physical damage, but also at long-term service value and digital efficiency. The



United Nations (2015), through the Sendai Framework, introduced the importance of sustainable infrastructure development that is resilient to disasters, and Aritonang (2021) formulated a risk-based decision-making framework that is able to balance government budget efficiency with public safety. Through this literature, it is clear that the future of coastal asset management lies in the balance between structural strength and environmental sustainability.

Digital Technology Integration in Asset Monitoring

The application of Building Information Modeling (BIM) and Digital Twin technologies has revolutionized the way infrastructure managers visualize the condition of assets in dynamic coastal areas. Love & Matthews (2019) explain that integrating BIM into asset management enables the creation of digital models that store historical maintenance data in a structured manner. Furthermore, The use of Digital Twin enables the simulation of disaster scenarios, such as sea level rise, on structural integrity virtually before physical failure occurs. This technology is supported by the findings of Davila Delgado et al. (2020), who state that asset digitization reduces uncertainty in estimating remaining service life, while Love & Matthews (2019) the importance of BIM data synchronization for complex city-scale infrastructure asset management.

To address aggressive material degradation in marine environments, the use of wireless sensors and the Internet of Things (IoT) provides a solution for real-time asset condition monitoring. Meyssignac (2017) demonstrated that integrating sensors into coastal protection structures provides continuous, precise data on the hydrodynamic loads experienced by assets. Meanwhile, Mishra et al. (2020) reviewed the use of electrochemical sensors to detect chloride penetration and corrosion in reinforced concrete at an early stage, which often goes undetected by conventional visual inspections. Analysis from Scuro (2021) reinforces the argument that IoT-based Structural Health Monitoring (SHM) systems can trigger automatic alerts when structural deformation is detected this sensor data is crucial for calibrating long-term damage prediction models in coastal areas.

The integration of Geographic Information Systems (GIS) in asset management facilitates decision-making through spatial visualization of the distribution of critical assets (I N Muhammad et al., 2025b, 2025a; Muhammad et al., 2024). Heriandy et al. (2022) demonstrate how the use of GIS combined with InSAR satellite data can map the interaction between land subsidence and the stability of coastal protection infrastructure on a regional scale. Kuller et al. (2017) argue that GIS-based decision support tools facilitate the identification of maintenance priorities at points with the highest risk of failure to public safety. Furthermore, Marfai (2003) highlight the role of GIS in



integrating physical asset data with social vulnerability variables in coastal settlements, and Ikhlas Nur Muhammad et al. (2025) conclude that GIS-based asset management platforms enable more effective inter-agency data collaboration for comprehensive disaster mitigation.

Material Resilience and Infrastructure Sustainability

The durability of coastal infrastructure is highly dependent on its ability to withstand chemical attacks from the aggressive marine environment. Chidiac & Mahmoodzadeh (2009) explain that the penetration of chloride ions into the pores of concrete is the main cause of corrosion of reinforcing steel, which drastically reduces the structural capacity of coastal buildings. This deterioration is exacerbated by the wet-dry cycle caused by tidal fluctuations, which accelerates the rate of concrete carbonation Burcharth et al. (2014). In addition, a study by Meyssignac (2017) shows that the hydrodynamic load from extreme waves exerts additional mechanical stress that accelerates hairline cracks in structures, thereby providing a pathway for corrosive substances to penetrate deeper into the core of the structure. Therefore, a thorough understanding of the kinetics of material degradation is fundamental to determining the appropriate asset management strategy.

Faced with these degradation challenges, recent literature has begun to shift toward the use of materials that are both more durable and environmentally friendly. Wang (2019) proposed the use of concrete with cement substitution materials, such as fly ash or slag, which not only reduce the carbon footprint but also increase the porosity of concrete against chloride intrusion. The use of stainless steel or fiber-reinforced polymer (FRP) reinforcement is also discussed by Davila Delgado et al. (2020) as an effective solution for critical infrastructure that requires a long service life in marine environments. Additionally, Haigh & Sutton (2012) emphasize that material selection must align with sustainability principles, where the chosen materials should have low life-cycle costs and minimal environmental impact throughout their operational lifespan.

The sustainability of coastal mitigation infrastructure no longer relies solely on massive concrete structures, but has begun to adopt an integrated approach between civil engineering and natural ecosystems. UNDRR (2015), through the Sendai Framework, encourages the development of adaptive infrastructure, which is embodied in the concept of “green-gray” or hybrid infrastructure. For example, the integration of concrete sea walls with mangrove green belts has proven effective in reducing wave energy and protecting concrete structures from direct abrasion (Sayers, 2015). Artonang (2021) concludes that this hybrid approach significantly increases the resilience of coastal areas because it provides double protection: physical protection



from technical structures and ecological protection from nature. This synergy ensures that coastal asset management contributes to disaster mitigation and long-term environmental conservation.

Decision-Making Strategy and Risk Management

Decision-making in coastal asset management must be based on long-term economic considerations to ensure fiscal sustainability. World Bank (2019) emphasizes that investing in preventive maintenance and infrastructure reinforcement is far more efficient than the total reconstruction costs resulting from post-disaster structural failure. This is supported by the Life Cycle Cost Analysis (LCCA) approach promoted by Too (2010), in which each technical intervention is calculated based on the total cost of asset ownership over its service life, not just the initial construction cost. By implementing a risk-based maintenance strategy, managers can optimize limited budget allocations to extend the life of critical infrastructure plans in coastal areas that are vulnerable to extreme environmental loads.

In coastal areas with high population density, determining the priority scale of interventions is crucial to minimizing social and economic impacts. Ayyub (2014) proposes a multi-hazard risk management model that enables the identification of “frontline” assets that have the highest strategic value for protecting citizens. The integration of technical data with social vulnerability parameters is essential so that asset repair priorities are not only based on the level of physical damage, but also on the potential number of people protected. This approach ensures that the structural mitigation measures taken can provide maximum security for coastal communities living in areas at high risk of land subsidence.

The success of asset management as a disaster mitigation strategy is highly dependent on the coordination of data governance between relevant agencies. Aritonang (2021) notes that data fragmentation between infrastructure management agencies and disaster management agencies in Indonesia often hinders the effectiveness of technical responses in the field. Therefore, a policy framework is needed that requires the synchronization of digital information system-based asset databases to support coherent decision-making (UNDRR, 2015). The conclusion of this discussion emphasizes that asset management integration is not merely a matter of civil engineering, but rather a strategic governance instrument that connects real-time data, material innovation, and public policy to achieve sustainable coastal resilience.

CONCLUSION

This study concludes that the answer to disaster mitigation challenges in coastal areas can



no longer rely solely on physical infrastructure development, but rather on systematic asset management transformation. Through a comprehensive synthesis of selected literature, it was found that integrated infrastructure asset management is a determining variable that links the technical resilience of civil engineering with the sustainability of public services. This finding confirms that the failure of coastal infrastructure in densely populated areas is often caused by the absence of up-to-date asset condition data and neglect of long-term material degradation, thus requiring a paradigm shift from reactive maintenance to proactive management based on risk analysis and the entire asset life cycle.

Based on the results of SLR analysis, the effectiveness of disaster mitigation is highly dependent on the implementation of digital technologies such as BIM, GIS, and real-time sensors that can transform raw data into precise decision-making information. The integration of this technology, when combined with sustainable material innovations and a hybrid (green-gray) infrastructure approach, has been proven to significantly increase the planned lifespan of assets while reducing long-term maintenance costs through the principle of fiscal efficiency. This study provides strong literature evidence that coastal resilience can only be achieved if infrastructure managers are able to synergize technical material aspects with managerial strategies that are adaptive to the dynamics of sea level rise and land subsidence.

In conclusion, this study formulates an integrated asset management framework as a strategic instrument for policy-making in Indonesia. The conclusions of this systematic review indicate that the synchronization of data governance and the standardization of maintenance procedures are crucial steps to overcome the fragmentation of authority that has hitherto hampered disaster mitigation in the field. By adopting the asset management principles extracted from global literature, it is hoped that infrastructure development in densely populated coastal areas will not only be oriented towards short-term structural resilience, but also towards economic sustainability and public safety that is resilient to future climate uncertainty.

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