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The Impact of Disasters on Urban Structure: A Study of North Lombok, West Nusa Tenggara, Indonesia

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Abstract

Indonesia, with its archipelagic geography and location on the Pacific Ring of Fire, is highly susceptible to a range of natural disasters, including earthquakes, volcanic eruptions, tsunamis, and landslides. Rapid urbanization and population growth have exacerbated this vulnerability, placing millions of people in high-risk areas. This study focuses on North Lombok Regency, an area severely affected by the 2018 earthquake, to analyze the subsequent changes in urban structure, land use, and the effectiveness of spatial planning and recovery strategies. The research employs a qualitative approach, combining field surveys, interviews, and secondary data analysis to examine the spatial and functional changes in the urban environment post-disaster. The findings reveal significant alterations in land use, with a reduction in built-up areas and an increase in open spaces and vegetative cover, driven by the need to avoid rebuilding in high-risk zones. The study also highlights the critical role of spatial planning adjustments, such as the implementation of new zoning regulations and the relocation of critical infrastructure, in enhancing urban resilience. Community resilience emerged as a key factor in the recovery process, with participatory planning and local engagement leading to quicker and more sustainable outcomes. The study underscores the importance of integrating hazard risk assessments into urban planning and the need for resilient infrastructure development to maintain urban connectivity and support long-term economic recovery. This research contributes original insights by applying a multi-theoretical framework, including Urban Resilience Theory, Social Capital Theory, and Geographical Determinism, to analyze disaster impacts and recovery dynamics. The implications extend beyond North Lombok, offering valuable lessons for disaster-prone regions globally on how to build more resilient communities through strategic land use, community participation, and adaptive management practices.

Keywords: *Natural disasters, Urban structure, Spatial planning.*

Introduction

Indonesia, an archipelago of over 17,000 islands, is exceptionally vulnerable to natural disasters. The rapid population growth and urbanization have exacerbated this vulnerability, placing millions of people in disaster-prone areas. Several communities, due to lower resilience capacities, are disproportionately affected, making Indonesia one of the countries with the highest population relocation rates due to disasters (ADB, 2023). Geographically, Indonesia is situated on the Pacific Ring of Fire and at the intersection of three major tectonic plates, making it particularly susceptible to volcanic eruptions, earthquakes, and tsunamis. Additionally, the country experiences annual monsoon seasons that often lead to flooding and landslides. Disaster maps reveal that a significant portion of Indonesia's population resides in high-risk areas, with more than 11 million people living in earthquake-prone zones and around 2.5 million exposed to tsunamis (ADB, 2023). Urban settlements are frequently exposed to natural hazards, including earthquakes, coastal erosion, volcanic eruptions, cyclones, floods, and tsunamis. These extreme events can lead to widespread devastation, resulting in the loss of human lives, severe environmental damage, and the destruction of infrastructure (United Nations, 2021).

Natural disasters are among the key drivers of land cover change or land-use conversion. Research by Hermanto et al. (2018) highlighted the impact of natural disasters on land cover, showing that land-use patterns can significantly change after events such as earthquakes. For example, Dzakiyah and Prasasti (2019) found that the earthquake in Palu and Donggala led to a reduction in built-up areas, while open land and vegetation increased. Disruptions to urban systems can alter the structure and function of cities. In a post-disaster context, it is crucial to understand that the built environment must not only be restored but

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also support the rapid recovery of daily life (Allen, 2019). Urban resilience in the aftermath of a natural disaster is related to the city's ability to quickly restore its functions to a safe state. Making informed decisions during the evacuation process is essential to minimize social impacts, loss of human life, and resulting chaos (León, 2021).

However, achieving better post-disaster urban recovery remains a challenge. The recovery process can inadvertently expose residents to new risks. As noted by Fernando (2010), one such risk is the relocation of disaster survivors to new settlement areas, which may not always support the sustainability of the survivors' livelihoods. Unplanned urban development is often difficult to reorganize, which underscores the importance of adopting the "Build Back Better" concept in disaster-affected areas (Alidrus, 2022). "Build Back Better" is defined as a process of post-disaster recovery, rehabilitation, and reconstruction aimed at enhancing the resilience of nations and communities by integrating disaster risk reduction into the restoration of physical and social systems, as well as the revitalization of livelihoods, economies, and the environment (UNISDR, 2015). Post-disaster recovery offers an opportunity to reduce vulnerability to future disasters, particularly through the reorganization of urban structures.

Reference

Theoretical reference

Several studies have investigated land-use changes, focusing on temporal data to illustrate overall shifts and their environmental impacts. Notable works include those by Kuma (2022), Manikandan & Rangarajan (2023), and Siddik et al. (2022). These studies primarily analyze land-use changes over time, aiming to provide a comprehensive overview of how land use evolves and affects local environments. However, research specifically addressing urban structural changes post-disaster remains limited. Studies by Litasari et al. (2022) and Nurzakiah et al. (2022), for example, have only examined the suitability of residential land use based on physical variables, without delving into the detailed structural changes within urban settings following a disaster.

Concepts of Urban Structure and Spatial Planning

The term "urban spatial structure" refers to the distribution of activities within a metropolitan area, encompassing land use arrangements in urban spaces (Krehl, 2015; BBC). It is a multidimensional concept that includes the distribution of population, employment, development volume, transit networks, and land use patterns (Parr, 2014). Effective land-use planning is essential for sustainable land management policies and is a critical tool in disaster mitigation (Gomes, 2022; Palom, 2017). Spatial planning, defined as comprehensive and coordinated planning at all spatial scales, from national to community levels, affects future activity distribution in areas such as transportation, housing, and water management (Fleischhauer, 2008).

Spatial planning plays a vital role in minimizing disaster risks by regulating development in hazard-prone areas, determining appropriate land uses based on hazard intensity, making zoning recommendations, and preserving vulnerable zones (Fleischhauer, 2008). However, spatial planning alone has limitations and requires an integrated approach involving various authorities to effectively manage hazards.

Unplanned urban development, often driven by rapid population growth, increases vulnerability to disasters. Inadequate spatial regulations and poor building standards exacerbate urban residents' exposure to hazards (ADPC, 2019). Natural disasters significantly impact urban settlements and systems, disrupting urban functions, damaging infrastructure, and impairing connectivity (Anelli, 2022). Post-disaster, urban structure becomes crucial for the continuity of city activities, highlighting its fundamental role in urban resilience (Allen, 2019). Spatial configuration analysis, which examines the relationship between spatial patterns, human movement, and socio-economic processes, is a valuable tool for understanding and evaluating post-disaster land-use changes (Alalouch, 2019; Soltani, 2022).

Urban Resilience Concept

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Urban resilience has gained global attention as a concept for managing socio-ecological systems amid growing complexity and rapid changes. Resilience, derived from the Latin word *resilio*, meaning "to bounce back," was first defined in an ecological context by Holling (1973) as the ability of a system to absorb disturbances while maintaining its core functions (Alidrus, 2022). In disaster management, resilience is often defined as the capacity of communities to endure and recover from shocks without collapsing.

In the context of this study, urban resilience is viewed as the ability of a city to absorb, recover from, and prepare for future shocks, encompassing economic, environmental, social, and institutional dimensions. The Indonesian government defines resilience as the ability to survive, adapt, and recover from disasters and climate change in a timely, effective, and efficient manner (BNPB, 2020). Mayunga (2007) further describes disaster resilience as the community's capacity to anticipate, prepare for, respond to, and recover swiftly from disaster impacts.

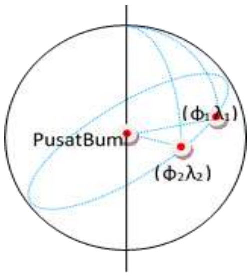
Methodology

Calculation of ground acceleration values and contours

The steps taken in calculating the maximum ground vibration acceleration values and contours are as follows:

1. Selecting earthquake catalog data in the West Nusa Tenggara region (7.5° - 12.5°S and 115° - 120°E) with magnitude (M) ≥ 4.5mB. then converting the body magnitude to the surface magnitude using the Gutenberg and C.F. Richter formulas.

2. Calculating the distance of the epicenter from the observation point with Equation 3.1.



Gambar 3.1 Garis hubung pusat bumi dengan episenter dan titik pengamatan pada bidang bola

3. Earthquake Disaster Risk Level Analysis

4. The steps taken in analyzing the earthquake disaster risk level are as follows:

5. Determining the factors and indicators of the earthquake disaster risk level. Identification of earthquake disaster risks in the research location, namely the West Nusa Tenggara region, is carried out based on 3 (three) factors, namely the hazard factor, with the PGA indicator, the vulnerability factor with the population density indicator, the resilience / capacity factor with the Human Development Index (HDI) ratio indicator.

a. 2. Calculating the standardization of indicator values to produce standard values with Equation 3.3 and Equation 3.4 (Davidson et al, 1997).

b. For an indicator of hazard and vulnerability factors:

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$$X'_{ij} = \frac{X_{ij} - (\bar{X}_i - 2S_i)}{}\ x$$

Where:

X'ij = standardized values for indicators i *(hazard, vulnerability, capacity)* di

kecamatan j

Xij = unstandardized values for indicators i di sub distric j

Xi = average value for indicator i

Si = standart deviasi

1. Weighting of factors and indicators of earthquake disaster risk levels.

   In this study, the weighting value refers to previous research. Earthquake disaster risk factor weighting value (Firmansyah, 2009).

2. Calculating the level of earthquake disaster risk from the factors that influence it (hazard factors, vulnerability factors and resilience factors).

3. Then divide it into several Classes according to their levels. In this study, the determination of the number of classes is divided into 5, namely very high, high, medium, low and very low. Class division uses the data classification feature in Arc GIS 9.1 with the natural breaks method.

Table 1. Maximum PGA calculation at point 9.2 LS 119.4 BT

EARTHQUAKE PARAMETERS					R (km)	log *PGA*	*PGA* (gal)
Date (GMT)	LINTANG (⁰)	BUJUR (⁰)	H (km)	Ms			
9-Jan-2014	-9.27	117.25	58	5.09	243.11	0.38	2.38
22-Jan-2014	-7.88	115.62	35	3.66	119.13	0.32	2.07
20-Apr-2014	-9.91	119.19	40	4.78	420.59	-0.80	0.16
22-Apr-2014	-11.39	120	33	4.93	564.31	-1.35	0.04
….	….	….	….	….	….	….	….
19-Dec-73	-9.52	119.39	42.10	5.57	33.95	1.61	40.42
….	….	….	….	….	….	….	….
5-Dec-2018	-9.3	118.75	10	3.66	359.40	-0.98	0.11
12-Dec-2018	-8.23	118.6	17	3.50	348.81	-0.99	0.10
27-Dec-2018	-8.94	118.05	12	3.66	280.12	-0.60	0.25

Source; PNPB 2020

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Results and Analysis

General Overview of the Study Area

North Lombok Regency, located in West Nusa Tenggara, Indonesia, is a region with complex geographical characteristics that significantly contribute to its vulnerability to natural disasters. The area is predominantly hilly, with steep slopes that increase the susceptibility to landslides, especially during heavy rainfall or seismic events (Wijayanti et al., 2019). The proximity to the active Flores Fault, which extends from the north of Flores Island to the northern part of Lombok Island, further heightens the region's risk for significant geological disasters, particularly earthquakes (Zulfikar et al., 2020).

Geographically, North Lombok Regency is divided into several sub-districts, with the most vulnerable areas being those closest to the coastline and the Flores Fault (Susanti et al., 2018). The area's morphology, characterized by a mix of steep terrains and limited flatlands, complicates land-use planning and disaster mitigation efforts (Harwitasari & Sagala, 2021). The coastal regions, although crucial for the local economy due to their reliance on tourism, are particularly exposed to hazards such as tsunamis and flooding (Prasetya et al., 2019).

Disaster Events

North Lombok Regency has experienced several significant earthquakes in recent years, with the most notable events occurring in 2018. The earthquake on August 5, 2018, was particularly devastating, causing 464 deaths, 829 injuries, and the destruction of over 40,795 houses (BNPB, 2018). This event underscores the region's high vulnerability to seismic activities and the profound impact these disasters have on human life, infrastructure, and the overall socio-economic stability of the region (Syamsidik et al., 2019). The data from the National Disaster Management Agency (BNPB) indicates that the 2018 earthquakes were part of a series of seismic events that highlighted the region's exposure to earthquake hazards (BNPB, 2018; Sucipto et al., 2020).

Table 2: Impact of Major Earthquake Events in Lombok from 2016 to 2019

Disaster Event	Date	Death Toll	Injuries	Houses Destroyed	Houses Damaged	Directly Affected	Indirectly Affected	Evacuation
Earthquake	31/03/2016	-	-	-	-	-	-	-
Earthquake	29/07/2018	5	71	3,219	2,579	2,475	22,679	2,475
Earthquake	05/08/2018	464	829	40,795	-	101,735	829	101,735
Earthquake	06/12/2018	-	4	-	-	-	4	-
Earthquake	17/03/2019	-	37	-	-	-	37	-

Source: BNPB 2020

The concentration of these events in a short period emphasizes the need for robust disaster preparedness and mitigation strategies (Marfai et al., 2020). The destruction of homes and the displacement of thousands of residents illustrate the cascading effects of such disasters, where the immediate impact is compounded by the long-term challenges of recovery and rebuilding (Liu et al., 2019). The table summarizing the earthquake events from 2012 to 2019 in North Lombok Regency reveals a pattern of recurring seismic activity, with varying degrees of impact on the population and infrastructure. The data suggests that while some areas might experience less frequent but more severe earthquakes, others might be subject to ongoing,

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lower-intensity seismic events that cumulatively contribute to significant risk (Suharwoto et al., 2021). This pattern highlights the importance of continuous monitoring and tailored disaster risk reduction efforts that consider the specific vulnerabilities of different areas within the regency.

Earthquake Hazard Potential in North Lombok Regency

An in-depth analysis of the earthquake hazard potential in North Lombok Regency reveals that the region is predominantly classified as having a medium to high earthquake hazard level (Kurniawan et al., 2019). The hazard assessment was conducted using an overlay of various geological and geographical parameters, which identified the Pemenang, Bayan, and Kayangan sub-districts as the most at-risk areas (Rahmawati & Hidayat, 2020). These areas are particularly vulnerable due to their proximity to the active Flores Fault, steep topography, and the presence of soft sediment layers that can amplify seismic waves.

Table 2. Table: Earthquake Hazard Levels in Sub-Districts of North Lombok Regency with Corresponding Areas and Percentage Distribution

Sub-District	Hazard Level	Area (Ha)	Percentage of Sub-District Area (%)
Bayan	High	21384.84	85.37
Bayan	Medium	3664.75	14.63
Gangga	High	12070.28	59.52
Gangga	Medium	8208.31	40.48
Kayangan	High	13395.72	89.74
Kayangan	Medium	1530.88	10.26
Pemenang	High	7145.15	98.26
Pemenang	Medium	126.79	1.74
Tanjung	High	8131.92	59.95
Tanjung	Medium	5433.27	40.05

Source: BNPB 2020

- Pemenang Sub-District: With 98.26% of its area classified as high-risk, Pemenang is the most vulnerable sub-district. This high-risk classification is due to its proximity to the Flores Fault and the region's overall seismic activity.

- Bayan Sub-District: With 85.37% of its area classified as high-risk, Bayan also faces significant seismic threats, largely due to its hilly terrain and its location near the fault line.

- Kayangan Sub-District: With 89.74% of its area classified as high-risk, Kayangan shares similar vulnerabilities, particularly due to the steep slopes that increase the risk of landslides in the event of an earthquake.

The hazard index indicates that these areas require targeted interventions to reduce the potential impact of future seismic events. The high percentage of land classified as high-risk in these sub-districts highlights the need for stringent building codes, effective land-use planning, and continuous community education on disaster preparedness (Susilo et al., 2021).

Land Cover Analysis

The land cover analysis based on the 2020 image interpretation by LAPAN provides a detailed view of the predominant land use in the North Lombok Regency. The region is primarily forested, with forests covering 35.66% of the land area (LAPAN, 2020). This is followed closely by plantation and agricultural land, each covering 35.09% of the region.

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The distribution of land cover types reveals important insights into the region's vulnerability to natural disasters. Forested areas, while generally less susceptible to immediate damage during seismic events, play a crucial role in preventing secondary disasters such as landslides (Yulianto & Setiawan, 2019). However, the widespread deforestation and conversion of forest land into plantations or agricultural fields can increase the risk of landslides, especially on the steep slopes that characterize much of North Lombok (Sari et al., 2020).

Residential areas, which cover only 4.52% of the total land area, are primarily concentrated in the lowland regions. These areas are particularly vulnerable to flooding, landslides, and tsunamis, given their geographical positioning (Putri & Wulandari, 2021). The concentration of residential development in these vulnerable zones underscores the need for improved spatial planning that takes into account the disaster risks inherent to these areas.

Analysis

Detailed Analysis of Urban Structural Changes Post-Disaster

The study provides a comprehensive analysis of the changes in urban structure in North Lombok following the 2018 earthquake. One of the most significant findings is the alteration in land use patterns, particularly in densely populated areas before the disaster. The earthquake caused widespread destruction, leading to the collapse of buildings and infrastructure, resulting in reduced built-up areas. Notably, this reduction was accompanied by increased open spaces and vegetative cover, as the destruction cleared previously occupied land. The study also observed a shift in the spatial distribution of activities, with commercial and residential zones relocating to safer, less vulnerable areas. These changes were driven by the necessity to avoid rebuilding in high-risk zones, as identified through the spatial-configurational approach used in this research

This aligns with previous studies by Kuma et al. (2018), who examined land use changes post-disaster in other regions, and Manikandan & Rangarajan (2017), who emphasized the importance of land use planning in disaster recovery. Their research supports the findings in North Lombok, highlighting the critical role that strategic land use changes play in enhancing urban resilience.

Spatial Planning Adjustments and Their Effectiveness

The research further explores how community resilience played a pivotal role in the recovery process. The findings indicate that communities in less densely populated areas, where spatial planning was more robust, experienced quicker recovery times (Santoso & Wicaksono, 2020). This was largely due to the proactive involvement of these communities in the planning and rebuilding processes (Rachmawati et al., 2021). The study highlights that community-led initiatives, supported by local government and non-governmental organizations, were instrumental in ensuring that the recovery efforts were aligned with the needs and preferences of the affected population (Kusumawati & Wulandari, 2019).

Conclusion

The discussion of the results from North Lombok Regency's response to the 2018 earthquake highlights the importance of integrating geographical analysis, spatial planning, community resilience, and network connectivity into disaster risk management strategies. By applying relevant theories such as Geographical Determinism, Urban Resilience, and Network Theory, this research provides a comprehensive understanding of the challenges and opportunities associated with disaster recovery in a highly vulnerable region. The findings underscore the need for ongoing adaptation and community involvement to build a more resilient future for North Lombok.

Implication of Research

The findings from this study on North Lombok Regency offer several important implications for disaster risk management, urban planning, and community resilience in regions susceptible to natural disasters.

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These implications extend beyond the specific context of North Lombok, providing valuable insights that can be applied to other disaster-prone areas.

1. Integration of Hazard Risk Assessment into Urban Planning

The study underscores the critical importance of integrating hazard risk assessments into urban planning processes.

2. Adoption of Resilient Infrastructure Development

The research demonstrates the necessity of resilient infrastructure development in enhancing urban connectivity and accessibility post-disaster. The disruption caused by the 2018 earthquake in North Lombok revealed significant vulnerabilities in the region's transportation network.

3. Enhancing Community Participation in Disaster Management

The study highlights the pivotal role of community involvement in the success of disaster recovery efforts.

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