

Research Article

Integrated Disaster Vulnerability and Mitigation Strategies for Gampong Deah Raya Coastal Settlement, Banda Aceh, Indonesia

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Abstract

Coastal settlements in Banda Aceh face compound exposure to earthquakes, tsunamis, and liquefaction due to their proximity to an active subduction zone, low-lying topography, and dense coastal development. This study aims to assess disaster hazard exposure, examine community risk perception, and formulate mitigation strategies for Gampong Deah Raya, a coastal settlement in Banda Aceh, Indonesia. A descriptive quantitative case-study approach was applied using spatial interpretation of disaster hazard maps, household survey data collected through a Likert-scale questionnaire, and descriptive statistical analysis in SPSS. The results show that Gampong Deah Raya is characterized by high earthquake and tsunamis, while liquefaction potential ranges from moderate to high in several parts of the area. Although residents demonstrate a relatively high level of risk awareness, non-structural preparedness and structural mitigation remain only moderately developed. This indicates a gap between risk perception and practical readiness at the community and settlement levels. Based on these findings, an integrated mitigation framework is proposed that combines community-based preparedness, routine evacuation drills, risk communication, early warning systems, evacuation routes, vertical evacuation buildings, ground improvement in liquefaction-prone zones, and coastal greenbelt protection. The study highlights that disaster mitigation in coastal settlements should not rely on a single intervention, but instead integrate physical, social, and spatial planning measures to reduce risk more effectively. The findings provide practical implications for coastal settlement planning and disaster resilience improvement in Banda Aceh and similar hazard-prone coastal areas.

Keywords: Community-based mitigation; disaster vulnerability; land-use planning; risk perception; urban resilience.

Introduction

Coastal settlement areas are among the most disaster-prone environments due to the interaction of tectonic, geomorphological, and socio-spatial factors. Indonesia, located along the

Article History

Received: 8 April, 2026; Revised: 19 June, 2026;

Accepted: 21 June, 2026; Published: 26 June, 2026



convergence of major active tectonic plates, experiences frequent seismic activities that pose significant threats to coastal cities, particularly in the form of earthquakes, tsunamis, and secondary hazards such as liquefaction [1,2]. These hazards are exacerbated in densely populated coastal settlements where building quality, land-use pressure, and uneven community preparedness increase disaster risk [3].

Aceh Province represents one of the most vulnerable regions in Indonesia, as it is strongly influenced by the Sunda megathrust system and active fault segments capable of generating large-magnitude earthquakes [4,5]. Studies have shown that Banda Aceh is characterized by high peak ground acceleration (PGA), which increases the probability of structural damage, especially in non-engineered residential buildings [6]. Earthquake events in coastal zones frequently act as triggering mechanisms for tsunamis and liquefaction, forming a cascading disaster pattern that threatens both human safety and the built environment [7].

Gampong Deah Raya, located in Syiah Kuala District, Banda Aceh City, is a coastal settlement directly exposed to these hazards, as shown in **Figure 1**. The gampong is situated near the shoreline with relatively low elevation, flat topography, and compact residential density, conditions that allow tsunami waves to penetrate deeper inland [8]. Previous studies indicate that coastal areas with gentle slopes and high settlement density tend to experience greater physical damage and higher casualty potential during tsunami events [9].

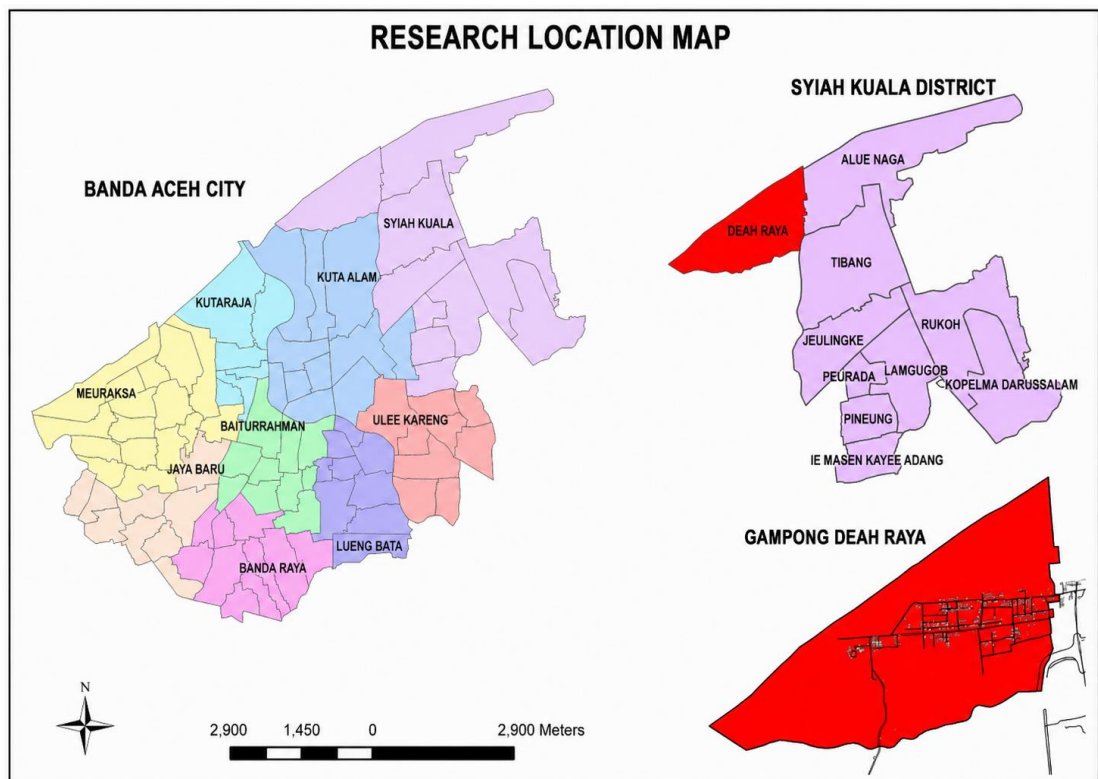


Figure 1. Location of Gampong Deah Raya within Banda Aceh City

In addition to tsunami hazards, liquefaction presents a critical threat to coastal settlements in Banda Aceh. The dominance of loose, saturated sandy soils in coastal zones significantly increases the likelihood of soil strength loss during strong ground shaking [10]. Empirical investigations conducted after major seismic events have confirmed that several areas in Banda Aceh exhibit high liquefaction potential, leading to foundation failure, tilting structures, and

infrastructure disruption [11,12]. These conditions highlight the importance of integrating geotechnical considerations into disaster risk assessment and mitigation planning.

Beyond physical vulnerability, social vulnerability plays a decisive role in shaping disaster risk. Community perception, knowledge, and preparedness strongly influence the effectiveness of mitigation efforts [13]. Several studies in tsunami-prone coastal areas in Indonesia demonstrate that residents often maintain moderate to low risk perception despite living in high-risk zones, particularly when long periods have elapsed since major disasters [14,15]. This declining risk awareness can reduce participation in evacuation drills, early warning response, and household-level preparedness measures.

Disaster mitigation in coastal settlements requires an integrated approach that combines structural and non-structural strategies. Structural mitigation includes earthquake-resistant housing, evacuation routes, vertical evacuation buildings, and land-use regulation, while non-structural mitigation emphasizes community education, disaster literacy, early warning systems, and institutional capacity building [16,17]. Research conducted in Banda Aceh indicates that mitigation effectiveness improves significantly when physical infrastructure development is accompanied by community-based preparedness programs [18].

Despite the recognized importance of integrated mitigation, comprehensive studies that simultaneously examine disaster vulnerability, community perception, and context-specific mitigation strategies at the gampong level remain limited. In particular, Gampong Deah Raya has not been extensively analyzed as a localized case study that links physical exposure, social perception, and mitigation planning.

Therefore, this study aims to (1) assess spatial disaster hazard conditions in the coastal settlement of Gampong Deah Raya, (2) analyze community perceptions regarding disaster mitigation, and (3) formulate context-specific mitigation strategies that align with the physical and social characteristics of the area. The findings are expected to contribute to disaster-resilient settlement planning and provide practical insights for coastal risk reduction initiatives in Banda Aceh and similar coastal cities.

Materials and Methods

This study employed a mixed-methods approach integrating spatial analysis and community-based assessment to evaluate coastal hazard exposure, community preparedness, and mitigation strategies in Gampong Deah Raya, Banda Aceh, Indonesia. The methodological framework was designed to capture both the physical characteristics of the coastal environment and the socio-spatial dimensions of community preparedness, ensuring a comprehensive understanding of disaster risk in tsunami-prone areas.

Study Area and Data Sources

The study area is Gampong Deah Raya, located in Syiah Kuala District, Banda Aceh City, Aceh Province, Indonesia. This area is classified as a high-risk coastal zone due to its exposure to earthquakes, tsunamis, and liquefaction hazards associated with the Sunda subduction zone [3,16]. The spatial boundary of the study area was defined based on official administrative village data obtained from local government sources.

Primary spatial data included administrative boundaries, land-use maps, road networks, coastline data, and elevation information. Demographic and socio-economic data were obtained from the Banda Aceh City Statistics Agency, particularly the Syiah Kuala District statistical report [1]. Disaster occurrence and hazard-related data were collected from the Indonesian Disaster Information Database (DIBI) managed by the National Disaster Management Agency (BNPB) [1,19]. Additional village-level preparedness data were obtained from the SIGAP Gampong Deah Raya database.

Research Design and Data Collection

Data collection was conducted through field surveys and document analysis. Field observations focused on identifying physical vulnerability indicators, including building conditions, settlement density, road accessibility, proximity to the coastline, and the availability of evacuation infrastructure. These indicators are commonly used in tsunami vulnerability and coastal disaster mitigation studies [9,20].

Social data were collected using structured questionnaires to assess community knowledge, attitudes, and preparedness related to earthquake and tsunami hazards. This approach follows community-based disaster risk assessment frameworks applied in tsunami-prone areas in Aceh and other Indonesian coastal regions [14]. In-depth interviews were conducted with village officials and local stakeholders to obtain qualitative information on existing mitigation programs, evacuation planning, and community response mechanisms [21].

Spatial Hazard Analysis and Evacuation Accessibility Assessment

Spatial analysis was performed using Geographic Information System (GIS) software to examine disaster hazard exposure and evacuation accessibility in Gampong Deah Raya. Existing earthquake, tsunami, and liquefaction hazard maps obtained from authorized government sources were overlaid to identify areas exposed to multiple hazards within the study area, following GIS-based hazard assessment and mapping approaches [9,20]. The hazard classifications presented in the maps follow the original classifications provided by the source agencies and were not reclassified by the authors. The resulting spatial analysis was used to evaluate the overall hazard exposure characteristics of the coastal settlement and to support the formulation of mitigation strategies [18].

Accessibility analysis was conducted to evaluate evacuation routes by measuring distance and connectivity between residential areas and designated evacuation points. This analysis aimed to identify areas with limited evacuation access and potential bottlenecks during emergency situations [9].

Community-Based Assessment

To complement the spatial analysis, a community-based assessment was conducted to evaluate local preparedness and mitigation capacity. Survey results were analyzed descriptively to identify levels of disaster awareness, evacuation knowledge, and participation in disaster training or simulations. The integration of community perception data with spatial hazard exposure findings enabled a more holistic interpretation of disaster risk and resilience at the village scale.

Data Analysis and Validation

Quantitative data from surveys were processed using descriptive statistical methods, while qualitative interview data were analyzed through thematic interpretation. Spatial outputs were cross-validated with field observations to ensure accuracy and relevance. The combination of spatial and social analyses strengthened the reliability of the findings and supported the formulation of context-sensitive mitigation strategies.

Results

This section presents the main findings of the study on disaster hazard exposure, community preparedness, and mitigation in the coastal settlement of Gampong Deah Raya, Banda Aceh, with a focus on earthquake, tsunami, and liquefaction hazards. The results are organized into

three parts: spatial vulnerability, community perception and preparedness, and the synthesis of mitigation conditions.

Spatial Disaster Hazard Exposure in Gampong Deah Raya

Spatial analysis reveals that Gampong Deah Raya is a highly exposed coastal settlement where physical setting and hazard characteristics converge to create layered disaster risks. The settlement is located immediately adjacent to the coastline, characterized by low elevation, flat coastal morphology, and dense residential development. These physical attributes not only increase individual hazard exposure but also intensify the interaction between hazards, allowing one event to amplify the impacts of another.

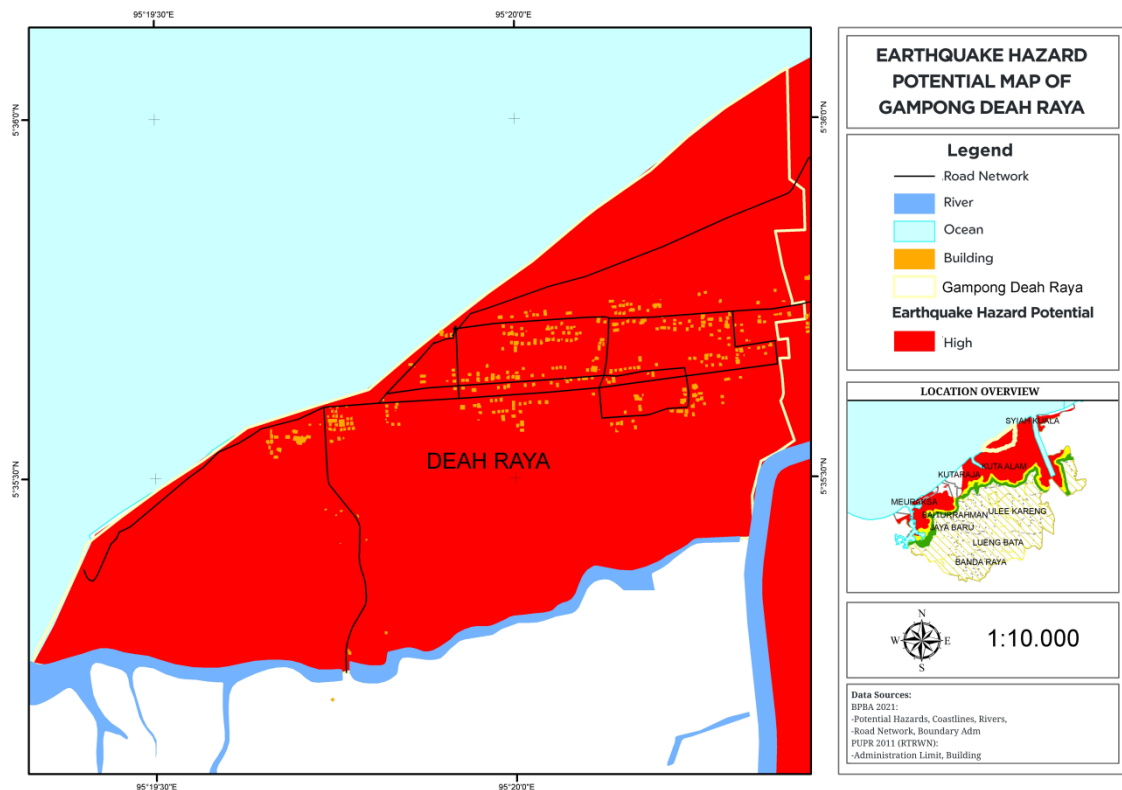


Figure 2. Earthquake hazard potential map of Gampong Deah Raya

The earthquake hazard map shown in **Figure 2** illustrates that all parts of Gampong Deah Raya are exposed to strong seismic shaking. The map does not display noticeable spatial differences, indicating that there are no areas within the settlement that experience lower levels of seismic exposure. This condition is closely related to the regional tectonic setting of Banda Aceh, where seismic energy from nearby subduction zones tends to affect the coastal plain in a relatively uniform manner. As a result, residential buildings, local roads, and public facilities across the settlement are likely to experience comparable levels of shaking during an earthquake.

In addition, the earthquake hazard depicted in **Figure 2** plays an important role in triggering secondary hazards. Strong ground motion can initiate offshore tsunami generation and promote soil liquefaction in vulnerable onshore areas. For this reason, earthquake hazard in Gampong Deah Raya should be viewed as a key factor driving cascading disaster impacts, rather than as an isolated hazard acting on its own.

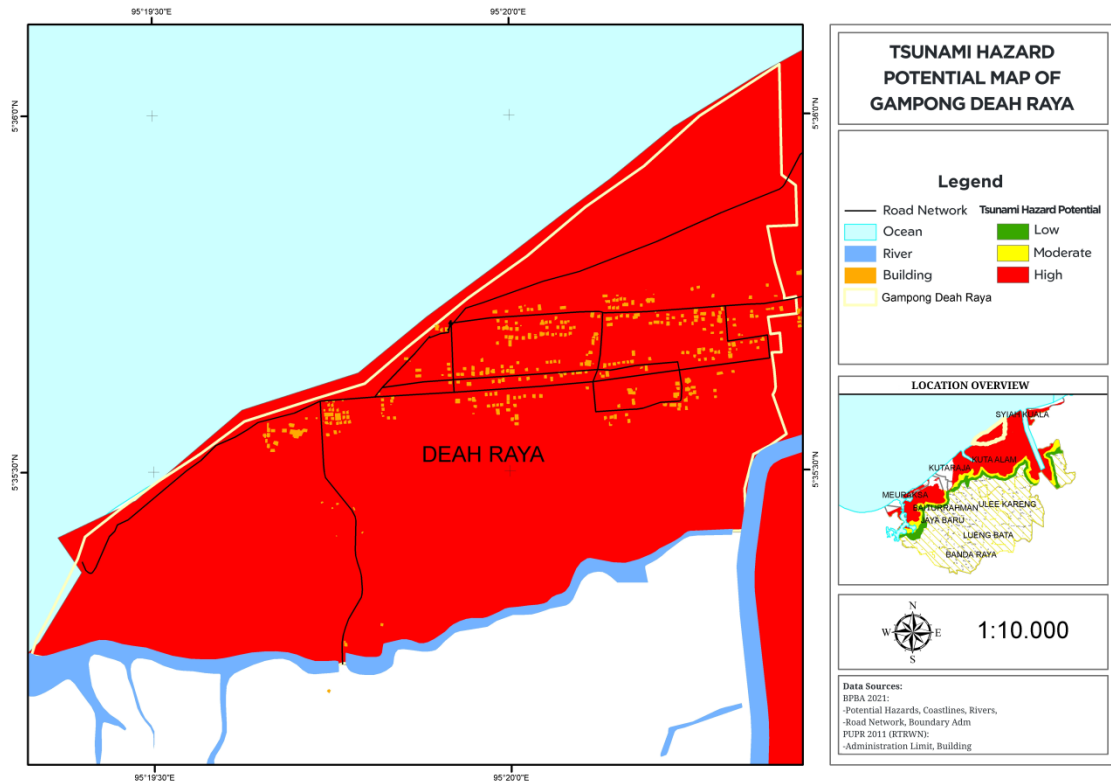


Figure 3. Tsunami hazard potential map of Gampong Deah Raya

The tsunami hazard map presented in **Figure 3** shows that almost the entire area of Gampong Deah Raya lies within the potential inundation zone. The highest levels of exposure are concentrated along the immediate coastal strip and gradually extend inland, following the generally flat topography of the settlement. In the absence of natural elevation features such as hills or raised landforms, tsunami waves are able to propagate inland with little resistance, allowing floodwaters to spread rapidly across residential areas.

This spatial pattern suggests that tsunami waves could reach housing clusters, community facilities, and local infrastructure within a very short period after wave generation. The close proximity of Gampong Deah Raya to the shoreline substantially limits the available time for evacuation, leaving residents with only a narrow window to respond once a warning is issued. In this context, tsunami represents the most immediate and severe life-threatening hazard faced by the settlement, particularly for vulnerable groups such as children, the elderly, and individuals with limited mobility.

Given these conditions, survival during a tsunami event is strongly influenced by the effectiveness of early warning dissemination and the community's ability to respond quickly. Clear, unobstructed evacuation routes that are well understood by residents become essential, especially in areas where horizontal evacuation distances are short but time is extremely limited. In addition, the availability of nearby vertical evacuation structures or elevated safe locations plays a critical role in reducing potential casualties, particularly in densely built sections of the settlement where access to higher ground is absent. These findings highlight the need for tsunami risk reduction strategies that prioritize rapid response capacity and accessible evacuation infrastructure within Gampong Deah Raya.

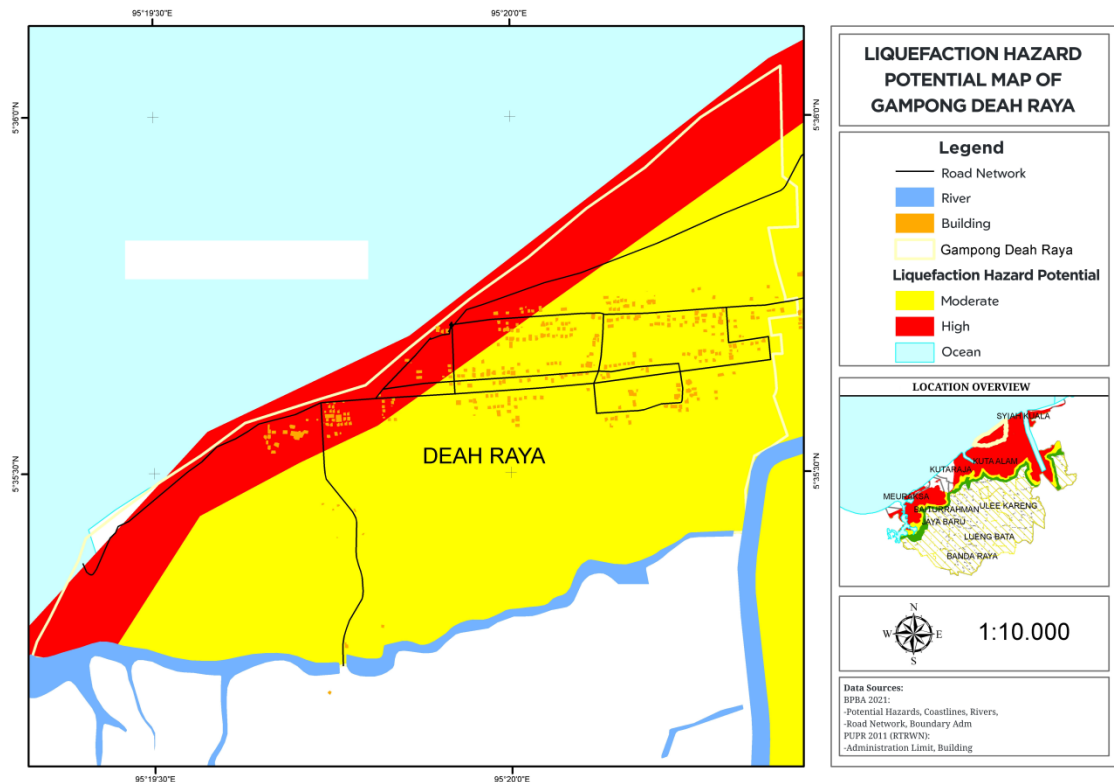


Figure 4. Liquefaction hazard potential map of Gampong Deah Raya

The liquefaction hazard map shows a distinct spatial pattern in Gampong Deah Raya, as shown in **Figure 4**, with the highest levels of exposure concentrated along the coastal zone. This high-exposure area forms a continuous belt parallel to the shoreline and is characterized by loose, water-saturated sandy soils combined with shallow groundwater conditions. These ground characteristics significantly increase the susceptibility of the area to soil strength loss during strong seismic shaking.

Residential areas and road networks located within this coastal strip are therefore highly vulnerable to ground deformation and foundation instability. Potential impacts include uneven settlement, structural damage to buildings, and disruption of road connectivity, which can severely affect accessibility during emergency situations. Such conditions not only increase physical damage but also pose serious challenges for evacuation and post-disaster response, particularly in densely built coastal neighborhoods.

In contrast, inland areas in the central and southern parts of the settlement exhibit relatively lower liquefaction exposure due to more stable soil conditions and greater distance from the coast. However, dense housing development in these areas means that even moderate levels of soil weakening may still interfere with access routes and emergency operations. Overall, liquefaction exposure gradually decreases from the coastline toward inland areas, indicating that risk distribution is strongly influenced by coastal proximity and local ground conditions rather than being uniform across the settlement.

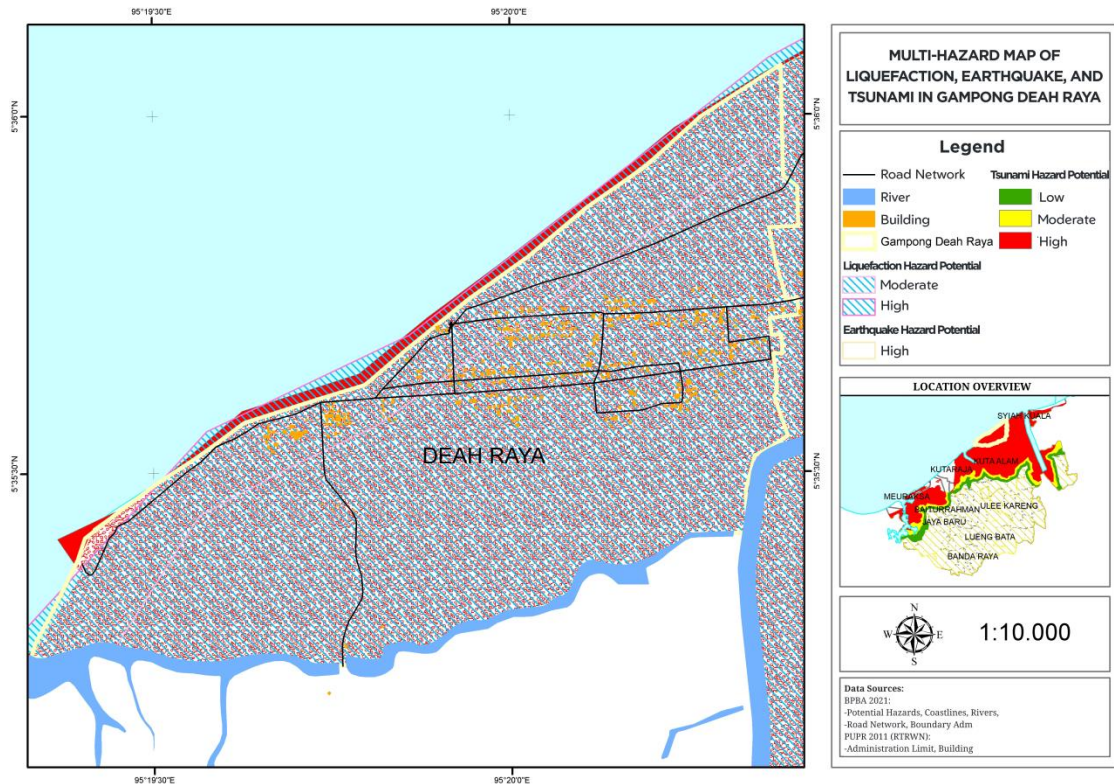


Figure 5. Multi-Hazard Map of Liquefaction, Earthquake, and Tsunami in Gampong Deah Raya

The multi-hazard overlay map presented in **Figure 5** shows that Gampong Deah Raya is dominated by high hazard exposure, where liquefaction, earthquake, and tsunami potentials spatially overlap across almost the entire settlement area. The map indicates that liquefaction hazard (moderate to high) covers nearly all parts of Gampong Deah Raya, reflecting the dominance of young coastal sediments and saturated soils. At the same time, the earthquake hazard potential is classified as high throughout the area, indicating that the settlement is highly susceptible to strong ground shaking. In addition, tsunami hazard zones—ranging from moderate to high extend inland from the coastline, intersecting with residential areas and critical infrastructure.

This overlay demonstrates that most built-up areas in Gampong Deah Raya are simultaneously exposed to multiple hazards, rather than being affected by a single dominant threat. The absence of clearly defined low-risk zones within the settlement highlights that a single seismic event may trigger compounded impacts, including structural damage from ground shaking, tsunami inundation, and ground failure due to liquefaction. Therefore, the spatial pattern shown in this map confirms that risk in Gampong Deah Raya is cumulative and overlapping, emphasizing that disaster mitigation and spatial planning must be designed using a multi-hazard approach, rather than hazard-specific or isolated mitigation measures.

Community Perception and Preparedness

A total of 152 respondents participated in the survey. The respondent profile shows that most participants were within the productive age group, the gender composition was relatively balanced, and the educational background ranged from lower to higher education levels. This demographic composition indicates that the survey sample adequately reflects the basic social structure of the settlement, as summarized in **Table 1**.

Table 1. Respondents' Demographic Profile

Demographic Variable	Category	Percentage
Gender	Male	52%
	Female	48%
Age	Under 17 years	5.3%
	17–30 years	37.5%
	31–45 years	47.4%
	46–60 years	9.9%
	Over 60 years	0%
Educational Background	Primary School	0%
	Junior High School	11.2%
	Senior High School	68.4%
	Higher Education	20.4%

The perception results indicate that residents have a high level of disaster risk awareness, especially regarding earthquakes and tsunamis. Most respondents understand that their settlement is exposed to major hazards, and the overall risk perception falls in the high category. This suggests that disaster awareness has been internalized within the community.

At the same time, the results show a mixed pattern in social vulnerability and preparedness. Residents strongly recognize the importance of protecting vulnerable groups during evacuation, but formal education is not perceived as the main determinant of preparedness. This indicates that local experience and social learning may be more influential than formal schooling in shaping disaster readiness.

The capacity results show that residents generally understand immediate protective actions during earthquakes, but household preparedness is still uneven. This means that knowledge of what to do during a disaster does not always translate into practical readiness at the family level. Non-structural mitigation results show that disaster education, socialization, and evacuation simulation are not yet evenly experienced by all residents. Some residents report moderate exposure to disaster information, while others still lack consistent access to preparedness activities. This points to a gap between risk awareness and practical preparedness at the community level.

Structural mitigation results show a moderate condition. Residents acknowledge that some evacuation facilities exist, but the availability and quality of routes, signs, and safety infrastructure remain uneven. This suggests that the physical support system for disaster response still requires substantial improvement.

Synthesis of Disaster Mitigation Conditions

The synthesis of spatial analysis and survey findings shows that disaster mitigation in Gampong Deah Raya needs to be addressed through an integrated system, as illustrated in **Figure 6**, which considers the interaction between earthquake-triggered tsunami and liquefaction hazards. Earthquake shaking acts as the primary trigger, while tsunami inundation and liquefaction function as secondary hazards that intensify damage, particularly in coastal and low-lying areas.

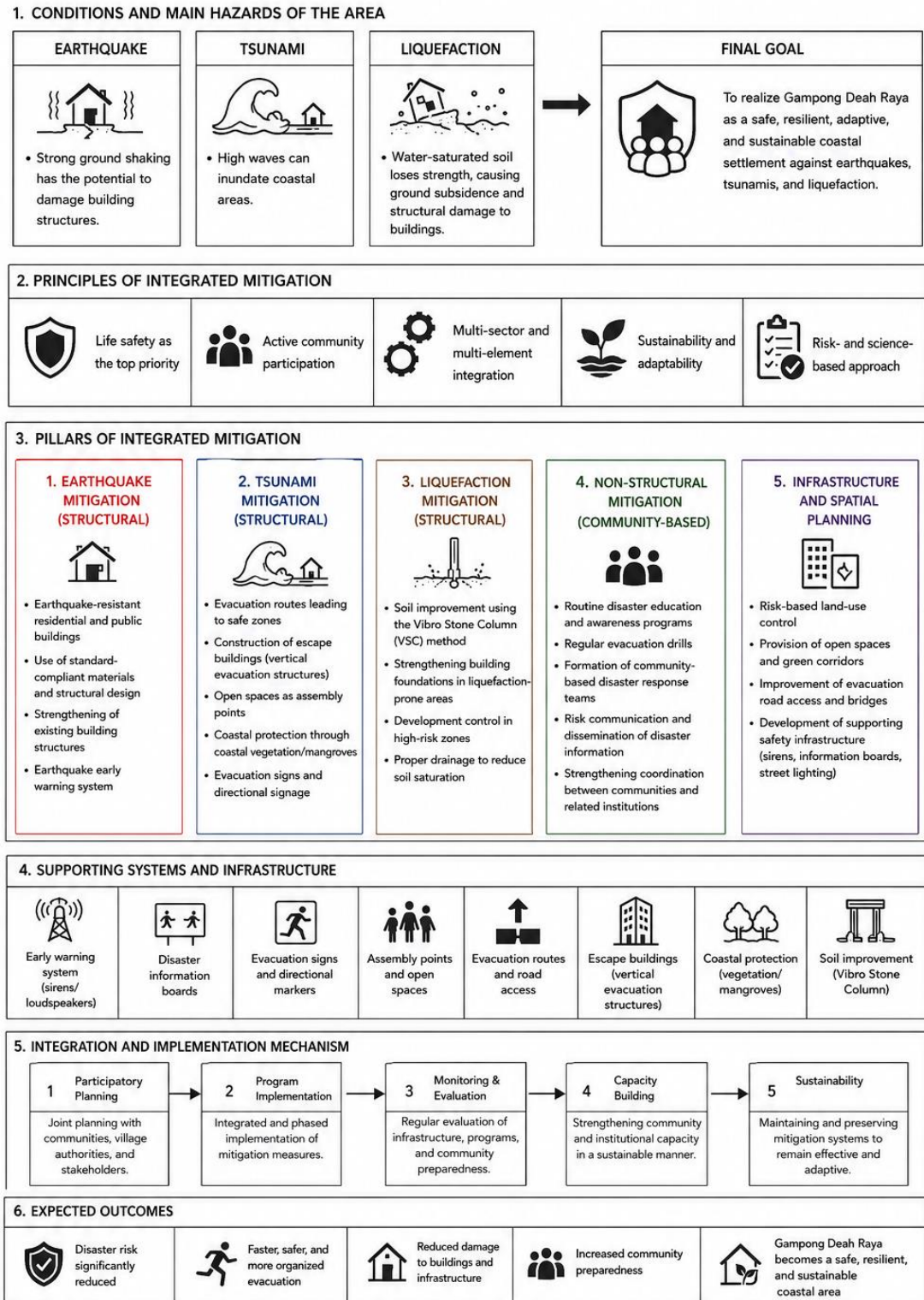


Figure 6. Integrated mitigation synthesis for Gampong Deah Raya

Based on this condition, the synthesis framework emphasizes the prioritization of life safety as the main mitigation objective, supported by active community participation, multi-sectoral integration, risk-based planning, and adaptive sustainability principles. These principles form

the foundation for coordinated mitigation actions at the settlement scale. The framework is operationalized through five interrelated mitigation pillars, consisting of structural earthquake mitigation, structural tsunami mitigation, structural liquefaction mitigation, community-based non-structural mitigation, and risk-oriented spatial and infrastructure planning. Each pillar addresses a specific hazard dimension while reinforcing the others, ensuring that mitigation measures do not operate in isolation.

The synthesis further highlights the role of supporting systems and infrastructure, including early warning systems, evacuation signage, open spaces, evacuation routes, escape buildings, coastal protection, and ground improvement measures, which collectively strengthen disaster response capacity. These elements are designed to function as a connected network rather than as stand-alone facilities.

Finally, the framework underscores that effective mitigation depends on participatory planning, phased implementation, continuous monitoring and evaluation, and sustained capacity building. Through this integrated approach, Gampong Deah Raya is directed toward reduced disaster risk, improved evacuation effectiveness, minimized physical damage, and enhanced community resilience against earthquake, tsunami, and liquefaction hazards.

Discussion

The findings show that Gampong Deah Raya is exposed to a compound disaster environment in which earthquake, tsunami, and liquefaction hazards interact rather than occur separately. This pattern is consistent with the tectonic setting of Aceh and the characteristics of great subduction-zone earthquakes, which can generate strong ground shaking, trigger tsunami inundation, and destabilize saturated coastal soils [2,4]. The spatial results therefore confirm that the settlement's hazard exposure is not only a function of its coastal location, but also of the cascading relationship among hazards. This is important for built-environment planning because a single seismic event may affect buildings, road networks, and evacuation functions simultaneously [10,11].

The community survey results complement the spatial findings by showing that residents are generally aware of earthquake and tsunami risks, yet their preparedness remains uneven. This pattern is similar to previous studies in Aceh and other tsunami-prone coastal communities, where post-disaster awareness remains relatively high but practical preparedness does not always develop at the same pace [14,15,17]. In Gampong Deah Raya, residents appear to recognize the danger, but household readiness, evacuation routines, and consistent exposure to mitigation programs are still moderate. This gap between risk perception and practical preparedness is critical because disaster response in coastal areas depends not only on knowledge, but also on the ability to translate that knowledge into immediate action.

The structural mitigation results also highlight an important issue in coastal settlement resilience. The availability of evacuation routes, signage, and safety infrastructure is only moderate, which means that physical preparedness does not yet fully match the settlement's hazard level. Previous research in Banda Aceh has shown that escape buildings and evacuation facilities are effective only when they are strategically located, accessible, and supported by community understanding [18,22]. Likewise, evacuation signage and route clarity are most effective when they are continuously maintained and linked to local movement patterns. In other words, mitigation infrastructure cannot function as a stand-alone solution; it must be integrated into daily settlement use and community practice.

For liquefaction, the findings reinforce the importance of soil conditions in coastal disaster mitigation. The moderate to high liquefaction potential identified in parts of Gampong Deah Raya is consistent with earlier geotechnical studies in Banda Aceh, which identified coastal sandy soils and shallow groundwater as major drivers of liquefaction susceptibility [10], [11]. This

means that building safety in the settlement is not determined only by structural quality, but also by the behavior of the ground beneath it. The implication for planning is clear: land-use decisions, foundation design, and soil improvement should be considered together, especially in areas planned for public facilities or dense housing.

The proposed mitigation synthesis in this study aligns with broader evidence that coastal risk reduction requires an integrated framework combining structural and non-structural measures. Structural measures such as evacuation routes, vertical evacuation buildings, greenbelts, and soil improvement should be paired with community education, drills, and risk communication [23-25]. Mangrove belts and coastal vegetation may reduce wave energy and provide an additional layer of protection, but they cannot replace evacuation systems or building-level safety measures [23,24]. Similarly, soil improvement methods such as vibro stone columns can strengthen liquefaction-prone areas, but they should be supported by spatial planning and building reinforcement [25]. These findings support the need for a combined strategy rather than a single-hazard solution.

From a spatial planning perspective, the findings suggest that disaster risk considerations should be more explicitly integrated into local land-use planning and development control. Areas exposed to high tsunami and liquefaction hazards require stricter regulation of future development, particularly for dense residential expansion and critical public facilities. The results also highlight the importance of coordination between local governments, spatial planning authorities, and disaster management agencies such as BPBD in implementing risk-sensitive planning, evacuation infrastructure, and community preparedness programs [17,21]. In Gampong Deah Raya, short-term priorities should focus on strengthening evacuation routes, signage, disaster education, and evacuation drills, while medium- to long-term actions should emphasize the development of evacuation infrastructure, coastal buffer protection, and risk-sensitive settlement planning [18,21]. Spatially, areas with high tsunami and liquefaction exposure should be prioritized for development control, evacuation facilities, and mitigation-oriented land-use management through the implementation of Banda Aceh's spatial planning policies (RTRW). Such measures are essential for controlling development in hazard-prone areas, reducing vulnerability, and enhancing long-term settlement resilience in multi-hazard coastal environments [3,18].

The role of early warning systems is also significant, but the results suggest that warning technology alone is not enough. Earthquake early warning tools may provide rapid alerts, yet the effectiveness of such systems depends on whether residents understand the warning and respond immediately [26,27]. Previous studies have shown that false alarms, missed detections, and weak public response can reduce the practical value of warning systems [26], [28]. In Gampong Deah Raya, this implies that early warning should be accompanied by repeated community drills, clear evacuation instructions, and local coordination mechanisms so that warning information can be translated into protective behavior.

Overall, the results indicate a clear mismatch between high hazard exposure, high risk awareness, and only moderate preparedness capacity. This mismatch is especially important in a coastal settlement where evacuation time is limited and cascading hazards are likely. The study therefore contributes to the built-environment literature by showing that coastal resilience is not achieved simply by mapping hazards, but by linking spatial vulnerability, community perception, and mitigation design at the settlement scale [3]. The case of Gampong Deah Raya demonstrates that integrated mitigation planning is necessary to reduce disaster risk in coastal settlements with similar physical and social characteristics.

Beyond its empirical findings, this study contributes to coastal settlement research by integrating hazard assessment, community risk perception, and mitigation planning within a single analytical framework at the gampong scale. While previous studies commonly focus on

either physical hazard assessment [20] or community preparedness and risk perception [14,15], this study links both dimensions to formulate context-specific mitigation strategies for a disaster-prone coastal settlement. This integrated perspective provides practical insights for settlement planning and disaster risk reduction at the local community level, particularly in coastal areas exposed to multiple interacting hazards.

A limitation of the study is that it focuses on one settlement and relies primarily on descriptive survey analysis and official spatial data. As a result, the findings are highly useful for local planning but should be generalized cautiously. Future research may expand the analysis to neighboring coastal settlements, apply comparative risk modeling, or evaluate the effectiveness of specific mitigation interventions after implementation.

Conclusion

This study confirms that Gampong Deah Raya is a coastal settlement with high exposure to a compound disaster environment dominated by earthquake, tsunami, and liquefaction hazards. The spatial analysis shows that most of the settlement is located in high-risk zones, which is closely related to its low elevation, coastal position, and soil conditions that increase exposure to cascading hazards. These physical characteristics make the settlement particularly susceptible to severe damage when a major seismic event occurs.

The community survey results show that residents have a relatively high awareness of disaster risk, especially regarding earthquake and tsunami threats. However, this awareness has not yet fully translated into strong practical preparedness. Non-structural mitigation, such as disaster education, drills, and risk communication, remains uneven, while structural mitigation, including evacuation routes and safety infrastructure, is only moderately available. This indicates a clear gap between risk perception and mitigation readiness at the settlement level.

Based on these findings, integrated mitigation planning is necessary for Gampong Deah Raya. Disaster risk reduction in this coastal settlement should combine structural measures, such as evacuation routes, vertical evacuation buildings, and building reinforcement, with non-structural measures, such as community education, evacuation simulations, and local risk communication. Such an integrated approach is essential for strengthening coastal settlement resilience and supporting safer and more sustainable disaster-oriented planning in Banda Aceh.

Acknowledgments

The authors would like to thank the Banda Aceh City Government and the Gampong Deah Raya community for their support and cooperation during data collection. The authors also acknowledge the assistance of relevant institutions in providing spatial and hazard data for this study.

Conflict of Interest

The authors declare no conflicts of interest.

Author Contribution Statement

Muhammad Rizky: Conceptualization, Data curation, Formal analysis, Investigation, Writing – Original draft. **Dyah Erti Idawati:** Supervision, Methodology. **Mirza Irwansyah:** Supervision, Methodology. **Asrul Mahjuddin Ressayang:** Supervision, Methodology.

Data Availability Statement

The data used to support the findings of this study are included within the article. Additional spatial data were obtained from authorized government institutions and are available upon reasonable request.

Ethics Approval

Not required.

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