

# Risk Analysis of the Tsunami Evacuation Infrastructure Based on the ISO 31000 in the Disaster-Prone Coastal Area in Teluk Palu

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## ABSTRACT

This study employs a structured risk assessment based on the ISO 31000 framework to evaluate tsunami evacuation infrastructure in Palu Bay, Central Sulawesi. Triggered by the 2018 triple disaster (earthquake, tsunami, and liquefaction) that revealed severe preparedness gaps, this study focused on the vulnerable coastal villages of Tondo and Mamboro. A mixed-methods approach combining field observations, spatial analysis, expert interviews, and Focus Group Discussions (FGDs) was used to identify and analyze risks along 10 evacuation routes and key assembly points. Field observations utilized a checklist containing predetermined variables, including road surface conditions, road width, the presence and clarity of signs, accessibility for people with disabilities, and route connectivity to safe zones. The findings indicated that critical risks, including route blockages, a lack of signs, and inadequate accessibility for people with disabilities, caused dangerous evacuation delays. Spatial analysis using Indonesian Topographic Maps (RBI) and tsunami hazard data overlays revealed that several routes were disconnected from safe zones, and maintenance and inclusive design issues were prevalent. A risk matrix was developed to prioritize interventions, identifying three routes with very high-risk scores (25, 20, and 20) that required immediate action. The study concluded that post-disaster reconstruction in Palu neglected systematic risk assessment and inclusive planning. Recommendations for infrastructure upgrades, regular evacuation drills, improved signage, and integration of geospatial data with real-time monitoring are proposed to address these gaps. By applying the ISO 31000 standard, this study provides a replicable model for enhancing evacuation infrastructure and fostering community resilience in other disaster-prone coastal areas.

*Keywords*-disaster risk assessment; tsunami evacuation routes; ISO 31000; Palu bay

## I. INTRODUCTION

Natural disasters profoundly impact people's physical, mental, and social lives. One disaster that severely hit Indonesia was the earthquake and tsunami that hit Central Sulawesi on September 28, 2018. The number of houses damaged by the disaster in four regions of Central Sulawesi Province was 41,852, with 12,845 severely damaged, 17,293 moderately damaged, and 12,717 lightly damaged in Palu City. In Donggala Regency, 21,378 units were damaged, consisting of 7,290 severely damaged, 6,099 moderately damaged, and 7,989 lightly damaged. In Sigi Biromaru Regency, the total number of damaged units was 30,236, consisting of 13,144 severely damaged, 6,099 moderately damaged, and 10,612 lightly damaged, and in Parigi Moutong Regency, as many as 5,550 units were damaged, consisting of 533 severely damaged, 826 moderately damaged, and 4,191 lightly damaged [1, 2]. Additionally, the disaster affected the lifestyle and survival of the community. Following the incident, the government and various humanitarian organizations attempted to restore the situation by providing permanent housing to the affected victims. However, significant challenges remain in disaster management efforts, especially in designing effective evacuation routes and assembly points to reduce the risk of further casualties during emergencies. The tsunami and liquefaction disaster of September 28, 2018, in Palu, drastically changed the physical and social landscape. Pre-existing evacuation routes and assembly points have been damaged, inundated, or rendered irrelevant. This study aims to analyze the risks inherent in these safety infrastructures using the ISO 31000 international standard framework to provide a structured, measurable assessment that can serve as a basis for more effective mitigation planning by the government.

Evacuation routes and assembly point planning are crucial components of disaster management, especially in disaster-prone areas such as the coast of Palu Bay. The disaster on September 28, 2018, which included an earthquake, tsunami, and liquefaction, highlighted the importance of an effective evacuation system to save lives and minimize losses. It has been shown that effective evacuation route planning must consider various factors, such as evacuation speed, route capacity, and accessibility for vulnerable groups, such as the elderly, children, and people with disabilities [3, 4]. In addition, safe and strategic assembly points must be selected to ensure that people can gather and receive assistance quickly [5, 6]. With a well-planned evacuation system, evacuations can be carried out more efficiently, reducing panic and increasing public safety in the face of disasters.

The importance of integrating geospatial data and simulation modeling in optimizing evacuation routes during emergencies, particularly during natural disasters, has been emphasized [7, 8]. Accurate geospatial data provide detailed information about the physical conditions of an area, whereas simulation modeling allows planners to test various evacuation scenarios. This enables the most efficient and safe evacuation routes to be identified, ensuring a swift and organized evacuation process. This is crucial for reducing risks to the community and expediting disaster management efforts. Data and simulation integration help ensure that the chosen route can

save lives by minimizing potential obstacles [9]. In emergencies, appropriate planning and implementation of evacuations are important to ensure a smooth and effective process and provide the maximum protection for victims.

AS/NZS ISO 31000 provides a systematic natural disaster risk management framework. Establishing context, risk identification, analysis, evaluation, control, monitoring, and review are significant for effective risk management [10]. Risk assessments involving various stakeholders, such as local governments and communities, can provide a more comprehensive understanding of the risks faced [11]. ISO 31000 defines risk as the effect of uncertainty on an objective. In this context, the objective is to ensure the safety of people through effective evacuation routes and assembly points [12]. This framework consists of several principles and processes. For this analysis, the present work focuses on the Risk Assessment Process, which consists of (a) Risk Identification, (b) Risk Analysis, and (c) Risk Evaluation. Risk acceptance is determined from the risk value produced by multiplying the probability and impact. Considering the level of risk acceptance, probability, and impact scale values, the risk acceptance scale is presented in Table I [2].

TABLE I. RISK ACCEPTANCE

Risk acceptance level	Risk acceptance scale
Unacceptable	$X > 15$
Undesirable	$5 < X > 15$
Acceptable	$3 < X > 5$
Negligible	$X < 3$

The unacceptable risk level describes a disaster scenario with a devastating impact and significant loss of life. Disasters, such as earthquakes, liquefaction, and tsunamis, fall into this category because they threaten life, damage infrastructure, and cause long-term environmental impacts. These unacceptable risks require immediate responses such as mass evacuations and large-scale emergency response operations. Undesirable risks are evident in coastal settlements that experience tidal flooding or small tsunamis annually. While these events may not result in fatalities, they can lead to recurring economic losses and social disruption. These risks can be mitigated through measures such as coastal protection, early warning systems, and improved spatial planning. A small-scale tsunami in an area with adequate defenses illustrates acceptable risk. Preparedness, including early warning systems, evacuation centers, and trained communities, can help manage this risk. Although material damage may occur, the loss of life can be greatly minimized. A negligible risk is, for example, a small tsunami wave hitting a coastline protected by a strong seawall or breakwater. The water may only reach the shoreline without entering residential areas. This is not dangerous, does not cause damage, and does not disrupt the lives of the residents. Existing protections render this level of tsunami threat negligible.

The present study was designed to assess the readiness of the tsunami evacuation infrastructure in the coastal areas of Palu Bay following the 2018 disaster. The objective was to identify vulnerable points on the evacuation route, analyze their risk levels using the ISO 31000 standard, and formulate measurable improvement strategies to reduce potential future casualties.

## II. RESEARCH METHODS

### A. Research Objectives

This study was conducted in the tsunami-affected coastal areas of Palu Bay, specifically in the Tondo and Mamboro Districts. Ten road sections were selected using purposive sampling to represent various critical characteristics that influence evacuation effectiveness. The sample selection considered factors such as road surface conditions, residential density, and the presence of physical barriers, like walls and fences, which impede movement.

TABLE II. SAMPLES COLLECTED FROM ROAD SECTIONS

No	Road segment name	Sub-district	Road surface type	Primary problem type (based on the analysis)
1	Jl. Uwe Boro	Tondo	Severely damaged asphalt with many potholes and cracks	Damaged road surface
2	Jl. Uwe Malariti	Tondo	Severely damaged asphalt with many potholes and cracks	Damaged road surface
3	Jl. Uwe Mpoaja	Tondo	Uneven/sunken paving blocks	Damaged road surface
4	Jl. Cendana	Mamboro	Dusty dirt road that becomes muddy when rainy	Slippery road surface
5	Jl. Mantilayo	Mamboro	Dusty dirt road that becomes muddy when rainy	Slippery road surface
6	Jl. Karana	Mamboro	Irregular dirt and stone road	Damaged road surface / slippery
7	Jl. Uwe Goda	Tondo	Potholed and uneven asphalt	Damaged road surface
8	Jl. Kayu Pilo	Tondo	Moderately damaged asphalt with some cracks	Damaged road surface
9	Jl. Latjera	Mamboro	Good condition asphalt	Poor road lighting / missing signs
10	Jl. Kaluku Pua	Tondo	Good condition asphalt	Missing signs / unclear directions

As shown in Table II, 10 sample roads were deliberately chosen to reflect the different attributes affecting tsunami evacuation effectiveness within the Tondo and Mamboro Districts of Palu Bay area. The selection process took into account road surface conditions and other physical factors that could hinder the flow of evacuation, including residential density and obstacles, like walls and fences, which restrict movement along evacuation routes. For example, roads such as Jl. Uwe Boro and Jl. Uwe Mpoaja were selected because they are located in densely populated residential areas with walls and fences encroaching on the roadway, highlighting the potential for congestion and debris during an evacuation. Conversely, lower-density roads like Jl. Latjera were included as comparison samples. The analysis of the 10 sample roads in the Tondo and Mamboro Districts revealed key damage patterns that could potentially hinder tsunami evacuation. Most roads (6 out of 10) experienced surface damage ranging from severe damage (Jl. Uwe Boro, Malariti, and Goda), uneven paving blocks (Jl. Uwe Mpoaja), to irregular soil/rock conditions (Jl. Karana). Two other roads (Jl. Cendana and Mantilayo) faced slippery surfaces due to dirt roads. Meanwhile, roads with good asphalt (Jl. Latjera and Kaluku Pua) experienced non-structural problems such as poor lighting and unclear signs. This variation suggests that evacuation

challenges are not only physical but also related to supporting systems, requiring specific mitigation strategies for each type of problem to be developed.

### B. Data Collection Techniques

#### 1) Field Observation

This technique was conducted using a pre-developed checklist based on key variables, which include: (a) physical condition of the route (surface type, damage, width, slope), (b) obstruction factors (road narrowing, debris, wild vegetation), (c) signs and information (presence, clarity, damage), (d) accessibility (availability of dedicated paths or ramps for wheelchairs), (e) lighting, and (f) connectivity (linking routes to assembly points and safe zones). Each segment of the route and assembly point was systematically checked using this checklist.

#### 2) Spatial Analysis

This analysis involved overlaying the existing evacuation route map with the Indonesian Topographic Map (RBI) and the tsunami inundation zone map. The goal was to visually and geospatially determine whether the routes were safely connected to assembly points outside the danger zone. The results are presented in a thematic map, indicating the risk level of each route segment.

#### 3) Expert Interviews

Interviews were conducted with representatives of the Regional Disaster Management Agency (BPBD) and relevant technical agencies. The purpose was to gather expert assessments of the likelihood and impact scores for each identified risk, which were then used to complete the risk matrix.

#### 4) Focus Group Discussions

FGDs were organized with community members to understand their perceptions of risk, capabilities, and challenges encountered during the evacuation process. This provided qualitative context that complemented the quantitative data from observations.

#### 5) Mixed Method Harmonization

The four methods were integrated systematically and complemented each other. Field observation data and spatial analysis provided an objective physical database. These findings were then enriched and validated through expert interviews (for technical perspectives) and community FGDs (for user perspectives). This integration ensured that the risk assessment considered not only the technical infrastructure conditions but also the social and institutional context.

### C. Data Analysis

Data analysis follows the risk assessment process outlined in ISO 31000:

- Risk identification: Risks were identified using observational, spatial, and FGD data. These risks were then categorized based on their sources (Table II).
- Risk analysis: The level of risk was analyzed by evaluating the Likelihood (L) and Impact (I) scores for each risk event.

These L and I scores were assigned through a consensus derived from observation, spatial analysis, and expert assessments (see Tables III and IV).

- Risk evaluation: The risk level was determined by multiplying L and I using the Risk Matrix (Table V). This calculation resulted in a Risk Map that visualizes the risk level for each route segment. The result is a Risk Map of Evacuation Routes and Assembly Points that presents the risk level visually (using a Green-Yellow-Red and Purple color gradient).

TABLE III. LIKELIHOOD CRITERIA (L)

Score	Likelihood level	Description
5	Almost certain	Occurs in almost every tsunami event (>90%)
4	Likely	Occurs in most tsunami events (70-90%)
3	Possible	Occurs in some tsunami events (30-70%)
2	Unlikely	Occurs in few tsunami events (10-30%)
1	Rare	Occurs very seldom, but possible (<10%)

TABLE IV. PRIMARY IMPACT ON HUMAN SAFETY (I)

Score	Impact level	Description (lives)
5	Catastrophic	Mass casualties (>100 people)
4	Major	Multiple fatalities (10-100 people)
3	Moderate	Several fatalities (1-10 people)
2	Minor	Serious injuries (no fatalities)
1	Insignificant	Minor injuries

Table V displays the risk values based on the possibility of the risk occurring and the impact resulting from the event. The effects are divided into categories: insignificant, minor, moderate, major, and catastrophic, and the possibilities of occurrence are almost certain, likely, possible, unlikely, and rare.

AS/NZS ISO 31000 serves as a vital international standard for risk management, offering robust principles and

TABLE V. RISK VALUE MATRIX

Likelihood (L)	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost certain (5)	5 (Low)	10 (High)	15 (Extreme)	20 (Extreme)	25 (Extreme)
Likely (4)	4 (Low)	8 (High)	12 (High)	16 (Extreme)	20 (Extreme)
Possible (3)	3 (Low)	6 (Medium)	9 (High)	12 (High)	15 (Extreme)
Unlikely (2)	2 (Low)	4 (Low)	6 (Medium)	8 (High)	10 (High)
Rare (1)	1 (Low)	2 (Low)	3 (Low)	4 (Low)	5 (Low)

TABLE VI. RISK SOURCE, RISK EVENT, POTENTIAL CAUSE, AND IMPACT

Risk source	Risk event	Potential causes	Consequences (impact)
Evacuation routes	Routes become impassable during evacuation [4].	Damaged/disrupted due to liquefaction. Blocked by debris/rubble.nadequate width for evacuee capacity. Excessively steep slope.	Fatalities, injuries, delayed evacuation.
Assembly points	Assembly points are unsafe or non-functional [5].	Located within tsunami inundation zone. Exceeds capacity. No access to clean water or logistics. Unstable ground (post-liquefaction).	Fatalities, panic, humanitarian crisis.
Signage and information	People become lost or disoriented [5].	Signs missing or damaged. Signs unclear or ambiguous. No public evacuation maps available.	Wrong direction taken, delayed evacuation.
Human factors	People cannot evacuate quickly enough [14].	Panic. Presence of vulnerable groups (elderly, children, people with disabilities). Lack of training and drills.	Fatalities, particularly among vulnerable groups.

frameworks to help organizations tackle various risks, including but not limited to disaster risks. The benefits of using ISO 31000 are multiple. First, it establishes a comprehensive approach to organizational risk management, leading to more thorough risk assessments. Furthermore, the standard is adaptable to diverse organizations and contexts, promoting effective and widespread implementation. The standard delivers precise guidance for understanding risk-related decisions, enhancing organizational responsiveness. Finally, ISO 31000 can foster improved stakeholder communication, expediting collaboration and proactive risk management [12]. The Disaster Risk Calculation Method (DRCM) is based on:

$$DR = H \times \left[ \frac{V}{C} - M \right] \tag{1}$$

DRCM provides a quantitative means to evaluate disaster risk by considering critical elements such as Hazard (H), Value (V), Capacity (C), and Mitigation (M). The DRCM reduces tangible data to support informed, data-driven decision-making, facilitates the assessment of a disaster's potential impact through relevant parameters, allows for strategic mitigation planning, identifies the most vulnerable areas, and accurately gauges the need for enhanced mitigation efforts [2, 13]. Adopting AS/NZS ISO 31000 provides organizations with a comprehensive framework for effective risk management in various scenarios, including disasters. This approach enhances communication and decision making. Although the DRCM method is essential for accurate quantitative disaster risk analysis, it is less flexible and more technical. Table VI systematically categorizes risk sources, events, causes, and impacts. This analysis shows that evacuation failures are caused by infrastructure damage (routes, assembly points, signs) and human factors, such as panic and vulnerability, significantly increasing the potential for loss of life.

TABLE VII. RISK ANALYSIS OF 10 EVACUATION ROUTES

Evacuation route name/Problem type	Likelihood (L)	Impact (I)	Risk level (L x I)	Recommended actions
Evacuation route 1: Disconnected at intersection	5	5	25 (Extreme)	Immediate repair. Construct connecting paths or clear alternative routes to address the blockage.
Evacuation route 2: Missing or severely damaged directional signs	5	4	20 (Extreme)	Immediate replacement. Install new, more durable signs equipped with emergency lights.
Evacuation route 3: No dedicated path/ramp for wheelchairs	4	5	20 (Extreme)	Infrastructure modification. Construct accessibility-compliant ramps.
Evacuation route 4: Poor road lighting	5	3	15 (Extreme)	Lighting installation. Add solar-powered street lights along dark sections.
Evacuation route 5: Damaged road surface (potholes/cracks)	4	4	16 (Extreme)	Road repair. Road recoating or repaving to ensure a flat and safe surface for all users.
Evacuation route 6: Blocked by waste or wild vegetation	4	3	12 (High)	Routine cleaning. Schedule regular cleaning and vegetation trimming.
Evacuation route 7: Unclear directions to assembly point	4	3	12 (High)	Signage improvement. Install larger and more intuitive evacuation maps and directional signs.
Evacuation route 8: No audio alerts for the visually impaired	3	4	12 (High)	Inclusive system. Install sirens or voice announcement systems at starting points and along the route.
Evacuation route 9: Slippery road surface when wet	3	3	9 (Medium)	Traction improvement. Apply anti-slip road markings or use non-slip surface materials.
Evacuation route 10: Inadequate route width for heavy traffic	3	3	9 (Medium)	Capacity evaluation. Widen the route if possible, or create parallel alternative paths.

III. ANALYSIS

A risk analysis of 10 evacuation routes identified three top priority issues: broken paths, damaged signs, and a lack of wheelchair access. Other high-risk issues include poor lighting, damaged roads, and unclear signage, which require immediate repairs and regular maintenance. The risk identified five critical issues with an "Extreme" risk level, making them the highest priority. These critical issues are:

- Evacuation route 1: Blocked at intersection (risk level 25).
- Evacuation route 2: Missing or severely damaged directional signs (risk level 20).
- Evacuation route 3: No wheelchair ramp (risk level 20).
- Evacuation route 4: Poor street lighting (risk level 15).
- Evacuation route 5: Road surface damage (potholes/cracks) (risk level 16).

Other issues, such as slippery roads and inadequate road width, have been categorized with "Medium" to "High" risk levels and require planned repairs. Table VII outlines the following priorities for addressing evacuation routes:

- Priority 1 (Extreme risk - purple): Allocate resources and budget primarily to Routes 1, 2, 3, 4 and 5. Issues on these routes are critical and could potentially lead to loss of life and complete evacuation failures.
- Priority 2 (High risk - red): Implement repairs and improvements on Routes 6-8. Problems in this category significantly hinder the speed and safety of the evacuation process.
- Priority 3 (Medium risk - yellow): Develop plans for improvements on Routes 9 and 10 in the medium term. Although these routes present a lower risk, their enhancement is essential for improving reliability and safety.

Following the 2018 disaster, the Palu Bay coastline suffered severe damage to infrastructure. Several reconstruction efforts have been undertaken, including the construction of new evacuation routes and the repair of existing ones. However, several problems remain, such as:

- Some evacuation routes are not correctly connected to safe assembly points, hampering evacuation processes and increasing safety risks during emergencies.
- Evacuation and directional signs are minimal, especially in some locations, which can cause confusion and delays in evacuation processes during emergencies.
- Limited accessibility and facilities are not fully accessible to people with disabilities and other vulnerable groups.
- Some evacuation routes that have been constructed are poorly maintained.

TABLE VIII. RISK ASSESSMENT MATRIX FOR TSUNAMI PREPAREDNESS

Hazard	L	I	Risk level (L x I)	Recommended actions
Evacuation routes not well-connected to assembly points	4	5	20 (Extreme)	Top priority. Redesign and rebuild infrastructure to ensure direct and safe connectivity.
Inadequate evacuation signs and directional guides	5	4	20 (Extreme)	Top priority. Install clear, bright, and weather-resistant signs at every intersection and confusion-prone area.
Facilities not friendly to disabilities and vulnerable groups	4	4	16 (Extreme)	High priority. Conduct accessibility audits and add facilities such as ramps, handrails, and inclusive warning systems.
Poorly maintained evacuation routes	4	3	12 (High)	Medium priority. Implement routine maintenance programs (road repairs, cleaning, lighting) to ensure that routes are always ready for use.

Based on Table VIII, the risk analysis of the four main issues in tsunami preparedness indicates two issues with the most critical risk level (Extreme). The problem of evacuation routes that are not well connected to assembly points (risk 20) and inadequate evacuation signs and directional signs (risk 20) are assessed as almost certain to occur with catastrophic to significant impacts, thus requiring the highest priority actions in the form of infrastructure redesign and installation of transparent and weather-resistant signs. Meanwhile, facilities that are not friendly to people with disabilities and vulnerable groups pose an Extreme risk (16) and require an accessibility audit, as well as the addition of supporting facilities. Poorly maintained evacuation routes are categorized as High risk (12) and require a routine maintenance program. Table VIII maps the urgency of each issue and provides specific and measurable recommendations.

#### IV. CONCLUSIONS

This study successfully achieved its objectives by identifying vulnerabilities in evacuation routes, analyzing their risk levels using the ISO 31000 standard, and formulating measurable improvement strategies. The identification of vulnerabilities revealed critical issues such as broken routes, lack of signage, and poor accessibility for individuals with disabilities. The risk level analysis, conducted using the ISO 31000 matrix, classified three routes as having "unacceptable" risk, indicating the need for immediate intervention and providing an objective basis for prioritization. Measurable improvement strategies have been developed, including technical recommendations for infrastructure enhancements, signage installation, and the integration of early warning systems. Overall, this study demonstrates that the ISO 31000 framework is an effective tool for evaluating disaster preparedness. Its application in Palu shows that a reconstruction approach focusing solely on physical development without a comprehensive risk assessment can create significant safety gaps. Therefore, the model proposed in this study can serve as a standard protocol for assessing and improving evacuation infrastructure in other disaster-prone coastal areas in Indonesia.

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