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A literature review of ecosystem-based strategies to reduce public building vulnerability to earthquakes: A case study of Tarakan City

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Abstract: Tarakan City, an archipelagic region in Indonesia, exhibits a high level of vulnerability to earthquake disasters, particularly regarding public infrastructure that has not been fully designed using seismic resilience approaches. Public buildings such as schools, hospitals, and government offices play a vital role in supporting social functions and basic services, making their earthquake resilience highly crucial. This study aims to identify and analyze ecosystem-based strategies that can be employed to reduce the vulnerability of public buildings to earthquakes. Through a systematic literature review method, this research examines various approaches involving technical, social, institutional, and environmental aspects in building infrastructure resilience. The results indicate that the integration of earthquake-resistant building design, community participation, risk-based spatial planning policies, early warning systems, and institutional capacity building forms an effective and sustainable resilience ecosystem. The contextual analysis of Tarakan City suggests the need for synergy between local government, the community, and the technical sector to strengthen the adaptive capacity of public infrastructure, particularly within the context of archipelagic regions facing logistical and resource constraints. This study provides a conceptual framework that can serve as a basis for developing resilient ecosystem-based mitigation policies for earthquake-prone areas.

Keywords: ecosystem; earthquake; infrastructure; resilience

1. Introduction

Indonesia is geologically situated at the convergence of several major tectonic plates, making it a country with an exceptionally high level of seismic activity and extreme vulnerability to earthquake disasters. This high exposure to seismic hazards poses a significant threat to the nation's built environment. The impact of earthquakes on public infrastructure including schools, hospitals, and government offices is particularly devastating, as these facilities are the backbone of community resilience (Sneddon, 2022). Damage to these structures does more than just cause physical loss; it disrupts essential basic services, hinders emergency response, and significantly slows down the post-disaster recovery process. Consequently, enhancing the resilience of public buildings has become a critical priority within national and regional disaster risk mitigation strategies (Knight, 2024).

Tarakan City, an archipelagic territory located in North Kalimantan, serves as a unique and critical case study in this context. As an island city, Tarakan faces distinct geographical and logistical challenges that complicate the development of earthquake resilient infrastructure (Prihartanto et al., 2024). These challenges include restricted logistical access for heavy equipment and specialized construction materials, as well as limitations in local technical capacity for advanced seismic engineering.

Furthermore, the city's geological profile characterized by alluvial soil and coastal areas increases the risk of secondary seismic effects such as liquefaction and erosion, which can lead to severe structural failure in public buildings (Atmaja et al., 2024; Mayor of Tarakan, 2021).

Historically, disaster mitigation has relied on conventional approaches that focus almost exclusively on the technical and structural aspects of individual buildings. However, such "hard" engineering solutions are often insufficient to address the multifaceted risks found in complex archipelagic environments like Tarakan (Haryanto et al., 2021). Technical fixes alone do not account for the social dynamics, institutional barriers, or environmental conditions that influence how a city survives and recovers from a disaster (Badan Nasional Penanggulangan Bencana, 2023). To address these gaps, an ecosystem-based approach offers a more integrated approach. This perspective views public infrastructure not as isolated structures, but as part of a larger, multi-dimensional system that integrates technical, social, institutional, and environmental dimensions.

An ecosystem-based strategy emphasizes the necessity of multi-stakeholder collaboration, involving synergy between local governments, the community, the private sector, and technical institutions to build adaptive and sustainable infrastructure systems (Paudel, Dhakal, et al., 2024). In this study, ecosystem-based strategies are framed within the Eco-DRR approach and operationalized through nature-based solutions (NbS) as practical implementation mechanisms. By incorporating elements such as nature-based solutions (e.g., mangrove restoration to stabilize coastal land), risk-based spatial planning, and community-driven maintenance of green infrastructure, this approach provides a low-cost and locally relevant alternative to traditional methods (Haryanto et al., 2021; Paudel, Parajuli, et al., 2024).

This systematic literature review aims to identify and analyze ecosystem-based strategies that are both relevant and effective in reducing the vulnerability of public buildings to earthquakes. Unlike previous studies that primarily emphasize technical or structural approaches, this research highlights the novelty of integrating ecosystem-based dimensions within the unique context of an archipelagic city. By focusing on Tarakan City, which faces distinct logistical and geophysical challenges, the study advances existing knowledge by offering a conceptual framework that not only enriches the theoretical discourse on Eco-DRR but also provides practical guidance for local governments in developing resilient, resource-sensitive mitigation policies.

2. Material and methods

This research employs a Systematic Literature Review (SLR) method to identify and analyze ecosystem-based strategies for reducing the seismic vulnerability of public buildings in archipelagic regions, specifically Tarakan City. The study follows a qualitative descriptive-analytical approach to gain a comprehensive understanding of disaster risk mitigation concepts, practices, and policies.

2.1 Research design and approach

This study is designed as a systematic literature review (SLR) aimed at identifying and analyzing ecosystem-based strategies to reduce the vulnerability of public buildings to earthquake disasters, with a specific focus on archipelagic regions such as Tarakan City. To achieve a comprehensive understanding, the research employs a descriptive-analytical approach within a qualitative framework. This method prioritizes an in-depth exploration of existing concepts, practical applications, and disaster risk mitigation policies that have been implemented or proposed globally and nationally. By utilizing a systematic review, the study ensures that the synthesis of information is grounded in a broad spectrum of verified academic and institutional knowledge, allowing for the development of a strategy that is not only theoretical but also contextualized for the unique geographical challenges of an island environment. The selection process involved identification (n = 50), screening, and final inclusion (n = 12), as illustrated in Figure 1.

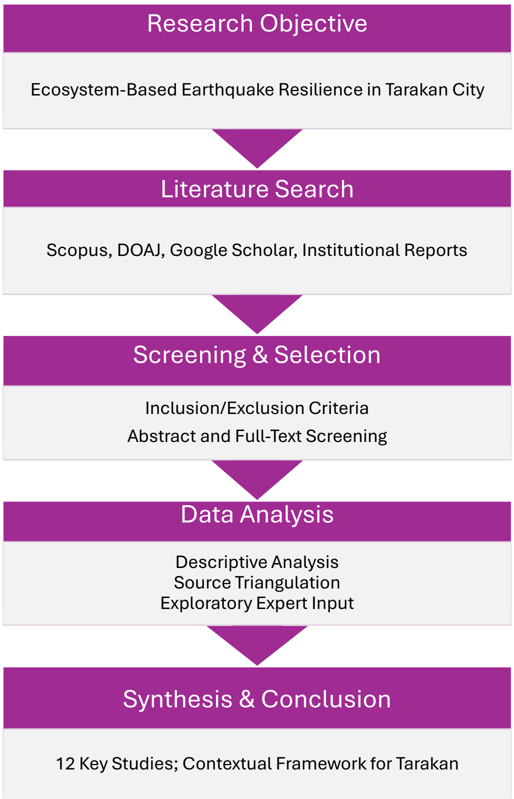

Figure 1. Research flow diagram of the systematic literature review (SLR) process

Figure 1 illustrates the overall workflow of the systematic literature review, including identification, screening, analysis, and synthesis stages, providing a clear and transparent overview of the research process.

2.2 Data collection and selection criteria

The data was meticulously gathered from six distinct categories of sources to ensure a robust theoretical and empirical foundation:

1. Scientific Journals: High-impact articles from Scopus, DOAJ, and Google Scholar were used to establish the theoretical framework for Ecosystem-based Disaster Risk Reduction (Eco-DRR) and infrastructure resilience.
2. Official Institutional Reports: Data regarding seismic risks, mitigation policies, and seismic maps were sourced from agencies such as BNPB, PUPR, UNDRR, and PVMBG.
3. Local Planning Documents: To ensure local relevance, the research analyzed Tarakan City's Spatial Plan (RTRW/RDTR) and the Infrastructure Masterplan.
4. Earthquake Case Studies: Empirical comparisons were drawn from previous seismic events in Palu, Lombok, and Ambon.
5. Technical Guidelines: Design standards and policy references were based on SNI 1726:2019 and international Eco-DRR guidelines from UNDRR/IUCN.
6. Thematic Literature: Comprehensive books and specialized articles on Nature-based Solutions (NbS) were reviewed to strengthen the conceptual ecosystem approach.

The literature search was conducted using databases such as Scopus, Google Scholar, and DOAJ, employing keywords including *"ecosystem-based disaster risk reduction," "nature-based solutions," "earthquake resilience,"* and *"public infrastructure."* The search was limited to publications from 2015 to 2025 to ensure relevance and recency. To achieve the research objectives previously outlined, a systematic procedure was applied to collect and filter relevant literature. The success of the synthesis in this study depends heavily on the quality and precision of the data sources utilized. Consequently, this study applies a rigorous set of selection criteria to ensure that all analyzed literature possesses high scientific credibility and contextual relevance to the characteristics of an archipelagic region. These criteria are designed to filter for the most up-to-date and applicable information, as detailed in the following subsection.

2.3 Literature selection criteria

To maintain the quality and validity of the synthesis, all gathered literature underwent a rigorous screening process based on specific inclusion and exclusion criteria:

1. Thematic Relevance: Focus must be on public infrastructure resilience against earthquakes.
2. Approach: Must incorporate ecosystemic or systemic dimensions.
3. Geographical Context: Priority is given to studies focusing on earthquake-prone archipelagic or coastal regions.
4. Recency: Sources must be published within the last 10 years, with a priority on the last 4 years to ensure contemporary relevance.

The selection process followed a PRISMA-inspired flow to ensure transparency in identifying, screening, and selecting relevant studies, resulting in the inclusion of 12 key articles from an initial pool of 50 sources, as illustrated in Figure 1. To ensure the analytical depth and validity of the findings, this research gathered data from various authoritative sources spanning international, national, and local scales. The integration of global scientific literature with technical policy documents specific to Tarakan City is crucial for producing a synthesis that is not only theoretically robust but also practically applicable. A total of 50 sources were initially identified and categorized as shown in Table 1. Following a screening and relevance assessment process, a subset of key studies was selected for in-depth synthesis, as presented in Table 2.

Table 1. Research data sources

Source category	Examples	Function in Study	Number of sources
Scientific Journals	Scopus, DOAJ, Google Scholar articles	Theoretical foundation of Eco-DRR and resilience	18
Institutional Reports	BNPB, PUPR, UNDRR	Risk data and policy framework	10
Local Documents	RTRW, RDTR Tarakan	Contextual planning data	6
Case Studies	Palu, Lombok, Ambon	Empirical comparison	5
Technical Guidelines	SNI 1726:2019, Eco-DRR guidelines	Design standards	4
Thematic Literature	NbS books/articles	Conceptual support	7
Total identified sources			**50**

Beyond ensuring the accuracy of source selection, another crucial aspect of the literature review methodology is guaranteeing that the synthesis of findings remains objective and free from researcher bias. To achieve a high level of reliability, this study implements a rigorous quality control procedure through cross-source verification and expert feedback. The systematic steps taken to strengthen the validity and reliability of this study are detailed in the following Validation and Triangulation section.

2.4 Validation and triangulation

To enhance the validity and reliability of the research results, source triangulation and external validation processes were conducted as follows:

2.4.1 Source triangulation

Source triangulation was implemented by cross-checking data and findings obtained from various types of authoritative literature and documents. This process involved four pillars of data sources:

1. Scientific Literature: Articles from reputable international and accredited national journals were used to explore the theoretical foundation of Ecosystem-based Disaster Risk Reduction (Eco-DRR) and the latest innovations in infrastructure resilience management.
2. Institutional Reports and Data: Documents from technical and disaster management agencies such as BNPB, UNDRR, PUPR, and PVMBG provided factual data on seismic risk maps, technical standards for earthquake-resistant buildings, and legally recognized mitigation frameworks.
3. Local Policy Documents: An analysis of Tarakan City's spatial plans (RTRW and RDTR) was conducted to align the recommended strategies with regional development plans and local land-use characteristics.
4. Empirical Case Studies: Evaluation of the impact and recovery processes of earthquakes in other archipelagic regions, such as Palu, Lombok, and Ambon, served as benchmarks to identify successful mitigation strategies in similar geographical environments.

This cross-source analysis aimed to identify points of convergence across different perspectives, thereby strengthening the generalization of findings and avoiding reliance on the bias of a single type of document.

2.4.2 External validation and expert consultation

External validation was a complementary stage intended to enhance the contextual relevance and practical applicability of the synthesized strategy framework. The resulting strategies were discussed through informal consultations with relevant experts and practitioners.

1. Academic Experts and Technical Institutions: Consultations focused on assessing the depth of technical analysis regarding the structural resilience of public buildings and the integration of ecosystem aspects into supporting infrastructure design.
2. Local Government Planning Practitioners: Discussions with urban planners in Tarakan City aimed to verify whether the proposed strategies align with budget capacity, island logistics availability, and the community's urgent needs.

These consultations were exploratory in nature and aimed to provide contextual insights rather than serve as formal validation. Feedback, criticisms, and suggestions from these discussions were considered to refine the analysis and strengthen policy recommendations, ensuring that this study provides a relevant contribution to the development of ecosystem-based mitigation policies in seismic-prone areas.

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3. Results and discussion

To enhance transparency and facilitate comparison, Table 2 summarizes the reviewed studies, including their methods, locations, main findings, and limitations. This overview highlights the diversity of approaches and evidence that informs the ecosystem-based strategies proposed in this study.

Table 2. Synthesized studies on ecosystem-based strategies for infrastructure resilience

Author (Year)	Method	Focus	Contribution to Study	Relevance
Prihartanto et al. (2024)	Case Study	Tarakan infrastructure	Identifies logistical and ecological constraints	High
Yudanagara et al. (2025)	Qualitative	Community resilience	Highlights role of participation in DRR	High
Khalqillah et al. (2025)	Technical	Seismic hazard	Provides hazard baseline for Indonesia	High
Sudmeier-Rieux et al. (2021)	Review	Eco-DRR	Strong global evidence for NbS	High
Ahmad & Hassan (2025)	Review	NbS urban resilience	Links ecosystem services with resilience	High
Rezvani et al. (2023)	SLR	Urban resilience	Integrates GIS & DRR systems	High
Akram et al. (2023)	Review	Mangrove ecosystem	Explains ecological protection functions	High
Benazir et al. (2024)	Review	Vegetation mitigation	Supports vegetation-based DRR	High
Rumondang et al. (2024)	Case Study	Mangrove management	Shows socio-ecological resilience model	High
Winterwerp et al. (2020)	Engineering study	Coastal protection	Demonstrates ecosystem engineering effectiveness	High
Narendra et al. (2021)	Review	Watershed resilience	Supports environmental stability concept	Medium
Kusuma et al. (2026)	Modeling	Flood & mangrove	Quantifies ecosystem contribution	High

The studies summarized in Table 2 indicate consistent evidence on the effectiveness of ecosystem-based approaches across different contexts, providing a concise overview of their methodologies, geographical contexts, main findings, and limitations. This summary enhances transparency and allows readers to compare the diverse approaches that inform ecosystem-based strategies for earthquake resilience. The table also reveals important gaps in the existing literature, such as the limited empirical evidence on long-term building performance in archipelagic regions and the underrepresentation of social dimensions in technical analyses. These gaps underscore the need for future research that integrates technical, social, institutional, and environmental perspectives more comprehensively, thereby strengthening the development of adaptive and context-specific mitigation frameworks for cities like Tarakan.

3.1 Identification of ecosystem-based strategies

The synthesis of the reviewed studies indicates that ecosystem-based strategies have significant potential to mitigate the vulnerability of public buildings to earthquakes, particularly in archipelagic regions such as Tarakan City. This approach represents a paradigm shift from traditional "hard engineering" toward a comprehensive framework known as Ecosystem-based Disaster Risk Reduction (Eco-DRR). In an archipelagic context, infrastructure resilience is not merely a product of structural strength but is deeply influenced by the stability of the surrounding natural and social environment.

Through thematic synthesis, this study identifies that effective seismic mitigation for public buildings requires the integration of diverse dimensions. The findings categorize these efforts into four primary strategies that address the specific geophysical and logistical challenges of Tarakan:

1. Natural Buffers: Utilizing coastal ecosystems and vegetation to stabilize land and mitigate secondary seismic effects (Sudmeier-Rieux et al., 2021).
2. Adaptive Land Management: Ensuring that public facilities are sited away from high-risk zones through rigorous spatial planning (Paudel, Parajuli, et al., 2024).
3. Social Integration: Leveraging local community participation to maintain protective infrastructure and enhance disaster preparedness (Yudanagara et al., 2025).
4. Technical Synergy: Merging technical building standards with environmental engineering, such as green drainage, to preserve soil integrity (Khalqillah et al., 2025).

These strategies demonstrate that an ecosystem approach, hereafter referred to as ecosystem-based strategies are both preventive and adaptive, offering a low-cost and sustainable alternative for resource-constrained island regions. These findings indicate that resilience is not solely determined by structural strength but by the interaction between ecological stability, institutional capacity, and social participation. These strategies are further operationalized into specific implementation measures, as detailed in Table 3.

Table 3. Identification of ecosystem-based mitigation strategies

No	Strategy	Dimension	Primary function
1	Mangrove Restoration and Coastal Vegetation	Environmental	Stabilizes soil, dampens wave energy, and reduces liquefaction risk.
2	Slope Stabilization Vegetation and Reforestation	Technical-Environmental	Prevents landslides and erosion in areas surrounding public buildings.
3	Risk-Based and Ecosystem-Oriented Spatial Planning	Institutional	Avoids construction in high-seismic zones and areas with unstable soil.
4	Community Participation in Green Infrastructure	Social	Increases public awareness and ensures the maintenance of ecosystem support systems.
5	Sustainable Urban Drainage Systems (SUDS) Integration	Technical-Environmental	Reduces waterlogging and reinforces the integrity of public building foundations.

The previously identified strategies provide a theoretical overview of the significant potential of ecosystem-based approaches in disaster mitigation. However, the effectiveness of these strategies depends heavily on the extent to which they are aligned with the unique characteristics of the region under study. As an archipelagic area with distinct geological and social dynamics, Tarakan City requires strategic refinement that considers local challenges and its inherent natural resource potential. The following section will provide an in-depth analysis of the contextual relevance of these ecosystem-based strategies specifically within the framework of Tarakan City.

3.2 Relevance in Tarakan City

Tarakan City, geographically an archipelagic region in North Kalimantan Province, presents a unique and challenging risk landscape for public infrastructure resilience. As a hub for economic activity and service provision in northern Kalimantan, the security of public buildings in Tarakan has strategic implications for regional stability. However, disaster risk reduction efforts in this region face complexities not found in the mainland. Tarakan's geographical, geological, and socio-cultural characteristics demand a shift from a purely structural mitigation paradigm toward a more integrative and ecosystem-based approach. This context reinforces the importance of Eco-DRR as a framework that integrates environmental and infrastructural resilience.

Geological conditions are the primary factor determining infrastructure vulnerability in this city. Tarakan is dominated by alluvial soil formations and coastal areas with a high water table. Such soil characteristics inherently possess high vulnerability to liquefaction and lateral spreading during seismic shocks. Public buildings with significant structural loads, such as hospitals and government offices, are often constructed on land that technically requires highly complex and expensive foundation engineering. Without the integration of environmental aspects in site selection and building design, these vital infrastructures are at risk of permanent structural failure that could paralyze public services post-earthquake.

In addition to geological constraints, Tarakan's status as an island region creates significant logistical challenges in the construction and maintenance process. Dependence on the distribution of construction materials from outside the island causes the cost of building earthquake-resistant infrastructure to be much higher than in mainland areas. Limited access to high-standard materials and heavy equipment in certain locations often forces compromises in construction quality. In this context, ecosystem-based strategies offer alternative solutions through the optimization of local resources and natural protection, which can reduce the workload on physical building structures, thereby minimizing dependence on high-cost technical interventions (Ahmad & Hassan, 2025; Rezvani et al., 2023).

Tarakan's ecological potential, particularly its extensive mangrove ecosystems, represents a mitigation asset that has not been optimally utilized. Technically, mangrove forests function as natural buffers against secondary earthquake impacts, such as coastal erosion or potential wave surges that damage the foundations of buildings on the coast (Akram et al., 2023; Benazir et al., 2024). The restoration and protection of mangrove areas around public infrastructure zones can serve as a "green belt" that protects overall land stability (Rumondang et al., 2024; Winterwerp et al., 2020). The existence of these ecosystems not only supports the physical resilience of buildings but also maintains the eco-hydrological balance crucial for infrastructure sustainability in archipelagic regions (Kusuma et al., 2026; Narendra et al., 2021). Lastly, social capital in the form of high community participation in environmental management in Tarakan is a vital pillar for the success of ecosystem-based mitigation. Local culture emphasizing community cooperation or "gotong royong" has great potential to be integrated into green infrastructure maintenance systems and independent risk monitoring. A mitigation strategy that combines technical strength with community participation ensures that the built resilience system is adaptive and sustainable. Thus, ecosystem-based strategies in Tarakan City are not merely optional additions but a strategic necessity that aligns infrastructure development with environmental carrying capacity and local social capacity in addressing future seismic threats.

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3.3 Thematic synthesis

The thematic analysis shows that the resilience of public buildings cannot be treated as isolated technical entities but must be understood as part of an interdependent ecosystem. This ecosystem-based approach aligns with Eco-DRR principles operationalized through NbS. Ecosystem-based strategies offer a more holistic and realistic framework for building infrastructure resilience to earthquakes, especially in archipelagic regions with unique characteristics like Tarakan City. The synthesis of various research findings leads to three main pillars of conclusions that reinforce the urgency of implementing an ecosystem approach in disaster mitigation policies. First, this study affirms that purely technical-structural approaches (hard engineering) are no longer sufficient to address the complexity of earthquake risks in archipelagic regions. Tarakan City, which has a high dependency on sea logistics routes, faces the risk of isolation when an earthquake damages port infrastructure or material distribution access. In this condition, buildings designed solely based on material strength without considering ease of maintenance and the availability of local resources will become a post-disaster burden. The literature synthesis shows that ecosystem strategies utilizing local materials and natural reinforcement can serve as a more flexible "line of defense" amid logistical distribution constraints and the geological vulnerability of unstable alluvial soil.

Second, the success of resilience largely depends on cross-dimensional integration covering technical, social, institutional, and environmental aspects. Structurally earthquake-resistant public buildings will not provide optimal protection if they are not supported by strict spatial planning policies (institutional), active community participation in maintaining building functions (social), and an ecologically stable surrounding environment. The thematic synthesis shows that infrastructure failure in many archipelagic regions is often not caused by technical design errors alone but by weak coordination between these dimensions. Therefore, building a resilience ecosystem means creating synergies where each dimension functions as an additional protective layer that adaptively responds to seismic threats.

Third, ecosystem-based strategies offer dual benefits that are highly relevant for the coastal and hilly areas of Tarakan. This approach not only enhances resistance to earthquake vibrations but also reduces secondary risks such as liquefaction, landslides, and erosion, which often exacerbate damage to public buildings. For example, the use of retaining vegetation and sustainable drainage systems helps maintain soil stability during seismic events while simultaneously functioning as flood and coastal abrasion control. Thus, this synthesis strengthens the argument that ecosystem-based strategies are not merely low-cost technical alternatives but essential components of a comprehensive resilience framework. These findings further reinforce the role of Eco-DRR operationalized through NbS as a practical and context-sensitive framework.

3.4 SWOT analysis of ecosystem-based strategies

Each identified strategy is evaluated using the SWOT (Strengths, Weaknesses, Opportunities, and Threats) framework to assess its implementation potential, barriers, and policy development opportunities in Tarakan City, highlighting how local natural and social assets can be optimized to overcome existing constraints. This systematic evaluation is crucial for ensuring that the resulting recommendations are realistic and operational for stakeholders, as detailed in Table 4.

The in-depth evaluation provided by the previous SWOT analysis offers an objective overview of the standing and potential of ecosystem-based strategies within the mitigation framework of Tarakan City. However, an understanding of current conditions must be followed by mapping out concrete strategic steps for the future. Consequently, this section outlines the development directions and the primary pillars required to transform this conceptual framework into operational, measurable, and sustainable policies for the protection of public infrastructure.

Table 4. SWOT analysis of ecosystem-based resilience strategies

Aspect	Strategic findings
Strengths	Highly adaptive to the local context; strongly community-oriented; cost-effective (low-cost); directly supports Sustainable Development Goals (SDGs) and Nature-Based Solutions (NbS).
Weaknesses	Lack of integration within current technical building and spatial planning regulations; absence of standardized ecosystem-based operational guidelines for local implementation.
Opportunities	High potential for cross-sector collaboration (synergy between government, community, and private sectors); availability of extensive natural assets such as mangroves and slope vegetation for mitigation.
Threats	Rapid land-use changes and urbanization; ongoing coastal environmental degradation; institutional resistance toward non-conventional or "soft" engineering approaches.

3.5 Directions for ecosystem-based strategy development

The systematic review highlights the urgent need to embed ecosystem principles into public infrastructure planning frameworks. Prihartanto et al. (2024) emphasize that Tarakan's mangrove ecosystems are critical in stabilizing coastal soils and mitigating secondary earthquake risks such as liquefaction and erosion. Similarly, Sudmeier-Rieux et al. (2021) demonstrates that natural buffers, including mangrove belts and slope vegetation, can significantly reduce vulnerability in coastal regions worldwide. These findings suggest that schools, hospitals, and government offices in Tarakan should not be treated as isolated technical entities but as integral components of a broader ecological landscape. In practice, this requires synchronizing site selection and building design with seismic hazard maps and land carrying capacity assessments provided by BNPB (2022). By mainstreaming ecological parameters at the pre-construction stage, planners can avoid high-risk zones and leverage natural buffers to enhance resilience. This approach is particularly relevant for Tarakan, where alluvial soil formations and high water tables pose substantial risks to building stability. Integrating ecosystem principles into planning ensures that infrastructure development aligns with the environmental dynamics of a vulnerable island city.

The literature also reveals a persistent gap between resilience theory and field practice, especially in archipelagic regions with limited technical resources. Yudanagara et al. (2025) show that community-driven initiatives in coastal Indonesia often succeed in maintaining green infrastructure, but institutional support and technical literacy remain weak. Without adequate knowledge of non-conventional mitigation techniques, local governments tend to rely on costly hard engineering solutions that are difficult to implement in resource-constrained island environments. Strengthening institutional and technical capacity therefore emerges as a second strategic direction. Targeted training programs for urban planners, policymakers, and technical personnel in Tarakan are essential to increase literacy on ecosystem-based disaster risk reduction (Eco-DRR) and Nature-Based Solutions (NbS). UNDRR (2025) underscores the importance of capacity-building initiatives to support innovative, ecosystem-based disaster risk governance, particularly in resource-constrained archipelagic regions such as Tarakan. Institutional strengthening should also include mechanisms for cross-sector coordination, ensuring that ecological, social, and technical dimensions are integrated into resilience planning. This direction directly addresses the logistical constraints identified in Tarakan, where limited access to specialized construction materials often compromises infrastructure quality.

A third strategic direction identified in the review is the formulation of standardized technical guidelines for implementing NbS in infrastructure development. While international frameworks such as the UNDRR/IUCN Eco-DRR guidelines provide general principles, localized standards tailored to the geophysical conditions of Indonesian archipelagic regions remain absent. Khalqillah et al. (2025) demonstrate that integrating green drainage systems can significantly improve soil stability in Lombok, but the lack of standardized procedures limits broader adoption. In Tarakan, technical guidelines should specify vegetation types suitable for stabilizing alluvial soils, design parameters for sustainable urban drainage systems (SUDS), and protocols for integrating ecological buffers into public building foundations. Standardization ensures that ecosystem-based interventions are scientifically grounded and technically accountable, reducing the risk of ad hoc or inconsistent implementation. Furthermore, guidelines should be embedded within national building codes, such as SNI 1726:2019, to provide legal and regulatory support for ecosystem-based practices (Badan Standardisasi Nasional, 2019). This direction is crucial for bridging the gap between conceptual frameworks and operational policies, ensuring that NbS are not merely experimental but institutionalized within infrastructure development processes.

The fourth strategic direction emphasizes the importance of cross-sector collaboration in testing and scaling ecosystem-based strategies. Sudmeier-Rieux et al. (2021) highlight that multi-stakeholder initiatives are more effective in generating empirical data and fostering community ownership of resilience measures. In Tarakan, collaboration between the local government, academic institutions, private sector, and community organizations is necessary to implement pilot projects that demonstrate the effectiveness of ecosystem restoration in protecting public infrastructure. For example, pilot projects could focus on establishing coastal green belts of mangroves around hospitals and schools, or slope-retaining vegetation near government offices located in hilly areas. These projects would not only provide immediate protective benefits but also generate empirical evidence on the performance of ecosystem strategies under seismic stress. Such data are invaluable for replication in other archipelagic regions facing similar challenges. Moreover, pilot projects foster community participation, leveraging Tarakan's strong social capital and traditions of "gotong royong" to maintain green infrastructure. This direction ensures that resilience strategies are adaptive, context-specific, and supported by empirical validation.

These four strategic directions collectively form an integrated framework for ecosystem-based resilience development in Tarakan. The integration of ecological parameters into planning, capacity building, standardized guidelines, and cross-sector collaboration are not isolated recommendations but interdependent pillars that reinforce one another. For instance, standardized guidelines cannot be effectively implemented without institutional capacity, and ecological integration into planning requires empirical validation through pilot projects. This synergy reflects the holistic nature of ecosystem-based resilience, where technical, social, institutional, and environmental dimensions converge to create adaptive systems. To enhance clarity and credibility, a visual model can be added to illustrate the four strategic pillars as interconnected components within a resilience ecosystem, emphasizing their synergy in addressing the unique geophysical and logistical challenges of archipelagic regions. By grounding each direction in empirical evidence and contextualizing them for Tarakan, this framework advances both theoretical discourse on Eco-DRR and practical pathways for policy development. Ultimately, the recommendations presented here provide a strategic reference for stakeholders in Tarakan and similar archipelagic regions, guiding future efforts to transition toward earthquake mitigation strategies that are holistic, sustainable, and adaptive to seismic challenges.

4. Conclusion

Based on the synthesis of 12 key studies, this research confirms that ecosystem-based strategies provide a viable and context-sensitive approach to enhancing infrastructure resilience in archipelagic regions. This study concludes that efforts to strengthen the resilience of public buildings against earthquakes in archipelagic regions, such as Tarakan City, require a transformation from purely technical approaches toward holistic ecosystem-based strategies. The analysis results indicate that the integration of technical, social, institutional, and environmental dimensions is key to addressing the complexity of seismic risks in areas characterized by geological alluvial soil vulnerability and logistical constraints. Strategies such as mangrove restoration as natural buffers, the implementation of risk-based spatial planning, and the strengthening of community capacity are identified as adaptive, sustainable, and contextually relevant solutions for Tarakan's local characteristics. Although the ecosystem approach is currently in the conceptual development stage, this research has established a strong thematic foundation for integrating environmental aspects into public infrastructure policy. Synergy between the government, academia, and the community is an essential prerequisite for transforming these strategies into tangible actions. This study provides a theoretical contribution to the literature on infrastructure resilience in archipelagic regions and serves as a strategic reference for developing more resilient and cost-effective disaster mitigation guidelines in the future. Further research is recommended to conduct empirical evaluations through pilot projects to measure the specific effectiveness of these nature-based interventions in protecting the physical structures of public buildings.

Author's declaration

Author contribution

Eko Prihartanto: Conceptualization, Methodology, Formal Analysis, Writing Original Draft, Visualization. **Widyo Nugroho**: Literature Review, Validation, Writing Review & Editing. **Budi Setiawan**: Data Curation, Investigation, Supervision, Project Administration.

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Minor language refinement was performed using standard editing tools. All content was manually verified and authored by the researchers.

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