Disaster risk reduction through the reform of spatial structure and land use planning in Banda Aceh City

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Abstract. Reform of spatial structure and land use planning aims to reduce disaster risk and protect development outcomes. Ignoring spatial reform will increase the risk of more significant damage. A resilient city has the essential character to survive and to bounce back in no time. This decade, the development of global countries has focused on investing in resilience to protect development outcomes, including livelihoods. This study aims to determine the index of tsunami risk, vulnerability, and capacity and the proposed concept of spatial planning reform in the city of Banda Aceh. The research uses explanatory methods with geographic information systems and literature studies. The formula for calculating the vulnerability index was derived from Perka BNPB No. 2 of 2012. The high level of land use changing into settlements in coastal areas since the rehabilitation and reconstruction period until now, accompanied by a higher level of vulnerability (v), tsunami hazard (h), and low capacity (c) to reduce vulnerability exposure, indicates that it is necessary to reform the spatial plan of Banda Aceh City for mainstreaming the resilience infrastructure. Through investing in resilience infrastructure, the city’s capacity will increase and reduce the risk (r), and finally, the protection of development and citizens can be realized.

1. Introduction

The devastating disaster of the 2004 Aceh earthquake and tsunami-affected countries in Asia made a firm path and momentum for disaster risk reduction in Indonesia and in global countries. This incident brought a change in the perspective of disaster and its management globally. In 2005, the Hyogo Framework for Action (HFA) was established and was adopted for the first time internationally for disaster risk reduction [1]. Then, the 2011 Japan Earthquake and Tsunami offered a lesson and resulted in a new DRR formulation, namely the Sendai Framework for Disaster Risk Reduction 2015-2030 [2]. The Sendai Framework for Disaster Risk Reduction (SFDRR) 2015-2030 is the first significant agreement on the post-2015 development agenda and provides member countries with concrete action to protect development outcomes from disaster risk [3].

Furthermore, the disasters in Japan proved that the sea wall was not solid and high enough to withstand the impact/overflow of a tsunami wave followed by the liquefaction and the impact of damage from various structures on the coast to the land. Indonesia, through BNPB (Indonesian National Board for Disaster Management), produced a mental model, such as "when we protect nature, nature will protect us." This mental model emphasizes the importance of disaster risk reduction through capacity
building and robust infrastructure investment in cities with high hazard indexes. Through this research, it is hoped that the local, provincial, and central governments can work together in reforming structural plans and land use plans based on resilience through the efficiency and effectiveness of municipal, provincial, and national expenditure budgets, including the use of special autonomy funds.

2. Methods
This study employed a case study approach and explanatory research design, selecting cities in the province of Banda Aceh-Aceh (at the tip of Sumatra island) as described in the introduction above. The data collected in this study also consisted of secondary data from previous observations and literature studies. Disaster risk analysis used the General Guidelines No. 02/2012 issued by the BNPB [4]. Meanwhile, a geographic information system (GIS) was used to process and overlay the data, which results in spatial maps with several index variables.

The steps of data analysis techniques included (1) statistical data processing, especially the economic, social, physical, and environmental variables to calculate the level of risk for each variable; (2) spatial data processing covering municipal areas, infrastructure, and urban service system centers; (3) the results of statistical data processing integrated with the spatial data, becoming spatial-based risk index information; (4) spatial data related to tsunami runoff using data from the city government superimposed on the various variables above; (5) analysis of structural reform and land use planning using the risk analysis that has been carried out and comparing several case studies in Japan and Palu. However, due to existing limitations, this research was limited to the risk of tsunami disasters and explanations on how to reduce the risk.

3. Results and Discussion
In this section, five essential things are discussed and are the research results: (1) the Indonesian National Policy-RPJMN (National Medium-Term Development Plan) on Resilient Cities; (2) the Aceh Regional Spatial Plan and the Banda Aceh City Spatial Plan; (3) Tsunami Disaster Vulnerability and Risk Index 2020; (4) Lessons on Spatial Planning for Tsunami Prevention in Tohoku – Sendai, Japan; and (5) Structural and Land Use Plan Reform to increase capacity.

3.1. The Indonesian National Policy-RPJMN on Resilient Cities
Law Number 24 of 2007 concerning Disaster Management in articles 6 (a) and 8 (c) states that the responsibility of the Government and Local Governments involves disaster risk reduction and the integration of disaster risk reduction with development programs [5]. This mandate demands that cooperation between the central and regional governments be realized to reduce disaster vulnerability through program integration. The National Medium-Term Development Plan (RPJMN) 2020-2024 mandates the development of areas to reduce inequality and equity; the policies and strategies taken are the enforcement of spatial plans based on climate change mitigation and disaster risk reduction to ensure the protection of spatial functions and the prevention of negative impacts on the environment due to space usage [6].

3.2. The Aceh Regional Spatial Plan and the City of Banda Aceh Spatial Plan
Aceh Qanun No. 19/2013 concerning the 2013-2033 Aceh Regional Spatial Plan mandates the construction of the Banda Aceh Outer Ring Road (BORR) (article 17) as a development of the primary collector road network system 1 (National Strategic Road). Paragraph seven of the article also explained that the road is a part of disaster mitigation [7]. It was also stated that zoning regulations in the tsunami area were limited to agricultural activities, plantations, fisheries, community forests, and production forests, likewise with Qanun Number 02 of 2018 concerning the Banda Aceh City Spatial Plan, which regulates the existence of a BORR development plan as a primary arterial road.
3.3. Tsunami Disaster Vulnerability and Risk Index in 2020.
The Tsunami Risk Assessment in Banda Aceh City uses the Risk Index formula (r), which is the result of multiplying the hazard index value (h) with the vulnerability index value (v), then dividing the product with the capacity index value (c) [8].

The results reveal that high-level tsunami hazard (h) covers the sub-districts of Meuraxa, Kuta Raja, half from Jaya Baru, half from Kuta Alam, and a half from Syiah Kuala. Then, the moderate tsunami hazard level covered the sub-districts: half of Jaya Baru, half of Baiturahman, half of Kuta Alam, and half of Syiah Kuala. Furthermore, the low-level tsunami hazard includes the following sub-districts: Banda Raya, Lueng Bata, Ulee Kareng, and half of Syiah Kuala (Figure 1 and Refs. [29,30]).

Furthermore, the Social Vulnerability Index (SVI) calculation results showed that all sub-districts (9 sub-districts) have a score of 2.17, i.e., moderate status. Social vulnerability variables include high population density, persons with disabilities, toddlers, children, pregnant women, the elderly, and the poor (Figure 2 and Refs. [29,30]). Then, the Physical Vulnerability Index (PVI) calculation results are also available in all sub-districts with a score of 2.4, i.e., moderate vulnerability status. These variables include the number of houses, public facilities, places of worship, sports facilities, economy, recreation, telecommunications, banks, and health facilities (Figure 3 and Refs. [29,30]).

![Figure 1. Map of tsunami impact by municipality.](image1)

![Figure 2. Map of social vulnerability index (SVI).](image2)

![Figure 3. Map of physical vulnerability index (PVI).](image3)

![Figure 4. Map of economic Vulnerability index (EVI).](image4)

Then, the Economic Vulnerability Index (EVI) is also visible in all sub-districts with varying productive land areas and the value of GRDP at the time of the research. If a disaster happens again, it is without a doubt that economic paralysis will reoccur, so measured disaster management is required. EVI has a score of 3.0 or a high vulnerability status, and the distribution of productive land in all districts can be seen (Figure 4 and Refs. [29,30]). Furthermore, the Environmental Vulnerability Index (ENVI) has a score of 3.0 or a high vulnerability status, where the variables include protected forests, especially in coastal and urban areas, mangrove areas, and ponds (Figure 5 and Refs. [29,30]). Then, based on the calculation of all tsunami risk vulnerability indexes, which were then superimposed with the history of high tsunami inundation, it was found that six sub-districts were at high risk, namely Meuraxa, Kutaraja,
Kuta Alam, Shia Kuala, Jaya Baru, and Baiturrahman. Three other sub-districts, namely Banda Raya, Lueng Bata, and Ulee Kareng, are at moderate and low risk (Figure 6, Figure 7 and Refs. [29,30]). The impact of the earthquake and tsunami caused people to lose their livelihoods, also the decline of environmental aspects, such as water, village infrastructure, and sanitation [9]. Land damaged by the earthquake and tsunami renders them unable to meet the needs of families. The complexity of the social problems occurring due to the earthquake's impact was very influential in the socio-economic life of the people after the earthquake [10].

The Capacity Index is a readiness variable that includes disaster management regulations and institutions, early warning, disaster risk reduction, disaster education, reduced essential risk factors, and preparedness on all fronts. The results show that the Banda Aceh City Government (including support from the Aceh Provincial Government and the Central Government) was at level three with a score of 2.4, which means that there has been a commitment from the government and some communities to disaster risk. Disaster risk reduction in a region has been achieved and is supported by a systematic policy, but this achievement is not yet comprehensive in reducing the negative impact of a disaster.

**Figure 5.** Map of environment vulnerability index (ENVI).

**Figure 6.** Map of risk index by municipality.

**Figure 7.** Map of risk index superimposed by the tsunami impact area.

3.4. **Spatial Planning for Tsunami Prevention in Tohoku - Sendai Japan.**

Japan experienced a devastating earthquake known as the Great East Japan Earthquake on March 11, 2011, in the Tohoku area. Many people lost their lives, and thousands of houses were damaged by the disaster. The most damaged areas were Iwate Prefecture, Miyagi Prefecture, and Fukushima Prefecture. Miyagi Prefecture decided to relocate its coastal housing to the highlands in its spatial plan, separating industrial areas. In the industrial area, a high-rise evacuation building will be built. In addition, some ideas for multi-role prevention from tsunamis are designed, such as coastal embankments and green
spaces placed on the shore. Furthermore, roads and railroads are planned to be located at each border of agricultural areas, commercial, industrial, and residential areas [11]. These facts also confirm that the old road was upgraded to prevent the tsunami waves from reaching urban areas.

3.5. Reformation of Spatial Structure and Land Use Plans to increase capacity.
There are two formulas for reducing risk: (1) reducing the level of vulnerability (v) and increasing the capacity value (c). Hospitality has various indicators of debilitating disasters, such as earthquakes, tsunamis, floods, dengue hemorrhagic fever, tornadoes, and even non-natural disasters that have become the global pandemic of COVID 19. However, the level of exposure is fast regardless of the indicator. The variable capacity (c) consists of various readiness levels, ranging from individuals, groups/communities, villages/sub-districts, regional officials, regional leaders, and the central government—starting from risk decisions, investment resilience, responsibility, and recovery [12].

Furthermore, the indication in the preamble of Law 26/2007 on Spatial Planning—that the geographic conditions of Indonesia's territory are in a disaster-prone area—requires spatial planning based on disaster mitigation to improve the safety and comfort of life and livelihoods. However, Law 23/2014 is not in line with the above laws as it has not yet been mainstreamed in regional development. The mandate only focuses on the allocation of disaster funds from the Central Government. Therefore, policy reforms are needed, especially investments in regional disaster resilience infrastructure.

The current spatial structure of Banda Aceh City, especially in the shoreline, continues to develop. As mandated in the Banda Aceh Provincial Spatial Planning and City Spatial Planning, the national strategic road infrastructure development plan, namely BORR, is significant infrastructure investment. A reform concept argues that the residential area is mainly located in the Ulee Lheue area and, thus, must be relocated from the shore. Then, green and grey infrastructure must be invested in the shoreline. However, further, development should change the road structure plan and may increase the surface of some road sections in high-risk areas as a part of the new investment in disasters [14]. In Japan's Sendai, the Great East Japan Earthquake (GEJE) is an example of history's worst-case scenario in green and grey infrastructure. The TSUNAMI-N2 model, which combines five structural scenarios, such as seawall, greenbelt, flyover, and highway, can provide optimal protection [15].

Likewise, the spatial pattern in sub-districts with a high tsunami risk continues to develop, especially for residential functions. A 2017 study stated that the community rebuilt houses in their original location by considering historical and heritage factors. Various houses for rehabilitation and reconstruction assistance were built without changing land use plans. However, rural areas have started to develop into slums because many migrants who work in urban areas rent housing [16].

Previous studies stated that housing areas in Banda Aceh City, especially in sub-districts with a high risk of tsunami, showed rapid growth; the increase in housing areas from 2005–2011 increased by 26%.
However, research in 2018 is more surprising because the total residential area in the Ulee Lheue area has reached 91%—almost the same as before the Indian Ocean Tsunami (IOT) [18]. In addition, observations from the 2004 IOT, the 2006 Java Tsunami, and the 2018 Palu Tsunami stated that light wood and lightweight concrete frame buildings are very vulnerable—including residential buildings [19].

The speed of housing construction followed the emergency response policy, which was fast and distributed. Meanwhile, the current spatial plan did not yet have a disaster-based approach and urban resilience infrastructure, thus the construction of the house continues. Furthermore, it was found that the factor of land and other factors determine the direction of urban development. This is indicated by the fact that cheap land prices are found in high tsunami-prone sub-districts, whereas the sub-districts with low risk have higher land prices. As a result, people have no other choice. In addition, a 2014 study stated that high-risk tsunami areas, such as Meuraxa Sub-District, Kuta Alam Sub-District, Kuta Raja Sub-District, and Syiah Kuala Sub-District must implement mitigation policies and strategies through zoning and regulations with restrictions on housing, trade, industry, and office development [20].

The observation of the Tsunami Vertical Evacuation (TVE) in Banda Aceh was surprising because many people did not trust the safety of the TVE building [21]. Therefore, public education and socialization to ensuring a healthy and logically sound mind are essential. The Tsunami Study in Palu Bay stated that the existing evacuation shelter buildings (ESB) had not yet reached all communities in the red zone. Therefore, the construction of the ESB, which costs much money, must be strategically carried out by improving public buildings, such as schools and government offices as ESB. However, the best strategy is to enforce land-use regulations by preventing further urban development in tsunami-prone areas, which is expected to reduce physical damage and potential casualties [22].

4. Conclusion

Based on the results of calculations and policy analysis, it can be concluded: Regarding risk index (r) for tsunami disasters (h), if the same disaster occurs with the same energy release in the next decade or century, several sub-districts that are at high risk of tsunamis are found, including Meuraxa, Jaya Baru, Banda Raya, Baiturrahman, Kuta Raja, and Syiah Kuala. The vulnerability index (v) in several sub-districts, especially in coastal areas, is very high; this is obtained from a number of variables, such as social, physical, economic, and environmental vulnerability. The capacity index (c), which includes the indicators described above, is still low and requires continuous support in the next few decades and centuries so that this index value continues to strengthen and can reduce the level of exposure.

Reform of spatial planning should begin, particularly in coastal areas, by directing investments in grey infrastructure resilience and green infrastructure to reduce the level of vulnerability and protect development outcomes. The construction of BORR can be an essential starting point, along with a few other programs, like road repairs, planting coastal pine plants, breakwaters, canal walls, evacuation posts, and reinforcement of public buildings as evacuation points. Infrastructure and facilities have a significant relationship with the preparedness to reduce tsunami risk [23]. The United Nations International Strategy for Disaster Reduction (UNISDR) has stated that critical infrastructure and essential services, namely health and education facilities, are encouraged to be designed as risk reduction infrastructure by 2030 [24].

Land use reform, especially in the management and political policies, focuses on urban resilience, from housing relocation, green areas, blue areas, public open spaces, fishing industrial areas, strategic areas, and tourism areas. Political budget policy focuses on protecting development outcomes, comfort, and livelihood security as well as the City Revenues and Expenditures Budget, Provincial Revenues and Expenditures Budget, National Revenues and Expenditures Budget, and refocusing the Special Autonomy Fund [25], on Resilient Infrastructure [26].

Finally, learning iteratively from Sendai, constructing high-rise reinforced concrete walls and buildings with concrete columns and walls is the right thing to do to protect residents and development results. However, the facts show that tsunami warning technology [27] and hazard maps do not guarantee the safety of people. The most important lesson is that one should not wait for official
information to act: a strong ground shaking is the first warning to take action. Public education and the three principles of Prof. Katada: distrusting hazard maps (recognizing predictive limits), making best efforts in any situation, and taking evacuation initiatives in the community [28].

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