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IMPROVING SUSTAINABILITY AND REDUCING DISASTER RISK THROUGH MAPPING POTENTIAL LAND FOR COMMUNITY RELOCATION IN BANDA ACEH

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Abstract

Banda Aceh's history of recurrent disasters highlights the urgency of prevention, mitigation, and strategic relocation planning. This study identifies potential relocation sites for communities affected by disasters based on sustainable site selection criteria. A GIS-based Multi-Criteria Decision Analysis (MCDA) is employed, incorporating seven criteria: safe zones from disasters, land use, sufficient area, land slope, soil type, and accessibility to various service facilities and infrastructure. The analysis focuses on peri-urban areas of Banda Aceh within Aceh Besar Regency. The GIS-based MCDA categorizes relocation sites into five suitability levels: very high suitability, high suitability, moderate, low suitability, and very low suitability. The findings suggest that highly suitable relocation sites cover a total area of 256,37 hectares, including eight villages in Darul Kamal and Darul Imarah districts. This study contributes to disaster mitigation literature by offering a scientifically grounded and socially inclusive framework for residential relocation planning in Banda Aceh.

Keywords: Community relocation, Disaster risk, Mapping, Potential land, Sustainability

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INTRODUCTION

According to the United Nations Environment Programme (UNEP), Asia accounted for 40% of global natural disasters between 2005 and 2014 (UNEP, 2015). Events such as the 2004 Indian Ocean earthquake and tsunami, which affected 14 countries and caused approximately 227,000 deaths, illustrate the region's extreme vulnerability. Comparable impacts were seen in the Sichuan earthquake, with nearly 87,000 fatalities, and the 2011 Tohoku earthquake, which resulted in more than 15,000 deaths. More recently, the 2020 South Asian floods affected millions across India, Bangladesh, Nepal, and Pakistan. In Indonesia, the Disaster Risk Index (2022) documents frequent hazards including floods, earthquakes, tsunamis, liquefaction, strong winds, and forest fires. Banda Aceh remains one of the country's most exposed regions due to its coastal location and repeated disaster history (Indonesia Disaster Data and Information, 2022).

Disaster Risk Management (DRM) encompasses risk assessment, preparedness, response, and recovery (UNDRR, 2019). Recovery efforts extend beyond emergency relief to ensuring safe, long-term resettlement for displaced communities (Kumar, 2017). Relocation becomes essential when original settlements are severely damaged or located in high-risk zones. Consequently, resettlement planning is a key component of post-disaster recovery (Imura & Shaw, 2009; Wu & Lindell, 2004). One persistent challenge, however, is securing land that is both safe and suitable. While relocation typically occurs after disasters, pre-disaster relocation is increasingly recognised as a necessary strategy for risk reduction (Dikmen, 2013).

Appropriate site selection requires integrating spatial and social considerations. Permana et al. (2017) stress the importance of vulnerability assessment and proximity to original settlements, whereas Utami et al. (2019) highlight the need to maintain access to livelihoods and essential services. Sustainable relocation should also account for future hazards, economic opportunities, land availability, and tenure security (Imura & Shaw, 2009; Nilsson, 2010; Oliver-Smith, 1991). Yet rapid urban expansion often reduces green areas and agricultural land, exacerbating land scarcity (Wijayanti, 2012). These pressures underscore the need for sustainability-oriented approaches to prevent new socio-environmental challenges in resettlement areas.

This study identifies and maps potential relocation sites for disaster-affected communities by prioritising sustainability and risk-informed criteria. Its novelty lies in integrating environmental, social, and economic dimensions into the site selection process to ensure long-term resilience. Unlike conventional relocation strategies, which frequently overlook sustainability and lead to inadequate infrastructure and socio-economic difficulties (Sabita et al., 2024; Permana et al., 2017), this research applies a GIS-based Multi-Criteria Decision

Analysis (MCDA) using ArcGIS to provide a systematic, data-driven basis for selecting safer and more sustainable resettlement locations.

LITERATURE REVIEW

Relocation as Disaster Risk Management Effort

Disaster Risk Management (DRM) provides a structured framework for reducing disaster impacts and guiding response and recovery (UNDRR, 2019). It comprises four phases: mitigation through regulations and early warning systems (Coppola, 2015); preparedness through improved planning, communication, and drills (Alexander, 2015); response involving search and rescue and emergency medical care (Coppola, 2015); and recovery that restores infrastructure, economic activity, and social systems (Tierney, 2019). Within this framework, relocation is a key strategy for communities exposed to recurrent hazards, reducing long-term risk by moving residents from unsafe areas. Although often resisted due to emotional and economic ties (Fernando & Punchihewa, 2013), relocation becomes necessary when displacement is extensive, areas are uninhabitable, or resettlement can prevent future losses (Jha, 2010). Effective relocation requires not only rebuilt housing and infrastructure but also restored livelihoods (Comerio, 2014), and may be implemented preventively, as seen in Cukur Village, Turkey, where residents were moved away from rockfall hazards (Dikmen, 2018).

Empirical experiences show varied relocation outcomes. In Donggala, Indonesia, post-disaster resettlement after the 2018 Sulawesi earthquake and tsunami successfully moved communities to safer areas with improved infrastructure and services (World Bank, 2021). In Chiang Rai, Thailand, relocation in flood-prone areas also provided safer housing, upgraded drainage, and livelihood support, reducing future displacement risks (UNDRR, 2019). Conversely, in Tsholotsho District, Zimbabwe, limited community participation and insufficient attention to cultural and economic factors led many residents to leave designated sites (Ngulube et al., 2024). These cases highlight that sustainable relocation relies on integrated, participatory, and context-sensitive planning aligned with community needs and socio-cultural conditions.

Criteria for Selecting Potential Land for Sustainable Relocation

Literature on sustainable relocation emphasises that resettlement must not only move communities from hazardous areas but also ensure long-term socio-economic stability. Dikmen (2018) highlights that successful resettlement protects lives while avoiding new risks, shaped largely by the suitability of the receiving site. Abe et al. (2014) likewise argue that relocation success depends on adequate infrastructure, viable economic opportunities, and preserved social cohesion. Fernando and Punchihewa's (2013) study in Batticaloa, Colombo, and Galle shows how distance and site conditions influence outcomes: communities

returning to original settlements maintained stability, those relocated nearby adapted more easily, while those moved up to 15 kilometers away faced job losses and weakened networks. These patterns are consistent with Shriver and Kennedy (2005), who note that relocation often results in economic loss, social fragmentation, and disconnection from familiar environments.

Collectively, these studies indicate that effective relocation requires integrating disaster-risk reduction, economic recovery, and strong community engagement. They also highlight that site evaluation and land acquisition are central, yet often challenging, components of the process, as unsuitable locations tend to intensify livelihood disruption and weaken community ties. Based on these considerations, this study applies the following criteria to assess potential relocation sites:

Safe zones from disasters (Hazard)

Relocation land must be free from major hazards, such as landslides, floods, fires, earthquakes, and liquefaction, especially in areas with moderate to high risk (Oliver-Smith, 1991; Imura & Shaw, 2009; Nilsson, 2010; Permana et al., 2017; Few et al., 2021; Fakhri & Jumadi, 2023). Such exposure can severely damage housing and infrastructure, making hazard-free zones essential for sustainable resettlement planning.

Sufficient Area (Non-Built-up Area)

Relocation sites must provide adequate non-built-up land to accommodate resettled households, with a minimum area of 3,000 m² (Eriawan & Setiawan, 2021; Nurfikasari & Yuliani, 2021; Fakhri & Jumadi, 2023). The land must also be designated for residential use in Regional Spatial Planning and possess adequate carrying capacity for future development.

Land Slope

SNI 03-1733-2004 specifies that land with a slope greater than 15% should be avoided for settlements due to landslide risks and construction challenges. Nurfikasari and Yuliani (2021) further recommend that residential development be situated on land with slopes of less than 8%, as steeper gradients can increase hazard exposure, particularly landslides.

Soil Type

Selecting suitable soil types enhances the safety and long-term resilience of relocated communities by minimizing environmental hazards. Alluvial, Latosol, and Mediterranean soils are recommended for residential development because of their stability and suitability for construction (Permana et al., 2017; Nurfikasari & Yuliani, 2021; Fakhri & Jumadi, 2023).

Accessibility, Infrastructure Services, and Public Facility Services

SNI 03-1733-2004 identifies eight key infrastructure components and six public facility criteria for settlements, whose availability strengthens the suitability of relocation sites (Eriawan & Setiawan, 2021; Nurfikasari & Yuliani, 2021; Fakhri & Jumadi, 2023). Adequate access to these services supports economic activity, enhances quality of life, and reduces environmental vulnerability.

Therefore, the selection of relocation sites must prioritize safety, accessibility, and socio-economic viability. A well-planned relocation not only minimizes risks but also strengthens community resilience and supports long-term stability for disaster-affected populations.

METHODOLOGY

This study utilizes GIS-based Multi-Criteria Decision Analysis (MCDA) to identify sustainable relocation sites for disaster-affected communities in Banda Aceh. MCDA facilitates a systematic evaluation of multiple spatial factors, using ArcGIS for spatial analysis. Malczewski (2006) emphasized the critical role of GIS-MCDA in complex spatial decision-making. However, certain technical limitations persist, particularly the reliance on existing map overlays, which may not account for real-time environmental changes, land tenure complexities, or data inaccuracies.

The search for potential relocation sites focuses on peri-urban areas of Banda Aceh within Aceh Besar. As transitional zones between urban and rural regions, peri-urban areas offer several advantages, including proximity to essential services, relative affordability, and opportunities for future spatial expansion (Adell, 1999; Nilsson, 2010; McGee, 1991). Their flexible land-use patterns and generally lower land values compared to fully urbanized zones further strengthen their suitability for sustainable resettlement. Accordingly, this study evaluates seven key criteria (Table 1), forming a structured framework that integrates technical, environmental, and socio-economic aspects to assess the overall feasibility of relocation sites.

Table 1: Criteria for Evaluating Potential Land Relocation

Categories	Criteria		Very High Suitability	High Suitability	Mode-rate	Low Suitability	Very Low Suitability
			(4)	(3)	(2)	(1)	(0)
Hazard Exposure	C1	Hazard	No hazard	Low hazard	Mode-rate hazard	High hazard	Very high hazard

Land Use	C2	Non-Built-up Area	Non-built-up area with >15.000 m ²	Non-built-up area with 10.000-15.000 m ²	Non-built-up area with 5.000-10.000 m ²	Non-built-up area with <5.000 m ²	Non-built-up area with built-up area
Geological Factor	C3	Slope	0-2%	2-8%	8-21%	21-40%	>40%
	C4	Soil	Alluvial. Gleiplanosol, hidomorf kelabu, laterita	Latosol	Brown forest soil, Non-calsic, brown, mediteran	Andosol, laterit, grumusol, podsol, podsolik	Regosol, litosol, organosol, renzina
Accessibility	C5	Proximity to roads	0-500 m	501-1000 m	1001-1500 m	1501-2000 m	>2000 m
	C6	Accessibility to infrastructures	Served by >6 types of infrastructure	Served by 4-6 types of infrastructure	Served by 2-4 type of infrastructure	Served by <2 type of infrastructure	Served by no infrastructure
	C7	Accessibility to Public Facilities	Served by >5 types of facilities	Served by 3-5 type of facilities	Served by 2-3 type of facilities	Served by <2 type of facilities	Served by no facilities

Source: Oliver-Smith, 1991; Imura & Shaw, 2009; Nilsson, 2010; Bronen & Chapin, 2013; Permana et al., 2017; Nurfikasari & Yuliani, 2021; Few et al., 2021; Eriawan & Setiawan, 2021; Fakhri & Jumadi, 2023

The application of GIS-based MCDA in disaster relocation planning has been extensively studied. Zaki et al. (2023) demonstrated its effectiveness in urban gardening site selection, while Sabita et al. (2024) employed overlay and scoring methods using Geographic Information System (GIS) applications to determine relocation areas following the Cianjur earthquake and landslide. While prior studies primarily emphasized site suitability, this research integrates spatial and sustainability factors to ensure that relocation sites are not only safe but also socially and environmentally viable and provides a scientific framework for disaster mitigation and sustainable relocation planning in Banda Aceh.

RESULTS AND DISCUSSION

Relocation for High-Risk Settlement Area

Banda Aceh is one of the Indonesian cities with the highest disaster exposure due to its low-lying coastal geomorphology and proximity to tectonic sources in the Indian Ocean. The 26 December 2004 tsunami exposed the magnitude of

destruction along the northern coast and redirected urban expansion toward the higher eastern and southern sectors. Yet, increasing density in these areas over the past decade has produced new spatial pressures that gradually push development back toward the northern corridor, reinforcing the need to control settlement expansion into officially identified hazard-prone zones (Akbar & Ma'rif, 2014; Al-fath, 2022; Irwansyah et al., 2025).

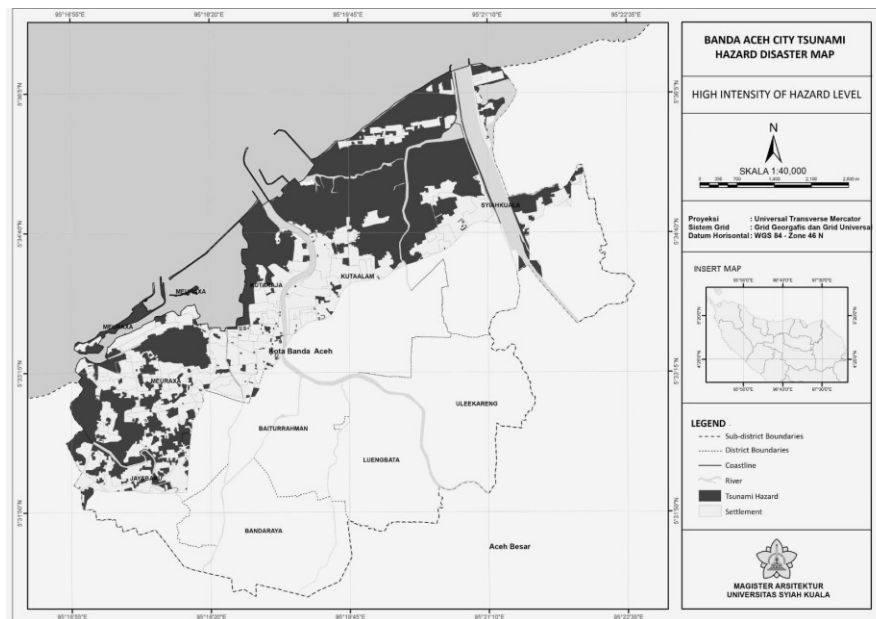


Figure 1: Tsunami Disaster Map

Figure 1 illustrates the spatial extent of tsunami hazard zones in Banda Aceh, shown in blue, relative to residential areas in yellow. The map reveals that much of the northern coastline, particularly Jaya Baru, Meuraxa, Kutaraja, Kuta Alam, and Syiah Kuala Districts, lies within a broad hazard band that directly overlaps existing settlements, indicating high exposure and the need for stricter spatial regulation. The inland continuity of this hazard zone suggests that all neighbourhoods within this corridor face substantial risk, reinforcing the necessity of relocation as a mitigation strategy. In addition to the threat of tsunamis, the area is also susceptible to liquefaction hazards.

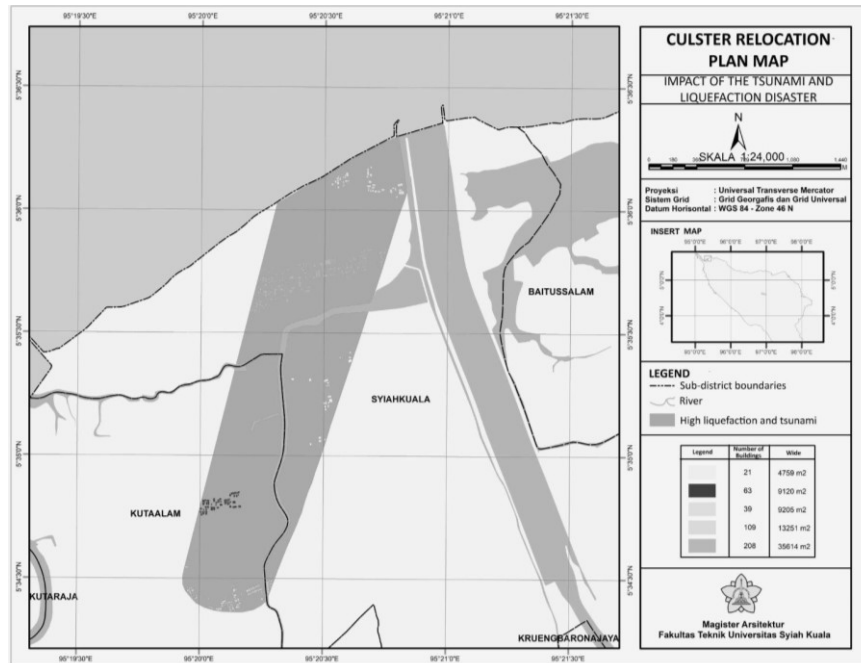


Figure 2: Liquefaction Disaster Map of Banda Aceh and the cluster recommendation

Figure 2 highlights areas simultaneously exposed to tsunami and liquefaction hazards, marked in pink, traversing several coastal gampong: Alue Naga, Deah Raya, Tibang, and Lambaro Skep, all of which also lie within the tsunami hazard zone shown in Figure 1. The combined map interpretation identifies 440 housing units across roughly 7.19 hectares within this dual-hazard area. To support more effective planning, the affected settlements are grouped into five clusters: Cluster 1 (9,205 m²; 39 houses), Cluster 2 (3.56 ha; 208 houses), Cluster 3 (4,759 m²; 21 houses), Cluster 4 (9,120 m²; 63 houses), and Cluster 5 (1.32 ha; 109 houses). This clustering offers a structured basis for systematic relocation, enabling clearer estimation of safe-land needs, phased resettlement planning, and assessment of receiving areas capable of supporting sustainable community relocation.

Spatial Analysis for Identifying Potential Relocation Sites for Communities Displaced by Disasters

Banda Aceh's vulnerability map shows that most of the city is highly hazard-exposed, while dense urbanisation limits safe relocation land, shifting feasible options to peri-urban districts of Aceh Besar—Peukan Bada, Syiah Kuala, Krueng Barona Jaya, Kota Baro, Darul Imarah, Darul Kamal, Ingin Jaya, and Darussalam. Aceh Besar spans 2,903.50 km², with the 2012–2032 RTRW

indicating dominant land uses such as secondary dryland forest (82,843.21 ha; 28.53%), dryland agriculture (40,165.63 ha; 13.83%), and savanna (54,778.43 ha; 18.87%), while settlements account for only 9,806.14 ha (3.38%). PERMEN PU No.41/PRT/M/2007 requires residential development on flat to gently undulating slopes (0–25%), as shown in Figure 3.

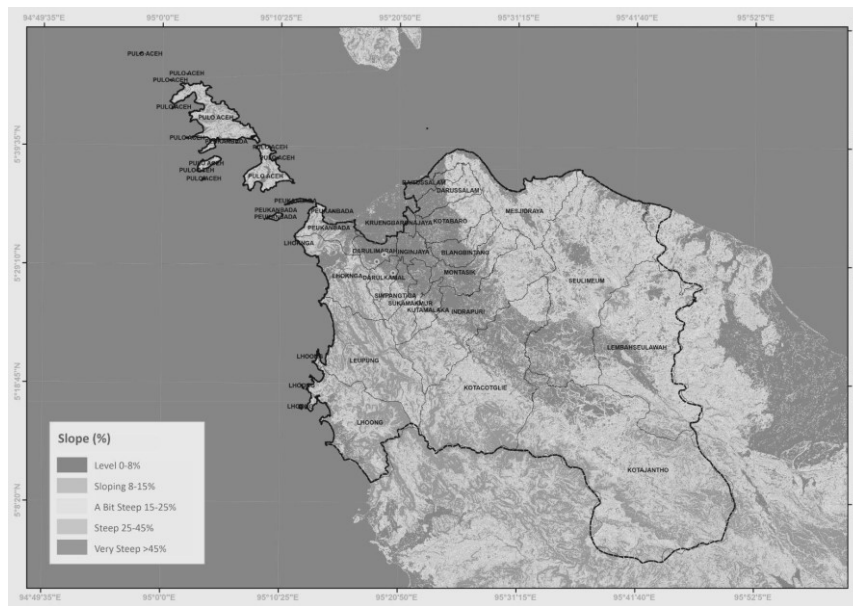


Figure 3: The land slope Map of Aceh Besar

Among the peri-urban zones, Darul Imarah and Darul Kamal emerge as the most suitable relocation areas due to their comparatively lower disaster risks (Inarisk, 2025). Both districts exhibit moderate earthquake exposure, low tsunami potential, and moderate-to-low flood vulnerability, positioning them as safer settlement alternatives. Their extensive agricultural landscapes (BPS Aceh Besar, 2023) with gentle 0–8% slopes further support sustainable residential expansion (Figure 3). Darul Imarah benefits from stronger infrastructure and direct connectivity to Banda Aceh, whereas Darul Kamal offers broader land availability. Figure 4 delineates their spatial boundaries, proximity to Banda Aceh’s urban core, existing settlement distribution, and remaining non-built-up land suitable for development.



Figure 4: Districts for relocation (Darul Imarah dan Darul Kamal)

Accessibility remains a crucial determinant of relocation success, as adequate infrastructure and social connectivity strongly influence community satisfaction. Empirical evidence shows that well-developed facilities enhance resettlement outcomes, whereas inadequate services and weakened social ties contribute to dissatisfaction (Abdul et al., 2021; Isa et al., 2021). The subsequent table provides descriptive statistics of the Multi-Criteria Decision Analysis used to evaluate land suitability for relocation.

Table 2: Descriptive Statistics of MCDA Criteria for Settlement Suitability

	Criteria	min	max	sum	mean	Std. dev
C1	Hazard	0	2	578	1.467005	0.556619
C2	Non-Built-up Area	0	2	534	1.35533	0.761134
C3	Slope	0	2	734	1.862944	0.948682
C4	Soil	0	1	569	1.444162	0.496872
C5	Proximity to roads	0	4	1502	3.812183	1.085321
C6	Accessibility to infrastructures	0	3	719	1.824873	1.023724
C7	Accessibility to facilities	0	2	526	1.335025	0.59562
LS	Land Suitability of Settlement Relocation	0	3	580	1.472081	0.600746

The analysis shows that the average hazard risk (C1) is 1.467 with a low standard deviation (0.557), indicating moderate and relatively uniform risk. Non-built-up areas (C2) average 1.355 with a higher standard deviation (0.761), reflecting notable variation in land availability. Slope (C3) has an average of 1.863 and a high standard deviation (0.949), suggesting substantial topographic differences, while soil quality (C4) averages 1.444 with moderate variability (0.497). Proximity to roads (C5) records the highest mean (3.812) and a standard deviation of 1.085, showing uneven accessibility. Access to infrastructure (C6) and public facilities (C7) averages 1.825 and 1.335, respectively, both with moderate fluctuations. The overall land suitability score (LS) averages 1.472 with a standard deviation of 0.601, indicating generally suitable yet spatially varied conditions for relocation.

While these quantitative results provide a sound technical foundation for relocation planning, several non-technical factors remain particularly challenging in the Acehnese context. Many residents are reluctant to relocate because land ownership in their pre-tsunami settlements is already well-established and secured, while relocation sites often lack clarity (Oliver-Smith, 1991; Shriver & Kennedy, 2005). Cultural preferences and a strong attachment to familiar environments also make communities hesitant to leave their comfort zones and adapt to unfamiliar settings (McMichael et al., 2019; Nilsson, 2010). In addition, proximity to workplaces and daily economic activities plays a crucial role in residents' willingness to move, as relocation to distant areas may disrupt livelihood patterns (Bower et al., 2023; Nalau & Handmer, 2018). These factors highlight that relocation feasibility is shaped not only by spatial suitability but also by social acceptance and livelihood considerations.

In relation to these challenges, the overlay analysis for Darul Kamal and Darul Imarah, based on seven relocation criteria, is shown in Figure 5 and classifies land into five suitability levels. As indicated in Table 3, no areas fall under the "very high" suitability category, reflecting inherent constraints within both districts. High suitability areas amount to 256.37 ha, while moderately suitable zones dominate with 4,373.05 ha. Low suitability areas extend across 2,935.47 ha, and very low suitability zones cover 144.21 ha. This distribution underscores that although ample land is available, the most optimal sites remain limited, necessitating careful prioritisation and phased planning.



Figure 5: Suitability map for relocation sites

Table 3: Land Suitability Classification and Area Size

Index	Land Suitable	Area (Ha)
4	Very High Suitability	0
3	High Suitability	256,37
2	Moderate	4373,05
1	Low Suitability	2935,47
0	Very Low Suitability	144,21

The primary recommended relocation sites fall under the high suitability category, located mainly on agricultural land in Teubalui, Neusok, Turam, Blang Kiree, and Lam Bleut (Darul Kamal), as well as Lheu Blang, Lamblang Manyang, and Lamreung (Darul Imarah). Moderately suitable zones may be used with strict land-use controls, while low and very low classes remain unsuitable. Although technically appropriate, these agrarian landscapes require careful planning for livelihood transitions, as coastal households reliant on fisheries and maritime activities may experience long-term income disruptions when shifted to agricultural environments (Wardana et al., 2020). Global evidence similarly stresses livelihood-sensitive relocation: experiences in Fiji, Bangladesh, and Merapi demonstrate that skills retraining and integration into agricultural value chains are essential for sustaining resettled populations (UNDP, 2013; Nalau & Handmer, 2018; McMichael, 2019). Without such

measures, top-down resettlement often erodes livelihood resilience (Bower et al., 2023), heightens risks of irreversible losses (Nand et al., 2023), and weakens adaptive capacity when access to natural resources is disrupted (Zhao et al., 2024).

The proposed villages in Darul Kamal District are characterised by productive agricultural landscapes, paddy fields, mixed crops, and livestock, which sustain local economies and food security. These areas are supported by essential infrastructure, notably paved roads and reliable electricity, which enhance mobility and enable diverse socio-economic activities. In Darul Imarah District, the three recommended villages lie on relatively flat, low-elevation terrain suitable for both agriculture and settlement. Their proximity to Banda Aceh (5–10 km) ensures access to urban services, while existing facilities such as mosques, primary schools, and community centres provide the social and religious functions necessary for daily life. Well-developed transportation and energy networks further support economic activity and overall living standards in both districts.

Such social infrastructures are particularly significant in Aceh, where mosques, meunasah, schools, and communal spaces anchor social cohesion. High physical suitability alone is insufficient if relocation separates communities from these networks; failures following Typhoon Haiyan highlight how disconnection undermines resettlement outcomes (Cuaton, 2019; Fernando & Punchihewa, 2013). Preventive relocation, such as in Cukur Village, Turkey, where residents were moved away from rockfall hazards, underscores the importance of aligning safety with social continuity (Dikmen, 2018). Accordingly, MCDA-based spatial suitability must be interpreted alongside community acceptance, cultural ties, and livelihood restoration to maintain social resilience (Comerio, 2014; Bower et al., 2023). This is consistent with international lessons: Japan post-2011 stresses combining hazard analysis with participatory planning (Jha, 2010), Christchurch demonstrates MCDA's effectiveness when paired with transparent engagement (Tierney, 2019), and cases from Sri Lanka, the Philippines, Indonesia, and Thailand show that technically optimal sites can still underperform when socio-cultural and economic factors are overlooked (Abe & Shaw, 2014; Cuaton, 2019; World Bank, 2020; UNDRR, 2019). Together, these findings affirm that spatial metrics must be complemented by socio-cultural and livelihood considerations to ensure sustainable post-disaster relocation.

CONCLUSION

This study demonstrates that successful relocation requires meeting a set of multidimensional criteria that extend beyond physical displacement. The analysis emphasises that suitable relocation sites must satisfy hazard-safety considerations, appropriate land characteristics, and sufficient accessibility to

public services, while also aligning with the social, economic, and cultural needs of affected communities. By applying these criteria, relocation becomes not only a risk-reduction strategy but also a pathway to enhancing long-term resilience, livelihood continuity, and sustainable settlement development.

Through GIS-based spatial assessment, the study identified eight villages in Darul Kamal and Darul Imarah Districts as the most suitable potential relocation sites. These locations, Teubalui, Neusok, Turam, Blang Kiree, Lam Bleut, Lheu Blang, Lamblang Manyang, and Lamreung, fulfil the established criteria in terms of hazard exposure, land capability, and integration with surrounding infrastructure. Their spatial characteristics provide a technical foundation for guiding government decisions on safer resettlement planning and contribute to a more systematic, transparent, and evidence-based approach to relocation in disaster-prone regions.

Nevertheless, despite providing a strong technical basis, this study acknowledges several limitations that may affect the transition from spatial assessment to practical implementation. The absence of detailed field verification limits the ability to fully confirm on-site conditions, including potential challenges related to land tenure security, where overlaps between formal property titles and customary claims may hinder legal clarity and compensation processes. In addition, environmental dynamics, such as rapid land-use change, evolving hydrometeorological patterns, and emerging climate-related hazards, may alter the long-term suitability of the identified sites. Equally important, this study did not directly assess community acceptance, even though social cohesion, cultural practices, and livelihood preferences are critical determinants of relocation success. To address these limitations, future research should incorporate systematic field surveys, comprehensive assessments of legal and institutional land-tenure frameworks, and participatory approaches such as stakeholder consultations and participatory mapping to validate GIS findings. Thorough documentation of these processes will enhance transparency, improve planning accuracy, and support the development of a relocation framework that is adaptive, inclusive, and effectively aligned with long-term disaster risk reduction goals.

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