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A Study on The Vulnerability of Coastal Areas to Earthquakes and Tsunamis, and A Swot Analysis for Mitigation Based on A Socio-Ecological Framework in West Ternate, Ternate City, North Maluku Province

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Abstract
The coastal area of West Ternate, Ternate City, North Maluku Province, is highly vulnerable to earthquake and tsunami hazards because of its direct exposure to the double-subduction system of the Molucca Sea. This study aimed to analyze the potential impacts of earthquakes and tsunamis, examine the relationship between coastal morphological characteristics and tsunami susceptibility, and formulate applicable and realistic disaster mitigation strategies. The study employed a qualitative approach using the Socio-Ecological Framework (SEF) integrated with SWOT analysis. Data were obtained through a literature review, analysis of seismic data from BMKG and the USGS, field observations, interpretation of satellite and drone imagery, and in-depth interviews with local communities and relevant stakeholders. The results indicated that the Molucca Sea region exhibited high seismic activity and recurrent earthquake and tsunami potential, while the coastal morphology of West Ternate, characterized by narrow bays and steep topography, contributed to tsunami-wave amplification. In addition, disaster risk was influenced by interactions among physical, social, and institutional factors. The study concluded that disaster mitigation strategies in West Ternate should be developed through an integrated approach that considers coastal geomorphological conditions, seismic hazard patterns, community preparedness, and local institutional capacity. The findings are expected to provide a scientific basis for area-based earthquake and tsunami disaster mitigation planning in West Ternate.

INTRODUCTION

Eastern Indonesia, particularly the Molucca Sea region, is one of the most tectonically complex and active regions in the world. This area is characterized by a double-subduction system in which two opposing subduction zones coexist: the Halmahera subduction zone to the east and the Sangihe subduction zone to the west. The presence of an inverted U-shaped subduction geometry (Survey, 2026) , often associated with the inverted U-shaped Halmahera slab, contributes to a very high level of seismicity (Humphrey & S, 2005) . The convergence rate between the plates reaches approximately 100 mm/year, predominantly in an east–west direction, resulting in substantial tectonic strain accumulation (USGS, 2026).

On April 2, 2026, an earthquake with a moment magnitude (Mw) of 7.6 occurred in the Molucca Sea region at a hypocentral depth of approximately 62 km. The epicenter was located at approximately 1.27° N and 126.26° E, about 127 km southeast of Bitung City and northwest of Ternate City. The earthquake exhibited a reverse-faulting mechanism with a generally southwest–northeast strike and an eastward-dipping fault plane. The earthquake source was estimated to be associated with double-subduction activity in the Molucca Sea (BMKG, 2026). Historically, the Molucca Sea has exhibited a very high level of seismic activity. Over the past 50 years, at least nine earthquakes with magnitudes greater than 7.0 have occurred within a radius of 250 km of the 2026 earthquake epicenter. One of the largest events was the Mw 7.5 earthquake in January 2007, which occurred close to the epicenter of the 2026 earthquake. This pattern indicates that the Molucca Sea region is characterized by repeated tectonic strain accumulation and release (USGS, 2026) (Kaufman et al., 1991). The western coast of Ternate directly faces the Molucca Sea and is therefore highly exposed to earthquake and tsunami hazards (Rosally et al., 2024) . According to data from the Central Statistics Agency (Ternate, 2025) , West Ternate Subdistrict is the largest subdistrict on Ternate Island, with a population of 9,478, representing 4.50% of the total population of Ternate City. The subdistrict also has the highest population growth rate and contains 20 tourist attractions, making it an important tourism center in Ternate City (Thornbury & D, 1969).

Geomorphologically, the western coast of Ternate is characterized by narrow bays that open directly toward the Molucca Sea. The terrestrial morphology is dominated by narrow coastal plains that transition rapidly into mountainous and steep terrain toward the slopes of Mount Gamalama. These landforms are primarily composed of accumulated pyroclastic materials and volcanic deposits derived from Mount Gamalama, while smaller portions of the coastal zone consist of alluvial deposits (Harlianto et al., 2016) . The combination of narrow bays, steep slopes, and limited coastal plains may enhance tsunami-wave amplification, particularly in areas directly oriented toward potential tsunami sources. This condition is of particular concern given the high seismic activity in the Molucca Sea region, including the Mw 7.6 earthquake of April 2, 2026, whose magnitude exceeded that of many major earthquakes recorded in the region over the past 125 years. Vulnerable coastal morphology, combined with population concentration and tourism activities, further increases earthquake and tsunami risk in West Ternate Subdistrict. However, many mitigation efforts implemented to date have remained predominantly technical and have not sufficiently incorporated social conditions or local realities. This study addressed this gap by applying SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to formulate mitigation strategies that are more applicable, realistic (Sammut-Bonnici et al., 2015) , and responsive to local conditions in West Ternate (Adger et al., 2005; Geofisika, n.d.; Ternate, 2025) . This approach was combined with coastal geomorphological analysis to examine the influence of physical characteristics on potential tsunami impacts and incorporated recent seismic data from BMKG and BPBD as part of the scientific basis for the analysis. By integrating these approaches, the study sought to develop a mitigation strategy that was not only conceptually robust but also applicable to reducing earthquake and tsunami risks in the coastal area of West Ternate (Harlianto et al., 2016) .

The research problem focused on the potential hazards associated with major earthquakes and tsunamis in the coastal area of West Ternate, Ternate City, as well as the formulation of appropriate disaster mitigation strategies. The study examined potential earthquake and tsunami hazards based on historical seismicity data, assessed tsunami hazard potential using coastal morphological characteristics and shoreline morphometric parameters, and formulated disaster mitigation strategies based on the Socio-Ecological Framework (SEF) by integrating coastal geomorphology (Lee et al., 2017) , historical seismic data, and SWOT analysis (Puyt et al., 2023) . The study was limited to the coastal area of West Ternate, Ternate City, North Maluku Province, with particular attention to earthquake sources associated with the double-subduction system of the Molucca Sea and their implications for coastal areas. The seismotectonic analysis was limited to the distribution and magnitude of earthquakes recorded over the past 125 years, while the tsunami analysis focused on assessing hazard potential and possible wave intensity based on coastal morphology and shoreline morphometry. The mitigation component was limited to the formulation of earthquake and tsunami mitigation strategies through the integration of SWOT analysis and coastal physical characteristics, without examining other hazards, such as volcanic eruptions, flooding, coastal erosion, or socioeconomic issues, in depth (Masselink et al., 2003) .

Despite the growing body of literature on disaster mitigation in coastal areas, several research gaps remain. Most existing studies have examined disaster mitigation from a predominantly technical perspective, including hazard mapping, early warning systems, and physical infrastructure (Irsyam et al., 2020; Mustafa et al., 2007; Prasetya et al., 2021) , while research integrating social, ecological, and institutional dimensions within a comprehensive framework remains limited. In addition, studies of disaster mitigation in the Molucca Sea region remain scarce, despite the region’s high level of seismic activity and history of destructive tsunamis (Pelupessy et al., 2024; Rosally et al., 2024) . Furthermore, existing research has not sufficiently explained how SWOT analysis can be integrated with the Socio-Ecological Framework (SEF) to formulate mitigation strategies that are applicable (Leigh & D, 2009) , realistic, and responsive to local conditions, particularly in the coastal area of West Ternate (Harrison & P, 2010) . To date, no study has specifically examined the development of earthquake and tsunami mitigation strategies through the integration of coastal geomorphological characteristics, historical seismic data, and SWOT analysis within the SEF framework in West Ternate, Ternate City, North Maluku Province (McCaffrey et al., 1980) .

The novelty of this research lies in three aspects. First, it integrates the Socio-Ecological Framework (SEF) with SWOT analysis to formulate disaster mitigation strategies that consider not only technical factors but also social, ecological, and institutional dimensions. Second, it focuses on the coastal area of West Ternate, Ternate City, North Maluku Province, which remains understudied despite its high vulnerability to earthquakes and tsunamis associated with the double-subduction system of the Molucca Sea. Third, it incorporates coastal geomorphological characteristics and recent seismic data from BMKG and USGS as the scientific basis for mitigation planning, thereby enriching the disaster mitigation literature within the context of socio-ecological systems (Sadisun & A, 2006) .

This study aimed to analyze the distribution of earthquake and tsunami events based on historical seismic data as a basis for hazard mapping, identify coastal morphological characteristics that influence tsunami vulnerability, and formulate SEF-based disaster mitigation strategies through the integration of geomorphological characteristics, historical seismic data, and SWOT analysis (Sadisun & A, 2006) . The study was expected to contribute academically to the development of knowledge regarding earthquake and tsunami hazards associated with the double-subduction system of the Molucca Sea, provide a reference for further research on the interaction between social and geological factors in disaster mitigation, and support the development of disaster risk assessment and geological hazard mitigation methods. In practical terms, the study was also expected to provide locally appropriate mitigation recommendations for the Ternate City Government, BPBD, BMKG, and other relevant agencies in developing contingency plans and disaster risk reduction measures (Reduction, 2015) , while strengthening the awareness and preparedness of coastal communities in West Ternate in facing earthquake and tsunami hazards (Ningrum et al., n.d.).

METHOD

This study aimed to analyze earthquake and tsunami hazards in the Molucca Sea and their implications for disaster mitigation in West Ternate Subdistrict, Ternate City, North Maluku Province. The study employed a qualitative approach using the Socio-Ecological Framework (SEF) integrated with SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis to examine geological, social, and institutional dimensions in formulating disaster mitigation strategies.

The study used both primary and secondary data. Primary data were obtained through in-depth interviews, field observations, drone imagery, and satellite imagery, while secondary data included seismic data from BMKG, relevant policy documents, Digital Elevation Model (DEM) data, and scientific literature. Participants were selected using purposive sampling and included community representatives from Takome, Loto, and Togafo Villages, as well as representatives of the Ternate City Regional Disaster Management Agency (BPBD) and the Ternate Geophysics Station of BMKG. Field observations were conducted to assess evacuation routes, warning signs, shelters, and coastal characteristics, supported by photographic documentation and drone-based mapping.

Interview data were transcribed and analyzed thematically using NVivo 15. The findings were subsequently categorized into strengths, weaknesses, opportunities, and threats and incorporated into a SWOT matrix to formulate SO, ST, WO, and WT mitigation strategies. Geomorphological data were analyzed using QGIS, Google Earth Pro, and DEM data to characterize coastal morphology, terrain slope, and potential tsunami inundation zones. Historical seismic data from BMKG were analyzed descriptively and spatially to identify seismicity patterns and areas potentially exposed to earthquake and tsunami hazards.

The results of the social, institutional, geological, and spatial analyses were integrated within the Socio-Ecological Framework and SWOT analysis to assess potential earthquake and tsunami impacts, delineate disaster-prone areas, and formulate locally appropriate mitigation strategies for disaster risk reduction in the coastal area of West Ternate.

RESULTS AND DISCUSSION

SWOT Analysis Results of Government Institutions

1. BMKG ST. Geophysics of Ternate

The research data was sourced from interviews conducted with key informants from the Meteorology, Climatology, and Geophysics Agency (BMKG) of the Ternate Geophysics Station. The informant in this study is a technical expert in seismology and geophysics who has direct access to seismicity data, tsunami modeling, and the operation of the InaTEWS early warning system in the North Maluku region (Indonesia, 2008) . The interviews included the theme of structured questions including, the tectonic characteristics of the North Maluku region, the capacity and infrastructure of the early warning system, operational weaknesses and gaps, opportunities for the development of mitigation systems, coastal geological and morphological threats, the condition of the social capacity of coastal communities (Garschagen et al., 2021) , recommendations for mitigation strategies and potential institutional collaboration. The results of the analysis are categorized into five important elements in the form of *strengths*, *weaknesses*, opportunities *and* threats (Wichmann & A, 1918) .

The findings of the study identified an important aspect of the disaster mitigation system in West Ternate, where BMKG has relatively high technical capabilities in generating and disseminated warning information, but this capability has not been fully maximized for communities in the West Ternate Coastal area who are very vulnerable to *multihazard* disastersto have a high level of safety (Dolan et al., 1975; Dyson & G, 2004; Fang et al., 2022) . This problem is certainly a major failure considering that sophisticated technical systems are not able to reach the most vulnerable populations at the most critical moments.

Table 1. SWOT Matrix of BMKG Ternate Geophysical Station

STRENGTHS	**WEAKNESSES**
• There are 17 seismograph units and 18 active *tsunami gauge* units in North Maluku. • Dissemination of earthquake information through InaTEWS lasted less than 3 minutes. • Tsunami early warnings are issued less than 10 minutes after the earthquake. • Tsunami modeling is available with a wave height of 4–6 meters and an arrival time of 12–14 minutes. • There are 4 units of WRS New Generation at strategic points in Ternate City.	• Dependence on the operational continuity of the sensor. • Tsunami sirens have not been installed in North Maluku. • West Ternate local data, such as earthquake re-periods and hazard maps, are still limited. • *The golden time* of evacuation is only about 15 minutes, making horizontal evacuation less effective. • Earthquake *Early Warning* (EWS) technology based on P waves has not yet reached North Maluku. • There are still *blind spot* sensors in the eastern region of Halmahera and Kao Bay. • Public literacy towards disaster information is still low.
PELUANG (Opportunities)	**THREATS**
• A total of 14 WRS units in North Maluku have been connected to the RRI network and are ready to be optimized. • A total of 17 active sensors by 2026 improve modeling accuracy compared to 2022 data. • There are collaboration opportunities with UMMU, Khairun University (Unkhair), IAGI, HAGI, and BRIN. • The topographic conditions of North Maluku support the implementation of vertical evacuation. • Mitigation models based on Mentawai local wisdom can be adapted. • The Earthquake Field School program has been running with an effectiveness of around 80%. • There are opportunities to integrate disaster mitigation materials into the basic education curriculum. • The existence of mangrove forests in Loto Village has the potential to become a natural barrier.	• The existence of an active splay fault on the Maluku Sea Plate (Heidarzadeh, 2021). • The potential for a megathrust earthquake with a magnitude of Mw 8.2–8.3 with an intensity of MMI VII–VIII. • Around 22,000 earthquake events were recorded during the period 1996-2026 which showed a very high level of seismicity. • Tsunami history in 2014 (M 7.4) and 2019 (M 7.2). • The morphology of a narrow bay beach (V-shaped bay) has the potential to amplify tsunami waves. • The relatively low level of public education can hinder the understanding of disaster information from BMKG. • The position of West Ternate, which is directly opposite the Maluku Sea Plate, places this region in the highest risk zone.

• The regulation of the 30-meter coastal boundary can be a reference in spatial planning based on disaster mitigation.

Source: Primary data, processed by the researcher (2026)

2. SWOT Analysis Results of Ternate City BPBD

The interview was conducted to respondents who are staff of the Ternate City BPBD with a background in disaster education. Based on the results of mapping and coding interview data, a number of factors were found that can be grouped into four SWOT dimensions. These factors reflect the real condition of the institutional capacity of the Ternate City BPBD in carrying out disaster mitigation functions in the coastal area of West Ternate (Table 4.3). One of the most important strengths that was successfully identified through the coding process was the success of the Ternate City BPBD in implementing the Disaster Resilient Village (KTB) program in 15 villages in the Ternate City area. The program is designed with a community orientation and is implemented on an ongoing basis every year. The statement indicates that BPBD has built a structured community empowerment framework at the sub-district level. The relevance of the KTB program to coastal disaster mitigation is very large, considering that people living in coastal areas are the most vulnerable group to the direct impact of tsunami waves.

Table 2. SWOT Matrix of BPBD Ternate City

POWER	WEAKNESSES
Disaster Resilient Village Program (KTB) Multisectoral Rapid Reaction Team (TRC) Digital Information Dissemination System Collaboration of Local Wisdom of the Sultanate of Ternate Involvement in Planning Spatial Planning	Chronic Budget Limitations KRB and DRR Planning Documents Expired from 2017 EWS Infrastructure Is Not Working and Missing Megathrust/tsunami regulatory vacancies. Limitations of BPBD's Institutional Authority
OPPORTUNITIES	**THREATS**
Access to Ready-to-Use Funds (DSP) and IDRIP Program Academic and Professional Collaboration The Potential of the Beach Tourism Sector Support of the Sultanate of Ternate as a Channel for Traditional Education Momentum of the Megathrust Issue for Strengthening Regulations	Dense Settlements in the Coastal Red Zone Vandalization and Theft of EWS Tools Community's Apathy Attitude to the Threat of Earthquakes Potential Megathrust Mw 8–9 and Destructive Tsunami Social Conflict in Red Zone Relocation

Source: Primary data, processed by the researcher (2026)

Based on the overall results of the analysis that has been presented, it can be concluded that the Ternate City BPBD is in a strategic position in the context of coastal disaster mitigation. This institution has a fairly solid institutional foundation as reflected in the KTB program that has been running, an active multisectoral TRC, a responsive digital communication system, and unique social capital in the form of collaboration with the Sultanate of Ternate. However, on the other hand, the existing capacity has not been balanced by adequate physical infrastructure, valid and up-to-date planning documents, and regulatory frameworks that provide sufficient authority. These three elements are technical prerequisites that cannot be ignored in building a comprehensive coastal disaster mitigation system. As long as these three prerequisites are not met, the existing institutional capacity will continue to operate below its optimal potential.

3. SWOT Analysis Results (Takome, Loto, and Togafo)

This study is a comparative study on the preparedness of coastal communities in facing the threat of megathrust disasters carried out in three administrative areas of Ternate City, North Maluku Province, namely Togafo Village, Takome Village, and Loto Village. The three locations were purposively chosen based on their geographical position directly facing the high seas and being in a high-risk zone due to tectonic activity of the Maluku Sea Plate, which historically and scientifically has the potential to produce earthquakes and destructive tsunami waves.

Demographic Profile and Respondent Capacity

The demographic composition of respondents in the three study sites showed significant and analytically relevant differences. In Togafo Village, 14 respondents were dominated by men with an average age of 26.5 years, a very young range and a majority of education levels in high school. On the other hand, Takome Village displays a more balanced composition with female dominance, a more mature average age (36.8 years), and a more diverse job profile with 7 housewives. Loto Village has unique characteristics with the highest proportion of women and the largest level of undergraduate education, reflecting a community that is formally more educated but not necessarily better prepared for disasters.

This demographic variation has important theoretical implications in the context of *the Socio Ecological Framework*. The dominance of young respondents in Togafo indicates the potential absence of historical experience of major disasters that tend to underestimate risks due to the absence of immediate disaster memory. Meanwhile, the dominance of housewives in Takome shows a gender dimension that needs to be considered, considering that women have consistently proven to be more vulnerable to major disasters such as earthquakes and tsunamis while also having a central role in family preparedness.

SWOT Analysis of Earthquake and Tsunami Disaster Preparedness

The SWOT analysis presented below is the result of a comprehensive analysis of all NVivo-based qualitative findings obtained from 41 interviews in three research locations.

1. Strength

Findings from the three research sites consistently identified some internal strengths that stem from the capacity that is already embedded in the community. First, earthquake alertness is the most universal force and is found in 100% of respondents in Togafo and Takome, as well as 11 out of 14 respondents in Loto Village. All respondents showed an appropriate self-evacuation response running out of the house and into an open space as a spontaneous reaction to the shock.

Second, knowledge of natural signs of tsunamis is an asset of local wisdom that is widely spread. In all three locations, knowledge of low tide as an early sign of a tsunami was shared by an average of 55-61% of respondents. Interestingly, in Loto Village, some respondents were even able to mention more specific ecological signs, such as animal migration and changes in air temperature. These findings show that local wisdom is a form of community knowledge that is inherited from generation to generation which in the SEF approach has a strategic function as socio-ecological capital to strengthen preparedness and early warning mechanisms at the community level

Third, in all research locations, individuals who play an important role in the community were found, such as teachers and members of the National Police in Togafo, the Head of Section with state civil servants and National Police personnel in Takome (Figure 4.15), as well as village heads and village staff in Loto Village who have a relatively higher level of education than the general public. This group shows a better understanding of disasters and has a strong motivation to participate in mitigation efforts. Within the framework of the Socio-Ecological Framework (SEF), their existence can be seen as an agent of change at the interpersonal and community level that has the potential to be the main driver in improving community preparedness for disasters.

Fourth, the three research areas have an informal communication mechanism involving information from BMKG and the local government. In addition, there are also traditional communication systems that are still used, such as delivering information through tapping on electric poles and announcements through mosques in Loto Village. The communication network that has been formed reflects the presence of strong social capital at the community level. From an SEF perspective, such social capital can be an important foundation for developing a more structured, effective, and sustainable community-based early warning system.

Figure 1. Interview activities in Takome Village
Source: Primary data, documented by the researcher (2026)

2. Weaknesses

The most fundamental and cross-site weakness is the low knowledge of megathrust earthquakes where 80% of all research sites have very low understanding. This finding is very critical considering that megathrust is the most destructive threat that has been scientifically documented for the North Maluku region (BMKG, 2021).

The second structural weakness is the absence of a structured family evacuation plan. In Togafo only 29%, in Takome 31%, and in Loto Village 21.4% of respondents who have evacuation plans and even existing plans are still generic without specific routes, gathering points, or division of roles. None of the respondents from the three locations said they had *emergency kits* or evacuation equipment prepared. The results of this study reinforce the findings that preparedness at the household level is an important component in disaster risk management. However, this aspect is often overlooked, which can reduce people's ability to respond and protect themselves effectively when disasters occur. The third theoretically most dangerous weakness is the phenomenon of biased optimism that is consistently detected in all three locations. In Togafo, 86% of respondents felt prepared, in Takome, 77% said the same while in Loto Village (Figure 4.16), the majority of respondents also expressed a sense of security that was disproportionate to their actual capacity (Gürel et al., 2017) . The fourth weakness is the incompatibility of the existing training program (Benzaghta et al., 2021; Bird & F, 2008) . Across all three locations, the disaster training respondents received consistently focused on the Mount Gamalama eruption scenario rather than earthquakes and tsunamis.

Figure 2. Interview activities in Loto Oportunidades Village *(Opportunities)*
Source: Primary data, documented by the researcher (2026)

Analysis of external factors identifies a number of strategic opportunities that can be leveraged to drive systemic preparedness improvement (Renn & O, 2017) . The first and most fundamental opportunity is the high demand of the community, all respondents in all three locations, without exception, express a strong desire to get better socialization, training, and infrastructure. Within the framework of SEF, this organic demand is an extraordinary social capital asset, because intervention programs initiated from community requests have proven to be more sustainable than programs implemented from the government to the community.

The second opportunity is the existence of BMKG's information infrastructure that is already functional and trusted by the community. In all three locations, BMKG is recognized as the only credible source of formal disaster information (Hutagalung et al., 2025) . This trust infrastructure is an invaluable foundation for the development of integrated early warning systems that reach the community level. The third opportunity is the national momentum related to the threat of Indonesia's megathrust which reaches the highest point of public attention in 2024-2025, opening up advocacy opportunities for a more substantial allocation of DRR (Disaster Risk Reduction) budgets from BNPB and BPBD. The fourth opportunity is specific to Loto Village, the existence of academic research precedents about the 1800 Ternate tsunami known by one of the respondents and the history of involvement of IPB research institutions are assets that can be converted into historical evidence-based educational materials. The fifth opportunity is the topographic condition of the three locations located close to the mountains, allowing the development of vertical evacuation routes that utilize natural altitude as a safe zone.

3. Threats

The threat dimension in the three study sites was dominated by factors that were structural and difficult to modify in the short term. The first and most critical threat is the geographical position of the three villages that face the open sea and are in the active subduction zone. The three locations face *multi-hazard risks* , namely the threat of tsunamis and earthquakes from the Maluku Sea plate, and the potential disaster in the form of the eruption of Mount Gamalama that can trigger *a volcanic* tsunami, a scenario that has not been included in the local alert plan at any of the research sites.

The second critical threat is the absence of an adequate early warning system (EWS). In Takome, 85% of respondents confirmed that there were no tsunami sirens in Loto Village, the conditions were similar. Only in Togafo (Figure 4.17) were there reports of the existence of partial sirens, but when visiting the location did not find the presence of the siren. This means that when a disaster strikes, most residents will not get adequate formal warnings to begin evacuation. The third threat is the fiscal limitations of local governments that limit the capacity to invest in DRR infrastructure, thus creating a dependence on central programs that are not necessarily available in a sustainable manner.

The fourth threat is that most of the communities experience a phase without a tsunami disaster in the West Ternate area which creates a perception imbalance in the disaster which is considered to have never occurred, so that the occurrence of earthquake and tsunami disasters in their area is underestimated. In all three locations, none of the respondents had experienced a tsunami directly. This condition, combined with the optimism of the bias that has been identified, creates a vulnerability that is cumulative.

Figure 3. Interview activities in Togafo Village

Source: Primary data, documented by the researcher (2026)

4. Implementation of SEF-Based Mitigation Strategies

a. SWOT Analysis

The development of strategy analysis in this study began with the TOWS matrix approach (Weihrich & H, 1982) which is an operational form of SWOT analysis which will later become an important aspect in the development of *the Socio Ecological Framework* strategy. This matrix results in four strategic quadrants that each represent a different combination of internal and external factors: the SO strategy (harnessing strengths to seize opportunities), the WO strategy (addressing weaknesses through opportunities), the ST strategy (using strengths to minimize threats), and the WT strategy (minimizing weaknesses while avoiding threats). These strategies are then organized hierarchically based on the urgency and feasibility of their implementation.

Table 3. Matrix strategy SWOT

Matrix TOWS	Strength (S)	Weakness (W)
Odds (O)	SO Strategy: Develop DRR education modules based on local wisdom (natural signs) that are strengthened by BMKG scientific data, replacing anecdotal knowledge with scientific literacy. Optimize the role of key actors (teachers, Polri, village heads, Kasi) as facilitators of preparedness training at the community level through the Training of Trainers (ToT) program. Integrate existing communication networks (SMS, BMKG SMS, mosque announcements, village government WhatsApp groups) into a structured community early warning system. Develop from an existing eruption mountain training base to a comprehensive multi-hazard module covering megathrust and tsunami scenarios. Take advantage of the enthusiasm of the community and the national momentum of megathrust to mobilize BNPB/BPBD support for DRR programs in the three locations.	WO Strategy: The formation of the Village Disaster Preparedness Team (TSB-K) facilitated by BNPB/BPBD to fill the gap in preparedness human resources in the three locations. Require each family to prepare a Family Emergency Plan and have a minimum emergency kit through a structured Family Disaster Preparedness (KSB) program. Use social media and digital platforms that young respondents have used to disseminate megathrust educational content massively and sustainably. Document the history of the local tsunami (including the 1800 Ternate research data) and integrate it into collective memory-based educational materials to build urgency.
Threat (T)	ST Strategy: The formalization of the community's instinctive response became a documented Village Evacuation SOP, socialized, and tested through periodic simulations. Strengthen the role of the village government as a disaster information command center to close the gap in the absence of formal sirens in most research sites. Carry out a tsunami evacuation community drill at least 2 times per year, utilizing the existing BMKG-BASARNAS network and public trust in the institution. Integrate local knowledge of tsunami natural signs into formal SOPs as the first layer of early warning before sirens or digital notifications are activated.	WT Strategy: Prioritize the construction and widening of tsunami evacuation routes equipped with signs, lights, and directions as the most urgent investment in life safety infrastructure. Install an even tsunami siren network in all residential zones of the three villages and there should be no zones that are beyond the range of acoustic warnings. Conduct a mass evacuation simulation involving all levels of citizens to correct biased optimism through measurable hands-on experience. Advocacy for the preparation of a Disaster Management Plan (RPB) at the village level which explicitly includes earthquake, tsunami, and Mount Gamalama eruption scenarios. Mapping and registration of vulnerable

	Include the cascade disaster scenario (Gamalama eruption → tsunami) in the village contingency plan as a scenario that must be anticipated.	populations (elderly, pregnant women, disabilities) as the basis for the preparation of equitable evacuation plans that do not leave marginalized groups.

Source: Primary data, processed by the researcher (2026)

b. Socio Ecological Framework *(SEF)* Based Strategy

The conversion of the SWOT strategy into the framework of the *Socio-Ecological Framework* (SEF) shows that earthquake and tsunami disaster mitigation in West Ternate District cannot be understood only as a technical problem of disasters, but as a layered system that connects individual capacity, social relationships, communities, organizations, policies, and coastal ecological conditions. BMKG data shows that this area is in the context of a high geological threat, characterized by the potential for large earthquakes, very short tsunami arrival times, and limitations of early warning systems. BPBD data shows that there is an institutional foundation through KTB, multisectoral TRC, digital communication, and collaboration with the Sultanate of Ternate, but it is still limited by budgets, not yet up-to-date planning documents, and suboptimal EWS infrastructure. Meanwhile, data from the Takome, Loto, and Togafo communities show spontaneous vigilance, knowledge of natural signs, informal communication networks, as well as serious weaknesses in the form of low megathrust literacy, the absence of family evacuation plans, the absence of *emergency* kits, and optimistic bias towards tsunami risk.

1) Level Individu

At the individual level, mitigation strategies are directed at increasing risk literacy, establishing household preparedness, and correcting people's optimism biases. The results of the interviews showed that most of the respondents in Takome, Loto, and Togafo had the correct spontaneous response when they felt the earthquake, namely leaving the house and going to an open space. However, the response has not developed into planned preparedness because knowledge of megathrust is still low, family evacuation plans have not been drawn up in detail, and no emergency equipment readiness has been found. Therefore, strategies at this level need to transform spontaneous vigilance into individual capacity that is structured through megathrust education, the preparation of *family emergency plans*, the introduction of the nearest evacuation route, and the habituation of each family to have basic evacuation equipment.

The integration of BMKG data at the individual level is important because technical information such as the estimated *golden time* of about fifteen minutes, the potential *for tsunami run-up*, and wave arrival time need to be translated into simple and operational educational messages. It is not enough that this information is only available at the institutional level, but must be understood by citizens as a basis for quick decision-making. Thus, individual strategies are not simply to increase knowledge, but to build the ability to make independent evacuation decisions without waiting for formal instructions when strong tremors are felt or natural signs of tsunamis are observed.

2) Level Interpersonal

At the interpersonal level, mitigation strategies focus on strengthening relationships between family, neighbors, local leaders, teachers, village officials, the National Police, and community groups that have social influence. The findings of the study show that in the three villages there are key actors who have better knowledge and motivation than the general public. The existence of teachers, police personnel, village heads, village staff, section heads, and community leaders can be converted into a network of local facilitators through the *training of trainers* mechanism. This strategy is relevant because the people of West Ternate not only receive information through formal channels, but also through daily social relations based on trust.

Interpersonal strategies also need to strengthen family- and small-group-based communication. The absence of a family evacuation plan shows that preparedness has not yet become a social practice that is discussed and agreed upon in households. Therefore, education is not enough to be carried out in the form of general socialization, but needs to be directed to family communication exercises, division of roles during evacuation, determination of meeting points, and mechanisms for checking the condition of family members. In the context of Takome, which has a large proportion of housewives, interpersonal strategies need to place women as managers of family preparedness, not just vulnerable groups, as they have a central role in nurturing, household communication, and early decision-making when disasters occur (Ostrom & E, 2009) .

3) Community Level

At the community level, mitigation strategies are directed at the establishment of a village-based preparedness system that combines local knowledge, informal communication, and scientific information. Community data shows that Takome, Loto, and Togafo already have social capital in the form of communication mechanisms through mosque announcements, electric pole knocks, local government information, digital communication groups, and references to BMKG information. This social capital can be developed into a structured community early warning system, with the village as the coordination center and the community as the recipient and disseminator of information.

Community strategies need to integrate natural signs of tsunamis known to the community, such as low sea levels, animal migration, and changes in environmental conditions, with formal information from BMKG. This integration is important because the very limited evacuation time makes it impossible for communities to fully rely on formal warnings. In this context, nature signs can serve as the first layer of early warning, while BMKG and BPBD information serve as the basis for further validation and coordination. Thus, the most relevant community strategies are the preparation of urban village evacuation SOPs, the implementation of periodic evacuation simulations, the formation of the Urban Village Disaster Preparedness Team, and the mapping of gathering points and evacuation routes that are understood by all residents.

4) Organizational Level

At the organizational level, the mitigation strategy emphasizes the integration of the roles of BMKG, BPBD, village governments, schools, religious institutions, the Sultanate of Ternate, academics, and professional organizations. BMKG data shows that there is technical capacity in the form of seismograph networks, *tsunami gauges*, WRS *New Generation*, tsunami modeling, and the ability to disseminate information in a short time. However, this technical capacity has not fully reached the coastal communities of West Ternate in the form of easy-to-understand operational instructions. On the other hand, BPBD has KTB programs, multisectoral TRCs, digital communication systems, and community empowerment experience, but faces budget constraints, outdated planning documents, and dysfunctional or missing EWS infrastructure. Based on these conditions, organizational strategy needs to be built through a clear division of functions.

a) BMKG plays a role as a provider of scientific information, hazard modeling, and early warning systems,
b) BPBD plays the role of a coordinator of preparedness, institutional strengthening of the village, and implementation of simulations,
c) The village government becomes the node of the local command
d) Schools become repetitive educational spaces
e) Mosques and traditional leaders become social communication channels
f) Academics and professional organizations support the preparation of educational materials and the updating of risk data.

This integration creates an *up-down* strategy that is not one-way, as technical information from formal institutions is translated through local social networks, while the needs and experiences of the community become feedback for institutional program improvements.

5) Policy Level

At the policy and governance levels, mitigation strategies are directed at strengthening regulations, updating planning documents, budgeting, and tsunami risk governance. BPBD data shows structural problems in the form of non-up-to-date KRB and DRR documents, gaps in specific regulations regarding megathrust and tsunami, limited institutional authority, and chronic budget limitations. This condition makes the existing institutional capacity unable to work optimally, especially when dealing with the threat of megathrust, dense settlements in coastal red zones, and potential social conflicts in relocation.

The strategy at this level needs to prioritize the preparation of a Disaster Management Plan at the village level which explicitly contains earthquake and tsunami scenarios. Local governments also need to strengthen coastal border regulations, control of settlements in red zones, as well as budget allocations for evacuation routes, signs, sirens, and maintenance of EWS infrastructure. The momentum of the megathrust issue can be used as a basis for policy advocacy so that disaster risk reduction is not positioned as an additional program, but as an urgent coastal development agenda (Nasional, n.d.) . Thus, mitigation policies must connect BMKG's scientific data, BPBD's operational capacity, and the real needs of the community in Takome, Loto, and Togafo.

6) Environmental and Ecological Level

At the environmental and ecological level, mitigation strategies place the physical characteristics of the West Ternate coast as the main determining factor of intervention design. BMKG data shows that this region is dealing with a high seismic threat from the Maluku Sea Plate, the potential for large earthquakes, tsunami history, and bay morphology that can strengthen local waves. Community data also shows that the three villages are directly facing the open sea, while the topography close to the mountains opens up opportunities for the development of vertical evacuation based on natural height. Thus, ecological strategies focus not only on infrastructure development, but also on the use of landscapes as part of the safety system.

At this level, the most relevant strategies are the establishment of evacuation routes to high areas, safe zone mapping based on local topographic conditions, coastal border protection, and the use of ecological elements such as mangroves in Loto Village as coastal protection reinforcements. However, the existence of ecological elements should not be understood as a substitute for evacuation, but rather as an additional layer in risk reduction. Since tsunami arrival times are relatively short and horizontal evacuation is not always possible, the use of natural altitudes and the regulation of coastal spaces is a very important ecological strategy to reduce people's direct exposure to tsunami waves.

Thus, the most appropriate mitigation strategy for Takome, Loto, and Togafo is an *up-down strategy* that connects the technical capacity of formal institutions with the social capital of local communities. Scientific information from BMKG needs to be translated by BPBD and the village government into practical evacuation procedures, then disseminated through trusted community social networks. On the contrary, local knowledge, residents' needs, and community experiences need to be the basis for refining institutional programs so that interventions are not uniform, but in accordance with the socio-ecological character of each village. This SEF approach shows that the resilience of the coastal communities of West Ternate can only be built if technical, social, institutional, policy, and ecological strategies are developed in an integrated manner in one sustainable mitigation system.

Table 4. Mapping of Mitigation Strategies Based on the Socio-Ecological Framework (SEF)

Level SEF	Summary of SWOT Findings	Mitigation Strategy Direction	Main Actors	Priority Implementation
Level Individual *(Microsystem)*	The community has a spontaneous response to the earthquake, but megathrust literacy is low, family evacuation plans are not detailed, emergency kits are not available, and there is a bias of optimism.	Transforming spontaneous vigilance into individual preparedness that is planned and based on BMKG scientific information.	Residents, heads of families, women/house wives, and young groups.	Megathrust education, preparation of family emergency plans, introduction of evacuation routes, and provision of family emergency kits.
Level Interpersonal *(Mesosystem)*	There are key actors such as teachers, the National Police, village heads, village staff, section heads, and community leaders who have better capacity than the general public.	Strengthen social networks, family communication, and the role of local actors as preparedness facilitators.	Teachers, the National Police, community leaders, village officials, families, and women's groups.	Training of Trainers, family communication training, division of evacuation roles, and determination of family meeting points.
Community Level *(Exosystem)*	The community has social capital in the form of mosque announcements,	Building a village preparedness system that combines local	Kelurahan, Kelurahan Disaster Preparedness	SOP for village evacuation, periodic evacuation

	electric pole knocks, digital communication groups, local government information, and knowledge of tsunami natural signs.	knowledge, informal communication, and formal information from BMKG/BPBD.	Team, religious leaders, community leaders, and residents.	simulations, mapping of gathering points, and community-based early warning systems.
Organizational Level	BMKG has the technical capacity for early warning, while BPBD has KTB, multisectoral TRC, digital communication, and customary collaboration, but is still limited by budgets, planning documents, and EWS that are not optimal.	Integrate the technical capacity of formal institutions with local social mechanisms so that mitigation strategies run operationally and contextually.	BMKG, BPBD, village governments, schools, mosques, the Sultanate of Ternate, academics, and professional organizations.	Sharing institutional roles, dissemination of operational information, strengthening KTB/TRC, and updating risk education materials.
Government Level (Macrosystem)	Budget constraints were found, KRB/DRB documents that were not up-to-date, gaps in megathrust/tsunami regulations, dense settlements in red zones, and potential relocation conflicts.	Strengthening risk governance through regulation, planning, budgeting, and control of the use of coastal space.	Local governments, BPBD, village governments, planning institutions, and disaster stakeholders.	Preparation of the village RPB, updating KRB/PRB documents, DRR budget allocation, coastal boundary regulations, and strengthening EWS infrastructure.
Environmental/ Ecological Level	West Ternate is directly facing the open sea, is in an active seismic zone, has a short tsunami arrival time, coastal morphology that increases exposure, as well as opportunities for vertical evacuation through high altitudes and mangrove potential in Loto.	Tailor mitigation strategies to coastal geomorphological characteristics, local topography, and ecological elements as an additional layer of risk reduction.	Local governments, urban villages, coastal communities, BPBD, BMKG, and local communities.	Mapping of safe zones, evacuation routes to high areas, protection of coastal borders, the use of mangroves as natural barriers, and the regulation of coastal spaces.

Source: Primary data, processed by the researcher (2026)

Identification of Disaster Vulnerability Zones

Based on the results of BMKG seismicity data analysis, coastal geomorphological conditions (Verstappen & Th, 1983) , and SWOT analysis, the coastal area of West Ternate, which includes Takome, Loto, and Togafo Villages, has a high level of vulnerability to earthquakes and tsunamis. Therefore, several evacuation points have been set that take into account elevation, distance from the coastline, accessibility, and travel time so that people can evacuate quickly when a disaster occurs (Helms et al., 2010) .

In Takome Village, which is a coastal tourist area as well as the area with the greatest potential for casualties, several evacuation locations are recommended based on the megathrust Mw 8.2 earthquake scenario from BMKG with an estimated tsunami height of 4-6 meters and an arrival time of about 12-14 minutes. The temporary evacuation location is at an elevation of about 26 meters with a distance of about 47 meters from the beach, while the main evacuation location is at an elevation of about 42 meters with a distance of about 387 meters from the coastline. In addition, additional evacuation points are provided in the northern, central, southern, and tourist areas of Lake Tolire to accommodate the extended settlement pattern and high tourist activity.

Loto Village is a medium to high vulnerability zone. Although the northern part has a higher elevation than Takome, the southern part is more vulnerable because it is located on a lower plain and has more dense settlements. Therefore, two evacuation points are recommended, namely in the northern part of Loto at an elevation of about 90 meters and in the southern part of Loto at an elevation of about 62 meters. Both locations were chosen so that they could be reached by the public in less than 15 minutes.

Meanwhile, Togafo Village is the area with the highest risk level based on the results of the integration of seismicity, coastal morphology, and SWOT analysis. Topographic conditions and the proximity of settlements to the coast cause this area to have a great potential to be affected by tsunamis. To support a quick evacuation, it is recommended to have one evacuation point at an elevation of about 108 meters with a distance of about 700 meters from the coastline that has adequate road access for pedestrians and vehicles.

Overall, the vulnerability map and evacuation route were compiled based on the integration of BMKG seismic data, coastal geomorphological analysis, and SWOT analysis results. The results show that the West Ternate Coast has a high potential threat of megathrust earthquakes and tsunamis, supported by the record of large earthquakes over the past 125 years as well as the characteristics of narrow bay beaches that can amplify tsunami waves. In addition to physical factors, low community preparedness and lack of optimal institutional capacity also increase the level of disaster risk. Therefore, this research produces a mitigation strategy based on the Socio-Ecological Framework (SEF) that integrates geological, geomorphological, and social aspects as the basis for the preparation of a more effective and community-based mitigation system in the coastal area of West Ternate.

CONCLUSION

Based on the findings, the coastal area of West Ternate, Ternate City, North Maluku Province, was highly vulnerable to earthquake and tsunami hazards because of its location within the double-subduction system of the Molucca Sea. Coastal morphological characteristics, including narrow bay configurations and steep nearshore bathymetry, further increased the potential impacts of tsunami waves in the area. The findings also showed that disaster risk was influenced by interactions among physical, social, and institutional factors, including population concentration, limited evacuation routes, low levels of community preparedness, and mitigation policies that were not yet fully adapted to local conditions. The application of the Socio-Ecological Framework (SEF) integrated with SWOT analysis indicated that community preparedness remained relatively low, highlighting the need for an integrated, practical, and multi-stakeholder mitigation strategy. Therefore, local governments should develop mitigation policies based on seismic data and regional characteristics, while BPBD and other relevant agencies should strengthen disaster education, simulation activities, evacuation infrastructure, and other mitigation facilities. Communities should also be encouraged to develop a stronger culture of disaster preparedness. Future research should incorporate quantitative modeling and more detailed spatial analysis to support more effective and sustainable disaster risk reduction in the coastal area of West Ternate.

REFERENCES

Adger, N, W., Hughes, P, T., Folke, C, Carpenter, R, S., Rockstrom, &, & J. (2005). *Social-ecological resilience to coastal disasters. Science, 309(5737), 1036-1039. https://doi.org/10.1126/science.1112122*.

Benzaghta, A, M., Elwalda, A, Mousa, M, M., Erkan, I, Rahman, &, & M. (2021). *SWOT analysis applications: An integrative literature review. Journal of Global Business Insights, 6(1), 55–73. https://doi.org/10.5038/2640-6489.6.1.1148*.

Bird, & F, E. C. (2008). *Coastal geomorphology: An introduction (2nd ed.). Wiley-Blackwell. https://books.google.com/books?id=2MfKEAAAQBAJ*.

Dolan, R, Hayden, P, B., Vincent, &, & K, M. (1975). *Classification of coastal landforms of America. Zeitschrift für Geomorphologie, dalam Encyclopedia of Beaches and Coastal Environments (hlm. 72–88).*

Dyson, & G, R. (2004). *Strategic development and SWOT analysis at the University of Warwick. European Journal of Operational Research, 152(3), 631–640. https://doi.org/10.1016/S0377-2217(03)00062-6*.

Fang, G, Zhang, J, Hao, T, Miao, &, & D. (2022). *The causal mechanism of the Sangihe Forearc Thrust, Molucca Sea, northeast Indonesia, from numerical simulation. Journal of Asian Earth Sciences, 237, Article 105350. https://doi.org/10.1016/j.jseaes.2022.105350*.

Garschagen, M, Sandholz, S, Hagenlocher, M, Mechler, &, & R. (2021). *Too big to ignore: Global risk perception gaps between scientists and business leaders. Economics of Disasters and Climate Change, 5, 171–188. https://doi.org/10.1007/s41885-020-00081-2*.

Geofisika, B. M. K. dan. (n.d.). *Badan Meteorologi Klimatologi dan Geofisika. (2026, April 2). Gempabumi tektonik M7,6 di Pulau Batang Dua, Ternate, Maluku Utara, berpotensi tsunami (Siaran pers).*

Gürel, E, Tat, &, & M. (2017). *SWOT analysis: A theoretical review. The Journal of International Social Research, 10(51), 994–1006. https://doi.org/10.17719/jisr.2017.1832*.

Harlianto, B, Suwarsono, & Supiyati, &. (2016). *Bahaya penguatan gelombang tsunami akibat cekungan Teluk Sungai Serut untuk mitigasi penduduk Kelurahan Pasar Bengkulu dan Pondok Besi, Kota Bengkulu. Dalam Prosiding Seminar Nasional Pengelolaan Pesisir dan Daerah Aliran Sungai ke-2 (12 Mei 2016). Fakultas Geografi, Universitas Gadjah Mada, Yogyakarta.*

Harrison, & P, J. (2010). *Essentials of strategic planning in healthcare. Health Administration Press. https://www.ache.org/learning-center/publications/books/2147*.

Helms, M, M., Nixon, &, & J. (2010). *Exploring SWOT analysis – where are we now? Journal of Strategy and Management, 3(3), 215–251. https://doi.org/10.1108/17554251011064837*.

Humphrey, & S, A. (2005). *SWOT analysis for management consulting. SRI Alumni Association Newsletter, December 2005, 7–8. https://alumni.sri.com/newsletters/2005/AlumNews-Dec-2005.pdf.*

Hutagalung, S, S., Yulianto, Y, Rosalia, &, & F. (2025). *Global trends in social-ecological systems and disaster research: Bibliometric insights. Jàmbá: Journal of Disaster Risk Studies, 17(1), Article a1874. https://doi.org/10.4102/jamba.v17i1.1874*.

Indonesia, P. R. (2008). *Undang-Undang Nomor 21 Tahun 2008 tentang Penanggulangan Bencana. Lembaran Negara Republik Indonesia Tahun 2008, Nomor ... (tambahkan nomor LN/TLN jika ada). https://peraturan.go.id/*.

Irsyam, M, Cummins, R, P., Asrurifak, M, Faizal, L, Natawidjaja, H, D., Widiyantoro, S, Meilano, I, Triyoso, W, Rudiyanto, A, Hidayati, … J, A. (2020). *Development of the 2017 national seismic hazard maps of Indonesia. Earthquake Spectra, 36(1_suppl), 112–136. https://doi.org/10.1177/8755293020951206*.

Kaufman, A, R., Herman, &, & J, J. (1991). *Strategic planning in education: Rethinking, restructuring, revitalizing. Technomic Publishing Co.*

Lee, C, B., Bendixsen, C, Liebman, K, A., Gallagher, &, & S, S. (2017). *Using the Socio-Ecological Model to Frame Agricultural Safety and Health Interventions. Journal of Agromedicine, 22(4), 298–303*.

Leigh, & D. (2009). *SWOT analysis. In R. Watkins & D. Leigh (Eds.), Handbook of improving performance in the workplace (Vol. 2, pp. 115–140). Pfeiffer. https://doi.org/10.1002/9780470587089.ch5*.

Masselink, G, Hughes, &, & G, M. (2003). *An Introduction to Coastal Processes and Geomorphology. Hodder Arnold. (Buku referensi standar internasional, banyak dikutip di jurnal Geomorphology dan Journal of Coastal Research).*

McCaffrey, R, Silver, A, E., Raitt, &, & W, R. (1980). *Crustal structure of the Molucca Sea Collision Zone, Indonesia. In D. E. Hayes (Ed.), The Tectonic and Geologic Evolution of Southeast Asian Seas and Islands (Geophysical Monograph Series, Vol. 23, pp. 161–177). American Geophysical Union. https://doi.org/10.1029/GM023p0161*.

Mustafa, A, M., & Yudhicara, &. (2007). *Karakteristik pantai dan risiko tsunami di kawasan pantai selatan Yogyakarta. Jurnal Geologi Kelautan, 5(3), 159–167. https://doi.org/10.32693/jgk.5.3.2007.143*.

Nasional, P. S. G. (n.d.). *Pusat Studi Gempa Nasional (PUSGEN) Pusat Litbang Perumahan dan Permukiman, 2017, Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017 (Map of Indonesia earthquake sources and hazards in 2017), Pusat Penelitian dan Pengembangan Perumahan Pemukiman, Badan Penelitian dan Pengembangan Kementerian Pekerjaan Umum dan Perumahan Rakyat, Jakarta.*

Ningrum, W, R., Suryanto, W, Wahyudi, W, Sholihun, S, Lessy, R, M., Oryza, al., D. et, 2025, Jailolo', 'Application of numerical simulation method integrated SfM-UAV to tsunami hazard map in, & 17, J. J. of D. R. S. (n.d.). *Ningrum, R.W., Suryanto, W., Wahyudi, W., Sholihun, S., Lessy, M.R., Oryza, D. et al., 2025, 'Application of numerical simulation method integrated SfM-UAV to tsunami hazard map in Jailolo', Jàmbá: Journal of Disaster Risk Studies 17(1), a1813. https://doi.org/10.4102/jamba.v17i1.1813*.

Ostrom, & E. (2009). *A general framework for analyzing sustainability of social-ecological systems. Science, 325(5939), 419–422. https://doi.org/10.1126/science.1172133*.

Pelupessy, D, Maarif, S, Amri, &, & A. (2024). *Exploring Indonesian coastal communities' responses to the 2019 Ambon earthquake. International Journal of Disaster Risk Reduction, 99, 104120. https://doi.org/10.1016/j.ijdrr.2023.104120*.

Prasetya, G, Lange, D., W, Borrero, J, Schindele, &, & W. (2021). *InaTEWS: Indonesia tsunami early warning system post-evaluation after major tsunami events. Pure and Applied Geophysics, 178(6), 2131–2148. https://doi.org/10.1007/s00024-021-02747-4.*

Puyt, W, R., Devos, G, Peteghem, & Van, & J. (2023). *The origins of SWOT analysis.*

Reduction, U. N. O. for D. R. (2015). *Sendai Framework for Disaster Risk Reduction 2015–*

2030. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030.

Renn, & O. (2017). *Concept of risk: An interdisciplinary review – Part 2: Integrative approaches. GAIA – Ecological Perspectives for Science and Society, 20(3), 175–183. https://doi.org/10.14512/gaia.20.3.5*.

Rosally, R. R., Ningrum, S. O. P., & Chalidyanto, D. (2024). Analysis of the effect of patient experience and patient satisfaction on patient loyalty. *International Journal of Nursing and Midwifery Science, 8*(2), 211–221. https://doi.org/10.29082/IJNMS/2024/Vol8/Iss2/606

Sadisun, & A, I. (2006). *Pengenalan karakteristik bencana dan upaya mitigasinya di Indonesia. Pusat Mitigasi Bencana, Institut Teknologi Bandung. https://bnpb.go.id/storage/app/media/uploads/migration/pubs/470.pdf*.

Sammut-Bonnici, T, Galea, &, & D. (2015). *SWOT analysis. In Wiley encyclopedia of management (Vol. 12). John Wiley & Sons. https://doi.org/10.1002/9781118785317.weom120103*.

Survey, U. S. G. (2026). *M 7.4 – Molucca Sea. https://earthquake.usgs.gov/earthquakes/eventpage/us6000slss/executive*.

Ternate, B. P. S. K. (2025). *Kota Ternate dalam angka 2025 (Ternate municipality in figures 2025) (Vol. 23). BPS-Statistics of Ternate Municipality.https://ternatekota.bps.go.id/id/publication/2025/02/28/547a02830ed6220514c23a25/kota-ternate-dalam-angka-2025.html*.

Thornbury, & D, W. (1969). *Principles of geomorphology (2nd ed.). John Wiley & Sons. https://archive.org/details/principlesofgeom00thor*.

Verstappen, & Th, H. (1983). *Applied geomorphology: Geomorphological surveys for environmental development. Elsevier. https://books.google.com/books/about/Applied_Geomorphology.html?id=LF3uAAAAMAAJ*.

Weihrich, & H. (1982). *The TOWS Matrix: A tool for situational analysis. Long Range Planning, 15*(2), 54–66. https://doi.org/10.1016/0024-6301(82)90120-0*.

Wichmann, & A, C. E. (1918). *Die Erdbeben des indischen Archipels bis zum Jahre 1857. J. Müller. https://catalog.hathitrust.org/Record/100144133*.