Evaluation of Disaster Risk and Mitigation Strategies for Post-Disaster Permanent Housing in the Palu Koro Fault Area

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Received: 3 October 2024 | Revised: 25 October 2024, 30 October 2024, and 4 November 2024| Accepted: 5 November 2024

 DOI: https://doi.org/10.48084/etasr.9165

ABSTRACT

The Palu Koro Fault in Sulawesi, Indonesia, an area with very high seismic activity, with a historical record of large earthquakes, including the devastating event on September 28, 2018. This earthquake, accompanied by a tsunami and liquefaction, caused significant damage to infrastructure and residential areas in Palu City, Donggala Regency, and Sigi Regency. A future similar event needs to be studied based on technical aspects related to disaster vulnerability criteria. The SNI 03-1733 (2004) establishes the disaster risk criteria in residential areas, such as landslides, floods, and earthquakes. BNPB has also created a disaster-prone map in Indonesia. However, studies on safe housing emerging from various disasters, such as earthquakes, tsunamis, liquefaction, and other risks, specifically being in the path of planes or near high voltage currents, are still limited. This research aims to assess disaster risk in post-disaster permanent residential relocation using the AS/NZS ISO 31000 risk management framework, which includes vulnerability conditions, evaluation of technical aspects, disaster risk analysis, and development of recommendations, combining quantitative and qualitative approaches. Data were analyzed using a scale-based method, with descriptive statistics to calculate frequency, averages, and percentage of the risk categories at each location. Qualitative analysis produces narratives regarding the impact of risks on community safety and residential infrastructure. The current study results show that high-risk factors, including earthquakes, floods, and landslides, require immediate mitigation. Additionally, immediate action should be taken for risks categorized as unacceptable, involving building strengthening, drainage system improvement, and soil stabilization, to reduce the risk of liquefaction. Concerning moderate risks, which belong to the undesirable category, they also require further treatment to minimize the impact of future disasters. The current study also emphasizes the importance of community survivors' participation in the relocation and disaster preparation process. This underlines the need for an integrated approach to disaster risk management to strengthen the resilience of communities and infrastructure in disaster-prone areas.

Keywords-permanent housing relocation; disaster risk; AS/NZS ISO 31000; Palu; disaster vulnerability

I. INTRODUCTION

Palu Koro is an active fault located in Sulawesi, Indonesia. This fault has a long history of seismic activity, including an earthquake with a 7.9 magnitude on December 1, 1927, which has become an essential indicator in studying the geology and disasters of this region [1]. Since 1927, seismic activity along the Palu Koro Fault has continued, with four significant shocks having occurred between 1938 and 2018. The earthquake on September 28, 2018, with a magnitude of 7.7 on the SR scale, was a turning point for disaster management in the region. The National Disaster Management Agency stressed this earthquake's significant impact on Palu City, Donggala Regency, and Sigi Regency [1]. The earthquake caused a tsunami and liquefaction, which triggered infrastructure damage and resulted in thousands of housing units being damaged in several areas, including Palu City and Sigi Regency. The damage caused by this disaster was extensive, covering various basic infrastructures, such as office buildings, educational facilities, places of worship, and residential areas. In the context of reconstruction and rehabilitation, residential houses are the main focus because the number of damaged houses reaches tens of thousands of units [2]. Research shows that post-disaster recovery must be carried out with an approach that considers technical and social factors to ensure the sustainability of the reconstruction process. The number of houses damaged after the disaster in four cities and districts in Central Sulawesi province, namely Palu City, was 41,852 units, consisting of 12,845 units with heavy damage, 17,293 units with moderate damage, and 12,717 units with light damage. In Donggala Regency there were 21,378 damaged units out of which, 7,290 were heavily damaged, 6,099 moderately damaged, and 7,989 lightly damaged. In Sigi Biromaru Regency a total of 30,236 damaged units were documented, with 13,144 of them being heavily damaged, 6,099 moderately damaged, and 10,612 lightly damaged. Finally, in Parigi Moutong Regency there was a total of 5,550 damaged units, that is, 533 units with heavy damage, 826 units with moderate damage, and 4,191 units with light damage [2].

Vulnerability and resilience are essential concepts in disaster risk management. Vulnerability reflects how much a community can be affected by a disaster, while resilience demonstrates a community's capacity to recover after a disaster [3]. Authors in [4] showed that measuring vulnerability must involve analyzing social, economic, and environmental factors. The evaluation of the vulnerability conditions for post-disaster permanent residential relocation is crucial in the Palu Koro context. The participation of survivors in the post-disaster relocation process is an important aspect that is often overlooked. Authors in [5, 6] demonstrated that survivor involvement in relocation site selection is usually low. These findings also align with studies in other countries, such as India and Sri Lanka, where citizen participation in the relocation process was minimal according to [7, 8]. In Japan, a disaster mitigation training program for high school students highlighted the importance of increasing awareness of the disaster impact on people's everyday lives [9]. The management aspect of post-disaster relocation is often a weak point in the recovery process. In [10, 11], it was exhibited that managing relocation organizations is not always practical, impacting the reconstruction process's smoothness. In [12], the necessity to increase the capacity of construction workers and disaster survivors through training on anti-seismic building guidelines and standards in Indonesia was highlighted. The design of relocation infrastructure also plays a crucial role in ensuring accessibility and desirability. Authors in [13] emphasized the need to plan a sound transportation system to support citizen mobility. Other research also proposed optimal physical infrastructure with the purpose of meeting citizen needs [14, 15].

There is an urgent need to increase the competence of construction workers in post-disaster reconstruction. Training focusing on anti-earthquake building standards aims to make the construction process run safely and efficiently [12]. Several studies have revealed that a skilled and experienced workforce can reduce the risk of future damage, with the disaster risk mitigation approach being an integral part of risk management. Research in Japan has stressed the importance of interdisciplinary collaboration in developing disaster mitigation programs [16]. Additionally, research in the Philippines, following Typhoon Haiyan, has highlighted the need to consider disaster risk in relocation planning [17]. Although many studies have discussed various aspects of post-disaster relocation, there is still a lack of elaboration of the disaster risk criteria and sub-criteria specific to permanent housing relocation. AS/NZS ISO 31000 provides a systematic natural disaster risk management framework. Establishing context, risk identification, analysis, evaluation, control, and monitoring are crucial to managing risk effectively [18]. Risk assessments involving various stakeholders, such as local governments and communities, can provide a more comprehensive understanding of the former [19]. Risk acceptance is determined from the risk value produced by multiplying the probability and the impact. The risk acceptance scale can be seen in Table I.

TABLE I. RISK ACCEPTANCE [20]

Risk acceptance level	Risk acceptance scale
unacceptable	$X \geq 15$
undesirable	$5 \leq X \geq 15$
acceptable	$3 \leq X \geq 5$
negligible	$X \leq 3$

Table I analyzes the categories, which will help clarify disaster risk severity [20].

- Unacceptable risk constitutes a dire situation where the scale of destruction and potential casualties is very high. Examples include earthquakes, liquefaction, and tsunamis, which can destroy large settlements, causing many deaths, infrastructure damage, and long-term environmental impacts. This risk type is considered unacceptable because it threatens human safety and requires an immediate response, namely mass evacuation and large-scale emergency response.
- Undesirable risk may address to annual floods in residential relocation areas with poor drainage. Even though the scale of damage and number of victims may not be as large as during an earthquake, these liquefaction and flood tsunamis cause significant economic losses, damage to infrastructure, and major disruption to daily life. Although undesirable, this risk often cannot be avoided. However, it can be managed through infrastructure improvements and flood risk management.
- An acceptable risk example is a medium-strength earthquake in an area that has been adequately prepared with earthquake-resistant buildings and fast disaster response. Although there is still the potential for damage and injury, this risk can be appropriately managed with preventive measures for its impact to be minimized.
- Negligible risk is when the disaster risk is strong, but the area in which it occurs is well prepared. Such a risk may be a heavy rain in an area that has an effective drainage system. Although there is the potential for minor

disturbances, such as fallen trees or standing water, these risks do not significantly affect daily activities or pose no serious threat to life or property.

The current research objectives include assessing vulnerability conditions, identifying, and analyzing the vulnerability conditions of permanent residential relocation around the Palu Koro fault line after the 28 September 2018 disaster may help prevent potential future disasters. Evaluation of technical aspects of the permanent residential relocation based on disaster risk criteria and sub-criteria, including earthquakes, floods, landslides, tsunamis, liquefaction, aircraft trajectories, and high voltage currents. Disaster risk analysis, which constitutes assessing the risk level of each disaster that could affect the relocation area, and the impact of related technical factors. Recommendation development based on the evaluation and analysis results, aiming to increase resilience and mitigate risks in the permanent residential relocation.

II. RESEARCH METHODS

A. *Research Objectives*

The disaster risks were assessed and analyzed at Huntap locations, Tondo 1, Tondo 2, Talise, Petobo, Duyu, Balaroa, Loli Dondo, Tasiburi, Ganti, Wani, Lampio, Tompe, Lende, and Pombewe, while appropriate mitigation recommendations based on the risk analysis results are provided.

- Literature review: Secondary data were collected and analyzed from previous research and related disaster reports. Relevant risk criteria, such as landslides, earthquakes, floods, liquefaction, and flight paths, were identified.
- Data collection: Direct observations and interviews with the residents were carried out for the collection of data about the physical and environmental conditions in each location.
- Geospatial documentation: Maps and geospatial data were analyzed to support risk identification at each location.
- Risk analysis: The AS/NZS ISO 31000 method was deployed to assess risk on a scale from 1 to 25. Risks were classified by category at each location, with results having been documented as either unacceptable (scores 20-25) or undesirable (scores 9-16).

Table II shows the risk value based on the possibility for it to occur and its resulting impact. The impact is divided into the very light, light, moderate, heavy, and very heavy categories, and the occurrence possibility into sure to happen, almost inevitable, possible, nearly unlike, very unlikely categories [20]. AS/NZS ISO 31000 serves as a vital international standard for risk management, offering robust principles and frameworks to help organizations tackle various risks, including but not limited to disaster risks. One of its benefits is the establishment of a comprehensive approach to organizational risk management, leading to more thorough risk assessments. Another one is the adaptability to diverse organizations and contexts, promoting effective and widespread implementation. Also, it delivers precise guidance for understanding risk-related decisions, enhancing organizational responsiveness. Finally, it fosters improved stakeholder communication, expediting collaboration, and proactive risk management [20]. The Disaster Risk Calculation Method (DRCM) is given by:

$$\mathrm{DR} = \mathrm{H} \times [\frac{\mathrm{V}}{\mathrm{C}} - \mathrm{M}] \quad (1)$$

TABLE II. RISK VALUE MATRIX [20]

Risk category		Impact				
		very light	light	moderate	heavy	very heavy
Probability	about to happen	5	10	15	20	25
	almost inevitable	4	8	12	16	20
	possible	3	6	9	12	15
	nearly unlike	2	4	6	8	10
	very unlikely	1	2	3	4	5

TABLE III. CRITERIA AND SUBCRITERIA

Criteria	Sub criteria	Source
Landslide	drainage condition	[22, 23]
	overload	[23]
	land used	[22, 23]
	slope gradient	[22-24]
	soil density	[23, 24]
	soil shear strength	[22, 24]
	high rainfall	[22, 23]
	earthquake	[22, 23]
Earthquake	affected area	[25]
	earthquake-prone area	[25]
	located on the seismic zone	[25]
	probability of exceedance 2% years	[26]
	located on the fault line	[26]
Tsunami	shallow focus earthquake	[27]
	plate dip angle	[28]
	fault type (normal/reverse fault)	[27]
	epicenters in the ocean	[28, 29]
	coastal characteristics	[27], [28]
Liquefaction	liquefaction occurrence probability	[30]
	groundwater depth < 10 m	[31, 32]
	sand thickness < 12 m	[31]
	surface earthquake acceleration	[31-33]
	soil density	[32]
Flood	land cover	[34]
	drainage conditions	[34]
	overload	[23]
	erosion	[34]
	slope gradient	[34]
	soil density	[23]
	soil shear strength	[23]
	high rainfall	[23, 34]

DRCM provides a quantitative means to evaluate disaster risk by considering critical elements, such as Hazard (H), Value (V), Capacity (C), and Mitigation (M), with its advantages being described below. Tangible data are reduced to support informed, data-driven decision-making. This facilitates the assessment of a disaster's potential impact through relevant parameters, allowing for strategic mitigation planning. The most vulnerable areas are identified, and the need for enhanced mitigation efforts is accurately assessed [4]. 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. This literature review evaluates various sources related to criteria and sub-criteria for disaster risks. The reviewed literature includes previous research, technical guidelines, and documents discussing disaster risk assessment at settlement sites. The criteria and sub-criteria used in this study are detailed in Table III.

B. Data Analysis Methods

This research uses quantitative and qualitative approaches to evaluate disaster risk using scale-based analysis methods. Descriptive statistical data analysis was carried out by calculating frequencies, averages, and percentages for the risk categories at each location. Next, qualitative analysis was performed having developed a narrative explaining the results, including risk implications for community safety and permanent residential infrastructure.

III. ANALYSIS

Table IV depicts the risk analysis in Palu city. It can be concluded that each location faces significant risks and requires serious attention.

TABLE IV. MATRIX FOR DISASTER RISK ANALYSIS FOR RELOCATION IN PALU CITY

Criteria	Sub-Criteria	Tondo		Tondo 2		Talise		Petobo		Duyu		Balaroa	
		Risk Value	Risk Category	Risk Value	Risk Category	Risk Value	Risk Category	Risk Value	Risk Category	Risk Value	Risk Category	Risk Value	Risk Category
Landslide	drainage conditions	9	moderate	12	heavy	2	very light	9	moderate	12	heavy	9	moderate
	overload conditions	9	moderate	15	heavy	15	heavy	12	heavy	15	heavy	15	heavy
	land cover	9	moderate	12	heavy	9	moderate	12	heavy	12	heavy	12	heavy
	slope gradient	6	moderate	12	heavy	12	heavy	9	moderate	9	moderate	9	moderate
	soil density	8	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	soil shear strength	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy
	high rainfall	9	moderate	16	heavy	16	heavy	12	heavy	16	heavy	12	heavy
	magnitude of the earthquake	9	moderate	9	moderate	3	very light	9	moderate	6	moderate	12	heavy
Earthquake	affected area	9	moderate	9	moderate	9	moderate	9	moderate	15	heavy	9	moderate
	earthquake risk zone	9	moderate	9	moderate	9	moderate	9	moderate	15	heavy	9	moderate
	situated in a seismic zone	16	heavy	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	probability of exceedance 2% years	12	heavy	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	situated directly on a fault line	16	heavy	9	moderate	12	heavy	12	heavy	16	heavy	12	heavy
Liquefaction	probability of liquefaction events	0		3	very light	0		8	moderate	4	moderate	9	moderate
	depth of groundwater level < 10 m	0		0		1	very light	12	heavy	6	moderate	9	moderate
	sand soil thickness < 12 m	0		3	very light	2	very light	9	moderate	4	moderate	9	moderate
	surface earthquake acceleration	0		3	very light	6	moderate	12	heavy	9	moderate	9	moderate
	soil density	0		6	moderate	6	moderate	9	moderate	6	moderate	9	moderate
Flood	lowland area	20	very heavy	20	very heavy	20	very heavy	20	very heavy	16	heavy	20	very heavy
	availability of drainage facilities	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy
	river border area	6	moderate	15	heavy	9	moderate	15	heavy	15	heavy	15	Berat
	flood-prone areas post	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	catchment area	6	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	erosion and sedimentation occur	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	degree of surface slope	9	moderate	6	moderate	6	moderate	9	moderate	6	moderate	9	moderate
	there was high rainfall	12	heavy	3	very light	12	heavy	9	moderate	12	heavy	9	moderate
Flight path	15 km radius with a max height of 150 m	20	very heavy	20	very heavy	16	heavy	16	heavy	16	heavy	20	very heavy
	13 km radius with a max height of 130 m	16	heavy	16	heavy	16	heavy	16	heavy	16	heavy	16	heavy
	12 km radius with a max height of 110 m.	9	moderate	9	moderate	16	heavy	16	heavy	9	moderate	9	moderate
	8 km radius with a max height of 90 m	9	moderate	9	moderate	16	heavy	16	heavy	0		0	
High voltage currents	66 kV hvt transmission line tower."	0		12	heavy	12	heavy	15	heavy	0		0	

TABLE V. MATRIX FOR DISASTER RISK ANALYSIS FOR RELOCATION IN DONGGALA REGENCY

Criteria	Sub-Criteria	Wani		Loli Dondo		Loli Tasiburi		Ganti		Lampio		Lende	
		Risk Value	Risk Category	Risk Value	Risk Category	Risk Value	Risk Category	Risk Value	Risk Category	Risk Value	Risk Category	Risk Value	Risk Category
Landslide	drainage conditions	9	moderate	9	moderate	9	moderate	9	moderate	12	heavy	9	moderate
	overload conditions	15	heavy	12	heavy	15	heavy	12	heavy	15	heavy	15	heavy
	land cover	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy
	slope gradient	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	soil density	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	soil shear strength	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy
	high rainfall	12	heavy	12	heavy	16	heavy	12	heavy	12	heavy	12	heavy
	magnitude of the earthquake	12	heavy	12	heavy	8	moderate	12	heavy	12	heavy	12	heavy
Earthquake	affected area	15	heavy	15	heavy	15	heavy	15	heavy	15	heavy	15	heavy
	earthquake risk zone	15	heavy	15	heavy	15	heavy	15	heavy	15	heavy	15	heavy
	situated in a seismic zone	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	2% probability of exceedance within 50 years	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	situated directly on a fault line	16	heavy	16	heavy	16	heavy	16	heavy	16	heavy	16	heavy
Tsunami	a shallow-focus earthquake	0		15	heavy	15	heavy	0		20	very heavy	20	very heavy
	dip angle of the plate	0		12	heavy	12	heavy	0		16	heavy	12	heavy
	upthrown fault / downthrown fault	0		9	moderate	9	moderate	0		20	very heavy	9	moderate
	the earthquake's epicenter was located in the middle of the ocean	0		9	moderate	9	moderate	0		20	very heavy	9	moderate
	physical characteristics of the beach	0		3	very light	9	moderate	0		20	very heavy	9	moderate
Liquefaction	depth of groundwater level < 10 m	12	heavy	12	heavy	12	heavy	8	moderate	12	heavy	12	heavy
	sand soil thickness < 12 m	9	moderate	9	moderate	9	moderate	15	heavy	9	moderate	9	moderate
	surface earthquake acceleration	9	moderate	9	moderate	9	moderate	15	heavy	9	moderate	9	moderate
	soil density	3	very light	3	very light	9	moderate	15	heavy	9	moderate	3	very light
Flood	lowland area	15	heavy	20	very heavy	20	very heavy	20	very heavy	20	very heavy	20	very heavy
	availability of drainage facilities	12	heavy	12	heavy	12	heavy	16	heavy	12	Berat	12	heavy
	river border area	15	heavy	15	heavy	15	heavy	15	heavy	20	very heavy	15	heavy
	Flood-prone areas post	9	moderate	9	moderate	12	heavy	12	heavy	9	moderate	12	heavy
	catchment area	6	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	erosion and sedimentation occur	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	degree of surface slope	9	moderate	9	moderate	6	moderate	9	moderate	9	moderate	6	moderate
	there was high rainfall	16	heavy	12	heavy	12	heavy	12	heavy	16	heavy	12	heavy
High voltage currents	66 kV high voltage transmission line tower	0		12	heavy	12	heavy	15	heavy	0		0	

- Severe risk (scale 20-25): This category includes various main criteria, such as floods, earthquakes, landslides, flight paths, and high-voltage currents. These risks are categorized as unacceptable, indicating the need for immediate mitigation measures to reduce potential impacts. Locations, such as Huntap Tondo 1, Tondo 2, Talise, Petobo, Duyu, and Balaroa, face the severe risks of earthquakes, floods, and landslides that require immediate intervention.
- Moderate risk (scale 9-16): This category entails various criteria that still require attention, namely landslides, earthquakes, floods, liquefaction, and flight paths. These risks are categorized as undesirable, requiring further mitigation measures to be reduced. Additional attention is needed to prevent increased risk possibility and an even more serious impact in the future.

Overall, these sites require targeted and immediate mitigation measures, especially for severe risks that could significantly influence the safety and sustainability of permanent relocation. Table V illustrates the risk analysis in several residential areas of the Donggala regency. The following are general conclusions drawn regarding the risks faced:

- Severe risk: Almost all locations face serious risks, especially based on the criteria of earthquakes, floods, and, in some cases, tsunamis. Sub-criteria, such as earthquake-prone areas, areas affected by earthquakes, and land cover in the flood category are often included in the unacceptable scale. This condition requires immediate mitigation measures to reduce the potential impact of possible future disasters.

- Moderate risks: This was found in almost all locations, including the criteria for landslides, earthquakes, floods, liquefaction, and tsunamis. Although this category is on the undesirable scale, the risk remains significant and requires special attention for further mitigation. A more intensive mitigation strategy is needed so that the impact of this risk can be minimized effectively.

In conclusion, each location requires special attention concerning the severe and moderate risks encountered, and implementing appropriate mitigation measures to ensure the shelter's safety and sustainability, as can be seen in Table V. Table VI exhibits that Huntap Pombewe, Salua, and Lambara face significant risks:

- Severe, unacceptable, risks: In Huntap Pombewe, severe risks are found in the criteria for earthquakes (sub-criteria for earthquake prone areas and areas affected by earthquake effects) and flooding (sub-criteria for land cover and excessive load). Similar risks were detected in Huntap Salua and Lambara, where the sub-criteria of earthquakes, landslides (overload), and flooding fall into the unacceptable category, indicating severe safety threats and requiring immediate mitigation measures.
- Moderate, undesirable, risk: At the third location, moderate risk was identified in the landslides, earthquakes, floods, and liquefaction criteria. Even though it is included in the undesirable category, this risk type still requires attention for potential losses and negative impact on residents to be reduced.

TABLE VI. DISASTER RISK ANALYSIS MATRIX FOR RELOCATION IN DONGGALA REGENCY AND SIGI REGENCY

Criteria	**Sub-Criteria**	**Tanjung Pandang**		**Tompe**		**Pombewe**		**Lambara**		**Salua**	
		Risk Value	**Risk Category**	**Risk Value**	**Risk Category**	**Risk Value**	**Risk Category**	**Risk Value**	**Risk Category**	**Risk Value**	**Risk Category**
Landslide	drainage conditions	9	moderate	12	heavy	9	moderate	6	moderate	9	moderate
	overload conditions	20	very heavy	12	heavy	15	heavy	9	moderate	9	moderate
	land cover	12	heavy	12	heavy	12	heavy	9	moderate	9	moderate
	slope gradient	9	moderate	9	moderate	9	moderate	9	moderate	12	heavy
	soil density	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	soil shear strength	12	heavy	16	heavy	12	heavy	12	heavy	12	heavy
	high rainfall	16	heavy	16	heavy	12	heavy	16	heavy	12	heavy
	magnitude of the earthquake	4	moderate	12	heavy	6	moderate	12	heavy	12	heavy
Earthquake	affected area	15	heavy	15	heavy	15	heavy	9	moderate	15	heavy
	earthquake risk zone	15	heavy	15	heavy	15	heavy	9	moderate	15	heavy
	situated in a seismic zone	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	2% probability of exceedance within 50 years	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	situated directly on a fault line	12	heavy	16	heavy	12	heavy	12	heavy	12	heavy
Tsunami	a shallow-focus earthquake	20	very heavy	16	heavy	0		0		0	
	dip angle of the plate	12	heavy	16	heavy	0		0		0	
	upthrown fault / downthrown fault	9	moderate	16	heavy	0		0		0	
	the earthquake's epicenter was located in the middle of the ocean	9	moderate	16	heavy	0		0		0	
	physical characteristics of the beach	16	heavy	16	heavy	0		0		0	
Liquefaction	probability of liquefaction events	10	heavy	15	heavy	2	very light	9	moderate	3	very light
	depth of groundwater level < 10 m	8	moderate	12	heavy	2	very light	9	moderate	6	moderate
	sand soil thickness < 12 m	8	moderate	9	moderate	2	very light	9	moderate	6	moderate
	surface earthquake acceleration	12	heavy	9	moderate	6	moderate	9	moderate	9	moderate
	soil density	12	heavy	3	very light	2	very light	9	moderate	6	moderate
Flood	lowland area	20	very heavy	20	very heavy	20	very heavy	20	very heavy	20	very heavy
	availability of drainage facilities	12	heavy	12	heavy	12	heavy	12	heavy	12	heavy
	river border area	15	heavy	15	heavy	15	heavy	9	moderate	12	heavy
	Flood-prone areas post	12	heavy	12	heavy	9	moderate	9	moderate	12	heavy
	catchment area	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	erosion and sedimentation occur	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	degree of surface slope	9	moderate	9	moderate	9	moderate	9	moderate	9	moderate
	there was high rainfall	12	heavy	20	very heavy	12	heavy	12	heavy	12	heavy
High voltage currents	66 kV high voltage transmission line tower	0		12	heavy	12	heavy	12	heavy	0	

IV. CONCLUSION AND RECOMMENDATIONS

The current research was conducted using the risk assessment method outlined in AS/NZS: ISO 31000 identifying 45 disaster risk sub-criteria across seven main criteria. The prioritized main criteria are flood, landslide, tsunami, earthquake, liquefaction, high current voltage, and aircraft trajectory. The ten highest-ranked sub-criteria address various risk factors, including floods, tsunamis, landslides, earthquakes, and liquefaction. Sub-criteria related to aircraft trajectories and high voltage currents are out of the top ten priorities.

- Assessing vulnerability conditions: This research assessed vulnerability conditions at permanent housing relocation sites following the September 28, 2018, disaster near the Palu Koro fault line. The analysis revealed that several locations face significant risks from potential disasters, including earthquakes, floods, landslides, and liquefaction. Most locations fall into the unacceptable and undesirable risk categories, indicating a pressing need for attention to be given to these vulnerabilities.
- Evaluation of technical aspects: An evaluation of technical aspects based on disaster risk criteria indicates that earthquakes in prone areas, floods resulting from land cover changes, and landslides due to excessive loads present the most significant risks that must be managed. Additionally, flight path and high voltage current risks require further evaluation to ensure the safety and viability of permanent residences.
- Disaster risk analysis: Utilizing the AS/NZS: ISO 31000 method, the disaster risk analysis shows that several relocation sites face severe risks categorized as unacceptable, particularly concerning earthquakes, floods, and landslides. These risks necessitate immediate mitigation measures. Moreover, moderate risks categorized as undesirable also require additional mitigation efforts to reduce future impacts.

The recommended immediate mitigation actions are:

- Strengthening of building structures: It is needed to construct earthquake-resistant buildings according to standards to reduce earthquake risk and protect buildings from potential landslides in vulnerable areas.
- Improvement of drainage systems: It is recommended to repair and upgrade existing drainage systems to reduce flood risks, with a focus on managing land cover and preventing system overload in vulnerable areas.
- Soil assessment and strengthening: A thorough assessment of landslide risk must be conducted and soil strengthening techniques must be applied to mitigate the risk of liquefaction, which can affect soil stability.
- Community education and training: Comprehensive training on disaster risk, including practical mitigation strategies, should be provided to enhance community preparedness and ensure safety in disaster-prone areas.

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