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Prioritizing Disaster Risks for Post-Disaster Permanent Housing Relocation in Palu, Indonesia: An Analytic Hierarchy Process (AHP) Approach

Andi Asnudin[1]*, Amar Akbar Ali[2], Tutang Muhtar Kamaludin[3], Andi Rizal[4], William Arrang Sarungallo[5]
[1-5]Tadulako University, Palu, Central Sulawesi

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ABSTRACT

This study employs the Analytic Hierarchy Process (AHP) to conduct a technical evaluation of disaster risk in the selection of sites for Permanent Housing (HUNTAP) for survivors of the 2018 earthquake, tsunami, and liquefaction disaster in Palu, Central Sulawesi. The analysis integrates five main disaster criteria (floods, landslides, tsunamis, earthquakes, and liquefaction) and 31 sub-criteria compiled from literature and expert judgment. The AHP results show that flood risk is the dominant factor in relocation decisions (relative weight 47.07%), followed by landslides (23.85%), tsunamis (12.52%), earthquakes (11.19%), and liquefaction (5.38%). Key sub-criteria such as lowland areas, river border zones, and drainage conditions are the most significant flood risk indicators. This research provides a structured, multi-criteria decision-making framework to ensure that post-disaster relocation prioritizes the most critical hazards, thereby enhancing the safety and sustainability of settlements in complex disaster-prone regions like Palu. The findings recommend targeted, risk-based mitigation strategies for each hazard priority.

Corresponding Author:

Andi Asnudin
Tadulako University, Palu, Central Sulawesi
Email: a.asnudin@gmail.com

INTRODUCTION

The Palu-Koro Fault, identified in the early 20th century, is the main source of notable seismic activity in the Palu region. On September 28, 2018, a magnitude 7.7 earthquake originating from this fault triggered a catastrophic series of events, including a tsunami and extensive liquefaction (Dwiantoro, Robert 2023); (Asnudin, A, Ali, A. A, and Muhtar, T. 2024). The disaster caused significant damage to infrastructure and settlements in Palu City, Donggala Regency, and Sigi Regency. In response, the Indonesian government launched a large-scale initiative to construct Permanent Housing (HUNTAP) in safer locations, which involved both in-situ development and relocation to satellite areas (BMKG 2018).

However, post-construction realities have revealed significant challenges. For instance, in December 2023, HUNTAP Tondo 1 experienced severe flooding due to inadequate drainage capacity, a problem repeated in HUNTAP Tondo 2 in August 2024. These incidents underscore that merely relocating settlements to so-called safe zones is insufficient. A robust, technically-grounded assessment integrating multiple disaster risks is crucial. While studies on post-disaster relocation have addressed aspects such as community participation, management, and design, a significant research gap persists. There needs to be a comprehensive, quantitative framework that integrates and prioritizes multi-hazard risk criteria for relocation site selection, particularly in a multi-threat environment like Palu. Standards such as the Indonesian National Standard (SNI) and BNPB risk maps provide criteria but do not offer a method to weigh their relative importance in a specific local context. This study aims to fill this gap. We pose the central research question: What are the relative priorities of different disaster risks (floods, landslides, tsunamis, earthquakes, liquefaction) and their specific sub-criteria in determining safe locations for permanent housing relocation in Palu? Using the Analytic Hierarchy Process (AHP), this research synthesizes expert judgment to create a weighted, hierarchical model of disaster risk. The objective is to provide a scientifically derived decision-support tool that ensures relocation planning is based on a transparent and accurate assessment of the most critical hazards, moving beyond intuition toward evidence-based planning.

Research on post-disaster housing relocation has been extensively conducted in various countries, including Indonesia, focusing on critical aspects such as survivor participation, management, design and planning, construction workforce competence, accessibility, and disaster risk assessment. Here is a summary of findings from several significant studies:

Community Participation: Research conducted in Turkey by Dikmen and Nese (2007) and Oliver-Smith (1991) reveals that survivor participation in selecting relocation sites is often limited, with their livelihoods frequently overlooked. Similar findings were observed in India and Sri Lanka, where research by Sangasumana, Pinnawala (2019) highlighted survivors' lack of active involvement in the relocation process, leading to relocations that were poorly aligned with local needs and conditions. On the other hand, Japan has developed disaster mitigation training programs for high school students to enhance their understanding of how disasters directly affect their daily lives (Kimura, R. and Aikawa, K. 2024).

Management Aspects: Research indicates that post-disaster relocation management needs improvement. Studies by Bilau, Witt, and Lill (2015) and Mukherji (2017) reveal several areas for improvement in managing relocation efforts, including suboptimal planning, execution, and monitoring. In Indonesia, various recommendations have been proposed to enhance the effectiveness of relocation processes. One critical approach is to improve the skills of construction workers and survivors through comprehensive training and socialization on seismic-resistant building guidelines and standards. This approach has been partially implemented following major disasters, such as Aceh in 2004, Yogyakarta in 2006, West Java in 2009, and West Sumatra in 2009. These initiatives aim to address the shortcomings observed in previous disaster responses by strengthening both technical and managerial aspects of post-disaster recovery (Pribadi et al., 2014).

Design and Planning: Research on relocation design and planning highlights the importance of ensuring accessibility and developing adequate infrastructure. Studies by Tan, Waters, and Arcaya (2022) and Mukherji (2017) emphasize the necessity of carefully planned transportation networks, while (Tan, Waters, and Arcaya 2022) and (Di Gregorio and Soares 2017) focus on the need for optimal physical infrastructure to effectively meet the needs of survivors. (Di Gregorio and Soares 2017) advocates for incorporating psychosocial recovery, social capital, livelihoods, and settlement governance into the planning process. Additionally, (Wijegunarathna et al. 2018) point out the importance of flexibility in planning to accommodate future modifications, including changes to house layouts, room configurations, lighting, and ventilation.

Construction Workforce Competence: In Indonesia, there is a need to enhance construction workers' competence in post-disaster reconstruction and relocation through training and socialization on seismic-resistant building standards (Pribadi et al., 2014).

Accessibility: Research underscores that accessibility is a critical component of relocation planning. This includes designing effective transportation systems and building adequate infrastructure to support the mobility of both survivors and residents (Tan, Waters, and Arcaya 2022).

Disaster Risk: In Japan, extensive interdisciplinary research has been conducted to develop disaster mitigation programs that draw on insights from the sciences, engineering, humanities, and social sciences (Kimura, R. et al., 2020). Similarly, a study on post-Typhoon Haiyan relocations in the Philippines by Bodine, Tracy, and Javernick-Will (2022) highlights the crucial need to integrate disaster risk factors into the planning process to reduce future hazards. However, there remains a significant lack of detailed research on the specific criteria and sub-criteria for assessing disaster risk in future permanent housing relocations.

LITERATURE REVIEW & CRITERIA DEVELOPMENT

Research on post-disaster housing spans a range of critical domains. Studies in Turkey, India, and Sri Lanka highlight the frequent oversight of survivor participation and livelihood needs in relocation planning. In contrast, Japan emphasizes integrated disaster education. Management research points to consistent shortcomings in the planning, execution, and monitoring of relocation projects. In the Indonesian context, training for construction workers on seismic-resistant standards has been a key focus after major earthquakes.

Concerning site-specific risks, although there are studies on individual hazards, an integrated approach is missing. For example, research on tsunami formation primarily examines seismic parameters, while flood risk studies concentrate on hydrology and land cover. There is a lack of a comprehensive synthesis to inform relocation planning. This study aims to consolidate established risk parameters from previous research, technical guidelines, and government documents to create a holistic set of criteria. Based on this synthesis, the study defines five main criteria and 31 sub-criteria, as detailed in Table 1.

Table 1. Disaster Risk Criteria and Sub-criteria for Relocation Site Assessment

Criteria	Sub-criteria (Indicators)	Key Sources
Landslide	Drainage Condition, Overload, Land Use, Slope Gradient, Soil Density, Soil Shear Strength, High Rainfall, Earthquake Magnitude	(Somantri, Lili 2008), (BPBD Kabupaten Bogor 2022), (Apriyono, Arwan 2009)
Earthquake	Affected Area, Earthquake Prone Area, Located on Seismic Zone, Probability of Exceedance (2% in 50 yrs), Located on Fault Line	(BMKG 2021), (Kementerian PUPR 2017)
Tsunami	Shallow Focus Earthquake (<33 km, >6 M), Plate Dip Angle, Fault Type (Normal/Reverse), Epicenter in the Ocean, Coastal Characteristics	(Prawiradisastra, Suryana 2011), (AP. Sutowijoyo 2005), (Marwanta, Bambang 2005), (Sudarmono 2005)
Liquefaction	Liquefaction Occurrence Probability, Groundwater Depth < 10 m, Sand Thickness < 12 m, Surface Earthquake Acceleration, Soil Density	(Putri,Maya Efiarni Eka, Siregar,Rahmat Nawi, and Singarimbun, Alamta 2021), (Suciati, Yudiantoro, and Purwanto 2022), (Farid, Akmal 2021)
Flood	Lowland Area, Drainage Conditions, River Border Area, Flood Prone Areas, Catchment Area, Erosion, Slope Gradient, High Rainfall	(BPBD Kabupaten Bogor 2022), (Farid, Akmal 2021), (Isnanto, Bayu Ardi 2023)

RESEARCH METHODS

Study Location and Data Collection

The study examines 18 HUNTAP locations, which encompass approximately 6,097 housing units, situated in Palu City, Sigi Regency, and Donggala Regency. Data collection involved structured interviews and questionnaires administered to a panel of experts, including a structural engineer, a settlement area specialist, a hydrologist, and a geotechnical expert. Additionally, input was gathered from two representatives of technical government agencies and three service providers who are involved in the planning and construction of HUNTAP.

Analytical Method: The Analytic Hierarchy Process (AHP)

To translate expert preferences into measurable priority weights, this study adopted the Analytic Hierarchy Process (AHP) developed by Saaty. This methodology was executed through a series of systematic steps. First, a decision hierarchy was constructed with safe relocation at the top, the five disaster criteria at the intermediate level, and the 31 sub-criteria at the bottom. Second, experts performed pairwise comparisons of all criteria and sub-criteria using a standard 1-9 importance scale. Third, eigenvalues were calculated to derive local and global priority weights for each element. Finally, a Consistency Ratio (CR) was calculated for each matrix; a $CR \leq 0.10$ was accepted as an indicator of logical consistency in the expert judgments, thereby validating the reliability of the results.

The AHP method by Saaty was used to weigh and prioritize the criteria. The steps were as follows (Saaty, T. L. 1980):

Hierarchy Construction: A decision hierarchy was built with the goal (safe relocation) at the top, the five disaster criteria in the middle, and the 31 sub-criteria at the bottom.

Pairwise Comparison Matrices: Experts performed pairwise comparisons for criteria and sub-criteria using a standard 1-9 scale of importance.

Priority Weight Calculation: Eigenvalues were calculated to derive local and global priority weights for each element.

Consistency Check: The Consistency Ratio (CR) was calculated for each matrix. A CR value of ≤ 0.10 was deemed acceptable, indicating reliable and consistent judgments.

Study Location and Data Collection

To enhance validity, data from expert surveys were cross-verified with field observations from the HUNTAP sites and relevant technical documents, ensuring the analysis reflected on-the-ground conditions.

RESULTS AND DISCUSSION

The pairwise comparison and normalization processes yielded the priority weights for all criteria and sub-criteria. The Consistency Ratios for all matrices were below 0.10, confirming the consistency of expert judgments.

Table 2. Priority Weights and Ranking of Main Disaster Criteria

Criteria	Relative Weight	Priority Rank
Flood	0.4707 (47.07%)	1
Landslide	0.2385 (23.85%)	2
Tsunami	0.1252 (12.52%)	3
Earthquake	0.1119 (11.19%)	4
Liquefaction	0.0538 (5.38%)	5

The pairwise comparison and normalization processes in the AHP method successfully produced quantified priority weights for all disaster criteria and sub-criteria. This was accomplished through expert judgments that assessed the relative importance of each element, systematically converting qualitative evaluations into quantitative weights. Importantly, all comparison matrices achieved Consistency Ratios (CR) below the threshold of 0.10. Meeting this standard statistically confirms that the expert judgments were consistent and logically coherent, thereby validating the reliability of the derived weights and ensuring they are free from significant contradictions.

The synthesized AHP results, summarized in Table 2, reveal a clear hierarchy of disaster risk priorities for permanent housing relocation in Palu. Flood emerged as the dominant factor, accounting for 47.07% of the relative weight, making it the most critical consideration. Landslide ranked second with a weight of 23.85%, followed by tsunami (12.52%) and earthquake (11.19%). Liquefaction received the lowest priority weight of 5.38%. This distribution of weights provides an objective guide, indicating that mitigation efforts and site selection must proportionally prioritize flood and landslide risk management while still integrating considerations for other threats. This finding shifts the paradigm from a generalized approach to an evidence-based strategy, enabling resources to be allocated more effectively according to the urgency of each specific hazard.

The global priority ranking of the top 10 sub-criteria (out of 31) is presented in Table 3, highlighting the most influential factors in site selection (Table 3).

The AHP results provide a clear, quantitative hierarchy of disaster risks for HUNTAP relocation in Palu. The dominance of flood risk (47% weight) is the most critical finding. This aligns directly with the recent flooding incidents in HUNTAP Tondo, confirming that the flood hazard was underestimated in the initial site selection. The top-ranked sub-criteria—Lowland Area and River Border Area—are precisely the conditions present in several problematic HUNTAP sites. This indicates that a priori application of this AHP model could have flagged these locations as high-risk.

Landslide risk ranking second underscores the importance of slope stability in Palu's rugged topography. The high priority of Overload Conditions suggests that planning must strictly control building density and foundation design on hillsides.

The relatively lower weight for tsunami risk compared to floods does not diminish its lethality but reflects a spatial limitation: it only applies to coastal HUNTAP sites. For those specific sites, the sub-criterion Shallow Focus Earthquake becomes the paramount concern for early warning and evacuation planning.

Table 3. Top 10 Global Priority Sub-criteria for Relocation Site Assessment

Global Rank	Sub-criteria	Parent Criteria	Global Weight	Key Implication for Site Selection
1	Lowland Area	Flood	0.148	Avoid sites in topographically depressed zones prone to water accumulation.
2	River Border Area	Flood	0.099	Maintain a mandatory safe buffer distance from active river channels.
3	Drainage Conditions	Flood	0.067	Sites must have or be able to support engineered drainage networks capable of handling extreme rainfall.
4	Overload Conditions	Landslide	0.067	Avoid excessive construction load on slopes; enforce building density regulations on hillsides.
5	Shallow Focus Earthquake	Tsunami	0.059	For coastal sites, seismic sources near the coast with specific magnitude/depth parameters are the primary tsunami trigger.
6	Affected Area	Earthquake	0.053	Consider the spatial footprint of potential strong ground shaking.
7	Post-Disaster Flood Prone Area	Flood	0.052	Heed historical and recent post-disaster flood data, as landscape changes (e.g., liquefaction) can create new floodplains.
8	Soil Shear Strength	Landslide	0.044	Conduct thorough geotechnical investigations to assess slope stability.
9	Catchment Area	Flood	0.041	Assess the upstream water catchment area draining towards a potential site.
10	High Rainfall	Landslide	0.035	Account for local rainfall intensity as a direct trigger for slope instability.

The low priority for liquefaction is a notable result. This may stem from expert perception that its effects are highly localized and can be mitigated through ground improvement techniques at the building foundation level, making it a manageable geotechnical challenge rather than a dominant site-selection factor. Conversely, floods and landslides are perceived as more pervasive and difficult to control through structural measures alone.

Methodological Contribution and Implications: This study demonstrates that AHP is a powerful tool to translate complex, multi-hazard risk landscapes into a structured decision-making framework. It moves beyond qualitative checklists by assigning explicit weights, enabling planners to allocate resources to mitigating the most significant risks. The derived hierarchy can serve as a template for developing scoring systems for future potential relocation sites.

Limitations: This study's findings are based on the judgments of a specific panel of technical experts. While consistent, they do not incorporate community risk perception or socio-economic criteria, which are vital for holistic, sustainable relocation. Future research should integrate these aspects into a broader Multi-Criteria Decision Analysis (MCDA) framework.

CONCLUSION

This study successfully developed and applied an Analytical Hierarchy Process (AHP) model to prioritize disaster risks associated with permanent housing relocation in Palu. It conclusively identifies flood risk as the most critical factor, followed by landslides, tsunamis, earthquakes, and liquefaction. The prioritized list of 31 sub-criteria offers a detailed technical checklist for evaluating potential relocation sites.

Based on these findings, the following evidence-based, operational recommendations are proposed:

For Flood Mitigation (Highest Priority):

1) Zoning Regulation: Development of HUNTAP in areas identified as Lowland Areas or within a designated River Border Area buffer zone is prohibited, or should proceed with extreme caution.
2) Mandatory Drainage Master Plan: A detailed, climate-resilient drainage master plan is required for every HUNTAP cluster, with capacities calculated based on projections for extreme rainfall. Natural water channels must be preserved and integrated into the plan.
3) Land-Use Planning: Upstream catchment areas should be designated as protected zones to help reduce the velocity and volume of surface runoff.

For Landslide Mitigation:

1) Slope Density Control: Enforce strict limits on building density and load for structures on sloping terrain, based on geotechnical reports.
2) Slope Stabilization: Implement mandatory engineering measures, such as retaining structures and soil nailing, for HUNTAP developments built on moderate to steep slopes.
3) Vegetative Cover: Require robust vegetative cover on slopes above HUNTAP sites and ensure its maintenance to reduce erosion.

For Tsunami Mitigation (for coastal sites):

1) Defense-in-Depth Strategy: Implement a combination of natural buffers, such as mangrove restoration, and structural barriers, such as seawalls and dykes where appropriate, as well as mandatory vertical evacuation structures for areas affected by HUNTAP. These should be located in zones where horizontal evacuation is not feasible within the expected arrival time of the tsunami.
2) Community Preparedness: Establish clear evacuation routes and conduct regular drills focused on the threats identified by the Shallow Focus Earthquake parameter.

For Earthquake and Liquefaction: 1. Building Code Enforcement: Ensure strict adherence to seismic building codes for all structures. For micro-zones within a site that are prone to liquefaction, mandate ground improvement techniques (e.g., compaction, stone columns) as part of the site development costs.

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