Enhancing readiness for seismic resilience in Kota Belud, Sabah through a comprehensive vulnerability assessment

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ABSTRACT Seismic resilience is of paramount importance in regions vulnerable to seismic activity, and this study focuses on enhancing seismic resilience in Kota Belud, Sabah. The unique geological and geographical context, compounded by its proximity to tectonic plate boundaries, exposes Kota Belud to significant seismic risks. The Ranau 2015 earthquake, which occurred in the vicinity, serves as a stark reminder of this vulnerability. Moderate earthquakes, with the potential to cause significant damage, have a range of approximately 100 kilometers from their epicenters, a critical consideration for Kota Belud. This paper explores the damages caused by the Ranau earthquake, emphasizing the need for comprehensive vulnerability assessment and enhanced seismic resilience in the region. The study employs the Rapid Visual Screening (RVS) method to assess the seismic vulnerability of 16 buildings in Kota Belud. The methodology involves preliminary work to streamline on-site RVS surveys, and damage assessment based on FEMA P-154 standards. Results indicate that most buildings fall within Potential Damage Grade 3, highlighting the importance of seismic resilience strategies. A Geographic Information System (GIS) map is created to visualize the seismic risk distribution across Kota Belud, providing valuable insights for disaster mitigation and emergency response planning. The study underscores the necessity of addressing seismic resilience challenges in Kota Belud to ensure the safety and resilience of its communities.

KEYWORDS: Vulnerability Assessment; RC Buildings; Damage Score; RVS; Kota Belud
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INTRODUCTION

Seismic resilience is an integral aspect of disaster preparedness and urban planning, particularly in regions susceptible to seismic activity. This journal, titled "Enhancing Seismic Resilience in Kota Belud, Sabah's District through a Comprehensive Vulnerability Assessment," focuses on the distinct challenges and opportunities that Kota Belud presents in its pursuit of seismic resilience, with a primary focus on the utilization of the Rapid Visual Screening (RVS) method. To fully grasp the distinctiveness of Kota Belud in the context of seismic resilience, it is imperative to first consider its geological and geographical context, including the plate tectonics that underlie the seismic risks facing this remarkable region.

Kota Belud, nestled along the northern coast of Borneo, is a place of exceptional geological and cultural significance. This district's uniqueness lies in its intricate blend of natural beauty, diverse ecosystems, and vibrant communities. It boasts a captivating landscape with the majestic Crocker Range to the east and the South China Sea to the west. The area also includes the alluring Mantanani Island, a renowned international tourist destination, attracting visitors from various regions across the globe (Hussin *et al*., 2015).

However, one facet of Kota Belud's distinctiveness is its vulnerability to seismic activity. Sabah, as a whole, is seismically active due to its position sitting on the semi-stable South China Sea to a certain extent influenced by the active mobile belts in Sulawesi and Philippines (Tongkul, 2020). Kota Belud, in particular, is situated on the Sulu Trench, a subduction zone where the Philippine Sea Plate is subducting beneath the Sunda Plate. The study from Tongkul (2017) reveals that the stress generated by the deep westward subducting slab of the Philippine Sea is being absorbed by shallow eastward and southward subduction of the Celebes Sea and Sulu Sea plates based on the earthquake data. In Sabah, this stress appears to be absorbed by active thrust faults, resulting in shortening and gradual uplift of Sabah (Figure 1). This complex tectonic setting renders Kota Belud susceptible to seismic events, with potentially significant and devastating consequences for the local population and infrastructure.

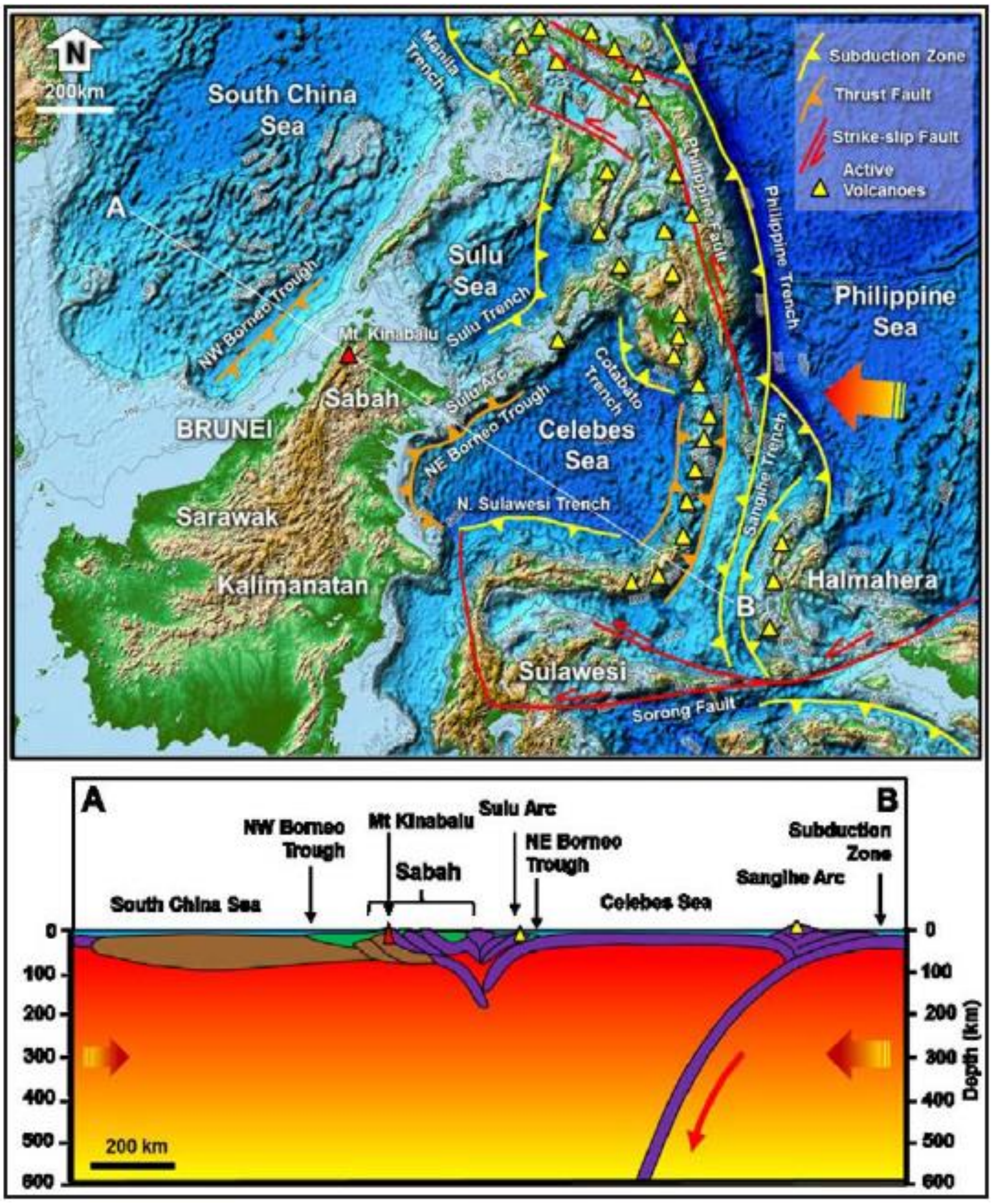

Figure 1. Summary of active plate movements of Sabah (Tongkul, 2017).

This vulnerability is exemplified by the Ranau 2015 earthquake, an event that occurred in close proximity to Kota Belud, the study area. The earthquake serves as a stark reminder of the seismic risks faced by this region. In context, it's essential to consider the potential impact of moderate earthquakes. An earthquake with the Richter magnitude between 6.1 to 6.9, also in range for moderate earthquakes can be destructive in areas extending up to approximately 100 km from their epicenters, particularly in densely populated regions (Hampton Roads Planning District Commission, 2017). The relevance of this becomes evident when the Ranau earthquake's epicenter was situated at approximately 37 km from Kota Belud. This proximity places Kota Belud well within the range of potential impact for a moderate earthquake.

In the year 2015, the district of Ranau experienced a devastating earthquake with a magnitude of six, resulting in a tragic loss of lives and extensive structural damage. This seismic event had a profound impact, notably affecting a total of 61 buildings, encompassing 23 educational institutions, hospitals, and places of worship, such as mosques within the vicinity (Tongkul, 2020; Harith *et al*., 2018). The aftermath of this seismic event, coupled with over 100 aftershocks, inflicted substantial harm to the 22 roads and 22 slopes in addition to the damage sustained by the buildings (Harith *et al*., 2018). Moreover, Adiyanto et al. (2017) conducted a comprehensive study on these damages, revealing that infill walls, particularly in structures such as minarets, experienced significant harm. These walls became detached from the primary building structures and, in some cases, completely collapsed due to the seismic forces exerted during the Ranau earthquake.

Given Kota Belud's geographical distinctiveness and the potential seismic risks it faces, there is a compelling need for an in-depth understanding of its vulnerability and the development of resilient strategies. The RVS method emerges as an invaluable tool in this endeavor, facilitating a rapid yet effective assessment without the need for intricate calculations and prioritization of seismic vulnerability (Shah *et al*., 2018 & Harirchian et al., 2020). The objectives through this method's implementation are to assess the buildings' vulnerability of Kota Belud on parameters such as type of structures, height, and irregularities, and to develop building damage prediction map of each surveyed buildings, forming the foundation for informed decision-making and disaster mitigation efforts. The study by Harith *et al.* (2023) primarily examined the seismic vulnerability in Sabah with a specific focus on Kota Kinabalu, Ranau, Kudat, Kota Marudu, Tawau, Lahad Datu and Semporna, and utilized the same method, RVS.This paper concentrates on a different area, specifically Kota Belud.

METHODOLOGY

The study utilizes the RVS technique to swiftly evaluate the seismic vulnerability of 16 buildings within the study area. RVS offers an efficient means of assessing buildings' seismic vulnerabilities, thereby informing seismic risk assessment and prioritizing retrofitting measures. The RVS methodology, depicted in Figure 2, outlines the assessment process.

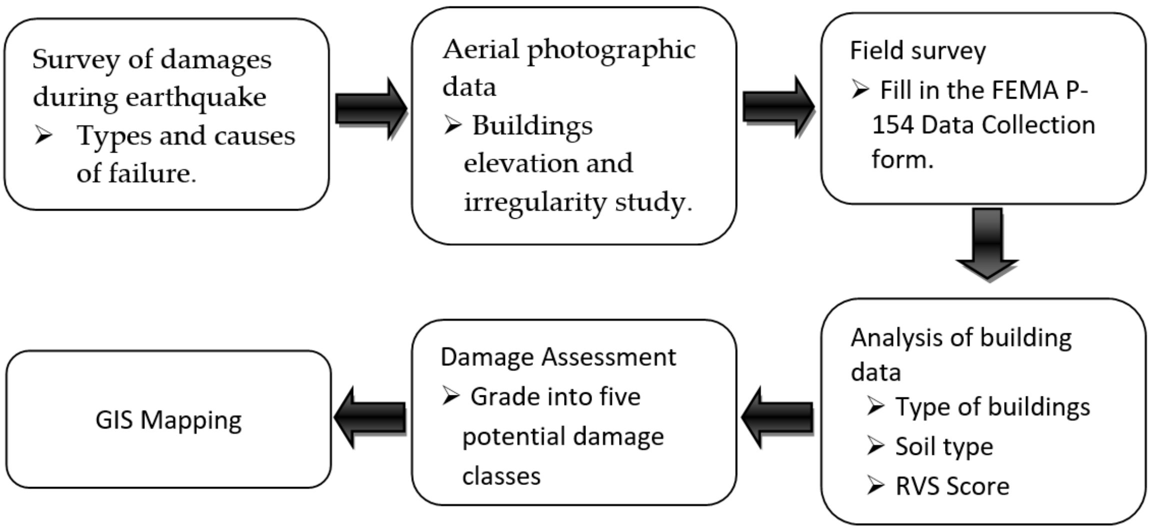

Figure 2. Flowchart of the RVS methodology on building damage assessment for Kota Belud region

Preliminary Work

Before the on-site visit, a preliminary study is conducted to streamline on-site activities and reduce field time. This phase involves reviewing earthquake-induced damages to identify structural failure types, their causes, and potential irregularities. Additionally, an aerial photographic data analysis, using tools like Google Earth Pro, helps plan the site visit by determining geographic coordinates, building elevations, plan irregularities, and critical geotechnical data. Identifying soil types is particularly essential as they may not be visually apparent during the site visit.

On-Site Rapid Visual Screening Survey

The on-site phase involves the continuation of data collection using the FEMA P-154 Data Collection form. A building survey datasheet is meticulously completed, providing extensive data on the surveyed structures. Both exterior and interior surveys are conducted to identify potential hazards and assess seismic vulnerabilities. During the site visit, community engagement helps gather information about building history, reconstruction after seismic events, and construction years. Evaluations of structural cracks, building adjacency, and vertical irregularities contribute to understanding the buildings' seismic performance. In summary, the on-site visit phase plays a vital role in data collection, validation, and comprehensive vulnerability assessments. The combination of pre-field preparations and the site visit enhances the reliability and success of the study's results.

Damage Assessment

The RVS score for each building is determined based on its type and seismicity region. A Score Modifier adjusts the Basic Score based on the building's design and construction date. The Screen Level score (S) is derived for each building by adding the circled Score Modifier to the Basic Score, determined by its designated building type. Figure 3 illustrates the example of score modifier section in the FEMA P-154 data collection form. The final level score (S) is calculated using the formula:

$$\text{Final Score (S)}=\text{Basic Score (BS)}+\text{Score Modifier (SM)} \quad (1)$$

BS SM

BASIC SCORE, MODIFIERS, AND FINAL LEVEL 1 SCORE, S_{L1}

FEMA BUILDING TYPE / Do Not Know	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic Score	**5.1**	**4.5**	**3.8**	**2.7**	**2.6**	**3.5**	**2.5**	**2.7**	**2.1**	**2.5**	**2.0**	**2.1**	**1.9**	**2.1**	**2.1**	**1.7**	**2.9**
Severe Vertical Irregularity, V_{L1}	-1.4	-1.4	-1.4	-1.2	-1.2	-1.4	-1.1	-1.2	-1.1	-1.2	-1.0	-1.1	-1.0	-1.1	-1.1	-1.0	NA
Moderate Vertical Irregularity, V_{L1}	-0.9	-0.9	-0.9	-0.8	-0.7	-0.9	-0.7	-0.7	-0.7	-0.7	-0.6	-0.7	-0.6	-0.7	-0.7	-0.6	NA
Plan Irregularity, P_{L1}	-1.4	-1.3	-1.2	-1.0	-0.9	-1.2	-0.9	-0.9	-0.8	-1.0	-0.8	-0.9	-0.8	-0.8	-0.8	-0.7	NA
Pre-Code	-0.3	-0.5	-0.6	-0.3	-0.2	-0.2	-0.3	-0.3	-0.3	-0.4	-0.3	-0.2	-0.2	-0.2	-0.2	-0.1	-0.5
Post-Benchmark	1.4	2.0	2.5	1.5	1.5	0.8	2.1	NA	2.0	2.3	NA	2.1	2.5	2.3	2.3	NA	1.2
Soil Type A or B	0.7	1.2	1.8	1.1	1.4	0.6	1.5	1.6	1.1	1.5	1.3	1.6	1.3	1.4	1.4	1.3	1.6
Soil Type E (1-3 stories)	-1.2	-1.3	-1.4	-0.9	-0.9	-1.0	-0.9	-0.9	-0.7	-1.0	-0.7	-0.8	-0.7	-0.8	-0.8	-0.6	-0.9
Soil Type E (> 3 stories)	-1.8	-1.6	-1.3	-0.9	-0.9	NA	-0.9	-1.0	-0.8	-1.0	-0.8	NA	-0.7	-0.7	-0.8	-0.6	NA
Minimum Score, S_{MIN}	*1.6*	*1.2*	*0.9*	*0.6*	*0.6*	*0.8*	*0.6*	*0.6*	*0.3*	*0.3*	*0.3*	*0.3*	*0.2*	*0.3*	*0.3*	*0.2*	*1.5*
FINAL LEVEL 1 SCORE, $S_{L1} \geq S_{MIN}$:	0.7	S															

Figure 3. Score Modifier Parameters based on the Data Collection Form Provided (FEMA P-154, 2015)

The RVS score plays a crucial role in determining the potential grade of damage to the buildings. Based on the RVS score, the buildings will be categorized into different ranges, as indicated in Table 1. The damage potential is classified into five grades, ranging from Grade 1, which signifies negligible to slight damage, to Grade 5, which indicates complete destruction of the building.

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Table 1. Grade Damage Based on The RVS Score

RVS Rating	Damage possibility
S<0.3	There is a strong likelihood of Grade 5 harm and a very high likelihood of Grade 4 damage.
0.3<S<0.7	There is a strong likelihood of Grade 4 harm and a very high likelihood of Grade 3 damage.
0.7<S<2.0	There is a strong likelihood of Grade 3 harm and a very high likelihood of Grade 2 damage.
2.0<S<3.0	There is a strong likelihood of Grade 2 harm and a very high likelihood of Grade 1 damage.
S>3.0	The likelihood of Grade 1 damage

RESULT AND DISCUSSION

In this section, the results of the comprehensive vulnerability assessment in Kota Belud, Sabah is presented. A total of 16 buildings with vary in height and structure type were surveyed mainly located in Kota Belud, Sabah. The data is analysed based on the guidance by FEMA P-154 (2015) standards. Figure 4 shows the classification of surveyed buildings based on the number of storeys.

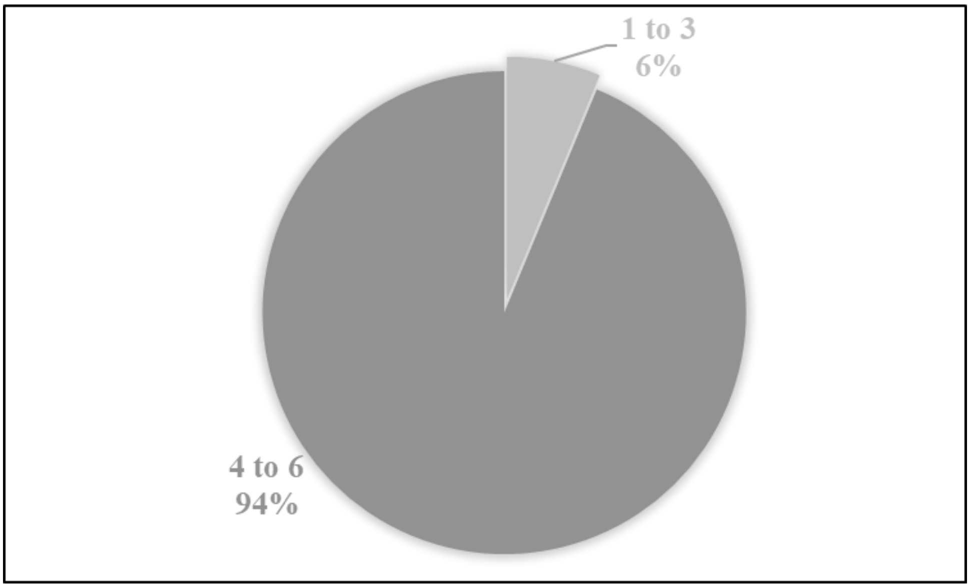

Figure 4. Percentage for total buildings in accordance with number of storey in Kota Belud

One of the parameters analysed is building story. In terms of the number of stories, the surveyed buildings were categorized into three ranges: 1 to 3 stories (low-rise structures) comprising one building, 4 to 6 stories (medium-rise structures) consisting of 15 buildings, and 7 stories and above (high-rise structures) with no representation in the survey, as illustrated in Figure 4.

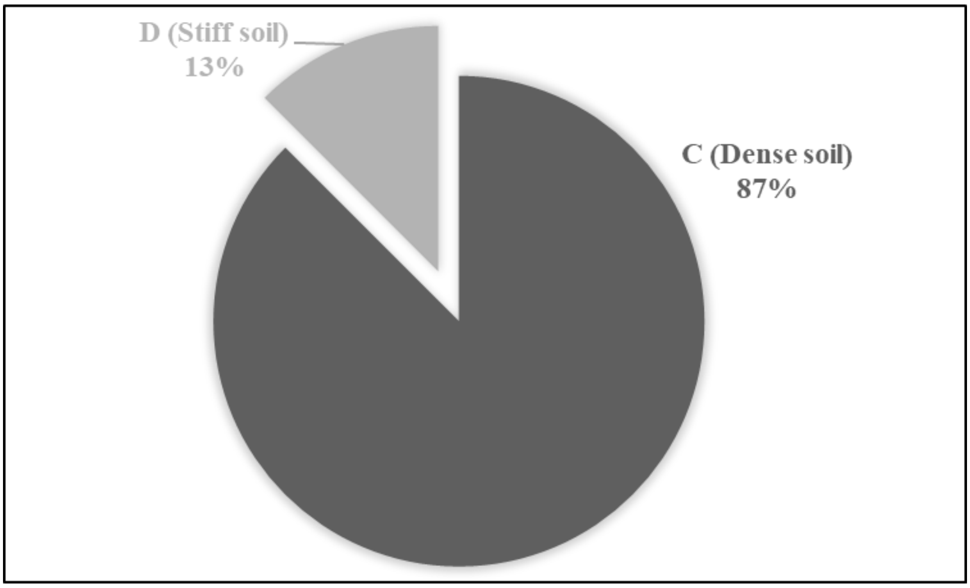

Figure 5. Number of buildings based on soil type in Kota Belud.

Moreover, the second parameter is soil type, and the classification is illustrated in Figure 5. The type of soil is determined based on the National Earthquake Hazards Reduction Program (NEHRP) classification. The NEHRP has defined six different site classifications based on the rock and type of soil including hard rock, average rock, dense soil, stiff soil, soft soil, and poor soil. Hard rock, being the hardest, produces the least wave amplification, whereas soft soil, on the other hand, exhibits the highest amplification. Based on the graph in Figure 5, 14 buildings were situated on Type C (Dense soil), and 2 buildings were on Type D (Stiff soil).

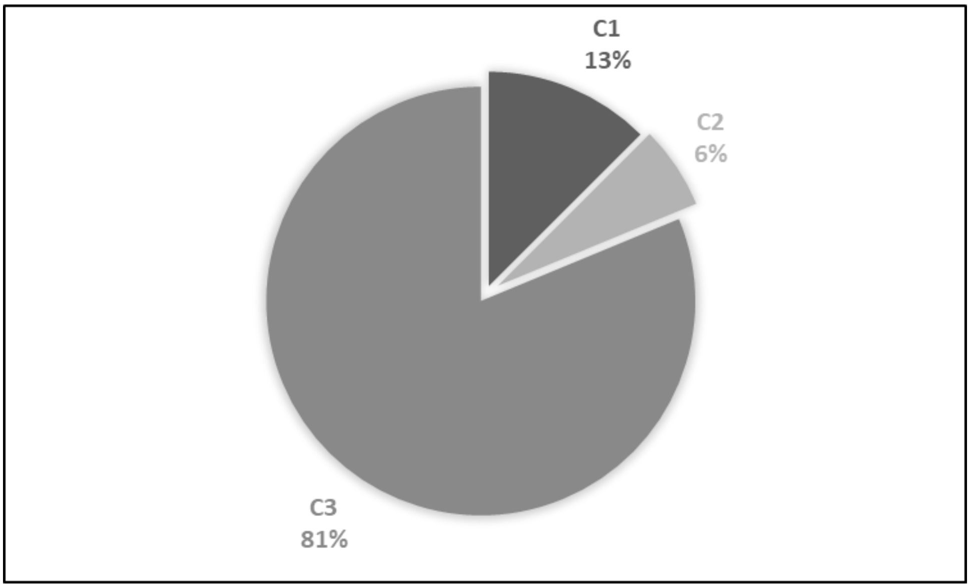

Figure 6. Building type classification in Kota Belud.

Furthermore, Figure 6 indicates the building type classification in study area, Kota Belud. The classification of buildings is one of the most important responsibilities in estimating the seismic risk of a structure. The FEMA P-154 RVS procedure includes 17 different building types. However, the building type for the surveyed buildings in Kota Belud only classified into three classes consisting of C1, C2, and C3. Regarding the type of building, the majority were C3 (Concrete frame buildings with unreinforced masonry infill walls), which accounted for 13 buildings. C1 (Concrete moment-resisting frame buildings) and C2 (Concrete shear wall buildings) represented 2 and 1 building, respectively based on Figure 6 above.

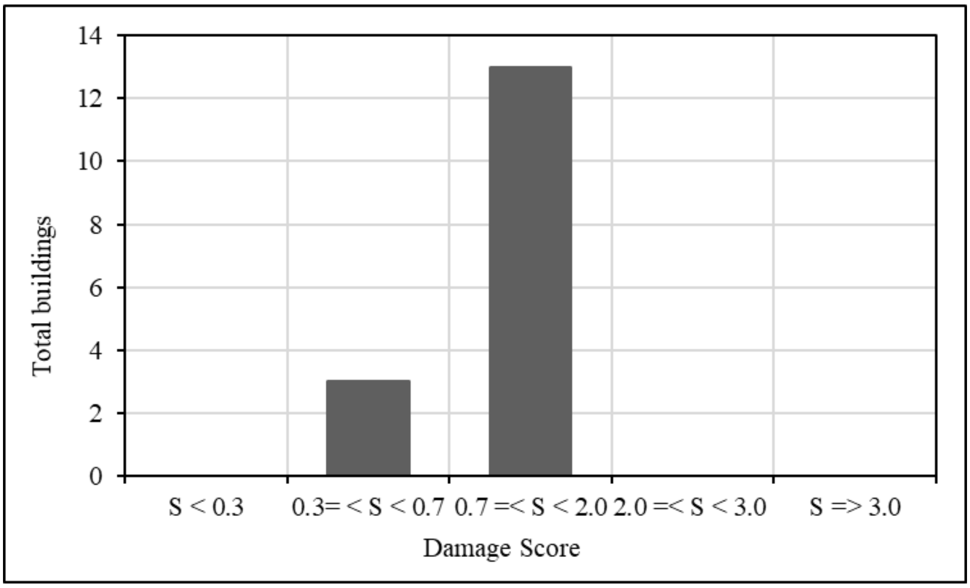

Figure 7. Total buildings and respective damage score in Kota Belud (S: score modifier).

Additionally, the result for potential damage score is illustrated in Figure 7. Calculating the RVS score is essential as it serves several important purposes in assessing the seismic vulnerability of buildings. The damage probability was considered under five categories based on the European Macroseismic Scale (EMS-98) based on RVS score. Referring to Figure 7 above, buildings with scores between 0.3 and 0.7 were classified as Potential Damage Grade 4 (3 buildings), while those with scores between 0.7 and 2.0 were categorized as Potential Damage Grade 3 (13 buildings). Notably, most surveyed buildings in Kota Belud fell within Potential Damage Grade 3. Table 2 and Table 3 show the cross analysis for the potential damage Grade 3 and Grade 4, respectively.

Table 2. The cross analysis of Potential Damage Grade 3

Potential of Grade 3 damage					
Building Type		Soil type		Number of Story	
C3	84.6%	C (Dense soil)	84.6%	3	7.7%
C2	7.7%	D (Stiff soil)	15.4%	4	30.8%
C1	7.7%			5	53.8%
				6	7.7%

Table 3. The cross analysis of Potential Damage Grade 4

Potential of Grade 4 damage					
Building Type		Soil type		Number of Story	
C3	66.7%	C (Dense soil)	100%	5	66.7%
C1	33.3%			4	33.3%

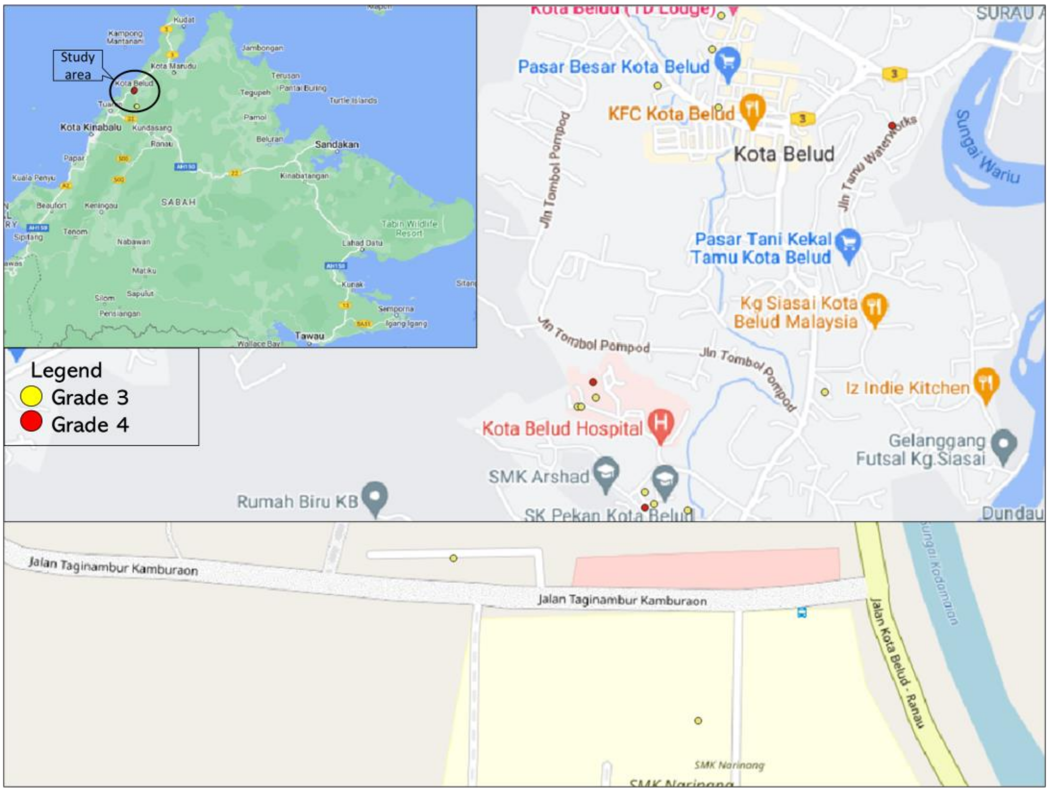

Figure 8. The 2D GIS Map of buildings in Kota Belud based on potential grade damage.

A Geographic Information System (GIS) map is created to visualize the seismic risk distribution across the study area based on the potential grade of damage (Figure 8). This map serves as a valuable tool for assessing and understanding the vulnerability of buildings in the region to potential earthquake-induced damage. The map provides a clear and visually informative representation of the seismic risk distribution in Kota Belud by employing various colors to differentiate buildings with different potential damage grades. The map allows researchers and policymakers to identify high-risk zones where buildings are more susceptible to damage during seismic events. The map also facilitates emergency response planning by providing critical information on areas with high potential for building damage and contributes to public awareness and education about earthquake risks in Sabah.

CONCLUSION

Kota Belud, situated in a region exposed to seismic risks due to its geological and geographical context, presents unique challenges and opportunities for enhancing seismic resilience. The Ranau 2015 earthquake's impact on the vicinity underscores the urgent need for comprehensive vulnerability assessment and mitigation efforts. Moderate earthquakes have the potential to cause significant damage, and Kota Belud's proximity to the epicenter of the Ranau earthquake highlights the critical importance of seismic resilience. The utilization of the Rapid Visual Screening (RVS) method in assessing the seismic vulnerability of buildings in Kota Belud provides valuable insights for risk assessment and prioritizing retrofitting measures. The results of the study demonstrate that most buildings in the area fall within Potential Damage Grade 3, emphasizing the necessity of implementing seismic resilience strategies. The Geographic Information System (GIS) map created in this study serves as a powerful tool for visualizing seismic risk distribution in Kota Belud. It aids in emergency response planning, public awareness, and education about earthquake risks, contributing to the region's overall resilience. In conclusion, addressing the seismic resilience challenges in Kota Belud is vital to ensure the safety and sustainability of its communities in the face of seismic events.

This study lays the groundwork for informed decision-making, mitigation efforts, and the development of a more resilient Kota Belud.

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REFERENCES

[1] Adiyanto, M. I., Majid, T. A. & Nazri, F. M. 2017. Nonstructural damages of reinforced concrete buildings due to 2015 ranau earthquake. *AIP Conference Proceedings,* 1865(1), 090002.

[2] FEMA P-154 2015. *Rapid Visual Screening of buildings for potential seismic hazards: a handbook (FEMA P-154)*. Federal Emergency Management Agency. (January), 388.

[3] Harirchian, E., Kumari, V., Jadhav, K., Das, R., Rasulzade, S., & Lahmer, T. 2020. A Machine Learning Framework for Assessing Seismic Hazard Safety of Reinforced Concrete Buildings. *Applied Sciences*, 10(20), 7153.

[4] Harith, N. S. H., Hassan, N. I. H., Samir, S., Tom, N. M., Bakar, N. A., & Mohamad, H. M. 2023. Damage prediction observation for existing buildings in Sabah under moderate risk earthquakes. *Buildings*, 13(6), 1500. https://doi.org/10.3390/buildings13061500

[5] Harith, N. S. H., Kibata, L. H. C. & Mirasa, A. K. 2018. Suitability of DBELA Methods as Seismic Vulnerability Assessment for Buildings in Kota Kinabalu, Sabah. *International Journal of Engineering and Technology*, 10, 29-31. doi:10.26480/gbr.01.2018.29.31.

[6] Hampton Roads Planning District Commission. 2017. *Hampton Roads Hazard Mitigation Plan*. Final Report to Federal Emergency Management Agency through the Virginia Department of Emergency Management, via grant Agreement number HMGP-4072-001. pp. 76 (https://shorturl.at/hpCDF). Last accesssed on 22 December 2023

[7] Hussin, R., Kunjuraman, V., & Weirowski, F. 2015. Work Transformation from Fisherman to Homestay Tourism Entrepreneur: A Study in Mantanani Island Kota Belud, Sabah, East Malaysia. *Jurnal Kemanusiaan,* 24(1), 15 - 29.

[8] Shah, M. F., Kegyes-B., O. K., Ray, R. P., Ahmed, A. & Al-ghamadi, A. 2018. Vulnerability assessment of residential buildings in Jeddah: A methodological proposal. *International Journal of GEOMATE*, 14(44), 134–141.

[9] Tongkul, F. 2017. Active tectonics in Sabah – seismicity and active faults. *Bulletin of the Geological Society of Malaysia.* 64, 27–36.

[10] Tongkul, F. 2020. *Earthquake Science in Malaysia: Status, Challenges and Way Forward*. Kota Kinabalu: Penerbit Universiti Malaysia Sabah.