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Strategic land use optimization in tsunami-prone city of Banda Aceh: Building disaster awareness and resilience

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Abstract: Banda Aceh, the capital city of Aceh Province, is located at the northern tip of Sumatra Island. Geographically, it is particularly vulnerable to earthquakes and tsunamis. In 2004, a devastating earthquake struck the city, leading to a tsunami that destroyed and washed away many developed urban areas. Over the last decade, rapid development has significantly transformed the city's landscape. As reconstruction efforts continue, it is essential that they adhere to Banda Aceh's Spatial Planning, especially considering the region's susceptibility to disasters due to past tsunami events. This study aims to identify and analyze the tsunami-vulnerable regions in Banda Aceh resulting from the 2004 disaster, assess the spatial planning from 2009 to 2029 in these areas, and propose alternative safe zones for tsunami preparedness. The mixed-method approach employs scoring analysis, GIS software, and interviews with local residents and relevant agencies. The findings indicate that the tsunami inundation zones include the districts of Syiah Kuala, Meuraksa, Kutaraja, Jaya Baru, and Kuta Alam. Post-tsunami land use in Banda Aceh has evolved significantly, with vacant land decreasing from 2,519.2 hectares in 2005 to 341.55 hectares in 2014. Three alternative tsunami-safe zones are proposed, with the safest being parts of Jaya Baru, Kuta Alam, and Syiah Kuala districts.

Keywords: *Banda Aceh, Post-tsunami reconstruction, Spatial analysis, Tsunami-prone area, Urban spatial planning, Vulnerable.*

1. Introduction

Banda Aceh, the Capital City of Aceh Province, experienced a devastating tsunami at the end of 2004 [1]. According to the National Board for Disaster Management No. 8 of 2011, a tsunami is a series of giant sea waves caused by a shift in the seabed due to an earthquake [2]. The tsunami significantly damaged parts of Banda Aceh, particularly the coastal areas, including Meuraksa, Syiah Kuala, and parts of Kuta Alam and Kuta Radja districts [3]. This event left a profound impact, causing both physical and non-physical paralysis in the city. A decade after the tsunami, the Spatial Planning of Banda Aceh underwent substantial changes, with significant development activities undertaken by both the Banda Aceh City government and foreign aid [4]. This development is evident from the reduced land vacancy and the increased population, escalating demand for residential, commercial areas, and city infrastructure.

However, this urban growth has resulted in a cluttered city layout, necessitating proper urban planning. One critical effort in urban planning implementation is the adjustment of the Spatial Plans [5]. Rebuilding urban areas after a tsunami offers a valuable opportunity to promote sustainable urban planning. By optimizing developed areas in new growth centers, it is possible to enhance environmental sustainability and strengthen disaster resilience [6].

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The Spatial Planning encompasses several disaster-related planning aspects, including spatial structure and spatial pattern planning for disaster-prone areas. These plans are essential for disaster mitigation [7]. According to Indonesian Law No. 26 of 2007 on Disaster Management, mitigation involves a series of efforts to reduce disaster risk, including physical development and awareness-raising initiatives to enhance preparedness for disaster threats [8]. Given the high disaster risk in Banda Aceh, as evidence by the 2004 tsunami and subsequent land use changes, it is crucial to analyze land use in tsunami-prone areas based on the Spatial Planning of Banda Aceh (RTRW).

The research problem highlights that Banda Aceh is highly susceptible to earthquakes and tsunamis due to its location on the Sumatra fault line and predominantly coastal area [1]. The 2004 earthquake-triggered tsunami severely impacted almost all of Aceh Province, with Banda Aceh suffering the most damaged. The city was severely impacted by the devastating 2004 Indian Ocean earthquake and tsunami, which resulted in widespread destruction and loss of life [9]. Historical earthquake data indicate a significant likelihood of future tsunamis in Aceh. A decade after the tsunami, Banda Aceh has undergone considerable changes, with population growth and development potentially leading to chaotic urban planning, especially in disaster-prone areas. This situation is evident in the ongoing reconstruction of former tsunami-affected coastal zones. This condition is different from the development that occurred in the early stages of the rehabilitation and reconstruction process (2004-2009), where development was carried out away from the coast [6].

This research focuses on identifying the tsunami-prone areas in Banda Aceh as of 2004, assessing how land use in these disaster-prone areas has changed ten years after the tsunami, and providing alternatives for tsunami-safe zones. The study aims to analyze the tsunami-prone areas in Banda Aceh in 2004, assess land use based on the 2009-2029 spatial planning for tsunami disaster areas a decade after the disaster, and propose safe zone alternatives for potential future tsunamis. The practical benefits of this research include serving as a protective measure for the Banda Aceh Spatial Planning document, particularly in spatial structure and pattern planning for disaster-prone areas, contributing to future disaster mitigation efforts, and offering alternative solutions for safe zones in these areas. Scientifically, the research aims to provide valuable references and input for the government and people of Banda Aceh in their policy making and actions to safeguard against disaster threats, given Aceh's high vulnerability to natural disasters.

2. Material and Methods

This study is located in the City of Banda Aceh, especially in the area affected by the tsunami in 2004, including Syiah Kuala District, Meuraksa, Kutaraja, part of Jaya Baru Districts, and part of Kuta Alam District, which is about 5 km from the coastline (Figure 1). The scope of the study is limited to land use analysis based on spatial plans in tsunami disaster areas, which focuses on the accuracy of results. The research population is the community around the tsunami disaster area. The sampling technique used is incidental sampling, where the sample is determined based on a chance encounter with the researcher and is considered suitable as a data source. For the interview, it is assumed that one respondent represents each village as an informant to corroborate the data that has been obtained.

2.1. Research Concept

The conceptual framework for research on the impact of the 2004 tsunami in Banda Aceh focuses on post-disaster land use and regional Spatial Planning. The research began against tsunami devastation, followed by rebuilding, population increase, and land use intensity. The main issues discussed were the tsunami's impact, changes in land use 10 years later, and alternative tsunami-safe zones. The research aims to analyze the areas affected by the 2004 tsunami, assess land use based on the 2009-2029 Spatial Planning, and provide alternative safe zones. The analysis involves the vulnerability of residents, buildings, and coastlines using scoring analysis and overlay. The research results are recommendations for disaster mitigation and future spatial planning.

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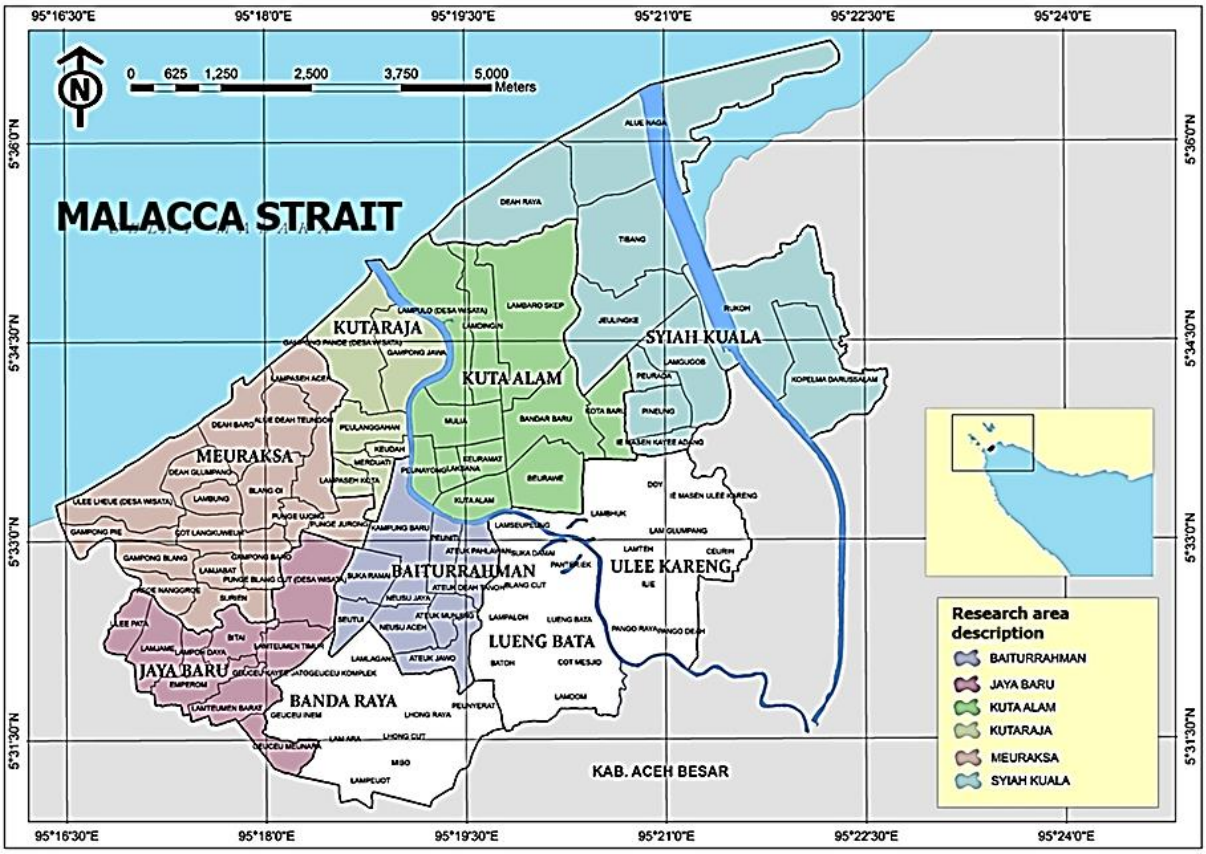

Figure 1.
Research Study Area.

2.2. Research Design

This study uses a combination method (mixed-method), which combines quantitative and qualitative methods to obtain more comprehensive, valid, reliable, and objective data. Quantitative methods include mapping the impact of tsunamis, land use based on the 2009-2029 Spatial Plans, and tsunami safe zones, while qualitative methods are carried out through interviews with people in disaster areas. The analysis descriptively used secondary data from Spatial Planning documents, land use maps, tsunami inundation maps, and primary data from interviews. The Banda Aceh Spatial Planning 2009-2029 (1:25.000) include studying disaster areas after the 2004 tsunami, focusing on disaster mitigation in coastal regions such as Meuraksa, Kutaraja, and Syah Kuala. This study will map post-tsunami land use in the disaster area of Banda Aceh City using ArcGIS®10.1 application with geoprocessing tools, resulting in the identification of land use, conformity with Spatial Planning, and alternative tsunami-safe zones (Figure 2).

2.3. Data Collection

This study uses primary and secondary data collection techniques. Primary data was obtained through interviews with people living in tsunami-affected areas to understand why they chose to stay, as well as field observations to directly observe the tsunami impact areas and post-tsunami development. Secondary data was collected from institutions related to the City of Banda Aceh (*Dinas Cipta Karya*, *Bappeda*, and the Aceh Disaster Management Agency) and through literature studies that examined Banda Aceh Spatial Plans documents and related literature. The survey involves an initial

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understanding of the study area, followed by an analysis of the disaster area using the collected data (Table 1). The data required includes maps through Geographic Information System (GIS) and other relevant information to support the analysis of land use in tsunami disaster areas based on the 2009-2029 Spatial Planning after 10 years of tsunamis.

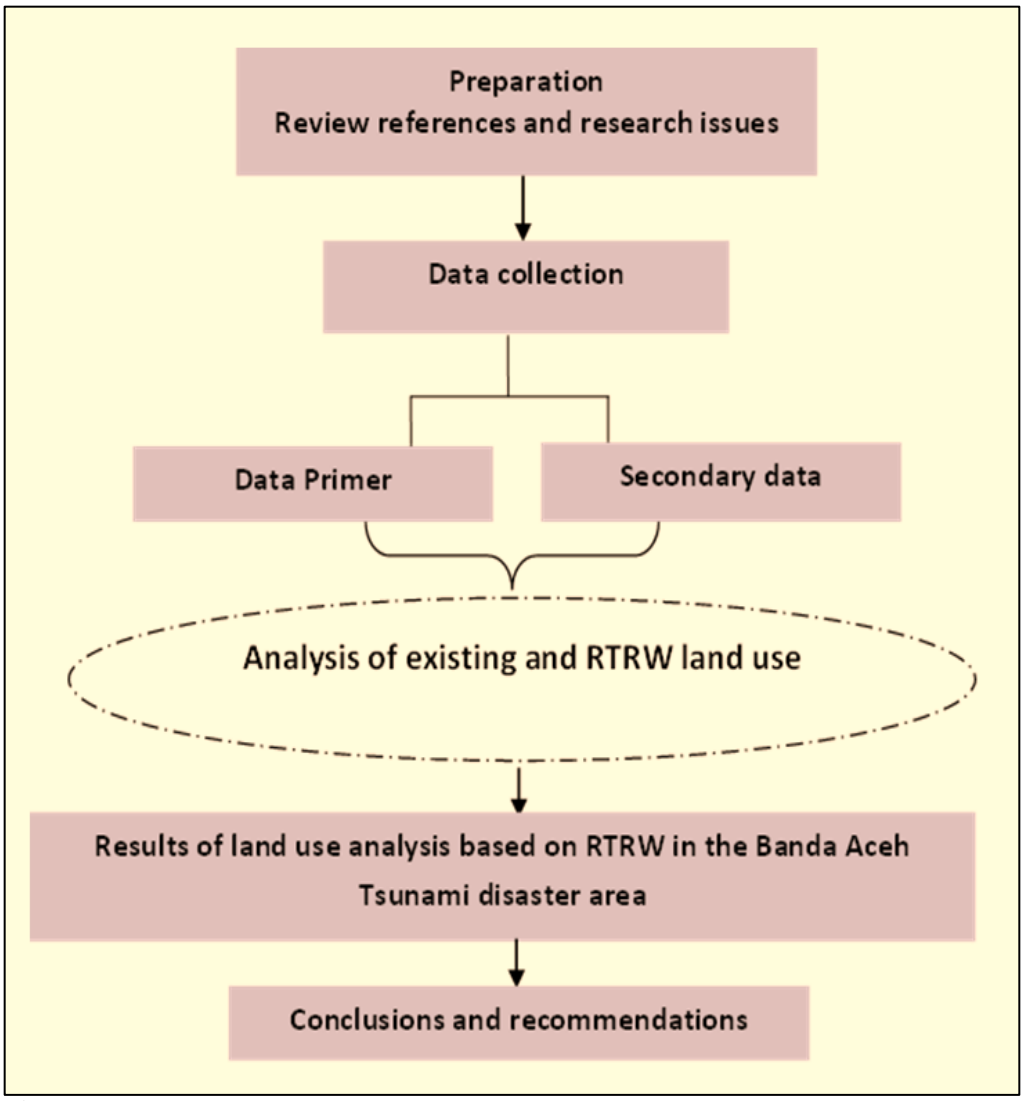

Figure 2.
Research flow.

2.4. Data Analysis

The analysis methods in this study include scoring analysis, descriptive analysis, and evaluative/spatial analysis. Scoring analysis provides a score on each variable used. Descriptive analysis solves problems based on the data described in pictures/maps, graphs, tables, and diagrams. (to obtain better study results). In addition, the analysis also uses a spatial model with digitization and map overlays related to the suitability of land use in the tsunami disaster area to the Spatial Planning of the Banda Aceh region after 10 years of the tsunami. Data analysis starts from input (data and facts), process (data scoring and map overlay), and output (analysis results and strategic plans)

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Table 1.
Research data and information.

No.	Data and Information	Source	Data Type	Year
1	Image Map of the tsunami disaster impact area (SHP)	Bappeda, PU BPBD Banda Aceh	Primary	2005 and 2011
2	Image Map of Destroyed Land in the Tsunami Area (SHP)	Bappeda, PU BPBD Banda Aceh	Primary	2005 and 2011
3	Banda Aceh in Numbers	BPS	Primary	2005 and latest
4	Land Use Map - RTRW 2009-2029 (shp)	Bappeda Banda Aceh	Primary	2014/ Latest
5	Banda Aceh RTRW Document	Bappeda Banda Aceh	Primary	Latest
6	Community interviews	Community	Seconds	Latest

3. Results and Discussion

This study uses the GIS to analyze tsunami-prone areas in Banda Aceh, evaluate land use changes 10 years after the tsunami, and determine safe zones. The results show that flat coastal regions are at high risk, while land use has changed significantly, with many areas being rebuilt or turned into green land. Safe zones are found in areas higher up and away from the coast, which are essential for evacuation planning and sustainable development. This approach provides valuable information for disaster mitigation and better spatial planning.

3.1. Analysis of Banda Aceh Tsunami Disaster Vulnerable Areas

This study aims to identify areas vulnerable to tsunami disasters in Banda Aceh by considering several factors such as population density, building density, distance from the coastline, and tsunami inundation areas. The City of Banda Aceh, which has an area of 6,136 Ha and is inhabited by 259.538 people (2023), shows an average population density of 3,892 people/km². Baiturrahman District has the highest density, with 7,150 people/km², followed by Jaya Baru District, which has an area of 3.78 km² with a density of 6,228 people/km². On the other hand, Kuta Raja District, with an area of 5.21 km², has the lowest population density of 2,140 people/km².

The analysis results based on the population density of Banda Aceh City show that the districts affected by the high vulnerability zone are the Baiturahman and Jaya Baru Districts. The district with the highest density level will cause high vulnerability, and the assumption is that the higher the population density of a district, the more casualties will be affected by the tsunami disaster. The population of Banda Aceh City will continue to increase every year, so it is necessary to make efforts to reduce the population. In this case, it will slightly reduce the loss of life and casualties. Areas with a high population will be more vulnerable to the impact of tsunamis. The density of an area affected by a disaster will cause many casualties. The formula determines the interval class of the population density. Low vulnerability (2,140 – 3,810 people/km²); Medium Vulnerability (3,810 – 5,480 people/km²); High Vulnerability (5,480 – 7,150 inhabitants/km²). The formula below will be classified into population density in Banda Aceh City based on each district [10].

$$\text{Vulnerability} = \frac{\text{Highest Population Density} - \text{Lowest Population Densityh}}{\text{Vulnerability Interval Class}}$$

$$\text{Vulnerability} = \frac{7.150 - 2.140}{3} = 1.670$$

Table 2 illustrates the classification of population density vulnerability in several districts in Banda Aceh based on population density, score, and vulnerability classification. Meuraksa District has a population density of 2,140 people and is classified as a low-vulnerability area with a score of 1. Jaya Baru and Baiturrahman districts have a population density of 7,150 people, both classified as high-vulnerability areas with a score of 3. Kuta Alam District has a population density of 3,810 people and is

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classified as an area with moderate vulnerability with a score of 2. Kuta Raja and Syiah Kuala districts each have a population density of 2,140 people, classified as medium (Kuta Raja) and low (Syiah Kuala) vulnerable areas with a score of 1. The average population density of all these districts is 4,088, and they are classified as an area with moderate vulnerability with a score of 2. This table shows the variation in vulnerability levels based on population density in different districts, which is essential for more effective disaster mitigation and spatial planning in Banda Aceh.

Population density-based vulnerability across districts in Banda Aceh is crucial for more effective disaster mitigation planning. The high population density in disaster-prone areas can increase risks to life due to limited evacuation access and the challenges of managing crowd movement in emergencies [11]. High-density areas like Kuta Alam and Baiturahman districts, for example, require special attention to prepare more efficient evacuation routes and adequate support facilities, such as temporary shelters and assembly points [12]. Population density data also aids in defining safe and vulnerable zones in more detail, allowing for more effective planning in resource allocation and the development of disaster-resistant infrastructure [13]. Thus, population density-based vulnerability mapping is a strategic tool for the government in formulating disaster management policies and spatial planning that responds to disaster risks in Banda Aceh.

Table 2.
Classification of Population Density Vulnerability.

District	Population Density	Score	Vulnerability Classification
Meuraksa	2,140	1	low
Jaya Baru	7,150	3	Hight
Baiturrahman	7,150	3	Hight
Kuta Alam	3,810	2	Moderate
Kuta Raja	2,140	1	Moderate
Syiah Kuala	2,140	1	low
Average	4,088	2	Moderate

In this analysis, building density indicates vulnerability to tsunami disasters. The buildings include housing, shops, school facilities, health facilities, offices, and other facilities and infrastructure. The higher the density level, the higher the vulnerability to damage due to tsunami disasters. On the other hand, the lower the density of buildings, the lower the damage due to tsunami disasters. In this analysis, Table 3 shows the total percentage of land allocation in Banda Aceh City. The building density of the city of Banda Aceh is identified from the number of areas and percentages where the number of building densities owned is very high, namely 919.9 Ha, medium building density of 765.92 Ha, and low building density of 1,868.13 Ha.

Table 3.
Land use of Banda Aceh City.

No.	Type of Use	Area (Ha)	Percentage (%)
1	Cultural Heritage Area	16.65	0.468
2	Mangrove Forest Area	434.38	12.222
3	Tourism Area	16.65	0.468
4	Port Area	11.76	0.331
5	Trade and Service Zone	434.38	12.222
6	Fisheries Area	32.07	0.902
7	Residential Areas	179.9	5.062
8	Office Area	552.72	15.552
9	Public Services	293.86	8.269
10	Green Open Space	552.72	15.552
11	Non-Green Open Space	25.39	0.714
12	River Boundary	179.9	5.062
13	Water body	482.02	13.563

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Figure 3 shows a map of the vulnerability of the Banda Aceh region to tsunami disasters based on population density, which is categorized into low (green), medium (yellow), and high (red) vulnerabilities. Areas with high vulnerability, such as Jaya Baru, Baiturrahman, and Banda Raya districts, have very high population density, making them vulnerable to tsunami impacts. Areas with moderate vulnerability, including Kutaraja and Kuta Alam Districts, have a relatively high population density but are not as dense as areas with high vulnerability. Meanwhile, low-vulnerability regions, such as Syiah Kuala District, Ulee Kareng, and most of Kutaraja and Kuta Alam Districts, have lower population density, so the risk of tsunami impact is negligible.

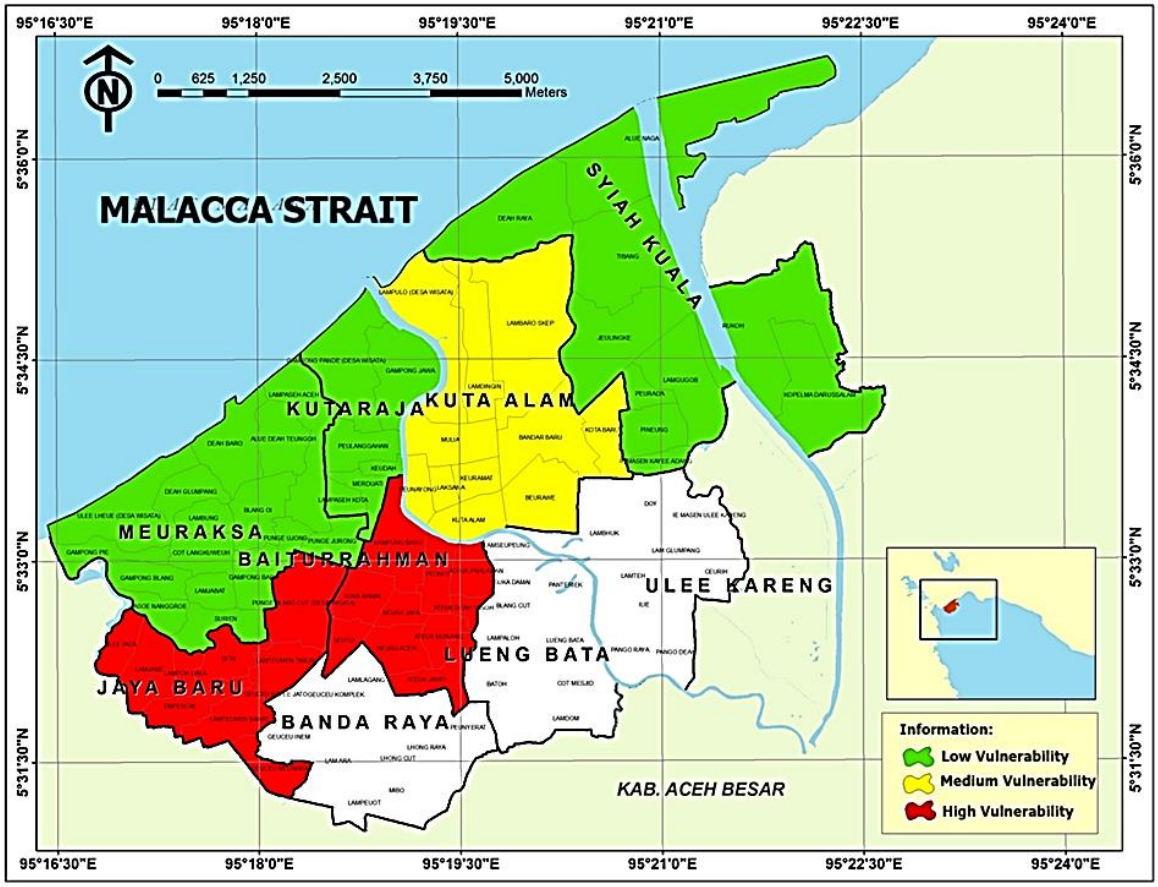

Figure 3.
Map of Vulnerable Areas by Population Density.

The map provides a clear visual guide to the distribution of population vulnerability to tsunamis in Banda Aceh, aiding in more effective mitigation and evacuation planning. This result has been analyzed using land use scoring in Banda Aceh City. It can be seen that the most physical vulnerability of building density is the low building vulnerability score of 53%, followed by the vulnerability score of high buildings as much as 26% and the vulnerability of low buildings as much as 21%. The results of this analysis are also implemented with a Vulnerability Area Map based on building density obtained from scoring results using ArGis with building density indicators [14].

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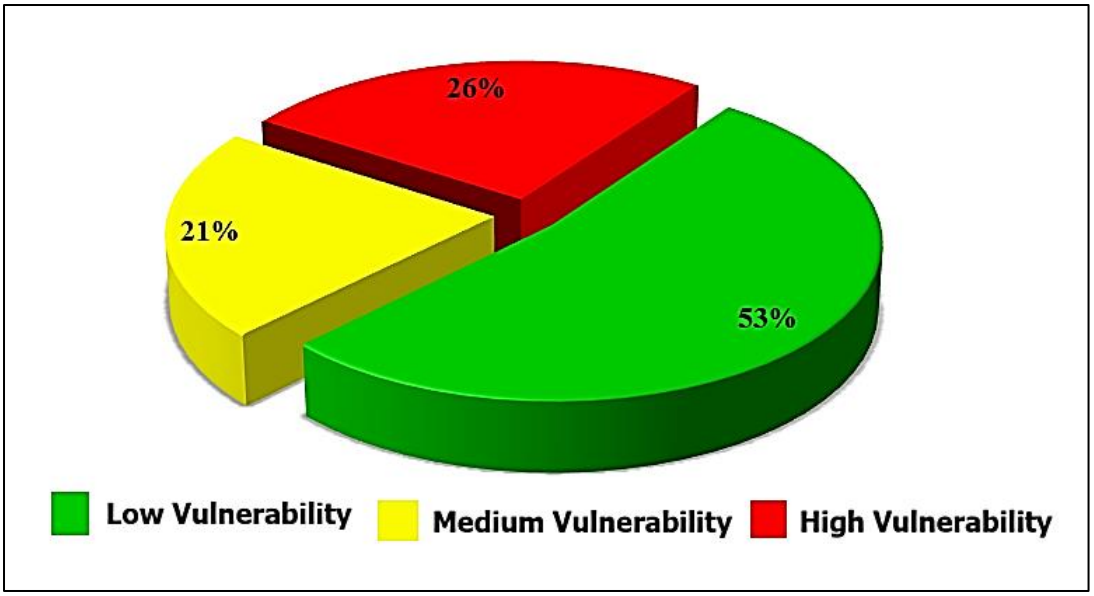

Figure 4.
Graph of land use percentages in Banda Aceh City.

The vulnerability score is based on buildings divided into three classes. The division of each class is seen based on building density, sea distance, and river distance (Figure 4). The score of 1 is low vulnerability, which is characterized by the absence of buildings, such as the use of vacant land and the use of land for water in some Meuraksa districts, parts of Kuta Alam districts, some Kuta Raja districts and some Syiah Kuala districts. Score 2 is medium vulnerability, with a dense building density and far from the sea and rivers. The area on score two consists of Jaya Baru district, Part of Baiturahman district, Part of Kuta Alam district, and Part of Syiah Kuala district. The density of tall buildings close to the sea and rivers marks a score of 3. The area consists of part of Meuraksa district, part of Kuta Alam district, part of Kuta Raja district, and part of Syiah Kuala district (Table 4).

Based on an analysis by Hastuti, et al. [15] the vulnerability to tsunamis increases along with the region's proximity to the coastline. Areas closer to the coastline are more vulnerable to tsunamis, while areas farther away are becoming less vulnerable [15]. This classification of vulnerability levels is illustrated in Figure 7, which shows that the highly vulnerable area is less than 100 meters from the coastline, as the coast is the first area to interact with a tsunami from the sea. Areas over 1000 meters from the coastline are less prone to tsunamis. Based on the coastline, the vulnerable areas include four districts adjacent to the sea: Meuraksa district, Kutaraja district, Kuta Alam district, and Syiah Kuala district.

The area within 100 meters of the coastline in Banda Aceh is considered highly vulnerable, as it is the first to be impacted by a tsunami. The immediate proximity to the coast amplifies the risk, as tsunami waves carry immense force and can inundate these areas with minimal warning [16]. Due to this direct exposure, buildings, infrastructure, and communities in this zone face a greater risk of severe damage or destruction. Preview research underscores that coastal areas require reinforced protective infrastructure, such as seawalls, breakwaters, and green buffers, to mitigate wave impact [17]. Rapid evacuation routes and early warning systems are critical for reducing casualties in these high-risk zones. Identifying and managing these highly vulnerable areas allows for more targeted disaster preparedness and resource allocation, it was recommended, ensuring that communities closest to the coast have the necessary protections and are better prepared for potential tsunami events [18].

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Table 4.
Classification of Land Use Vulnerability in Banda Aceh City.

No.	Land Use	Level/score	Vulnerability Classification
1	Cultural Heritage Area	2	Medium Vulnerability
2	Mangrove Forest Area	1	Low Vulnerability
3	Tourism Area	2	High Vulnerability
4	Port Area	3	High Vulnerability
5	Trade and Service Zone	3	High Vulnerability
6	Fisheries Area	1	Low Vulnerability
7	Residential Areas	2	Medium Vulnerability
8	Office Area	2	Medium Vulnerability
9	Public Services	3	High Vulnerability
10	Green Open Space	1	Low Vulnerability
11	Non-Green Open Space	1	Low Vulnerability
12	River Boundary	3	High Vulnerability
13	Vacant Land	1	Low Vulnerability
14	Water Body	1	Low Vulnerability

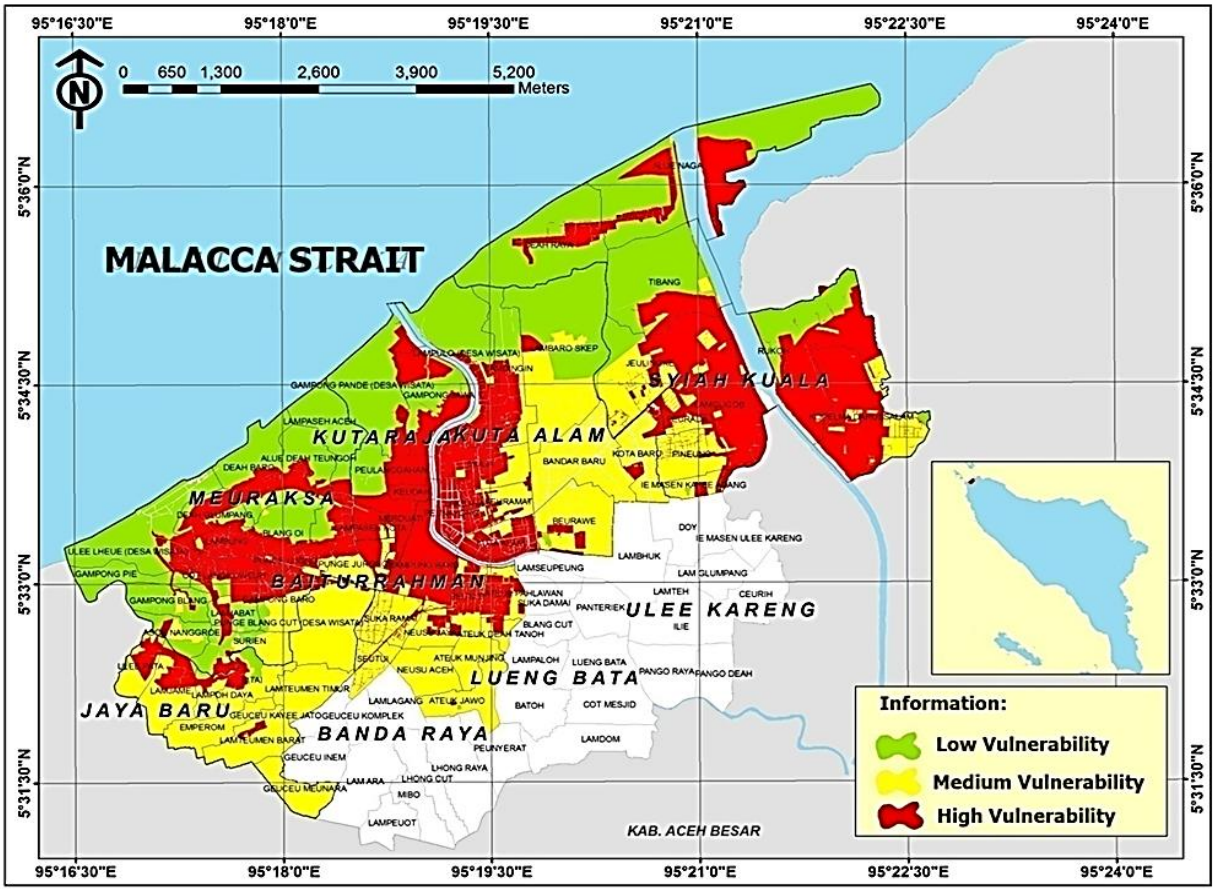

Figure 5.
Map of Vulnerable Areas by Building Density.

Figure 5 shows a map of tsunami vulnerability areas in Banda Aceh based on building density, with color scales: green for low vulnerability, yellow for medium vulnerability, and red for high vulnerability. Areas with high building density, especially those near the coastline, such as Meuraksa, Kutaraja, Kuta Alam, and Syiah Kuala districts, are marked red and vulnerable to tsunamis. In contrast, areas with low

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vulnerability, such as some parts of Jaya Baru and Banda Raya districts, are marked in green, indicating a greater distance from the coast or a lower density of buildings. Yellow indicates moderate vulnerability in the region between high and low vulnerability areas. These maps are essential for spatial planning and disaster mitigation, helping to identify areas that need special attention in infrastructure development, evacuation strategies, and community protection from potential tsunami threats.

Various physical, social, and environmental factors influence the vulnerability of Banda Aceh to tsunami disasters. Benazir, et al. [19] found that the flat topography of Banda Aceh's coastal areas allows tsunami waves to spread further inland, increasing the risk of damage [19]. This vulnerability is exacerbated by infrastructure development close to the shore and low public awareness of safe evacuation routes. Additionally, spatial analysis conducted by Rasyif, et al. [18] using GIS indicates that areas such as Ulee Lheue, Meuraksa, and Kuta Alam, located near the coast and at low elevations, are classified as high-risk zones for tsunamis [18].

Social structure also affects vulnerability levels. Satterthwaite, et al. [20] notes that lower-middle-income communities tend to reside in high-risk coastal areas due to limited access to safer housing options [20]. Based on recommendations from various studies, suggested mitigation measures include public education, disaster-resistant infrastructure development, and the establishment of effective evacuation routes. Perera, et al. [21] also emphasize the importance of building wave breakers and green zones along the coastline to reduce tsunami impact and the necessity of regular evacuation drills to improve community preparedness for potential future disasters [21].

3.2. Alternative Analysis of Tsunami Safe Zones

Currently, land use in Banda Aceh City is not following the disaster area plan, as seen from the high-density level affected by the tsunami. The analysis results show that areas with high vulnerability to tsunamis include Meuraksa district, Kuta Raja, parts of Jaya Baru, Kuta Alam, and Syiah Kuala districts. This aligns with the statement that the closer to the coastline, the higher the vulnerability to tsunamis [22]. This study aims to provide strategies for reducing the impact of tsunami disasters. An alternative tsunami-safe zone is shown in Figure 6, which results from an overlay of a map of vulnerable areas of population density, building density, tsunami inundation, and coastline.

As illustrated in Figure 6, an alternative tsunami-safe zone is developed by overlaying maps of vulnerable areas based on population density, building density, tsunami inundation zones, and proximity to the coastline. This comprehensive approach to mapping allows for a more accurate risk assessment by combining multiple vulnerability factors, ensuring that the designated safe zones are strategically located to minimize exposure to tsunami hazards [23]. By incorporating population and building density, the map considers the areas with higher concentrations of people and infrastructure, where evacuation may be more challenging in the event of a tsunami. The addition of tsunami inundation and coastline proximity data further refines these zones by considering the areas most likely to experience the brunt of a tsunami's force [24]. This multi-layered mapping technique aids disaster management agencies in planning effective evacuation routes and infrastructure development, focusing on areas that provide the highest level of safety for the population during a tsunami [25].

This overlay's results differ from those of the Tsunami and Disaster Mitigation Research Center (TDMRC) Universitas Syiah Kuala hazard map, which only considers tsunami hazards based on the distance from the coastline and inundation areas. According to the TDMRC map, the safe zone is marked by a long distance from the sea despite having a high population density [26]. The alternative map of tsunami disaster safe zones shows three categories: Alternative 1 (Very Safe Zone, Green), which is located in parts of Jaya Baru, Baiturahman, Kuta Alam, and Syiah Kuala districts; Alternative 2 (Safe Zone, Yellow) which is located in parts of Baiturahman, Kuta Raja, Kuta Alam, and Syiah Kuala districts; and Alternative 3 (Unsafe Zone, Red) which is 2 km from the coast and is located in Meuraksa district, parts of Kuta Raja, Kuta Alam, Baiturahman, and Syiah Kuala.

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This map provides strategic guidance in determining safe zones for future tsunami disaster mitigation, supporting previous findings on the need for comprehensive and evidence-based mitigation strategies [27]. The spatial analysis provides a more comprehensive view of how spatial planning can reduce disaster risk in disaster risk-based zoning [28].

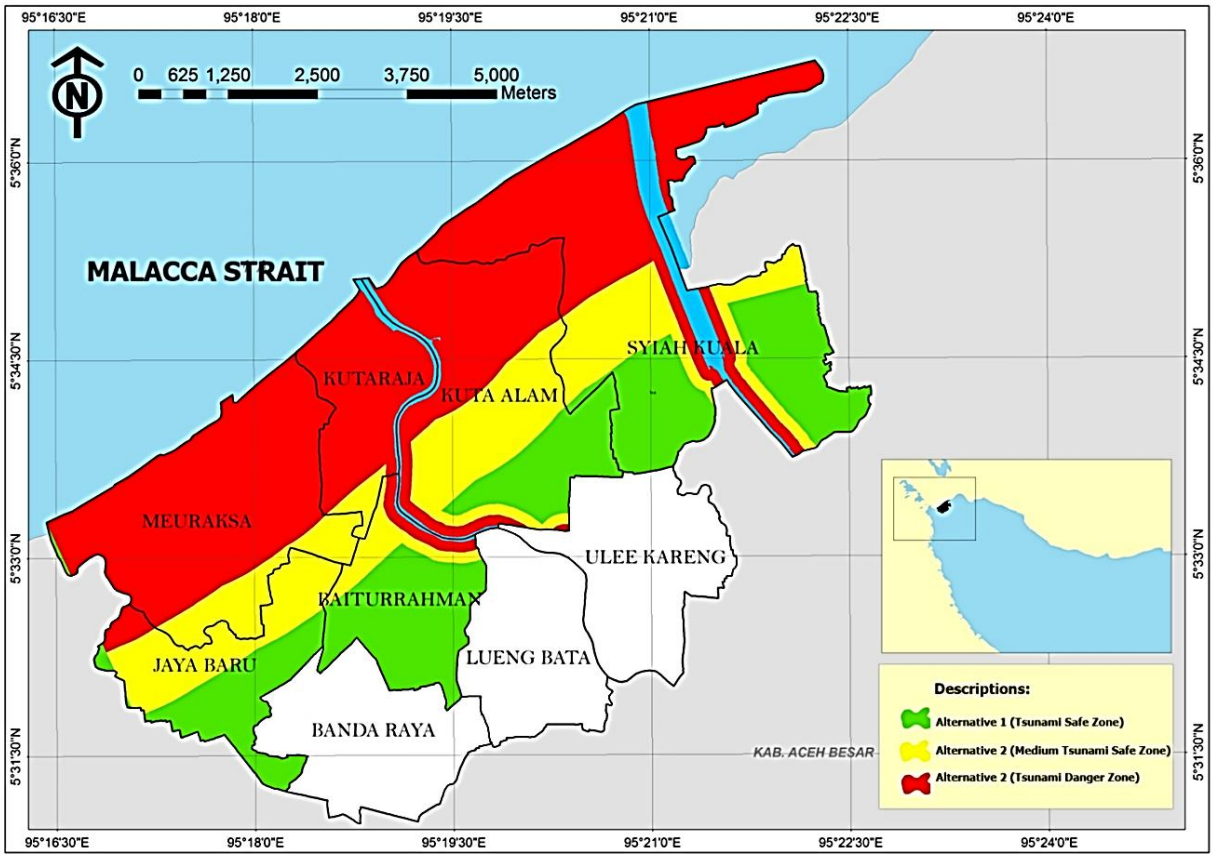

Figure 6.
Alternative map of tsunami disaster safe zones in Banda Aceh City based on analysis of tsunami disaster-prone areas.

The alternative map of tsunami disaster safe zones in Banda Aceh City is developed based on a thorough analysis of disaster-prone areas, incorporating factors such as proximity to the coastline, population density, building density, and historical tsunami inundation data.

This approach ensures a more nuanced understanding of safety zones, highlighting areas less likely to experience direct impact from a tsunami. They emphasize that regions farther from the coast, with lower population and building density, are generally safer and can serve as effective evacuation sites [29]. By overlaying various risk factors, this map identifies locations that offer relatively secure conditions in the event of a tsunami, particularly in inland zones that are elevated or shielded from direct wave impact [30].

The alternative map aids in planning for effective evacuation routes and establishing emergency facilities by identifying areas that provide sufficient distance from the coast and lower exposure to tsunami forces [31]. Additionally, It was recommended that the researcher integrate green buffer zones along the coastline, which, coupled with designated safe zones, offer added protection and act as a natural barrier against waves [32].

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This alternative map is a critical tool for disaster management and urban planning in Banda Aceh, enhancing the community's preparedness and resilience against potential tsunami events [9].

4. Conclusion

The research concludes that the tsunami-prone area in Banda Aceh extends around 5 km from the coast, covering districts like Syiah Kuala, Meuraksa, Kutaraja, parts of Jaya Baru, Kuta Alam, and Baiturahman. Although land use is expanding rapidly, waterlogged areas have significantly decreased, with vacant land reduced from 2,519.2 Ha in 2005 to 341.55 Ha in 2014. The alternative safe zone map, which categorizes areas into very safe (parts of Jaya Baru, Kuta Alam, and Syiah Kuala), secure, and unsafe zones, differs from the TDMRC hazard map by incorporating additional factors beyond distance and inundation. Recommendations include incorporating these findings into Banda Aceh's spatial planning, implementing coastal mitigation policies, and educating communities in high-risk areas like Meuraksa, Kuta Alam, Kutaraja, and Syiah Kuala on tsunami risks and mitigation.

5. Research Limitations

This research has several limitations, including the use of secondary data, which may not be accurate and complete; potential bias in interviews with local communities that rely on individual memories and perceptions; limited resolution of map data in spatial analysis using GIS and overlays; focus on areas already affected by the tsunami without considering the potential for climate change and sea level rise in the future; does not include economic and social factors in depth; as well as technical approaches in determining safe zones which may require integration with participatory approaches for more comprehensive and applicable results.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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