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Integrating UAV Data and Community Knowledge for Optimal Tsunami Evacuation Route Map in Coastal Loto Village, Ternate

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ABSTRACT

The coastal area of Ternate Island is an area that has a high potential for tsunami disasters and complex tectonics. The tsunami that occurred on Ternate Island was triggered by an earthquake in the Maluku Sea and the eruption of Mount Gamalama under the sea. The rapid development of Ternate, especially in the tourism sector, such as Loto Agrotourism Village, West Ternate, demands attention to the safety of visitors and residents. The main problem in Loto Village is the lack of evacuation routes, so an effective evacuation strategy is needed to minimize losses during a tsunami disaster. This study aims to determine evacuation routes using UAV data and participatory mapping in Loto Village, Ternate City. UAV aerial photos were processed using photogrammetry techniques with Agisoft Metashape Professional software, producing Ortho-Mosaic Maps and Digital Elevation (DEM), which were analyzed in QGIS software. The ortho-mosaic map was overlaid with a tsunami hazard map to create temporary evacuation routes and points (TES), which were confirmed through participatory mapping. The Final Map shows four TESs, which are accessible via footpaths, side roads, and main roads. The estimated average distance to the TES is between 350 and 650 meters, and the estimated evacuation time is 5–10 minutes, taking into account the average walking speed of the community. In the event of a tsunami, tourists and residents in the Lota Agrotourism area can use this map for evacuation. The map can also be an important reference for the government in forming disaster mitigation policies to ensure the safety of tourist destinations that are vulnerable to tsunamis.

INTRODUCTION

The escalating frequency of disasters over the past two decades has heightened experts' interest in investigating these phenomena. While many individuals prioritize studying the origins of disasters, their consequences, how catastrophes interact with one another, susceptibility, and resilience, it is equally crucial to include community readiness in managing disasters. According (Twigg, 2015), disaster preparedness aims to achieve two primary goals: first, to prevent disasters from to the occurrence, to establish strategies, resources, and processes to provide suitable support. Furthermore, (Lessy & Wahyuningrum, 2020) emphasized the significance of having a robust information and communication infrastructure to effectively disseminate information to affected individuals and the importance of incorporating evacuation, shelter protocols, and rescue tactics into preparedness planning.

Comprehensive disaster planning is essential for any disaster, in all areas, particularly for tsunami events. Tsunami disasters in coastal areas typically allow only a brief window for issuing early warnings and conducting evacuations (Lessy & Wahyuningrum, 2020). Responding promptly during such circumstances is imperative, ensuring that the coastal community is adequately prepared to carry out evacuation procedures correctly and independently. Therefore, implementing an evacuation plan is crucial since it constitutes the primary component of disaster risk mitigation.

The Eastern Indonesia region is located in the convergence of tectonic plates and falls within the Pacific Ring of Fire, making it highly prone to seismic and volcanic activity. The most significant earthquakes and volcanic eruptions that occurred are depicted in Figure 1. Based on the Indonesian Tsunami Catalog for 416 – 2021, the tsunami on Ternate Island was triggered by an earthquake that occurred in the Maluku Sea and the eruption of the Gamalama volcano underwater. The Maluku Sea is located in the subduction zone of three main plates, namely the Eurasian Plate, the Australian Plate, and the Pacific Plate, and forms the Maluku Sea Collision zone, which is experiencing convergence (Cardwell et al., 1980; Hamilton, 1979; Hatherton & Dickinson, 1969; Mccaffrey et al., 1980; Silver & Moore, 1978). The Maluku Sea is a unique example of an ocean basin formed by the collision of the Sangihe Arc and the Halmahera Arc (Widiwijayanti et al., 2004).

Ternate Island becomes the focal point for government, trade, and economy in the North Maluku region. Its economic growth in 2023 reached 5%, according to the (BPS, 2024). Establishing tourism infrastructure on Ternate Island is essential in supporting economic expansion, particularly in coastal tourism and agrotourism. The Ternate governance is now developing one of the locations for Agrotourism in Loto Village, West Ternate District.

The appealing combination of stunning coastal vistas, the presence of two lakes, and distinctive landscapes entice numerous travellers who visit this location. Regrettably, coastal tourist locations are typically more susceptible to tsunamis, particularly if they are located near the epicenter of earthquakes and volcanic activity. Hence, it is imperative to prioritize the safety and security of tourists and inhabitants while developing the Loto Village agrotourism destination. According to (Takabatake et al., 2017), visitors are typically less knowledgeable about the possibility of tsunami disasters than residents. Hence, it is imperative to prioritize establishing tourism places that are resilient to disasters. This is to ensure a feeling of assurance and solace for visitors, managers, and all those with a vested interest in tourism endeavours.

Based on the previous explanation, this study aims to develop disaster-safe tourism by compiling a tsunami evacuation route map in the Lotto village agrotourism area, West Ternate. The existence of a tsunami evacuation route will help individuals make informed decisions during the evacuation process. The evacuation route in Loto Village is a significant concern, so a strategy is needed to determine an efficient evacuation route that considers the presence of the community and visitors. Participatory community involvement in determining evacuation routes is used to obtain accurate data in the field. The community participatory approach can also be used as a disaster risk reduction approach (Grumbly et al., 2019; Samaddar et al., 2022).

Spatially integrated and participatory disaster preparedness planning is fundamental to minimizing exposure and to ensuring a fast and efficient evacuation in case of large tsunamis in high geotectonically active areas such as the coastal zones of subduction zones.

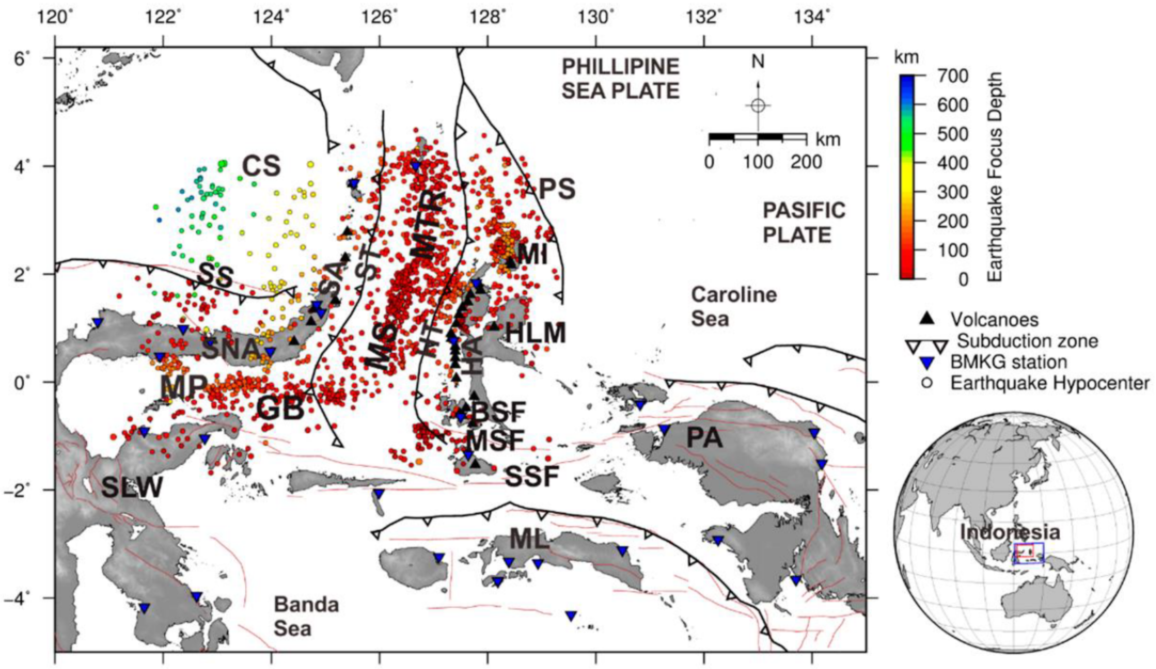

Figure 1. Tectonics of the Maluku Sea Complex (Source: Rachman et al., 2022)

Tsunami in Ternate Island

The word tsunami comes from Japanese, namely tsu (port) and nami (wave), because this is a wave that occurs due to resonance in the harbor after an earthquake occurs offshore (Bryant, 2008). A sudden and significant vertical movement of seawater produces a tsunami. Tsunamis have very long wavelengths compared to the depth of the sea. The amplitude of tsunami waves traveling in the deep sea is relatively small, making it impossible to detect a tsunami without specialized technology or tools. During propagation towards coastal areas, the height of the tsunami wave changes as the wave moves into shallower water, causing the wavelength to become shorter.

Based on historical tsunami data from the National Center for Environmental information (NCEI), (Handayani et al., 2022). It was recorded that the 1859 tsunami was triggered by an earthquake with a magnitude of 7 on the Richter scale in the Maluku Sea near Ternate Island, causing a maximum tsunami wave height of 10 meters. Tsunami waves were around 1.2 meters in the 1846 tsunami. The meeting of the plates in these areas, which form the subduction zone, causes earthquakes, volcanic eruptions, and landslides. Earthquakes that occur under the sea, especially along subduction zones, can trigger tsunamis.

Unmanned Aerial Vehicles (UAVs) and Geographic information Systems (GIS)

UAVs were first developed and used in military applications, for flight identification in enemy areas, unmanned inspection, surveillance, reconnaissance, and mapping of enemy areas without endangering human pilots (Remondino et al., 2011). The development of UAV technology and photogrammetry techniques is becoming increasingly sophisticated and reliable, particularly in disaster management. This is because UAV technology has become more affordable and easier to use, producing aerial photography data with high spatial resolution and detailed Digital Elevation Models (DEM) for determining evacuation routes in tsunami disasters (Marfai et al., 2018a; Yan et al., 2009). Digital Elevation Models (DEMs) using UAVs are more accurate than DEMs produced from NAS, because the photogrammetry method combines geometric error correction processes by utilizing Ground Control Points (GCP) and DEM data. Use of photogrammetry techniques: UAVs provide a more precise, accurate, and up-to-date evacuation strategy. UAVs have the potential to reach difficult-to-access locations and collect data quickly, thereby enabling a more effective response to emergencies.

Unmanned Aerial Vehicles (UAVs), commonly known as drones, are a cutting-edge technology for disaster management, providing images in the form of aerial photos (Khan et al., 2020). UAVs can be used for research related to tsunami disasters, such as determining evacuation routes in more detail (Marfai et al., 2021a). The results of the UAVs data are in the form of orthomosaic maps and DEM, which are used as material for planning evacuation routes based on the Geographic information System (GIS) (Ashar et al., 2018; Bonilauri et al., 2021; Wood et al., 2014).

GIS applications are used to determine evacuation routes because they are easy to use and manage, and can effectively organize geographic data, especially when making quick assessments. Several GIS applications can be utilized in disaster planning, including hazard mapping, zoning, and disaster evacuation and route planning (Setiyawidi et al., 2011). Through GIS analysis software, potential evacuation routes can be identified based on geospatial and visual data obtained from UAVs. Geospatial data comprises spatial features on the Earth, which are represented by a geographic coordinate system or projection (Wicaksono, 2023).

RESEARCH METHODS

The research was conducted at the Loto Village Agrotourism Destination in Ternate City, utilizing photogrammetry techniques with a DJI Mavic Pro 1 type drone, covering an area of 38 Hectares. UAVs can capture high-quality aerial images to map coastal regions and aid in planning evacuation routes for tsunami disasters (Marfai et al., 2019). The flight survey design was carried out using Drone Deploy software for UAV flights, making it automatic and easy to capture aerial photos with mobile applications, such as cell phones (Figure 2).

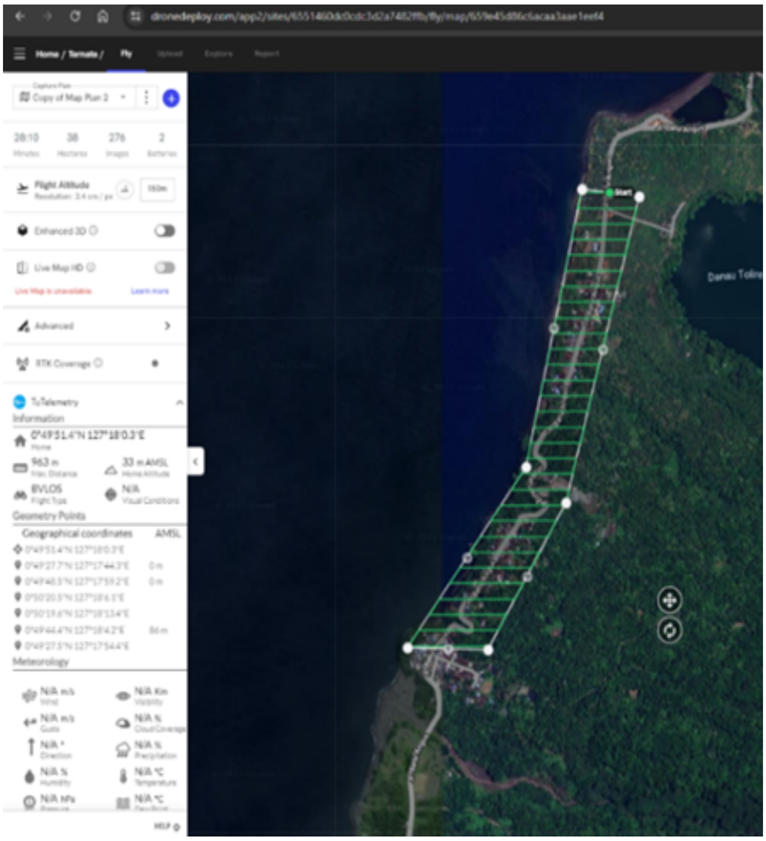

Figure 2. UAV Flight Survey Design In The Research Area (Source: Research Document, 2025)

The data processing technique resulting from UAV aerial photography is a photogrammetric technique using Agisoft Metashape Professional software. The results are orthomosaic maps and Digital Elevation Models (DEM) in the form of Digital Surface Models (DSM) and Digital Terrain Models (DTM) maps, created using ArcGIS and QGIS software.

DEMs created using photogrammetric techniques have a far higher spatial resolution than those produced using satellite remote sensing images, such as SRTM (30 m) and DEMNAS (8 m). By incorporating geodetic GPS, which enhances the precision of DEM processing, the accuracy of this method is further improved. As benchmarks for base map accuracy, geometric accuracy tests are conducted to evaluate the vertical and horizontal precision of coordinates derived from aerial photos. LE90, or linear error 90%, is used to measure vertical accuracy, whereas CE90, or circular error 90%, is used to measure horizontal accuracy (Ningrum et al., 2025).

The tsunami hazard map was calculated using the Hloss method (Berryman, 2006), which considers land use and slope as land factors that can hinder the speed of a tsunami, as shown in the following equation:

$$H_{loss} = \left(\frac{167.n^2}{{H_0}^{1/3}}\right) + 5.\sin S \dots\dots\dots\dots (1)$$

Where H_{loss} is Loss of tsunami height per 1 m of inundation distance, n is surface roughness coefficient, H_o is tsunami wave height at the coastline (m), and S is slope gradient (degrees). Five categories are used to classify tsunami hazard modeling results based on inundation height: very low (<1 meter), low hazard (1-2 meters), moderate hazard (2-3 meters), high hazard (5-15 meters), and very high (>15 meters).

The data analysis technique involves overlaying the tsunami hazard map with an orthomosaic map and then creating a road network using the Network Analysis method in QGIS. The road network is used to determine the shortest path when determining evacuation routes and temporary evacuation places, considering walking. The shortest path is used to determine the direction of migration and the time required for people to reach a safe area from the tsunami disaster (Ashar et al., 2018).

Determining a location to serve as a temporary evacuation site requires consideration of safety factors, including ease of access, proximity to other areas, and the capacity to accommodate large numbers of people (Trindade et al., 2018). The temporary evacuation route map was then confirmed using participatory mapping methods to determine evacuation routes and temporary evacuation points that were suitable for the research area's conditions. Participatory mapping is a mapping strategy that empowers communities to map their own territory (Boissiere et al., 2019).

The community participated in Focus Group Discussions (FGDs) to identify risk areas, determine the safest evacuation routes, and establish temporary assembly locations. This method combines technical information, such as topography and road access, with local knowledge. Accurate evacuation maps are then created by digitally processing FGD results using GIS software (QGIS). These maps are ensured to be relevant to local needs and field conditions through active community input (Amelia et al., 2024).

The outcomes of the focus group discussions (FGDs) were integrated with spatial data using a Geographic information System (GIS) to generate a comprehensive tsunami evacuation map. After that, community members and stakeholders confirmed the map's accuracy. Following completion, the mapping data was included in village-level official disaster mitigation planning documents. The evacuation map is reviewed frequently and shared with the community to ensure everyone is aware of it and guarantee sustainability.

The results of the data obtained are then overlaid to produce a comprehensive and detailed tsunami disaster evacuation route map. The research stages are illustrated in a flow diagram (Figure 3).

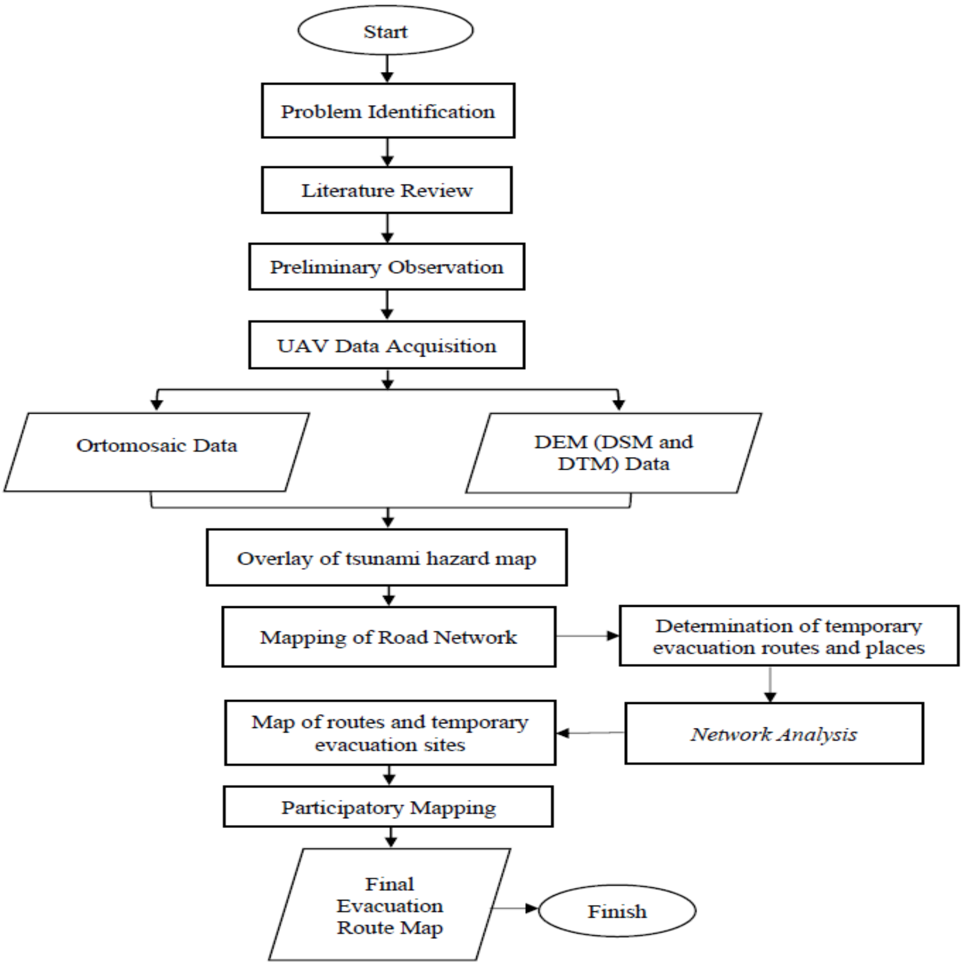

Figure 3. Research Flow Diagram (Source: Research Document, 2025)

RESULTS AND DISCUSSION

Characteristics of the Research Area

The research area shown in Figure 4 is located at coordinates 0.82-0.84 degrees N and 127.20-127.31 degrees E, in the coastal region of Loto Village, Ternate City. This area is highly vulnerable to tsunamis due to its seaside location and proximity to the Maluku Sea.

GCP and ICP Measurement Data Acquisition

Before the flight, it is necessary to install an X-shaped premark as a reference coordinate point on the ground to determine Ground Control Points (GCP) and Independent Control Points (ICP). The reference coordinate points are placed at locations that are easily recognized by the UAV, such as road intersections, building corners, or open fields. The survey instrument used to measure GCP and ICP with high precision is the Altus APS3G geodetic GPS, which is used for 10 to 20 minutes at each coordinate point. This geodetic GPS is used to measure 3 GCP coordinates and 1 ICP point. The results of the GCP coordinate points are then used as input for aerial photo data processing, providing spatial information in the aerial photo mosaic. ICP coordinates are used as control points to confirm the geometric accuracy of the aerial photo processing results (Wicaksono, 2023). The results of GCP and ICP measurements are shown in Table 1.

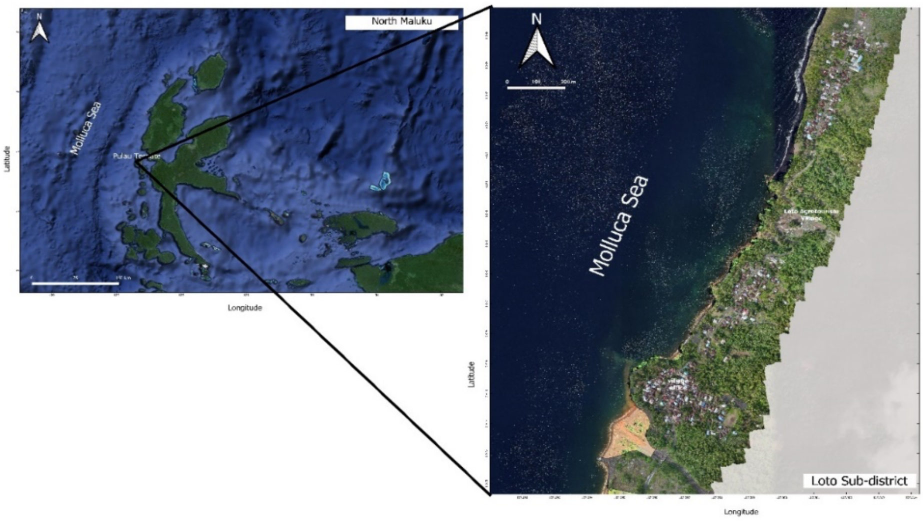

Figure 4. Coastal Loto Village, Ternate (Source: Research Document, 2025)

Table 1. Results of GCP and ICP measurements

Name	Coordinate		
	X	Y	Z
GCP1	0.83826	127.30217	22.497
GCP2	0.82335	127.29854	53.385
GCP3	0.81754	127.2953	17.722
ICP 1	0.81703	127.29674	36.506

(Source: Research Results, 2024)

Based on previous research, the accuracy of aerial photography using a UAV attached to a GCP and the ICP geometric accuracy test can reach 98% accuracy for the width of roads, rivers, buildings, and other vital objects (Arsyad et al., 2020; Marwan et al., 2020; Nizamuddin et al., 2023).

Acquisition of Aerial Photo Measurement Data

Geographical information on the research area was obtained using aerial photography data from measurements taken with a UAV or DJI Mavic Pro 1-type drone, which has a wide coverage area of 38 Hectares. Before carrying out a drone flight, plan the flight by determining the flight path, altitude, and shooting angle in the drone deployment application. The flight was conducted at a flight height of 150 meters with a speed of 7 m/s, a resolution of 3.4 cm/px, and end lap and side lap set at 80% and 70%, respectively, along a planned flight path of 21 lanes.

UAV Survey Data Processing

The initial stage in processing UAV survey data is preprocessing, which involves manually verifying image quality by checking for blurry and unnecessary photos. There were 458 aerial photos whose image quality had been manually verified and then automatically verified using the Estimate Image Quality tool in Agisoft software. This automatically generated Quality value is then recommended not to use photos with a Quality value of less than 0.5 (Agisoft LLC, 2023). Then, the aerial photo data is processed in the photo aligning stage, where it is aligned into a single image and georeferenced by integrating GCP coordinate points. The results obtained are a collection of point clouds (Figure 5) with 3-dimensional coordinates, which will be filtered using the Filter by Confidence tool to remove unreliable point clouds. This filter is applied to ensure that the resulting point cloud has a higher quality, more accurately representing the appearance in the field.

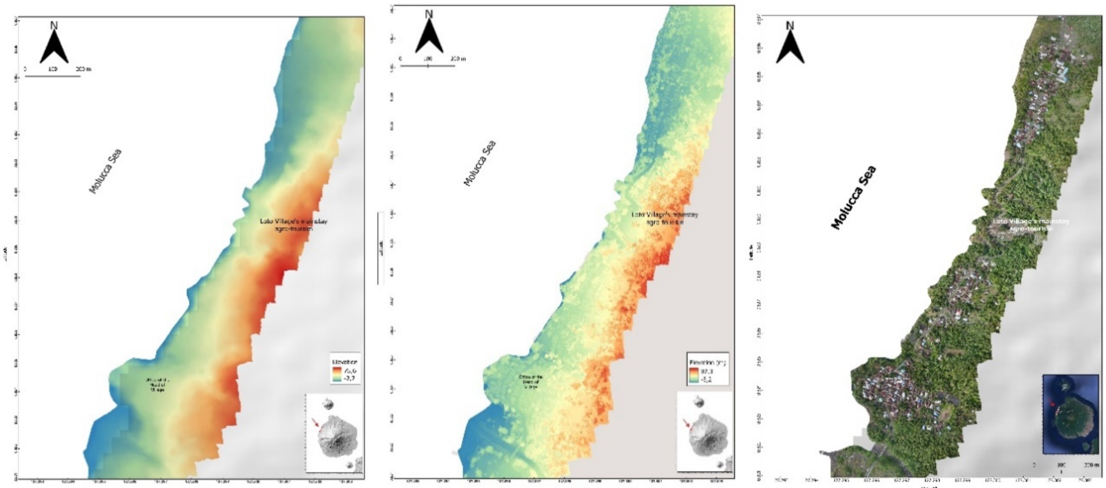

Figure 5. Map Results a). DTM, b). DSM and c). Orthomosaic (Source: Processed Data, 2025)

The process of processing aerial photo data is known as photogrammetry, a technique that produces regional topographic maps with high-resolution digital elevation in the form of Digital Elevation Models (DEM), Digital Surface Models (DSM), Digital Terrain Models (DTM), and orthorectified orthomosaic maps (Figure 5). The resulting DTM data is used as input to produce slope data using ArcMap and QGIS software. Next, it will be analyzed in mapping tsunami disaster vulnerability. Meanwhile, the orthomosaic map will be used to determine Temporary Evacuation Places along the tsunami disaster evacuation route in Loto Village. The results of the Root Mean Square Error (RMSE) calculation for GCP obtained an average value of 0.00043 meters, and for the ICP accuracy test, it was 0.000413 meters.

Table 2. GCP and ICP RMSE Results

No	Label	RMSE	CE90
1	TGF1	0,000116	
2	TGF2	0,000674	
3	TGF4	0,00029	
4	ICP1	0,000413	0,000627

(Source: Data Acquisition Results, 2024)

The accuracy value of the aerial photo map based on Circular Error (CE) 90 is shown in Table 2. In the geometric accuracy test, PERKA BIG No. 6 of 2018, concerning technical standards for Base Map Accuracy used in mapping scales, was utilized.

Tsunami Disaster Hazard Level

Analysis of the level of hazard to tsunami disasters uses data parameters such as elevation, distance from the coastline, slope, and surface roughness data from land cover. Elevation data uses aerial photography data with a resolution of 3.4 cm/px from UAVs to identify higher and safer areas as evacuation points. The morphological condition of the beach in Loto Village is rocky, with sandy beaches being the dominant type. Surface roughness data is obtained from digitizing orthomosaic maps and produces land cover data in the form of land cover maps (Figure 6). Loto Village land cover data can be used to interpret the descriptions of settlements (11.4 ha), agriculture (1.9 ha), plantations (40.6 ha), open space (4.8 ha), and water bodies (10.4 ha). The land cover area obtained from aerial photography is 69 Ha, with 5 types of land cover, including estimated areas for each type.

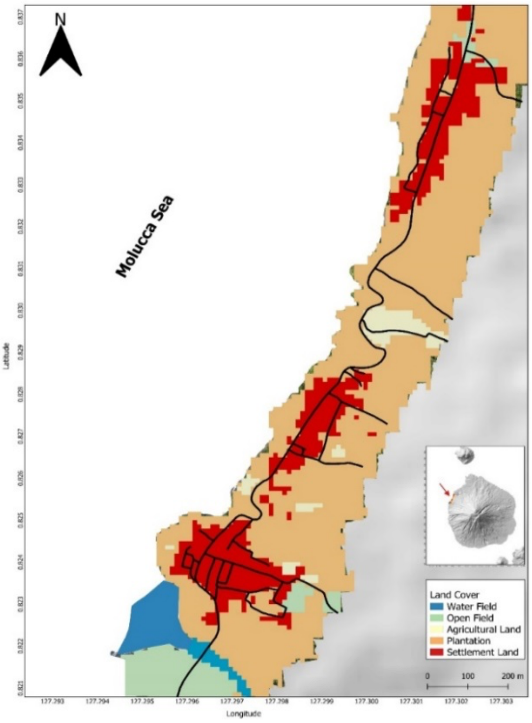

Figure 6. Land Cover Map From Aerial Photography
(Source: Ministry of Environment and Forestry of Indonesia, 2019)

Slope data was obtained from DSM data from aerial photography assisted by QGIS software, and a slope map with a classification of 5 classes was produced (Figure 7). The slope analysis in this coastal area is dominated by gentle and wavy slopes with percentages of 28% and 32%. This coastal area is in an active volcanic zone, so the hill is very dynamic and varied. This is caused by many variables related to geological processes and significant volcanic activity.

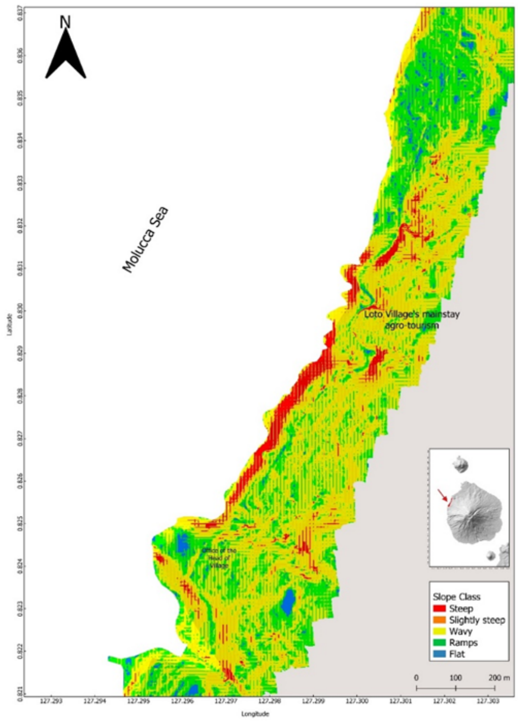

Figure 7. Slope Map (Source: Processed Data, 2025)

The calculation of the level of hazard to tsunami disasters is based on several parameters, including elevation data, coastline distance, slope, and surface roughness data from the land cover. This is then assisted by QGIS software using the Hloss formula approach (Berryman, 2006). The results of mapping the level of hazard to tsunami disasters are shown in Figure 8.

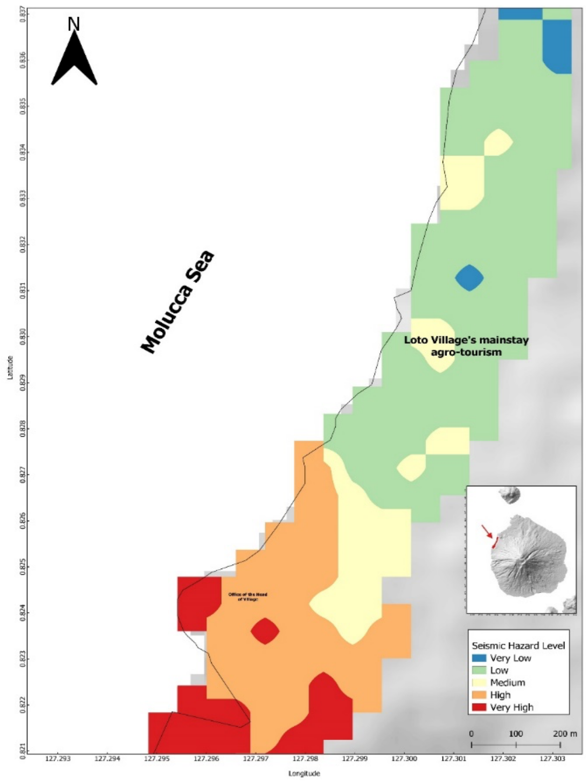

Figure 8. Tsunami Hazard Level Map (Source: Processed Data, 2025)

The characteristics of the research area are differentiated based on topography, the presence of agro-tourism destinations, residential buildings, potential tsunami vulnerability, and road infrastructure. The surface of the land or land in coastal areas greatly influences the behavior of tsunami waves when they reach that area. Thus, slope analysis is supporting information in tsunami hazard mapping (Achmad et al., 2023). This is because the slope value is directly proportional to the wave energy (Darlan, 1996).

One of the crucial steps in mitigating the tsunami disaster is identifying evacuation routes using UAV aerial photography data and community participation. The Loto Village agrotourism destination has the potential for educational tourism for the general public (Nasution et al., 2024). The Ternate City Government has just developed it in collaboration with the Department of Agriculture and the Department of Tourism. Apart from that, the aim of creating this agrotourism destination is to improve the welfare of farmers by combining tourism with agriculture. The Loto agrotourism development spans an area of 3.85 hectares, planted with various horticultural crops, including shallots, curly chilies, cayenne peppers, tomatoes, vegetables, bananas, and California papaya, which are managed by a combination of farmer groups (gapoktan) from Loto Village. Identifying and mapping evacuation routes for tourist destinations is crucial in reducing the possibility of a tsunami tragedy.

Aerial photography data has a short collection period and excellent spatial resolution; this data can serve as a basic reference source for mapping the research area. Aerial photos from UAV observations can be used in evacuation planning and tsunami disaster mitigation (Danardono et al., 2023; Marfai et al., 2018, 2019, 2021b). Based on the CE90 value obtained, the standard mapping scale can utilize a mapping scale of 1:1,000 because it is classified as a high scale and is suitable for tsunami disaster mapping.

The community's capacity for responding to the tsunami disaster in Loto Village is categorized as good, with a percentage of 62%, as determined by distributing questionnaires. It can be concluded that the community is well-prepared and has a good understanding of the risks posed by the tsunami, as well as the ability to recover from the tsunami disaster. So it can be relied on in determining temporary evacuation places and evacuation routes for tsunami disasters. The community needs to determine the safest temporary evacuation site by providing information about the area's characteristics and conditions. There are several key considerations when choosing a temporary evacuation site in Loto Village, including the location being in a safe zone that is not classified as a high-risk area, a sufficient land area to accommodate displaced people, easy access to roads, and the presence of suitable slope, height, and infrastructure, as well as supporting facilities.

The consideration chosen in determining the tsunami disaster evacuation route is accessibility, considering the fastest route to arrive at the temporary evacuation site. Community involvement is significant for planning and implementing tsunami disaster mitigation measures. In determining temporary evacuation places and evacuation routes for the tsunami disaster in Loto Village, the community is actively involved. Data from UAV aerial photography is used in participatory mapping to determine the best evacuation route, describing the current conditions of the research area in the form of an orthomosaic map. The map used in participatory mapping is an orthomosaic map overlaid with a tsunami hazard map.

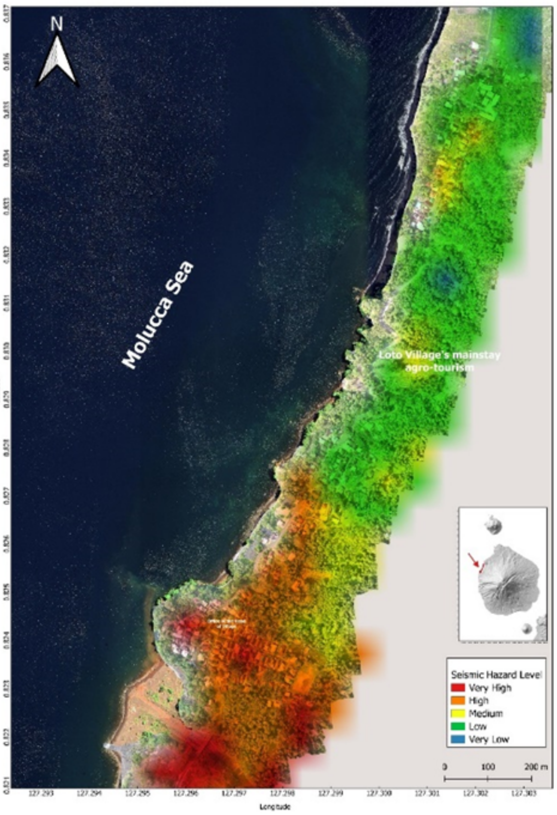

Figure 9. Map for Participatory Mapping in determining Temporary Evacuation Places and Evacuation Routes (Source: Processed Data, 2025)

Then, the community determines temporary evacuation sites and evacuation routes based on the results of discussions, taking several key considerations into account. The results showed that there were three recommendations for places that could be used as temporary evacuation sites in the event of a tsunami, namely the soccer field, the open field behind SDN 64 Ternate City, and the open area at the height behind SMPN 13 Ternate City. Temporary evacuation places and evacuation routes were determined in a participatory map before. Based on the results of participatory mapping and subsequent adjustments, the final map of the tsunami disaster evacuation route is shown (Figure 10).

Figure 10. Tsunami Disaster Evacuation Route Map (Source: Processed Data, 2025)

This map was reanalyzed by considering several factors, including the level of vulnerability to the tsunami disaster and the slope of the terrain in the research area. The percentage of changes made from participatory mapping to the final map of evacuation routes was approximately 60%, primarily involving the addition of one temporary evacuation place and the relocation of one existing temporary evacuation place. Temporary evacuation places were established, with evacuation routes using main roads, secondary roads, and footpaths.

The determination of the appropriate evacuation route should present more main routes that are spatially distributed more evenly and efficiently, with routes that algorithmically avoid topographical obstacles and select the fastest route to a safe point (Marfai et al., 2021a). However, in this case, the UAV-based tsunami evacuation route map for the Loto region only shows one main evacuation route designed to follow the national road infrastructure, with Temporary Evacuation Sites (TES) located at strategic points based on their proximity to densely populated areas.

The evacuation route map for the Loto region, based on UAV data, has significant advantages in terms of spatial visualization, information readability, and effectiveness in public Education. With high resolution, this map realistically represents environmental conditions, including buildings, vegetation, and road networks, making it easier for the community to recognize and understand the evacuation routes they use in their daily lives.

The estimated average distance to the TES is between 350 and 650 meters, and the estimated evacuation time is 5–10 minutes, considering the community's average walking speed. These routes are still within the safe time frame before the first tsunami wave is expected to arrive. Time and distance information is presented in a narrative format, which has proven to be easier for the general public to understand. Although it only shows one main route without alternatives, this approach is considered effective in avoiding confusion during the evacuation process. The route leads directly to a safe zone on high ground and utilizes access that is familiar to residents, although it may encounter obstacles on narrow sections of the road.

Overall, this participatory approach has successfully improved community preparedness in practical and visual terms. In contrast, the integration of UAV data with GIS analysis has improved the accuracy of tsunami hazard models and enabled the rapid and efficient identification of potential evacuation zones (Marfai et al., 2019).

CONCLUSION

From the results obtained, it can be concluded that the community in Loto Village is prepared to prepare and recover from the tsunami disaster, and their understanding is in the good category, so they can be relied on in determining temporary evacuation places and evacuation routes for tsunami disasters. For temporary evacuation places in Loto Village, four (4) temporary evacuation places use main roads, secondary roads, and footpaths. The temporary evacuation site in Loto Village is displayed as a map with the title 'Tsunami Disaster Evacuation Route Map,' so that the public and visitors to the Agrotourism Destination can see it.

This research also faced limitations during aerial photo data collection, namely the limitations of UAV battery life and range, as well as dependence on weather conditions. In addition, the integration of participatory community data in determining tsunami evacuation routes based on UAV data presents its challenges. Because it requires a deeper analysis, such as validation and additional corrections, the determination of tsunami disaster evacuation routes is more accurate. Further mitigation strategies need to be implemented, such as tsunami hazard modeling using the Numerical Simulation Method based on UAV data, which produces simulations of tsunami wave propagation, tsunami disaster risk mapping, and impact analysis of tsunami hazards on populations and buildings with the help of InaSAFE software. This is important to support comprehensive data in the preparation of disaster mitigation-based spatial planning documents.

The results of the tsunami disaster vulnerability level in Loto Village are in the very low to very high category. The medium category is on highland and steep slopes, such as Loto's flagship agrotourism area. Meanwhile, the high category is in areas with a gentle slope and close to the coastline and rivers, which may be dead due to the potential impact of tsunami waves. So areas with gentle slopes are more vulnerable to tsunami waves. However, the steep slopes increase the height of tsunami waves as they approach the coast.

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