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Research article

Sustainable Tourism Development in Labuan Bajo, Manggarai Barat, Indonesia: Integration of Multi-Hazard Risk Analysis into Spatial Planning

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Abstract

The rapid growth of ecotourism in island regions such as Labuan Bajo, Manggarai Barat, Indonesia, has not adequately considered the integration of comprehensive multi-hazard risk assessments into spatial planning. The area is becoming more vulnerable to a mix of geophysical, hydrological and climatological hazards as it is designated a "Super Priority" tourism destination in the country. However, current planning practices do not fully account for these hazards. This study examines how multi-hazard risk is incorporated into the Regional Spatial Plan of Labuan Bajo, Manggarai Barat, through a mixed-methods approach combining GIS-based multi-hazard analysis using spatial overlay techniques, together with qualitative insights from key stakeholders. A composite multi-hazard risk index was overlaid with land-use zoning, activity centres and transportation networks to evaluate spatial suitability and infrastructure exposure. The analysis indicates that planned land use does not align with the current risk levels, as high-risk areas have been designated for residential zones, tourism areas and major transportation corridors, demonstrating that spatial suitability varies according to multi-hazard risk levels in the study area. On the other hand, conservation areas are more suitable for low-risk environments. The results indicate that high-risk island tourism areas require more effective spatial planning based on risk information in order to remain resilient and sustainable in the long term.

Keywords: multi-hazard risk; tourism development; spatial planning; GIS-based analysis.

1. Introduction

Disasters are occurring more frequently and intensely in various regions, compounded by climate change and rapid urbanization (Hung *et al.,* 2024; Musiyam *et al.,* 2025). Integrated regional planning to create resilient areas is essential for sustainable development (Das, 2025; Li *et al.,* 2025). The challenge requires spatial planning that manages the allocation of resources across multiple development components, while fostering safer and more sustainable surroundings over the long term (Juwita *et al.,* 2021; Liu & Zhou, 2021; Solly, 2021). The Sendai Framework for Disaster Risk Reduction (2015–2030) and the Sustainable Development Goals (SDGs), specifically Goals 11 (Sustainable Cities) and 13 (Climate Action), emphasise the integration of disaster risk reduction (DRR) into all global development planning processes (Chmutina *et al.,* 2021; Hofmann, 2021). The framework advocates the application of spatial planning to improve resilience (UNDRR, 2015; Yamazaki-Honda, 2022). This integration serves as a proactive and cost-effective strategy for mitigating future losses by directing development away from disaster-prone regions and safeguarding the resilience of essential infrastructure (Dandoulaki *et al.,* 2023; Greiving *et al.,* 2025; Khanm *et al.,* 2024).

Previous studies have indicated that such integration possesses significant potential, but it also presents numerous challenges (Farinos *et al.,* 2025; Kostopoulou & Papageorgiou, 2025). Other research indicates that spatial planning serves as an effective non-structural approach to mitigating long-term disaster risk globally (Burby & French, 1981; Mallma, 2021). Policy promises and actions frequently exhibit inconsistency (Maru & Worku, 2022; Zhou *et al.,* 2023). In developed nations, especially within the European Union, fragmented governance and institutional obstacles between spatial planning and emergency management agencies frequently hinder comprehensive multi-hazard risk assessments (Greiving & Fleischhauer, 2006; Sakic *et al.,* 2024). Decentralised systems, such as that of the United States, may exhibit a variety of rules (Olsen *et al.,* 2015). In these systems, local economic incentives frequently outweigh long-term resilience factors, resulting in increased vulnerability (Burby, 2006; Cheng *et al.,* 2020). Studies on the recovery of tourism destinations post-disaster indicate that planning for effective and sustainable reconstruction while addressing the needs of all stakeholders is becoming increasingly challenging. The requirements of local communities and businesses significantly has significantly shaped spatial planning to achieve success (Chan *et al.,* 2020; Fountain & Cradock-Henry, 2020; Ningsih *et al.,* 2025). The global framework for adaptive spatial planning has not been effective in Indonesia and other developing countries that are particularly vulnerable to natural disasters (Akola & Charlotte, 2025;

Djalante *et al.,* 2012). Indonesia ranks among the countries with the highest disaster risk globally, necessitating the incorporation of DRR into the country's Spatial Planning Plan (RTRW) (Pamungkas *et al.,* 2024; Sudaryatno *et al.,* 2024). However, a disparity exists between planning and implementation (Talitha *et al.,* 2020; Wen *et al.,* 2022). Empirical studies consistently show that Indonesia experiences significant economic losses from disasters, exacerbated by rapid urbanisation, infrastructure expansion, and uneven governance capacity (Pamungkas *et al.,* 2024; Soejarwo *et al.,* 2025). The issue is compounded by inadequate communication among the "Wali Data" of disaster hazard maps, insufficient spatial planning skills, weak inter-agency collaboration, and an emphasis on short-term economic growth over resilience building (Dwirahmadi *et al.,* 2023; Harrison *et al.,* 2022; Kox & Luder, 2021; Sagala *et al.,* 2021; Setiawan *et al.,* 2025). This indicates misalignment between planning and land use, resulting in development in areas susceptible to hazards (Ernawati *et al.,* 2025; Firman *et al.,* 2011; Gunandar *et al.,* 2024; Hizbaron *et al.,* 2023; Karim *et al.,* 2024). Rather than proactively avoiding risk-prone areas, reactive measures are implemented post-disaster, thereby sustaining the cycle of risk (Dandoulaki *et al.,* 2023; Dasí *et al.,* 2025; Fitriyati *et al.,* 2024).

Despite the increasing volume of research on DRR and spatial planning, significant gaps remain that necessitate additional investigation (El Kouffi & El Kharim, 2025; Ramli *et al.,* 2021). Spatial evaluation is required to quantitatively and qualitatively assess the alignment or misalignment between designated development zones and multi-hazard risk layers (Chelariu *et al.,* 2023; Esen *et al.,* 2026; Gacu *et al.,* 2025). There is a particular lack of research on integrating spatial analysis with an examination of institutional and infrastructure factors that can promote or hinder risk-based planning, particularly in regions experiencing rapid tourism growth (Gatto *et al.,* 2025; Nunez & Rubio, 2025). Tourism destinations experience considerable pressure to develop their natural and cultural resources, presenting a significant challenge in implementation (Allahverdi *et al.,* 2025; Streimikiene *et al.,* 2021; Ziegler *et al.,* 2023). If spatial policies are not properly managed, the pursuit of economic growth may increase community vulnerability and disaster risk exposure (Kodag *et al.,* 2022; Mărgărint *et al.,* 2023; McMillan *et al.,* 2021).

This research aims to enhance current understanding of the issue by addressing the gaps through a targeted case study of Labuan Bajo, Manggarai Barat Regency, Indonesia. This region is experiencing significant transformation due to its designation as a national "Super Priority" tourism destination (Hendratno *et al.,* 2026), which has exerted considerable pressure on its spatial planning (RTRW 2012-2032). Such plans emphasise long-term growth through tourism, leveraging the designation of Komodo National Park as a UNESCO World Heritage Site (Sianipar *et al.,* 2024). However, the region is susceptible to various natural disasters, such as earthquakes, tsunamis, floods, landslides and droughts (Sejati *et al.,* 2023; Shalih *et al.,* 2026; Sudjono *et al.,* 2024). This situation presents an opportunity to examine methods for integrating multi-hazard risks into spatial planning within rapidly developing high-risk regions.

Recent studies have begun to develop more integrated multi-hazard assessment frameworks, including approaches that combine single and coupled hazard scenarios within a unified analytical model (Bakhtiari *et al.,* 2025a, 2025b; López-Saavedra & Martí, 2023; Shalih *et al.,* 2026a; Wang *et al.,* 2026). Although disaster risk information is becoming increasingly accessible, such information does not always translate into spatial planning decisions. This phenomenon is true even in tourist destinations facing rapid development pressures. In such contexts, economic objectives tend to take precedence over disaster risk considerations. Land-use allocations may conflict with existing hazard conditions. This underscores the importance of evaluating spatial planning documents based on multi-hazard risk distribution as part of planning practices that are more responsive to disaster risks (Adiguzel *et al.,* 2026; Ma *et al.,* 2025). Growing attention has been directed toward understanding how risk information is incorporated into planning and governance processes, rather than focusing solely on hazard assessment. This integration is of particular consequence in tourism destinations, as planning decisions shape the conditions under which communities and infrastructure face disaster risks.

Despite the growing body of research on this topic, significant gaps remain unaddressed. Many studies primarily concentrate on individual hazard assessment, overlooking the cumulative and interactive nature of multiple hazards (Dwirahmadi *et al.,* 2023; López-Saavedra *et al.,* 2023; López-Saavedra & Martí, 2023; Zhang *et al.,* 2024a). Several studies have emphasised the importance of integrating risk considerations into spatial planning (Papageorgiou, 2025a), although few have specifically evaluated the alignment between tourism development plans and the distribution of multi-hazard risks, particularly in rapidly developing ecotourism destinations in archipelago countries, such as Labuan Bajo.

This study addresses the primary research question: To what extent do existing spatial plans in Labuan Bajo, Manggarai Barat Regency, incorporate multi-hazard risk assessment to facilitate the development of resilient tourism destinations? It focuses on two specific objectives:

1. To spatially assess the alignment and mismatch between designated development zones and areas exposed to multiple hazards.
2. To examine how institutional practices, infrastructure development, and stakeholder perspectives influence tourism resilience and reveal the limitations of current spatial planning implementation

Recently, studies have developed the relationship between disaster risk and spatial planning, particularly in coastal and tourism areas exposed to multiple hazards. A multi-hazard approach is often used, as it provides a more comprehensive understanding of risk than single-hazard analyses, especially in the context of climate change and increasing development pressures (Uehara *et al.,* 2022, 2026). The integration of risk analysis into spatial planning is not only seen as a mitigation effort but also as part of a regional development strategy that is oriented towards long-term resilience, especially in tourism areas that are experiencing rapid growth (Laino *et al.,* 2024). This approach is increasingly relevant because many developing areas are located in regions with high exposure to multiple hazards. As a result, decisions regarding land use directly affect the level of vulnerability and resilience (Papageorgiou, 2025b).

The research emphasises the integration of multi-hazard analysis with spatial planning suitability evaluation. It focuses not only on risk identification and identifying areas exposed to multiple hazards but also on the implications of these conditions for more sustainable and resilient tourism development.

2. Methods

A mixed-methods approach was employed, combining qualitative policy analysis and quantitative geospatial modeling to evaluate the Manggarai Barat Regency Spatial Plan (RTRW 2012–2032). The research followed several main stages, including data collection, pre-processing, multi-hazard analysis, spatial suitability evaluation, and interpretation of results. To contextualise the spatial findings, a qualitative approach was also used, drawing on institutional and planning practices. The overall research workflow is presented in Figure 1.

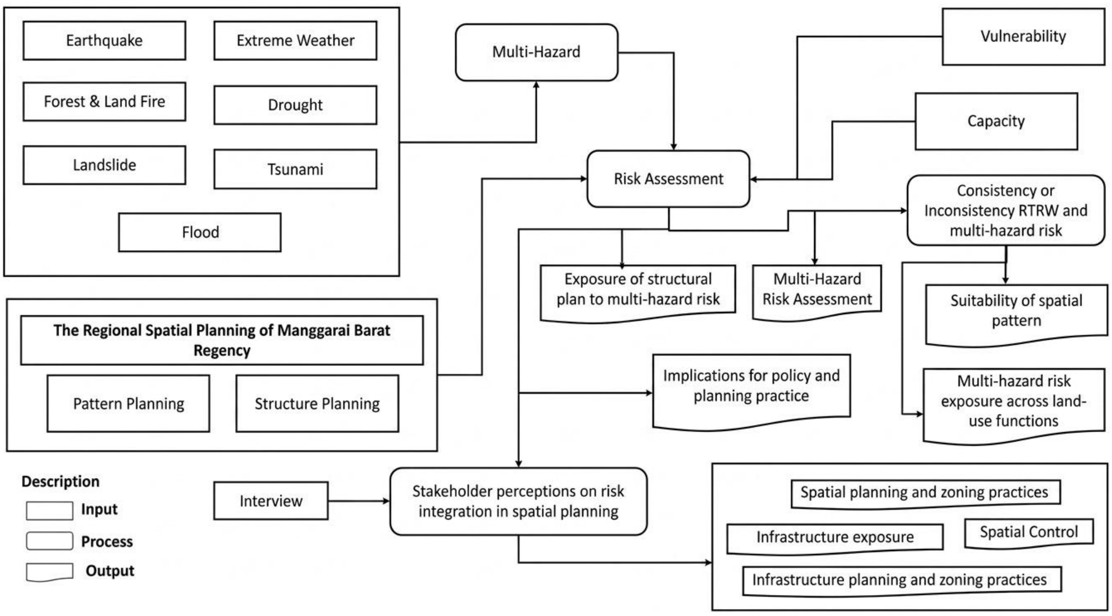

Figure 1. Research Workflow.

2.1. Study Area

Manggarai Barat Regency is located in the western part of Flores Island, East Nusa Tenggara Province, Indonesia, and consists of a mainland area and extensive archipelagic zone that includes Komodo Island Figure 2. The region is characterised by diverse physical settings, with hilly and mountainous terrain dominating the mainland and lowland coastal and island environments supporting marine and tourism activities.

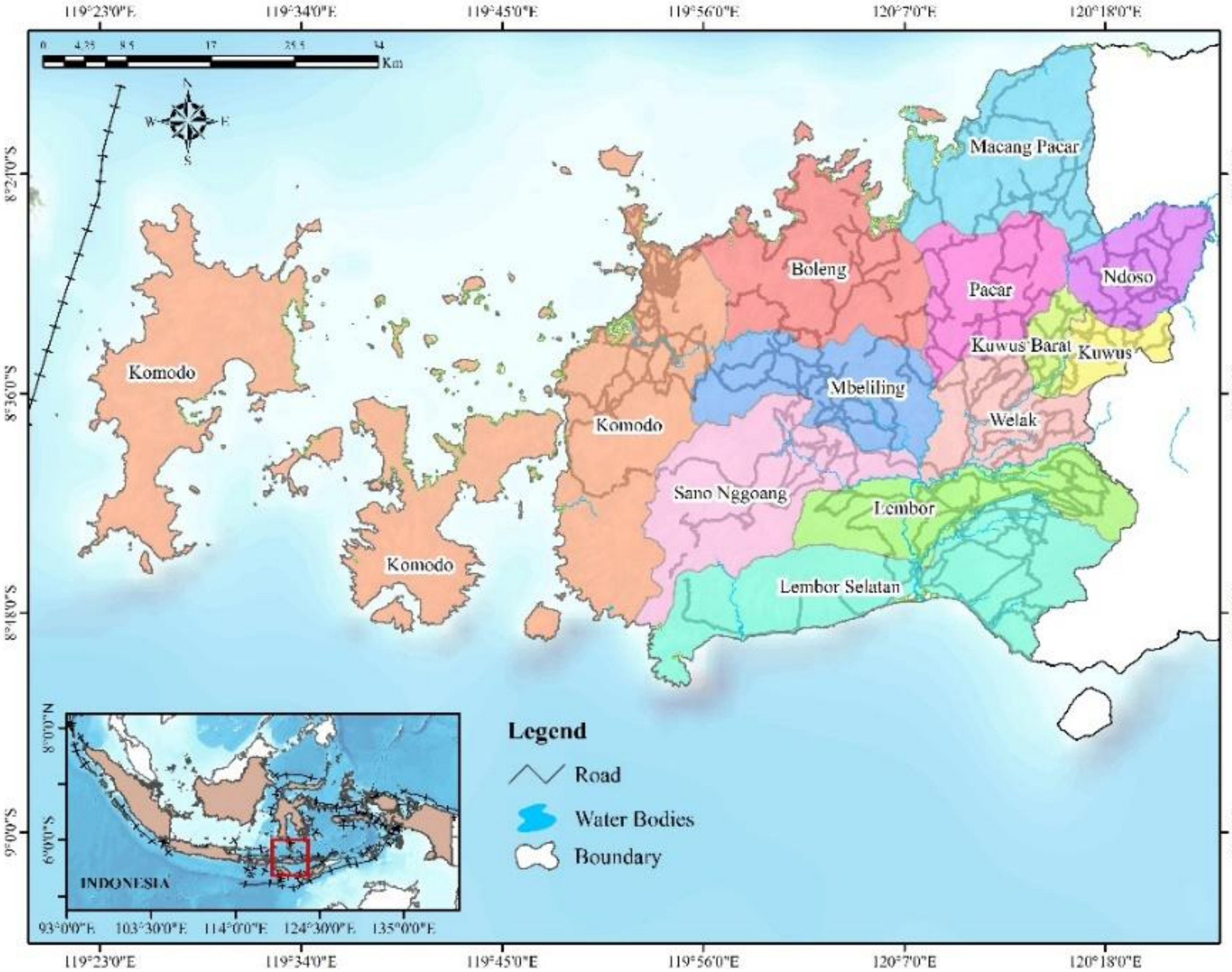

Figure 2. Research Location.

Manggarai Barat has developed into an important tourist destination, with Labuan Bajo as the main gateway to Komodo National Park. However, the region is prone to various natural disasters, including geological and hydrological ones, as well as extreme weather. These combined characteristics make the region a relevant case for examining the interaction between spatial planning, multi-hazard risk and tourism development sustainability.

2.2. Multi-Hazard Risk Characteristics of the Manggarai Barat Area

A comprehensive multi-hazard assessment was conducted for seven hazards relevant to archipelagic environments using the parameters and methods detailed in Table 1. Vulnerability and capacity considerations were tailored to each hazard type by incorporating demographic, infrastructural and environmental factors. The multi-hazard map was generated using the maximum value overlay method. This approach was applied to identify the dominant hazard conditions at each location (Krassakis *et al.,* 2023). It provides a spatially consistent basis for comparing hazard conditions with the land-use allocations specified in the Regional Spatial Plan (RTRW) at the regional planning scale. Although the method effectively reflects dominant hazard conditions, the potential for interactions between concurrent hazards remains outside the scope of this analysis and could be considered in future research. All analyses were conducted within a geographic information system (GIS) using raster overlay techniques, consistent with national guidelines (Perka BNPB No. 2/2012); see Table 1. All parameters for each hazard type were preprocessed, including reprojection to a common coordinate system and resampling to ensure consistent spatial resolution (Sekarjati *et al.,* 2025). Subsequently, the data were standardised to harmonise value ranges through relative reclassification. For certain parameters, such as floods and tsunamis, fuzzy membership functions were used to represent vulnerability levels on a continuous scale and then integrated into the classification and overlay process.

Table 1. Summary of Hazard Parameters and Modeling Techniques.

No	Hazard Type	Key Parameters	Data Sources	Modeling Approach
1	Earthquake	- Topographic class (slope, texture, convexity) - Peak ground acceleration (PGA) at bedrock and surface	FABDEM, PU, BMKG	AVS30 analysis (Irsyam *et al.,* 2017) and the ground amplification factor are used to estimate surface shaking (Matsuoka, 1994). PGA values are transformed into a hazard index.
2	Forest and Land Fire	- Land cover - Slope steepness - Distance from settlements - Historical fire hotspots	KLHK, FABDEM, Google Open Buildings	Weight of Evidence (WoE) (Carter, 2014). A quantitative statistical method for combining evidence from multiple spatial datasets to predict the probability of an event (in this case, fire).
3	Extreme Weather	- Land openness (from land cover) - Slope steepness - Annual rainfall	KLHK, FABDEM, BMKG	Weighted overlay analysis. Parameters are scored 0-1, normalised, and combined with equal weighting (33.3% each) based on expert judgment to create a composite index.
4	Drought	- 3-month Standardized Precipitation Index (SPI)	ERA5-Land (ECMWF)	Standardised Precipitation Index (SPI) (McKee *et al.,* 1993). A widely used index for quantifying meteorological drought. The frequency of drought events (SPI < -0.99) over a 42-year period is calculated and interpolated using Kriging to represent drought conditions throughout the study area (Oliver & Webster, 1990).
5	Tsunami	- Maximum tsunami wave height - Coastal slope - Surface roughness (from land cover)	BMKG (PTHA), BIG, KLHK	This method employs fuzzy logic (Zadeh, 1965) and the cost distance function, which relies on slope and roughness. The method, adapted from Berryman, models the inundation decay as the wave moves inland (Berryman, 2006).
6	Flood	- Slope steepness - Distance from river network - Geomorphic Flood Index (GFI)	FABDEM, BIG	Geomorphic Flood Index (GFI) (Manfreda & Samela, 2019). A DEM-based approach that identifies flood-prone areas based on geomorphology. Areas with GFI > -0.53 are classified as prone. Fuzzy membership functions are then used to refine the hazard index based on slope and distance.
7	Landslide	- Slope steepness (>15%) - Land movement susceptibility zone (PVMBG)	PVMBG, FABDEM	Heuristic overlay. The official PVMBG susceptibility map is refined by excluding areas with slopes <15%. PVMBG classes (low, medium and high susceptibility) are directly translated into hazard classes.
8	Multi-Hazard	Overlay MultiHazard	Outputs from all hazard analyses	Maximum value overlay. For each grid cell (e.g., 30 m x 30 m), the highest hazard index value from any of the single-hazard maps is selected. This identifies the worst-case scenario for any location.

The spatial evaluation was conducted using a multi-hazard map, which enables consideration of multiple hazard conditions within a single spatial planning framework. While single-hazard analyses yield valuable insights into specific risk characteristics, they remain insufficient for areas where multiple hazards spatially overlap, a condition that demands a more integrated planning framework (Gill & Malamud, 2014). In Manggarai Barat Regency, multiple hazards spatially coincide within the same development zones, making a multi-hazard approach necessary. A suitable framework is needed to evaluate the consistency of the RTRW with risk-informed planning principles. Within the scope of this study, the term 'multi-hazard risk' refers to the spatial distribution and co-occurrence of multiple hazards across the study area, serving as a basis for identifying areas with higher potential exposure to disaster impacts in spatial planning evaluation.

2.3. Spatial Overlay Analysis

Spatial overlay analysis was used as the primary method to assess the alignment between multi-hazard conditions and spatial planning directives in West Manggarai Regency. The composite multi-hazard map was overlaid with zoning regulations, spatial patterns and road network layers derived from the Regional Spatial Plan (RTRW) to quantify exposure levels across land-use categories and infrastructure systems. This approach enables a spatially explicit evaluation of whether planned development is located within areas of low, medium or high multi-hazard risk. The multi-hazard index is classified into three categories—low, moderate and high—using the natural breaks (Jenks) method. This method determines class boundaries based on natural groupings within the data distribution by minimising variation within classes and maximising variance between classes. The resulting value limits are 0.09–0.33 for the low category, 0.33–0.44 for the moderate category, and 0.44–0.79 for the high category. The use of these three categories allows the classification results to be directly linked to the level of restrictions on regional development in the evaluation of the suitability of RTRW spatial allocation.

The suitability classification was based on the spatial overlay between the Multi-Hazard Risk Map and the RTRW spatial pattern, in which each spatial pattern category was evaluated against its corresponding multi-hazard risk class. Where the designated land-use function was considered compatible with the risk level, the area was classified as suitable. Areas showing only moderate compatibility were classified as conditionally suitable, meaning development could still be permitted under specific conditions or with appropriate mitigation. Where the planned land-use function was found incompatible with the risk conditions, the area was classified as unsuitable. The resulting spatial suitability map highlights areas where planned land-use allocations are consistent with, or in conflict with, the prevailing multi-hazard risk environment, thereby providing a quantitative basis for evaluating spatial planning consistency (Wirawan *et al.,* 2021).

Structural exposure was assessed using an overlay-based approach focusing on activity centres and transportation networks (Pamungkas *et al.,* 2024). For activity centres, a spatial join operation was applied to assign multi-hazard risk values to points representing regional, local, area and neighbourhood service centres. For the road network, arterial, collector, neighbourhood and local roads were intersected with the multi-hazard risk polygons using the Intersect tool, producing segmented road sections corresponding to hazard class boundaries. Each segment was assigned a risk level, and its length was calculated to quantify total road exposure within low-, medium-, and high-risk zones. This analysis supported the identification of highly exposed infrastructure segments that may affect mobility, emergency access and tourism connectivity.

2.4. Perspectives on Multi-Hazard Integration in Spatial Planning

This component of the study complemented the spatial analysis by providing contextual explanations for the spatial patterns of multi-hazard risk and the spatial planning identified through GIS-based overlay analysis. The focus was on how risk considerations are interpreted and operationalised within spatial planning and tourism development practices in Manggarai Barat, rather than on generating independent social generalisations.

Semi-structured interviews were conducted with 30 purposively selected informants from government institutions (code: G); tourism related businesses (code: B); local communities (code: C); academia (code: A); media (code: M); and visitors (code: V), based on their involvement in spatial planning, disaster risk management or tourism development. Interview guidelines were informed by key issues emerging from the spatial analysis, including the integration of multi-hazard information into zoning and spatial control; infrastructure exposure and evacuation accessibility; development pressures in tourism areas; and the role of infrastructure (such as ICT for risk communication). The role of ICT infrastructure, including mobile communication platforms and digital tools, is increasingly recognised as critical for disseminating risk information, enhancing awareness, and supporting stakeholder engagement in reducing disaster risk (Johnston *et al.,* 2022).

All the interviews were conducted with informed consent, audio-recorded, and transcribed verbatim. The transcripts were then analysed using descriptive thematic analysis to identify recurring explanations and institutional constraints that inform the interpretation of spatial inconsistencies between planned land-use functions and multi-hazard risk levels.

3. Results and Discussion

The study highlights the spatial patterns associated with the concentration of multi-hazard risks in coastal and tourism areas in Manggarai Barat. The analysis reveals that a single type of disaster does not dominate, but rather different types overlap. The results show that several intensive land uses, mainly for tourism and its supporting activities, are located in zones characterised by moderate to high combined risks. This indicates that there is a spatial mismatch between planned land use and disaster risk conditions.

3.1. Multi-Hazard Risk Characteristics

The single hazard map in Figure 3 shows the spatial distribution across Manggarai Barat. Flooding hazard is primarily concentrated along river flows and downstream areas, while that of landslides is dominated by areas with steeper terrain in central Labuan Bajo and its hinterland.

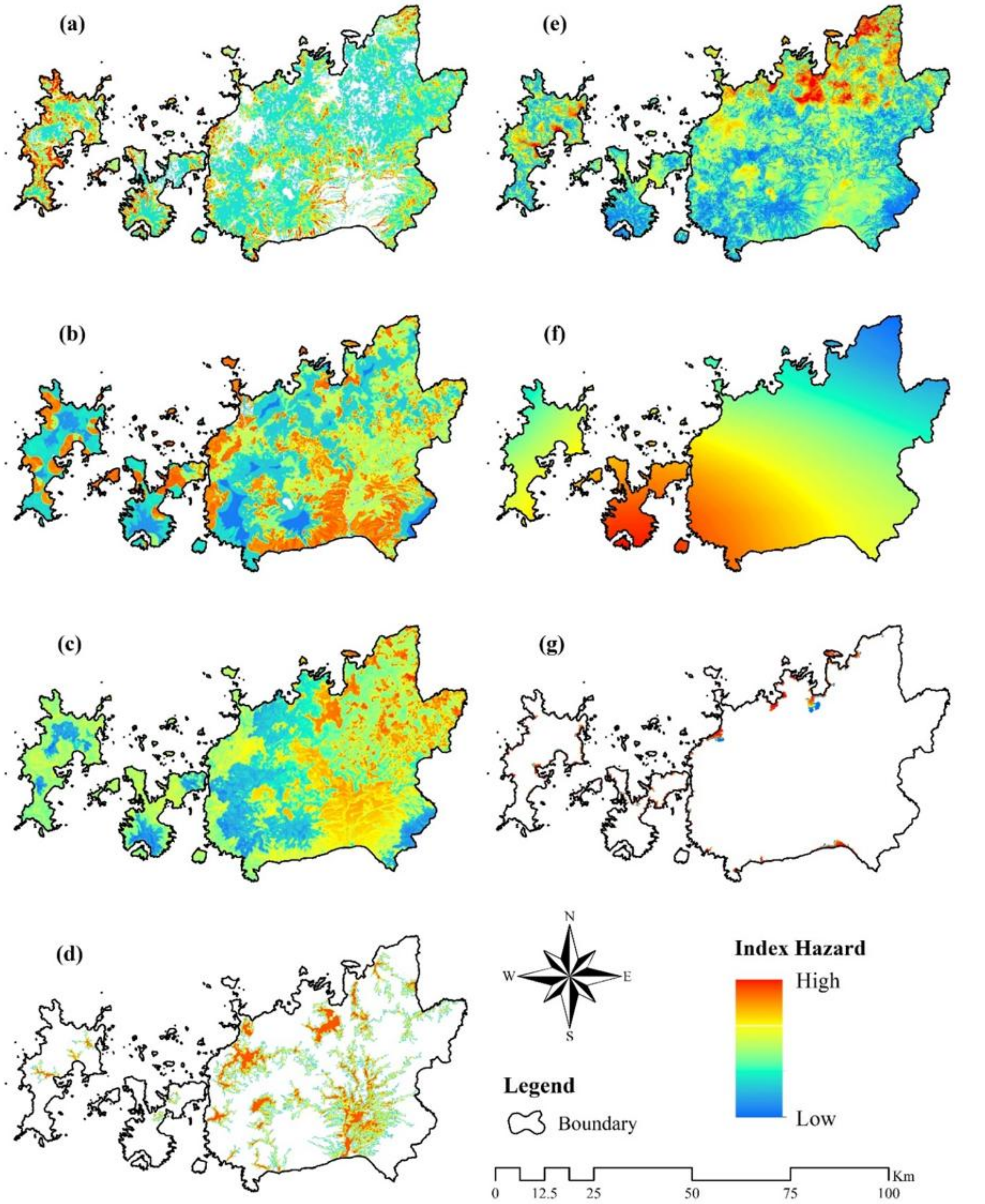

Figure 3. (a) Landslide Hazard, (b) Forest Fire Hazard, (c) Extreme Weather Hazard, (d) Flood Hazard, (e) Earthquake Hazard, (f) Drought Hazard, and (g) Tsunami Hazard in Manggarai Barat.

The analysis results indicate that the spatial distribution of drought and similar extreme weather hazards occurs in almost the entire Manggarai Barat region. The drought indicators are based on meteorological data that spatially reflect rainfall deficit conditions, and therefore primarily represent climatic conditions. Extreme weather hazards are distributed more evenly, indicating a broader local climate influence across the region. Earthquake hazards are also distributed throughout the region due to tectonic activity, while vegetation zones primarily distribute forest and land fire hazards. Coastal areas, particularly those with gentle coastal topography, limit the risk of tsunamis. Overall, these patterns show that spatial distribution in Manggarai Barat reflects regional hazards and local processes related to the topography and morphology of the region.

The results of the multi-hazard risk model show a clear spatial distribution across the region. Areas with high combined risk are mostly concentrated along the western and northwestern coastal zones, particularly in the main tourist area of Labuan Bajo. Coastal areas are more vulnerable to multi-hazard risks due to hydrometeorological factors, geomorphological conditions, and massive tourism development and infrastructure expansion (Firmansyah *et al.,* 2019; White *et al.,* 2025).

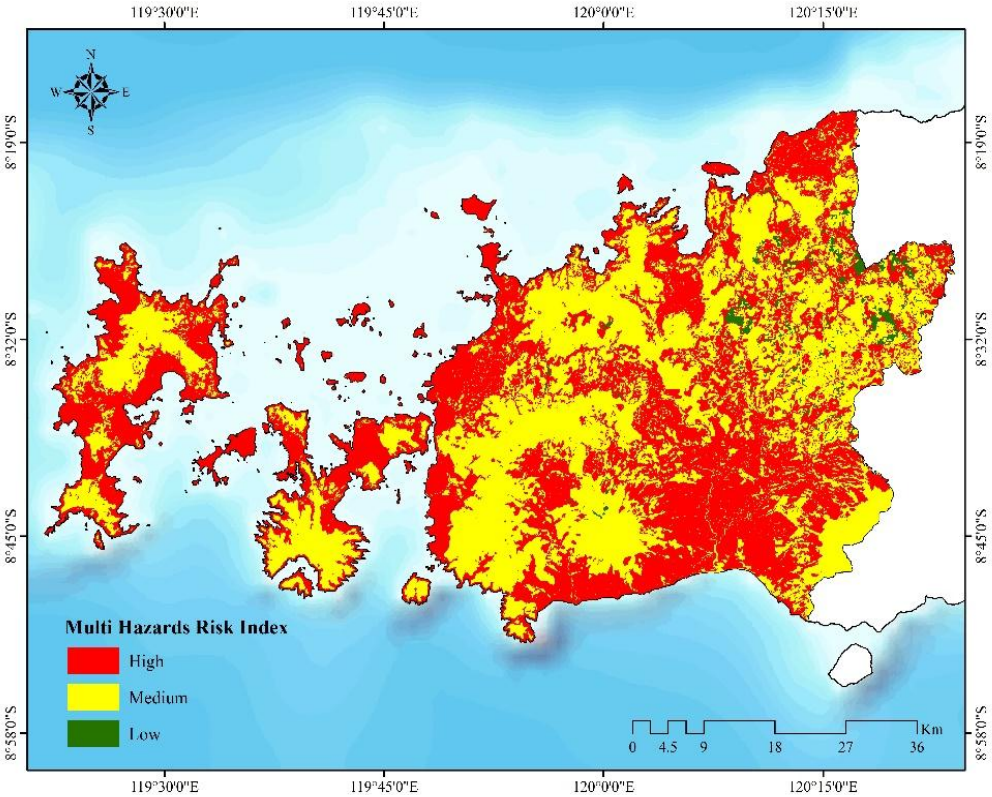

Figure 4. Multi-Hazard Risk Map.

Mountainous areas stretching from the central to southwestern parts of the region also exhibit high-risk conditions Figure 4. This region has steep slopes and high rainfall intensity, making it prone to hydrometeorological disasters. This is in line with multi-hazard research in tropical regions, where topography and rainfall play a dominant role in shaping hazard interactions and cumulative risks (Winarti *et al.,* 2018). Conversely, the eastern region exhibits low to moderate risk levels, with a comparatively limited spatial overlap between hazards. Overall, cumulative risk in coastal areas is relatively high, with the interaction between geomorphological conditions, hydrometeorological processes, and land-use change factors explaining this pattern. In practice, the analysis indicates that the spatial distribution of multi-hazard risks in tourist destinations is not only determined by natural factors, but is also influenced by how development pressures and planning decisions are managed at the local level.

The spatial distribution of multi-hazard risks analysed serves as an empirical basis for evaluating the suitability between current spatial plans (RTRW) and disaster risk conditions in tourism destinations. Previous studies emphasise that coastal and hilly areas oriented towards tourism require careful spatial planning because they threaten the long-term sustainability of destinations (Firmansyah *et al.,* 2019; Widantara & Mutaqin, 2024). Therefore, the results of our study highlight the relevance of integrating multi-hazard risk information into spatial planning analysis in disaster-prone tourism destinations.

3.2. Spatial Consistency Between RTRW and Multi-Hazard Risk

The analysis shows the extent to which current land use plans accommodate the level of risk in Manggarai Barat. It overlays composite multi-hazard risk maps and regional spatial plans (RTRW), with the resulting classification grouping land use into three categories: suitable, conditionally suitable and unsuitable. This classification helps evaluate the extent to which current spatial planning is consistent with varying levels of multi-hazard risk within the study area (Wirawan *et al.,* 2021).

3.2.1. Suitability Spatial Pattern (RTRW) Classification

The spatial pattern of land-use suitability in Manggarai Barat reflects the relationship between planned land-use functions and composite multi-hazard risk conditions. The suitability classification was determined by considering the compatibility between the intended land-use function and the corresponding risk level. As a result, areas with similar risk conditions may have different suitability classifications depending on their planned use.

Different land-use functions have different levels of sensitivity to hazard conditions. Development-oriented uses, such as settlements, tourism facilities, and infrastructure, generally require safer locations due to the concentration of people and economic activities. Conversely, conservation and protected areas are less dependent on physical development, allowing them to remain appropriate even in locations with relatively high risk.

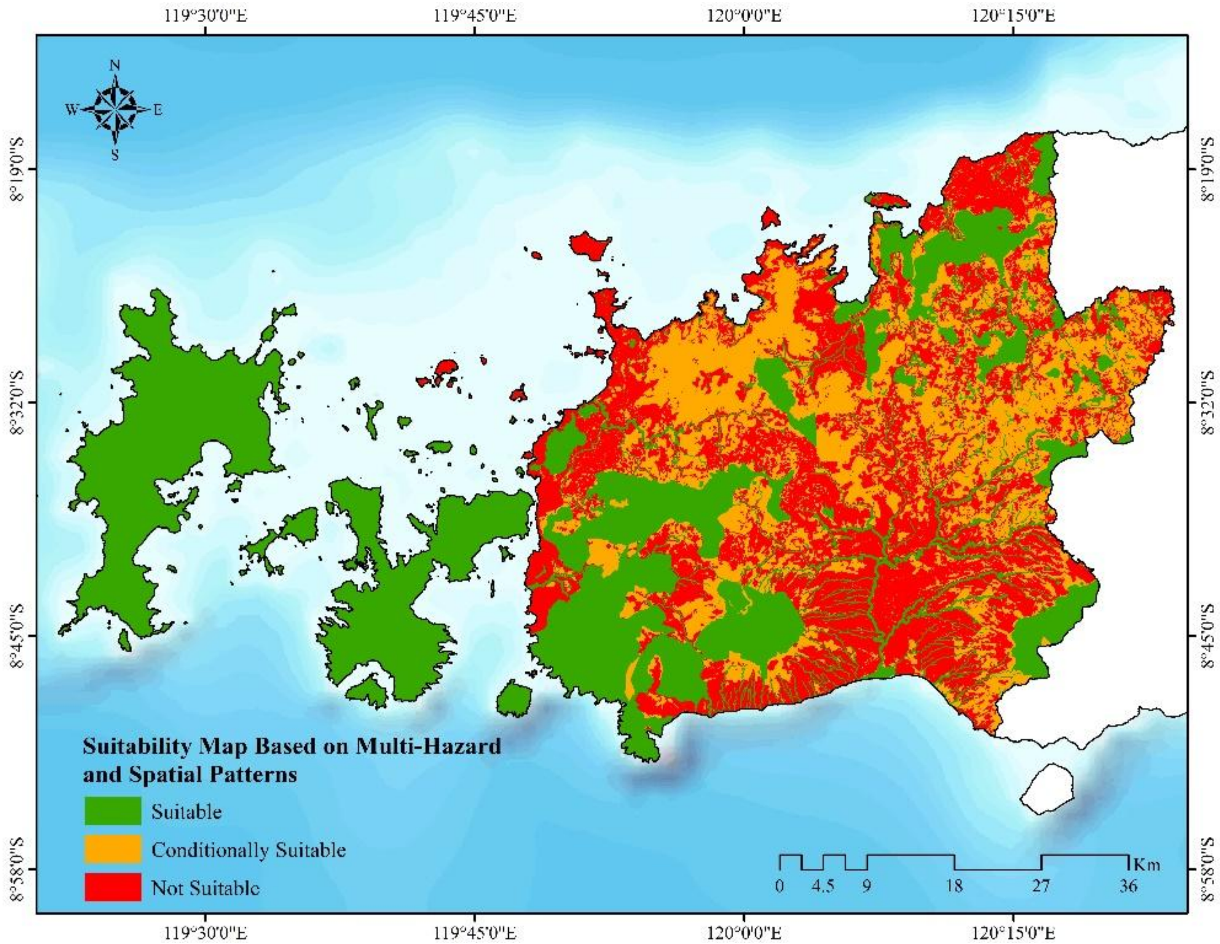

Figure 5. Classification of Spatial Planning Suitability Based on Multi-Hazard Risks.

Figure 5 shows the distribution of suitable, conditionally suitable and unsuitable areas resulting from the comparison between planned land-use functions and multi-hazard risk conditions. Areas classified as unsuitable are mostly concentrated in the southern and southeastern parts of the region, with smaller clusters in the central area. These locations generally coincide with areas affected by multiple hazards, including floods, landslides, forest and land fires, and extreme weather events. The concentration of unsuitable areas reflects the overlap between development-oriented land use and elevated multi-hazard risk conditions (Wirawan *et al.,* 2021).

Conditionally suitable areas dominate the central and eastern parts of mainland Manggarai Barat. These zones are generally associated with moderate multi-hazard risk conditions. While certain forms of development remain possible, their implementation requires greater attention to risk management and site-specific mitigation measures. The islands within Komodo National Park, particularly in the western part, are suitable areas. This region generally faces only rare threats of disaster but faces challenges due to limited carrying capacity and National Park regulations.

In areas with multiple hazards, spatial planning maps often fail to address safety aspects. In this scenario, the overlap of hazards exposes a similar gap: the creation of zoning regulations occurs without comprehensive understanding of the risks involved. This discrepancy aligns with findings from previous studies which have used combined hazard models. Regions with higher development pressures tend to neglect multi-hazard risk aspects. From a different angle, inadequate spatial planning also contributes to high disaster risk levels (Firmansyah *et al.,* 2019).

3.2.2. Multi-Hazard Risk Across Land-Use Functions

This section examines the relationship between the existing RTRW spatial pattern and the distribution of multi-hazard risk across Manggarai Barat. The results highlight how different land-use functions interact with varying levels of multi-hazard risk and reveal important implications for spatial planning and tourism development.

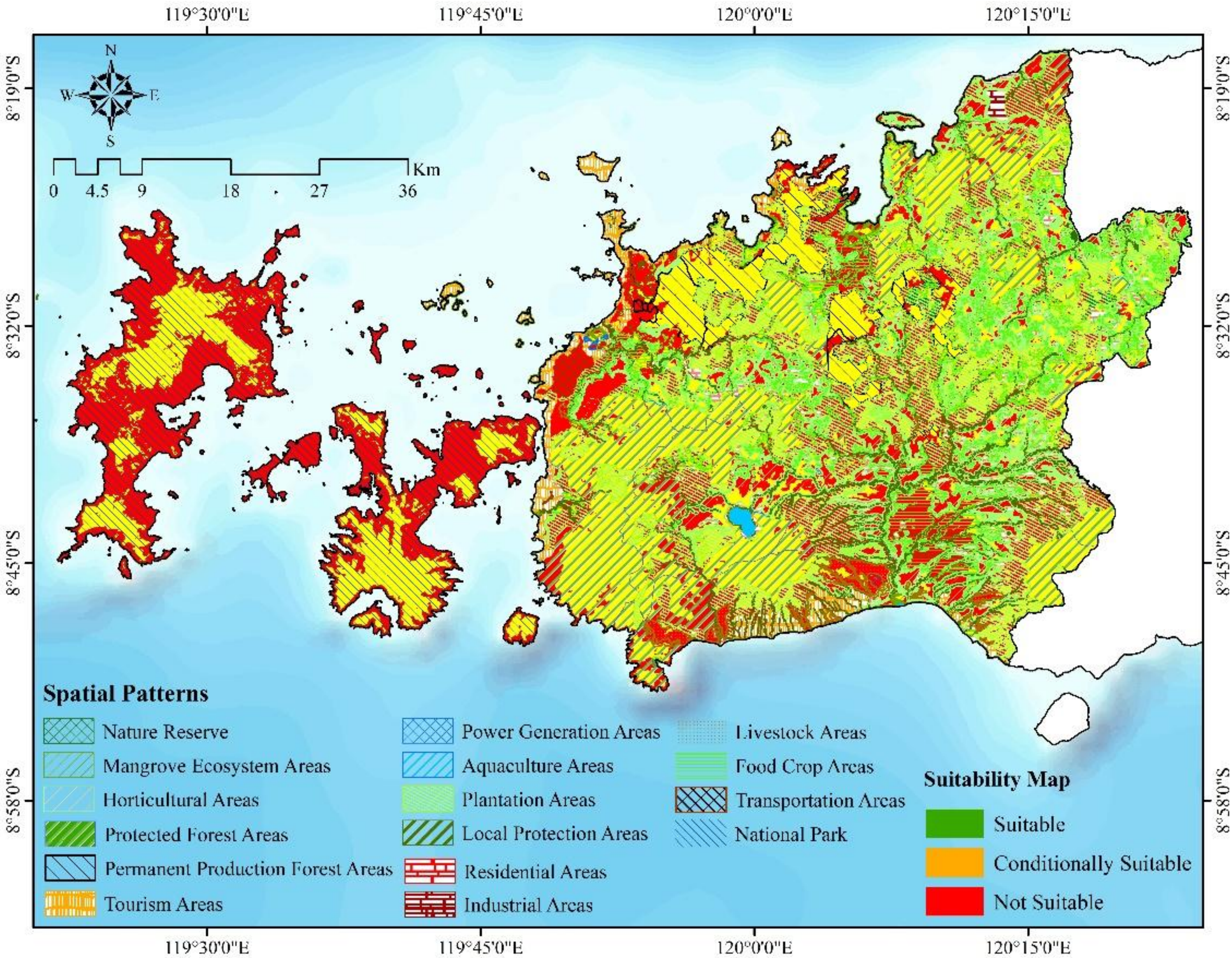

Figure 6. Integration of Risk Suitability Into Spatial Patterns of the Regional Spatial Plan (RTRW).

Figure 6 illustrates the resulting suitability patterns, while Table 2 details the corresponding areal distribution across land-use categories. Lower-risk environments predominantly host conservation-oriented land uses such as protected forests, nature reserves, mangrove ecosystems and water bodies. Spatial planning patterns that involve conservation areas can accommodate the threat of multiple disasters; green spaces function like sponges, absorbing the threat of disasters. These ecological areas act as buffers and support regional resilience. Their existence requires spatial planning to be more sensitive to the risk of multiple disasters.

Meanwhile, the spatial pattern of agricultural land is at moderate risk. Despite the land designation being for food crops, plantations, livestock and horticultural areas, practices applied must maintain sustainability. To manage agricultural land in areas at moderate risk, effective risk management, technical intervention and adaptive practices are still needed.

Tourism and residential areas account for a substantial share of land classified as conditionally suitable and unsuitable Table 2. This reflects the concentration of development in locations exposed to moderate and high multi-hazard risk. Tourism activities depend on accessibility, supporting facilities, and the attractions themselves, meaning that risk exposure extends beyond the main tourism areas of Labuan Bajo to surrounding settlements, access corridors, and other elements that support destination resilience.

Table 2. Assessment of Spatial Planning Suitability Based on Risk Exposure.

Spatial Pattern	Area (Hectare)		
	Suitable	Conditionally Suitable	Not Suitable
Permanent Production Forest	53	14,199	3,305
Industrial Areas	0	32	577
Transportation Areas	0	8	127
Tourism Zone	2	764	7,827
Power Generation Areas	2	23	162
Residential areas	1,288	3,018	8,419
Food Crop Areas	292	9,298	9,565
Livestock Areas	0	494	2,945
Plantation Areas	1,323	35,097	35,236
Aquaculture Areas	0	15	88
Horticulture Areas	1,321	16,382	30,101
Water Bodies	1,321	-	-
Nature Reserves	1,485	-	-
Mangrove Ecosystem Areas	1,837	-	-
Protected Forest Areas	53,691	-	-

Overall, the RTRW has incorporated disaster risk considerations into the spatial planning framework. However, development pressures continue to create challenges in aligning planned land-use allocations with multi-hazard risk conditions. Moderate-to-high-risk zones encompass a significant proportion of residential and tourism areas. As destinations such as Labuan Bajo continue to develop rapidly, balancing development objectives with disaster resilience is becoming increasingly important. This pattern is consistent with findings from previous studies which have highlighted the challenges of managing tourism growth in hazard-prone island regions (Karim *et al.,* 2024).

3.3. Spatial Planning Exposure to Multi-Hazard Risk

Overlaying the spatial plan (RTRW) on the multi-hazard risk map shows that many major transportation routes and activity centres in Manggarai Barat are at moderate to high risk due to various hazards. Starting from the south, the hilly landscape is an area where the main road crosses zones with moderate to high levels of danger. Along with the spatial structure and connectivity of networks that cross tourism activity centres, the level of hazard increases significantly. The combination of risks becomes clear when the structure map meets the multi-hazard risk model. Throughout Manggarai Barat, spatial structures and networks often cross areas that are prone to disaster.

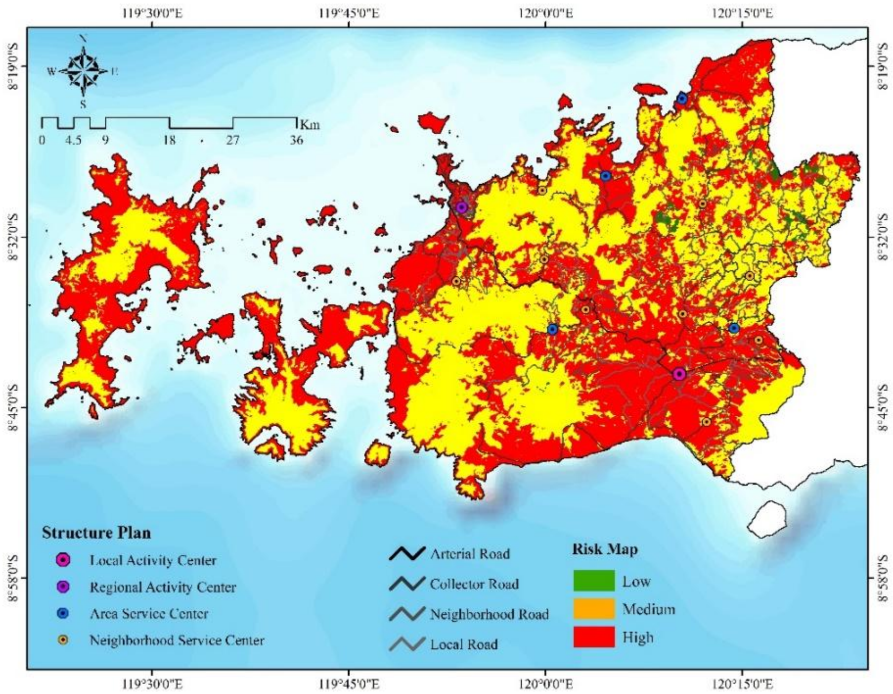

Figure 7. Structure Plan in Relation to Multi-Hazard Risk Levels.

Figure 7 illustrates the spatial relationship between the structure plan and multi-hazard risk levels. Most transportation corridors and planned development areas intersect zones classified as moderate to high risk, emphasising the need to strengthen risk considerations within spatial planning and land-use allocation decisions. This structure is particularly evident on the primary and secondary routes that cross the hilly southern and central parts of the region. The uneven terrain here overlaps with multiple hazards. As key connectivity routes, the roads link tourism activity centres, support facilities, and inland areas that form the tourism supply chain.

Table 3. Road Network Exposure Based on Risk Level

Road Class	Risk Class (meters)		
	Low	Medium	High
Arterial Road	3,261	23,590	58,578
Collector Road	50,241	178,020	359,162
Neighborhood Road	20,180	90,831	129,108
Local Road	54,455	240,847	362,256

Table 3 indicates that all types of roads have a significant share in medium- and high-risk areas. The highest-risk areas are located along the main routes connecting tourist centres and residential areas. Although local roads show lower concentrations, they still face significant risks. This is because these roads provide access to tourism support, such as agricultural products and rural area.

In primary connectivity, exposure to multi-hazard risk may affect the ease of public access to various locations. These routes are the main access points for mobility and visitor arrivals. Secondary roads show a similar pattern, indicating vulnerability across the entire destination. Previous studies indicate that connectivity systems in hazardous zones often suffer more severe damage, neglect hazards, and ignore structural mitigation (Mitrica *et al.,* 2025).

Local centres in high-risk areas will encounter challenges in maintaining safe operations. The community will receive support during a disaster, but significant constraints arise, with incidents significantly disrupting essential supply chains for commerce and transportation. Research shows that access points in vulnerable nations experience more adverse effects when tourist destinations encounter repeated hazards. The proximity of transportation routes or aid stations to hazardous areas increases safety risks (Barbhuiya & Chatterjee, 2020).

This indicates that the risk factors identified in the RTRW have not been completely incorporated into the design of the network or transportation hubs. In popular tourist locations, such as Labuan Bajo, it is increasingly important to conduct spatial planning that incorporates hazard assessment. However, identified risks have not been integrated into the spatial structure design to address multiple hazards. Busy tourist locations require proactive approaches embedded within their spatial plan. The early warning systems featured in the RTRW could affect access and security without modifications.

3.4. Stakeholder Perceptions of Risk Integration in Spatial Planning

The spatial analysis presented in the previous sections identified clear inconsistencies between the RTRW spatial pattern, the spatial structure, and the distribution of multi-hazard risk in Manggarai Barat. To better understand the factors underlying these patterns, this section presents the qualitative findings that explore how risk is perceived, understood and integrated by stakeholders within spatial planning practices.

Several areas were identified where planned development coincides with moderate to high multi-hazard risk conditions. According to the interview findings, these patterns are closely tied to the rapid expansion of tourism, ongoing land-use changes, and persistent difficulties in enforcing spatial planning regulations on the ground. Informants also noted that managing development pressures while remaining consistent with existing planning provisions has proven particularly challenging, a tension that helps explain some of the spatial mismatches observed in the overlay analysis.

3.4.1. Risk Considerations in Spatial Planning and Zoning

Official government documents acknowledge the incorporation of disaster risk within spatial planning frameworks. Previous studies reveal a limited application of hazard maps in informing zoning regulations (Jayasinghe *et al.,* 2024). Although map quality is significant, more complex concerns stem from the decision-making processes involved. Power structures and growth requirements frequently rationalise planning results. Analyses show that areas classified as moderate to high-hazard zones are predominantly characterised by the construction of residential structures, tourist attractions and roadways.

This aligns with information obtained from the interviews concerning the existence and implementation of regulations for protected areas in disaster-prone zones within Komodo National Park.

"[…] Komodo National Park (KTA 1) is intended to function as a conservation area with minimal infrastructure and intervention, indicating that zoning regulations do exist. However, in practice, its planning direction, as reflected in the master plan, has shifted toward designation as a 'main tourism area,' which potentially contradicts conservation principles […]." (Interview G4, 2025).

The interview highlights the challenges of balancing tourism development with existing planning provisions. In areas experiencing rapid growth, increasing demand for land and investment can place pressure on the implementation of spatial plans. As a result, development may continue to expand into areas exposed to elevated multi-hazard risks, despite the presence of zoning regulations and risk considerations.

Although disaster risk has been incorporated into planning documents, stakeholders noted that translating these considerations into zoning decisions remains challenging, particularly in areas experiencing strong development demand. This finding suggests that planning outcomes are shaped not only by risk information but also by broader development priorities and implementation challenges.

3.4.2. Infrastructure Exposure and Evacuation Accessibility

The Manggarai Barat region is characterised by both coastal and mountainous geographical features. The mountains link tourist centres, including Labuan Bajo, to the primary connectivity network in regions classified as having moderate to high risk. This access facilitates daily commuting and functions as an evacuation route during flooding or landslides. Weather conditions vary, influencing movement along these routes. Under typical conditions, traffic operates efficiently; however, during severe weather events and landslides, the resilience of these routes is essential.

Despite the implementation of initiatives for disaster-safe tourism planning, numerous tourist attractions remain inadequately prepared. In mountainous regions far from the coast, intense rainfall and landslides significantly jeopardise well-known sites. Access roads frequently exhibit narrow dimensions, inadequate maintenance, and insufficient capacity to accommodate emergency evacuations during a disaster.

"[…] In general, the implementation of sustainable tourism and resilience principles in Manggarai Barat has begun to show tangible progress. […] Coordination among agencies has improved. The use of weather and wave information from BMKG has increased. And several disaster-resilient hotels have emerged. However, inland destinations such as Wae Rebo, waterfalls, and hill-based attractions remain vulnerable to heavy rainfall and landslides. Indicating the need for strengthened risk information and evacuation routes […]." (Interview G3, 2025)

Businesses have demonstrated initiatives in adhering to disaster preparedness regulations. However, the full implementation of these regulations and standards remains incomplete. Current accommodation incorporates basic safeguards, including explicit evacuation instructions, routine team drills, and weather monitoring. These facilities are designed to provide services that ensure guests' safety.

"[…] Fire extinguishers and evacuation routes are already in place, and staff receive routine fire safety training. […] However, disaster-resilient hotel certification has not yet been obtained. Inspections are typically conducted by the fire department to verify safety equipment […]." (Interview B1, 2025)

The findings indicate that tourism facilities, including hotels and other accommodation, have established preparedness initiatives. While certain accommodation providers have made adjustments, evacuation routes continue to be susceptible to natural hazards. In line with previous studies, while certain accommodation sectors have started to adopt preparedness practices, road networks and evacuation routes to numerous tourist attractions still pass through disaster-prone regions (Zhang *et al.,* 2024b).

3.4.3. Spatial Control and Development Pressures

The significant growth of tourism in Labuan Bajo, Manggarai Barat, has directly influenced spatial management, particularly in coastal and urban regions. However, discrepancies exist between zoning regulations and actual land use due to evolving development dynamics. Despite current regulations, community-driven changes in land use occur at a pace that outstrips regulatory control. Significant investments in the tourism sector have resulted in emerging spatial usage patterns that may not align with planning frameworks.

Insufficient regulation of spatial utilisation leads to environmental degradation in both upstream and downstream regions of Manggarai Barat. The flooding observed in tourist and residential areas underscores deficiencies in spatial planning.

"[...] Flooding in strategic and tourism areas of Labuan Bajo over the past three years illustrates failures in integrating downstream development with upstream conservation. The issue stems from weak drainage systems and inadequate climate-oriented spatial planning. It is suggested that, without comprehensive planning and strong coordination, climate impacts will directly threaten the economic core of destination. [...]." (Interview A1, 2025)

Field observations further substantiate the discrepancy between spatial planning regulations and the actual development occurring on-site. Moreover, the situation indicates that substantial investments in tourism initiatives frequently occur without complete adherence to environmental and zoning regulations.

"[...] Many hotels and accommodation facilities, especially newly developed and large-scale projects, are suspected of violating environmental impact assessment (AMDAL) and spatial planning regulations. [...] Common issues include incomplete permits, improper waste disposal into coastal and terrestrial environments, damage to mangroves and coral reefs during construction, and development within restricted coastal buffer zones. [...]." (Interview M1, 2025)

The interview findings match the spatial overlay analysis. The designation of tourism and residential areas lacks synchronisation; land use plans in various locations directly intersect with multi-layered disaster-prone areas. This suggests that the swift expansion of tourism development will lead to conflicts in spatial planning. The weak capacity of planning agencies to design risk-responsive spatial plans exacerbates this issue. The findings demonstrate that the governance of official licensing instruments frequently fails to keep pace with the swift developments in the tourism sector, as evidenced by the situation in Labuan Bajo, Manggarai Barat.

3.4.4. Risk Consideration in Spatial Planning and Zoning Practices

The interview findings demonstrate that infrastructure, particularly information and communication technology (ICT), is crucial for disaster mitigation. Both the public and visitors depend on technology-based tools, especially social media, as the main avenue for disseminating disaster information (Ruslanjari *et al.,* 2023). Instant messaging applications are employed to rapidly disseminate information regarding potential natural hazards, while the presence of digital weather websites improves individuals' capacity to keep up-to-date with environmental condition forecasts. ICT serves as the foundational element of early warning systems.

ICT infrastructure also facilitates the direct monitoring of disaster threats. However, the readiness of communities and tourism operators for disasters remains comparatively insufficient.

"[...] People usually rely on information from BMKG (Badan Meteorologi, Klimatologi, dan Geofisika, the Indonesian Meteorology, Climatology, and Geophysics Agency) and social media such as Facebook, Instagram, and WhatsApp to monitor heavy rainfall and landslide potential. [...] However, there is no specific preparedness in place. [...]." (Interview C1, 2025)

This comment suggests that infrastructure such as ICT use contributes mainly to situational awareness rather than to longer-term or systematic risk reduction practices. Information received through digital channels is generally interpreted as short-term warnings and is rarely translated into proactive measures, such as risk-sensitive spatial control or development planning in hazard-prone areas.

From a media perspective, limited access to official risk data remains a major constraint in effective disaster communication. Informants emphasised that multi-hazard risk maps and supporting documents were not readily available to the public, restricting comprehensive risk reporting (Novianti & Jalaludin, 2025). Such limitations were consistently highlighted, encompassing the absence of accessible multi-hazard risk maps and associated planning documents, thereby constraining comprehensive risk reporting.

"[...] Despite the government's claims of conducting multi-hazard mapping, public access to detailed risk data remains extremely limited. Risk maps and documents are difficult for both media and the general public to obtain [...]." (Interview M1, 2025)

Overall, the findings reveal a gap between increased access to infrastructure such as ICT-based information and the institutional integration of risk considerations into spatial planning practices.

While infrastructure such as ICT plays an important role in supporting immediate responses by communities and tourists in Manggarai Barat, its use has yet to be formalised as part of a risk-informed spatial planning approach, particularly within residential and tourism areas.

3.5. Discussion

Previous studies have shown a mismatch between frameworks for disaster risk reduction and spatial planning (Dandoulaki *et al.,* 2023b; Greiving & Fleischhauer, 2006). The physical conditions in the Manggarai Barat region indicate that this mismatch is even more significant. This results from the convergence of various disaster risks and considerable vulnerability stemming from extensive development and tourism activities. Research on multi-hazard risk increasingly highlights that cumulative exposure involves not only a combination of hazard factors but also the location of infrastructure and activity centers in vulnerable regions (Shalih *et al.,* 2026).

In coastal tourism regions experiencing rapid transformation, this spatial concentration pattern may heighten systemic vulnerability. The Manggarai Barat region illustrates this broader pattern, especially whre tourism development intersects with disaster-prone areas. Regions with significant potential for various hazards are the chosen areas for tourism development. This situation highlights the frequent neglect of risk issues in development strategies. Because of economic aspirations economic aspirations, disaster protection is often deprioritised in favour of immediate benefits.

The findings also resonate with the growing literature on tourism resilience, which emphasises that resilience in destination areas depends not only on recovery capacity, but also on the anticipatory integration of risk knowledge into spatial development decisions (Della Corte *et al.,* 2021). In this sense, resilience is closely tied to how land-use planning aligns long-term tourism growth with environmental constraints (Jayasinghe *et al.,* 2024).

Our findings are consistent with previous studies on the continuing gap between disaster risk reduction (DRR) policies and spatial planning implementation (Dandoulaki *et al.,* 2023b; Greiving & Fleischhauer, 2006). However, they significantly enhance understanding by illustrating how the distinctive political economy of the state-designated "Super Priority" tourism destinations exacerbates this gap. In this context, the primary driver is not post-disaster recovery, but rather proactive growth geared toward national economic goals (Chan *et al.,* 2020). The national narrative of "Super Priority"-based tourism development fails to manage disaster risks in local destinations because it prioritises national tourism economic ambitions. Our research further develops the theory of planning failure by highlighting how multilevel and multistakeholder governance with conflicting priorities can systematically produce spatial vulnerability.

The findings are also consistent with previous studies on methods for modeling multi-hazard assessment frameworks that can provide strong support for governments or policymakers in planning disaster prevention, early warning systems, and mitigation strategies in vulnerable areas (Wang *et al.,* 2026). Our study used a mixed-methods approach to develop an integrated diagnostic framework which combines various methods of problem identification and evaluation, such as the use of models that analyse various threats to evaluate the effectiveness of risk mitigation plans with spatial planning. This framework also qualitatively analyses governance systems that result in inconsistencies and gaps in implementation. The use of the framework in Labuan Bajo is just one case study, but has the potential to be developed for new tourist areas facing similar problems and geographical conditions. It shows how to assess risks before a disaster occurs by providing policy priority options.

The results imply the need for stronger and more integrated policy measures. At the local planning level, legally binding regional spatial plans (RTRW) need to be amended immediately to incorporate a legally binding risk-based zoning approach. This policy would prohibit development in high-risk areas that are inappropriate, and risk suitability would be a strict and non-negotiable requirement for permits. For destination management, resilience must be a key competitive advantage. Destination management plans should include multi-hazard risk maps and sustainability certifications demonstrating evidence of risk-based site selection and infrastructure adaptable to disasters and climate change. At the same time, national policy needs to change how it assesses "top priority" destinations by adding resilience metrics, such as the level of new investment in low-risk areas, to economic growth indicators. Policies also need to provide greater technical and regulatory support to local governments so they can create risk-sensitive spatial plans, even when development pressures are high. This integrated approach is necessary to transform spatial planning from a tool for growth into a key part of long-term sustainability and resilient development.

The findings further highlight that the mismatch between spatial planning and risk is not solely due to technical limitations in risk mapping. Institutional dynamics, development pressures, and weak law enforcement also contribute to the mismatch. This indicates that integrating risk into spatial planning is not merely a matter of data availability, but also depends on how information is interpreted and implemented in decision-making processes. In short, our analysis identifies inadequate technical capacity as the cause of the observed mismatch between planning and risk in Labuan Bajo under the "Super Priority" strategy. This lack of technical capacity prevents risk information from being produced, updated and integrated into planning and decision-making processes. Furthermore, weak law enforcement ensures that even when risk information is available, it is not translated into binding land-use decisions. Consequently, land-use conversion is uncontrolled, and disaster risks are increasing.

The methodological limitations of the study are acknowledged and directions are proposed for further research. The multi-hazard model offers regional evaluations. However, its dependence on macro-scale data necessitates more detailed and location-specific modeling for each location. Furthermore, broader surveys of individual actors' risk perceptions could enhance the rich qualitative insights from stakeholders. Therefore, future research is recommended: first, to routinely monitor policies to assess the extent to which risk science is integrated into the RTRW revision process and how political issues are addressed; second, to create flexible hazard models using climate change projections to assess the extent to which current tourism zoning can adapt to future conditions, enabling better planning; and third, to conduct comparative studies with other tourism destinations to help develop sustainable and resilient tourism models to locate effective governance solutions for future tourism destinations with similar characteristics.

4. Conclusion

The study demonstrates that the existence of a formal spatial plan does not automatically translate into territorial resilience. In Manggarai Barat, although the RTRW provides a clear development direction, zoning regulations do not yet fully reflect the multi-hazard risk conditions identified in our study. Residential areas, tourism zones and infrastructure networks located within moderate- to high-risk areas continue to exhibit spatial mismatches. Tourism development areas, especially in coastal zones, primarily exhibit this mismatch, where tourism infrastructure overlaps with high-risk areas. This indicates that spatial planning in these regions is still largely driven by economic priorities and has not fully taken disaster risks into account in land-use allocation.

The results are of particular importance given the rapid expansion of Labuan Bajo as a designated tourism hub. The observed mismatches indicate that spatial control mechanisms have yet to fully operationalise disaster risk considerations. Consequently, development processes tend to outpace the capacity of spatial planning instruments to respond to existing and emerging risk conditions.

This study has several limitations. First, the spatial resolution of the data used may affect the accuracy of the analysis results; therefore, future research is advised to use higher resolution data. Second, the integration of multi-hazard risks in this study uses a simple overlay approach that does not account for further hazard interactions (compound and systemic risks). Therefore, more complex approaches, such as weighting based on severity, should be explored in the future.

Overall, the study calls for pressing official revision of Regional Regulation No. 11 of 2021 on the Regional Spatial Plan (RTRW) of Manggarai Barat Regency. Specifically, the clauses governing coastal zoning and hillside development in areas classified as extremely high-risk for disasters must be addressed. The construction of new housing and critical public facilities must be prohibited as a mitigation measure. Concurrently, a measurable resilience dashboard should be developed based on joint regulatory decisions by national and local authorities. This should be integrated into the master plan and publicly monitored. It should include indicators such as the proportion of disaster-resilient certified accommodation, the number of operational early warning sirens, the proportion of tourism workers trained in disaster response, the availability of emergency and recovery funds for business continuity, and the existence of service and business continuity plans. Finally, we recommend the formal establishment of a Tourism and Sustainable Resilience Coordination Forum in Labuan Bajo involving various stakeholders, designated representatives from the government, the business sector, academia, the community and the media, led by a Labuan Bajo Flores Authority Executive Board (BPOLBF) that coordinates the forum.

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Author Contributions

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Conflict of interest

All authors declare that they have no conflicts of interest.

Data availability

Example 1: "Dataset is provided in this URL: https://zenodo.org/records/10705588" or "Data is available upon request. ".

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