Journal of Infrastructure Planning and Engineering Vol. 3, No. 2, Year 2024, pp 41 - 49

JIPE Journal of Infrastructure Planning and Engineering

Journal of Infrastructure Planning and Engineering

Journal homepage: https://ejournal.warmadewa.ac.id/index.php/jipe

Assessing the Impact of Environmental Hazards on Educational Facility Structures in Karangasem Regency: Implications for Risk Mitigation

I Putu Ellsa Sarassantika[1*], Gde Bagus Andhika Wicaksana [2], Kadek Tania Utami Putri [3]

[1,2,3] *Warmadewa University, Jalan Terompong No. 24, Denpasar, 80239, Indonesia*
*iputuellsasarassantika@warmadewa.ac.id

Received on 6 December 2024, accepted on 10 January 2025

ABSTRACT

Educational facilities in Karangasem Regency face significant risks from environmental factors such as seismic activity, unstable soils, and extreme weather, which contribute to structural damage. This study aims to assess the extent of building damage in these facilities and understand its relationship with surrounding environmental conditions to inform risk mitigation strategies. A comprehensive method was employed, combining field surveys, structural inspections, and Geographic Information System (GIS) mapping. Damage levels were classified into minor, moderate, severe, and total destruction, based on structural and non-structural indicators. Disaster risk, including potential strong winds, potential floods, potential landslides, potential droughts, and potential earthquakes, were integrated to identify patterns and correlations with building damage. The findings revealed that 16.7% and 7.7% of facilities experienced light damage and moderate damage respectively, predominantly in areas with high winds, landslides, and earthquakes potential. Additionally, topographical challenges, such as slope instability, were identified as major contributors to damage severity. GIS analysis highlighted clusters of high-risk zones, underscoring the spatial relationship between environmental conditions and damage distribution. The study concludes that the integration of structural assessments with environmental analysis provides a robust framework for evaluating building vulnerabilities. Recommendations include the adoption of disaster-resistant construction materials, enhanced maintenance protocols, and strategic land-use planning. These measures are essential for mitigating risks and ensuring the safety and sustainability of educational facilities in Karangasem Regency. This research offers valuable insights into disaster risk management and contributes to developing resilient infrastructure in hazard-prone regions.

Keywords: Building Damage Assessment; Disaster Risk Mitigation; Geographic Information System (GIS)

1 Introduction

Educational facilities play a crucial role in supporting community development by providing safe and functional spaces for learning. However, in disaster-prone regions like Karangasem Regency, Bali, these facilities face significant risks from environmental factors such as seismic activity, landslides, and extreme weather conditions. Damage to school buildings not only disrupts educational activities but also endangers the safety of students and staff, emphasizing the need for comprehensive risk assessments and mitigation strategies.

Previous studies have explored structural vulnerabilities of buildings under various environmental stresses, highlighting the importance of integrating structural assessments with environmental analyses to identify risk factors and prioritize interventions [1]–[3]. However, research specifically targeting educational facilities in Karangasem, considering both damage assessment and environmental relevance, remains limited. This gap underscores the need for localized studies to inform tailored disaster risk reduction efforts.

This study aims to assess the extent of building damage in educational facilities-Elementary school across Karangasem Regency, employing a mapping approach to identify damage patterns and correlate them with environmental conditions and topography. The findings provide insights into how these factors influence the structural integrity of school buildings.

Using a combination of field surveys, Geographic Information System (GIS) analysis, and structural evaluations, this research addresses the need for a more nuanced understanding of building vulnerabilities in disaster-prone regions. The results will contribute to developing strategies for enhancing the resilience of educational infrastructure, ensuring the safety of the learning environment, and supporting sustainable development goals in the region.

This paper is structured to provide a detailed analysis of the problem, present the methodology employed, and discuss the findings, leading to practical recommendations for risk mitigation and future planning.

2 Data and Methods

The study was conducted in Karangasem Regency, Bali, a disaster-prone region characterized by diverse topographical and geological conditions, focusing on primary school buildings as the primary facilities for educational activities, listed in **Table 1** and **Figure 1**.

Table 1. Primary School in Karangasem District

Sub-District	Primary School	Building
Abang	8	67
Bebandem	5	51
Karangasem	6	29
Kubu	7	44
Manggis	4	22
Rendang	3	30
Selat	3	37
Sidemen	3	32
Total	**39**	**312**

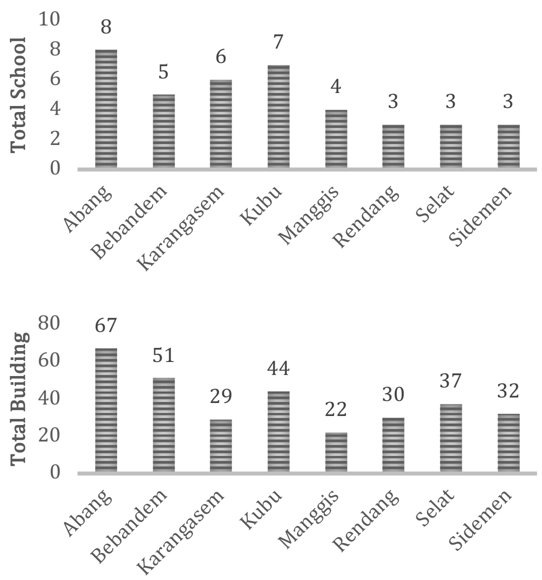


Figure 1. Primary School Statistic in Karangasem

The area covers approximately ±839.24 km^2 and consists of 8 sub-districts. The region is bordered by the Bali Sea to the north, the Lombok Strait to the east, the Indian Ocean to the south, and Klungkung Regency, Bangli Regency, and Buleleng Regency to the west shown in **Figure 2.**

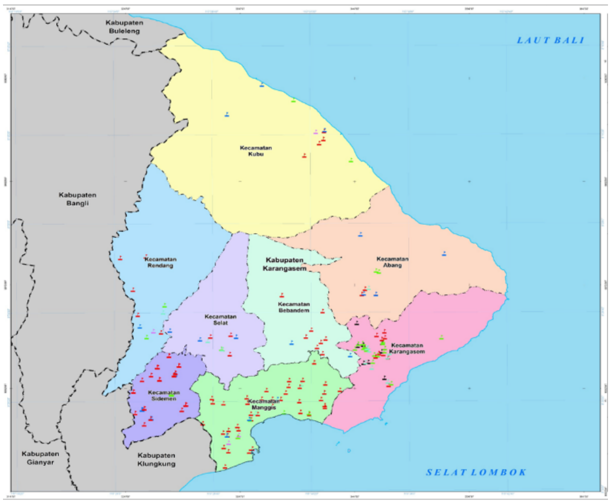


Figure 2. Karangasem District Map

The data used in this study comprised structural, environmental, and spatial information:

Structural Data: Field surveys were conducted to assess the physical condition of school buildings. Observations included cracks in walls, deformation in structural elements, and overall building stability, based on Pekerjaan Umum Dan Penataan Ruang (PUPR) guideline on Procedures for Damage Identification and Verification [4]. The surveying form is shown in **Table 2** and the assessment description shown in **Figure 3.** Damage levels were categorized into four classes: minor, moderate, severe, and total destruction.

Environmental Data: Information on soil type, topography, climate conditions, and proximity to fault lines was gathered from secondary sources, including government geological surveys and meteorological data.

Spatial Data: Geographic coordinates of each school were recorded, and a Geographic Information System (GIS) was used to integrate and analyze spatial patterns of damage.

Field Survey and Structural Analysis

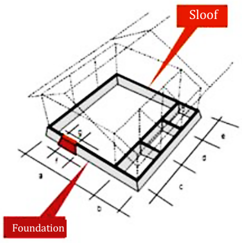
The structural condition of buildings was evaluated using a standard damage classification framework. Measurements of cracks, deflections, and material degradation were documented systematically.

Table 2. Surveying form for building damage assessment

No	System	Component	Unit	Vol.	Calculation of Damage Volume							Component Weight	Damage Level of Component to Building/Roof Mass
					Not Damaged	Very Light	Light	Medium	Heavy	Very Heavy	Component Not Suitable/Not Available		
1	Structure	Foundation/ Sloof	Estimate									10%	
		Column	Unit									13%	
		Beam	Unit									12%	
		Floor Slab	Unit									10%	
		Stair	Unit									3%	
		Roof	%									7%	
2	Architecture	Wall/ Partition	%									6.25%	
		Ceiling	%									8%	
		Floor	%									10%	
		Frame	Unit									1.5%	
		Door	Unit									1%	
		Window	Unit									1.25%	
		Ceiling Finish	%									3%	
		Wall Finish	%									5%	
		Frame & Door Finish	%									3%	
3	Utilities	Electrical Installation	Estimate									3%	
		Clean Water Installation	Estimate									1.5%	
		Drainage Wastewater	M1									1.5%	
Total damage value of building/room:													
Conclusion of the damage level of building/room:													

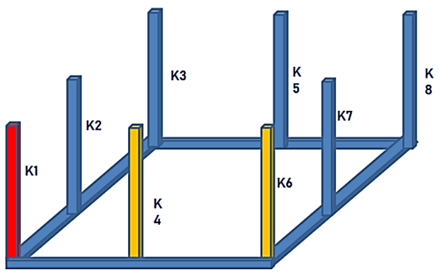
Component	Illustration	Assessment Explanation

Foundation



Foundation assessment can be identified by visually inspecting the condition of the foundation. If visual analysis of each foundation point is challenging, the assessment of foundation damage can be inferred from its impact on the structural elements above it. The simplest analysis method is observing cracks in the tie beams, columns, beams, joints, or walls.

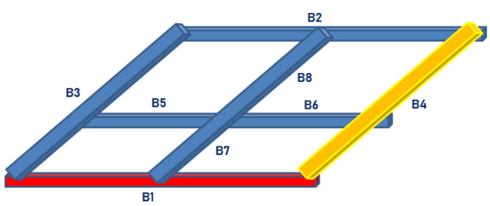
Column



Column assessment can be identified by visually inspecting the condition of the columns according to the damage description. For building structures using a portal system, plastic hinges should align with the structural design principle where columns are stronger than beams (strong column-weak beam). The percentage of column damage in one building mass or room is the resultant sum of damage to the columns in that building or room, calculated using the following formula:

Column Damage Percentage=
$\sum(K1+K4+K6)/\sum(K1+K2+K3+K4+K5+K6+K7+K8) * 100\%$

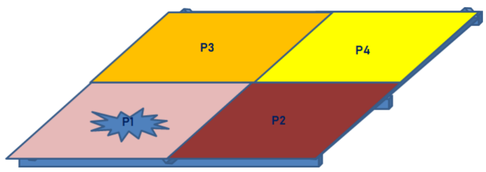
Beam



Beam assessment can be identified by visually inspecting the condition of the beams based on the described damage. The percentage of beam damage in one building mass or room is the resultant sum of the damage to the beams in that building or room, calculated using the following formula:

Beam Damage Percentage=
$\sum(B1+B4)/\sum(B1+B2+B3+B4+B5+B6+B7+B8)$

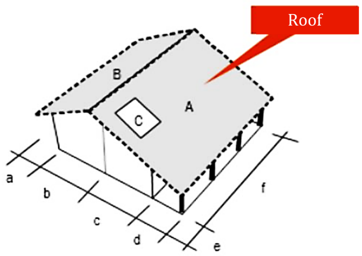
Slab



Slab assessment can be identified by visually inspecting the condition of the slabs based on the described damage. The percentage of floor slab damage in one building mass or room is the resultant sum of the damage to the floor slabs in that building or room. The calculation follows a similar approach:

Slab Damage Percentage= $\sum(P1)/\sum(P1+P2+P3+P4)$

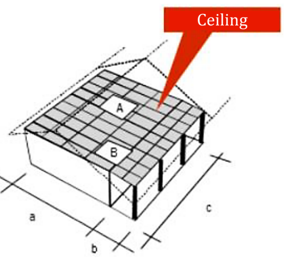
Roof



Roof assessment can be identified by visually inspecting the condition of the roof according to the damage description. The percentage of roof damage in one building mass or room is the resultant sum of the percentage of the roof that has sustained damage, compared to the total roof area of the building or room.

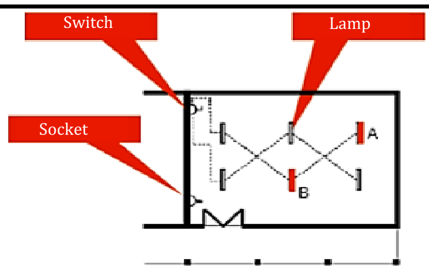
percentage of roof damage =
%Area C = ((Area C)/(Total Area)) x 100%

Ceiling



Ceiling assessment can be identified by visually inspecting the condition of the ceiling according to the damage description. The percentage of ceiling damage in one building mass or room is the resultant sum of the percentage of the ceiling and ceiling framework that has sustained damage, compared to the total ceiling and ceiling framework area of the building or room.

Electrical installation



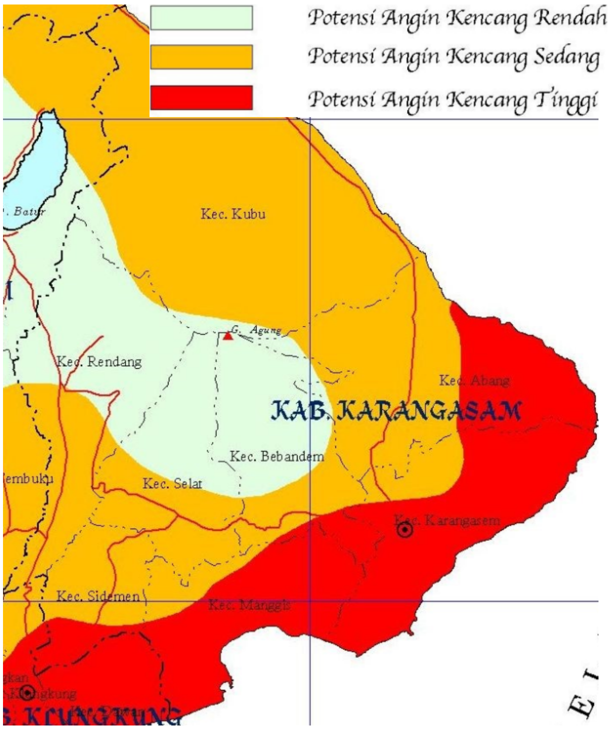
Electrical installation assessment can be identified by visually inspecting the condition of the electrical system according to the damage description. The percentage of electrical installation damage in one building mass or room is determined by evaluating the condition of the electrical components within that mass or room, such as the panel, cables, and fixtures.

Figure 3. Assessment description [4]

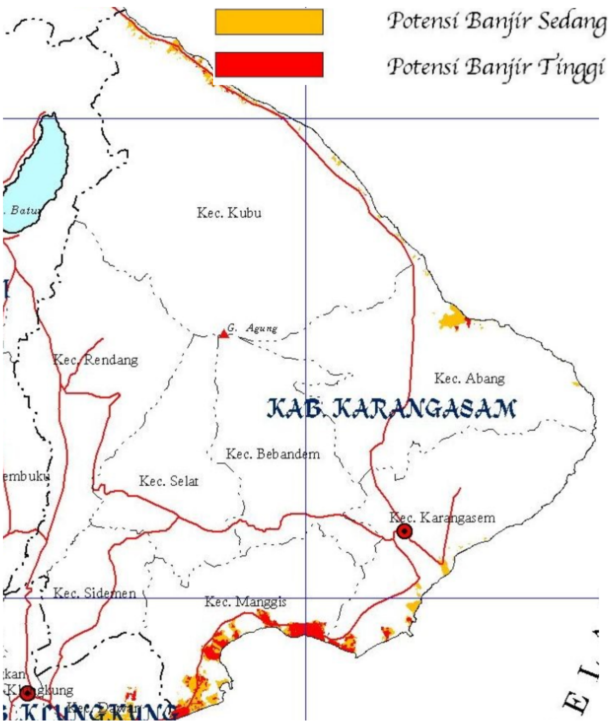
Geospatial Analysis

GIS tools were employed to map the locations of schools and overlay them with environmental data[5], [6]. The spatial relationship between damage levels and, disaster risk, such as Potential Strong Winds, Potential Floods, Potential Landslides, Potential Droughts, and Potential Earthquakes. The data of disaster risk map prepared by Regional Disaster Management Agency (BPBD) of Denpasar City. A risk map was prepared to visualize areas with higher susceptibility to structural damage, aiding in the prioritization of mitigation efforts, shown in **Figure 4.** The analysis assumes that structural vulnerability is influenced by environmental conditions, which align with principles in earthquake engineering and geotechnical studies. By integrating structural damage data with environmental parameters, this study provides a theoretical basis for risk assessment and mitigation strategies. The methodology incorporates standard GIS analysis techniques including buffer analysis and spatial overlay operations. Multiple data layers were processed using established geospatial analysis protocols to ensure accuracy. Data processing included careful cleaning and validation steps to maintain data integrity. The integration of multiple data sources required standardization of coordinate systems and spatial resolution.

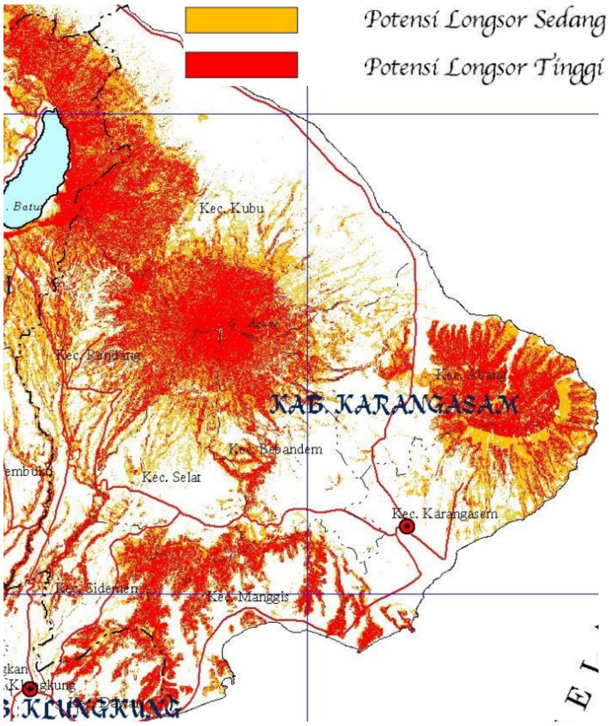
This approach ensures a holistic understanding of the factors contributing to building damage in Karangasem Regency, supporting informed decision-making for disaster risk reduction.



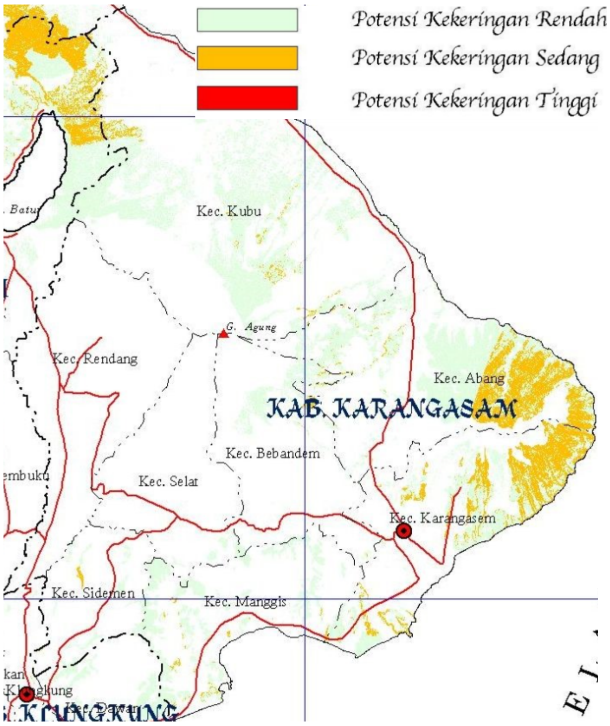
(a) Potential Strong Winds



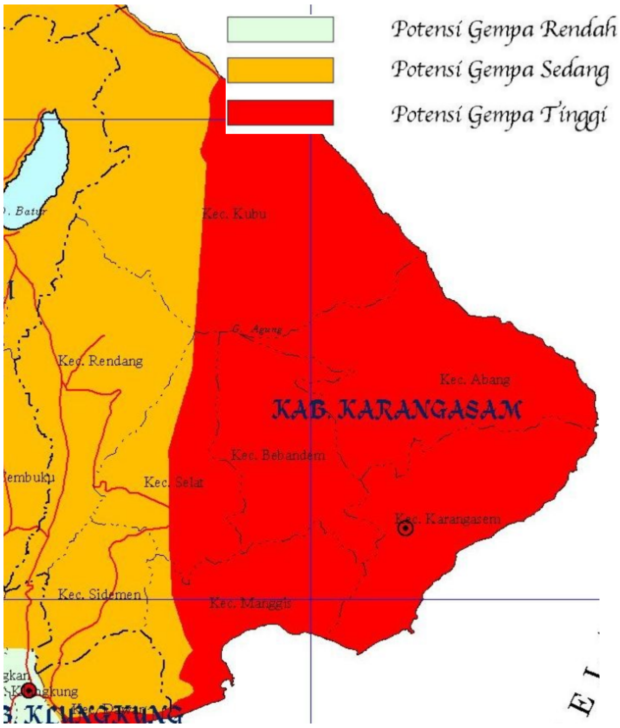
(b) Potential Floods



(c) Potential Landslides



(d) Potential Droughts



(e) Potential Earthquakes

Figure 4. The disaster risk map of Kabupaten Karangasem [5].

3 Results and Discussion

Based on the survey results in Abang Sub-district, the average damage to school buildings is 3.35%, categorized as LIGHT DAMAGE. Based on the survey results in Abang Sub-district, with a total of 67 buildings surveyed from 8 schools, the data shown in **Figure 5**.

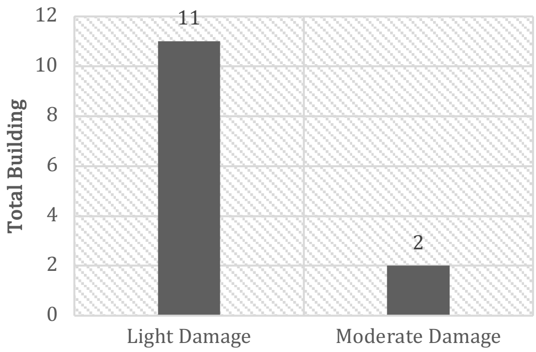


Figure 5. Survey results in Abang Sub-District

Based on the survey results in Bebandem Sub-district, the average damage to school buildings is 4.66%, categorized as LIGHT DAMAGE. Based on the survey results in Bebandem Sub-district, with a total of 51 buildings surveyed from 5 schools, the data shown in **Figure 6**.

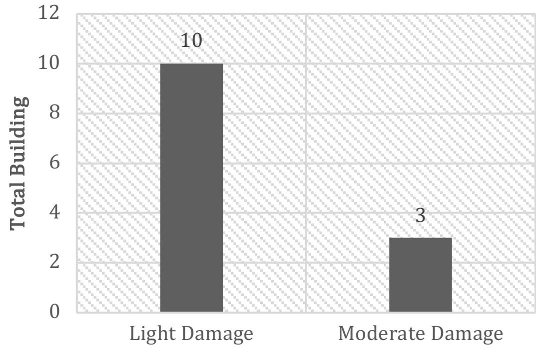


Figure 6. Survey results in Bebandem Sub-District

Based on the survey results in Karangasem Sub-district, the average damage to school buildings is 6.39%, categorized as LIGHT DAMAGE. Based on the survey results in Kubu Sub-district, with a total of 29 buildings surveyed from 6 schools, the data shown in **Figure 7**.

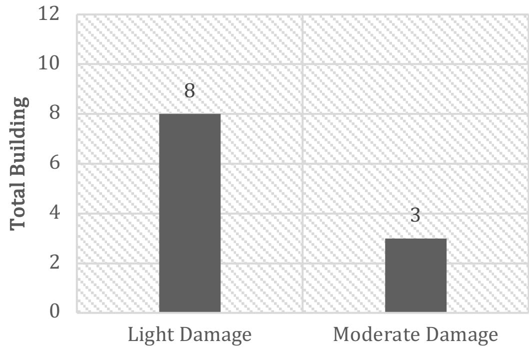


Figure 7. Survey results in Karangasem Sub-District

Based on the survey results in Kubu Sub-district, the average damage to school buildings is 4.36%, categorized as LIGHT DAMAGE. Based on the survey results in Kubu Sub-district, with a total of 44 buildings surveyed from 7 schools, the data shown in **Figure 8.** Survey results in Kubu Sub-District.

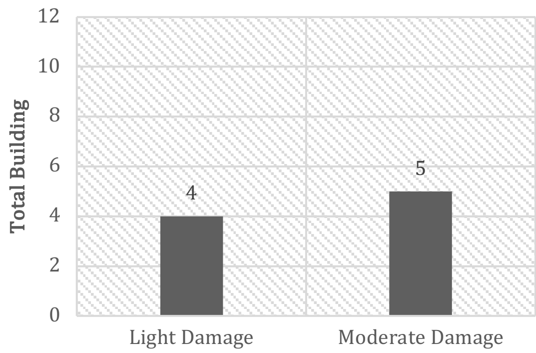


Figure 8. Survey results in Kubu Sub-District

Based on the survey results in Manggis Sub-district, the average damage to school buildings is 10.30%, categorized as LIGHT DAMAGE. Based on the survey results in Manggis Sub-district, with a total of 22 buildings surveyed from 4 schools, the data shown in **Figure 9**:

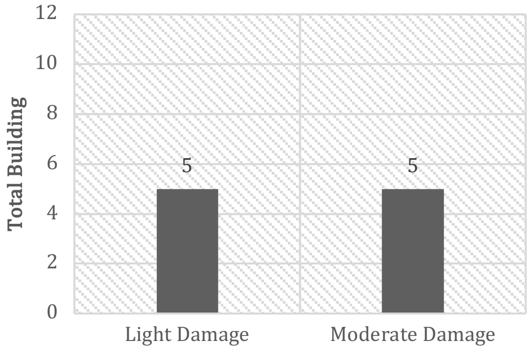


Figure 9. Survey results in Manggis Sub-District.

Based on the survey results in Selat Sub-district, the average damage to school buildings is 3.64%, categorized as LIGHT DAMAGE. Based on the survey results in Selat Sub-district, with a total of 37 buildings surveyed from 3 schools, the data shown in **Figure 10.**

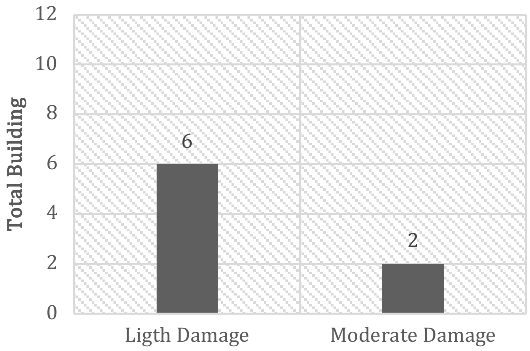


Figure 10. Survey results in Selat Sub-District.

Based on the survey results in Rendang Sub-district, the average damage to school buildings is 3.10%, categorized as LIGHT DAMAGE. With a total of 30 buildings surveyed from 3 schools, the data shown in **Figure 11**:

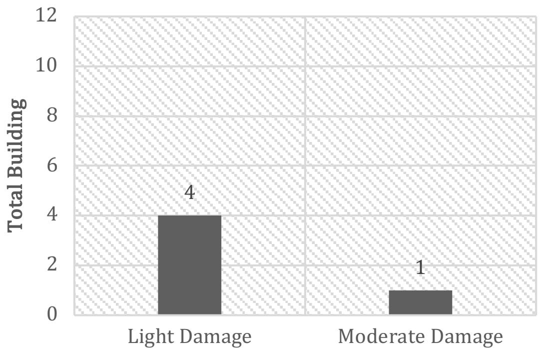


Figure 11. Survey Results in Rendang Sub-District.

Based on the survey results in Sidemen Sub-district, the average damage to school buildings is 4.50%, categorized as LIGHT DAMAGE. With a total of 32 buildings surveyed from 3 schools, the data shown in **Figure 11**:

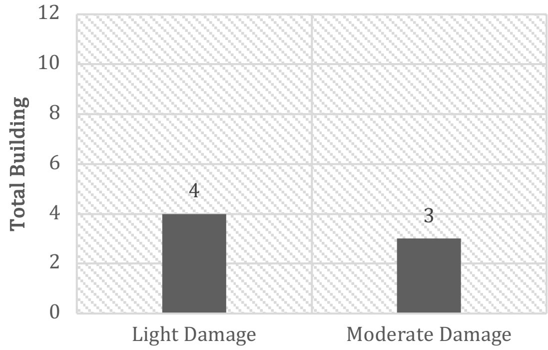


Figure 12. Survey Results in Sidemen Sub-District.

Based on the progress of the survey in 8 sub-districts in Karangasem Regency, the average damage to school buildings is predominantly categorized as LIGHT DAMAGE, which does not pose a significant risk to the safety of space usage. Based on the progress of the survey in 8 sub-districts in Karangasem Regency, with a total of 312 buildings surveyed from 39 schools, the data shown in **Figure 13** and **Figure 14**:

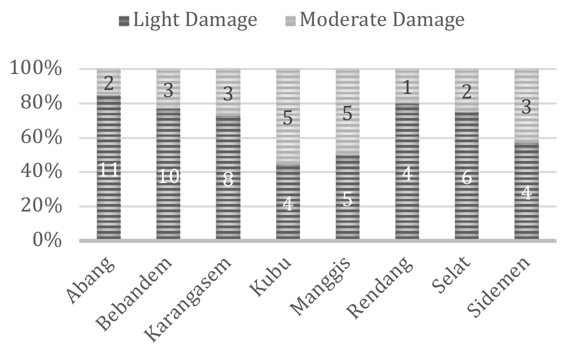


Figure 13. Survey results in Karangasem District.

The survey results revealed that 16.7% and 7.7% of facilities experienced light damage and moderate damage, respectively. The average damage percentage is at 5.01%. Despite having the fewest buildings, the areas with the highest damage percentages above the average are Manggis and Karangasem. If correlated with the potential disaster risks, both Manggis and Karangasem are exposed to high wind potential, higher than other sub-districts. In terms of landslide potential, Manggis and Karangasem are also in high-risk areas for landslides, even though they are relatively farther from Mount Agung compared to other sub-districts. The high earthquake potential also affects the entire areas of Manggis and Karangasem.

There are several theories that can explain how each of these factors interacts with the damage that occurs to infrastructure and housing. Building damage is caused by loads that exceed the structural capacity of the building. The potential for high winds, landslides, and earthquakes all increase this risk in different ways:

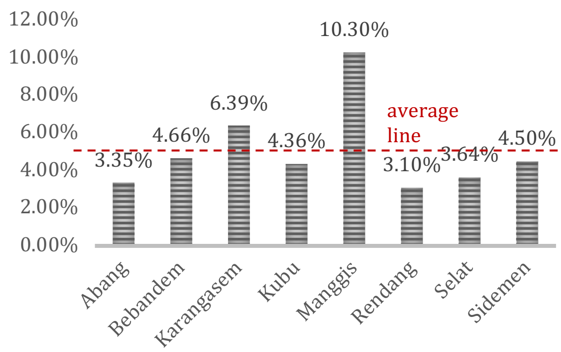


Figure 14. Damage presentation distribution.

- **High Winds**: High winds can cause structural damage to buildings, particularly to roofs and outer walls. In this theory, wind acts as a **dynamic load**, adding pressure to the building's structure. If the building is not designed with damping systems or lacks resistance to wind (for example, if it has a lighter structure or weaker materials), strong winds can cause significant damage. Areas like Manggis and Karangasem, which are exposed to high winds, will experience more severe damage if the infrastructure does not meet wind-resistant standards[7]–[9].
- **Landslides**: Landslides occur when slopes or land exposed to erosion are unstable. They can damage buildings located in landslide-prone areas. The **landslide damage theory** suggests that landslides can destroy a building's structure through **shear forces** and strong land displacement. If the building is located on a steep slope or near a landslide path, the impact can be severe. Although Manggis and Karangasem may be farther from Mount Agung, they are still in areas with high landslide risk due to the hilly and steep terrain[10]–[12].
- **Earthquakes**: Earthquakes create **seismic waves** that can exert tensile, compressive, and shear forces on buildings and infrastructure. Buildings that are not constructed with earthquake-resistant design standards are more vulnerable to severe damage. Earthquake damage can range from total structural collapse to partial damage, depending on the earthquake's intensity and the quality of construction. Given the high earthquake potential, both Manggis and Karangasem are exposed to significant damage risks for buildings that are not earthquake-resistant [13]–[15].

Building damage develops over time with ongoing exposure to natural disasters such as wind, landslides, and earthquakes. **Damage dynamics** suggests that damage is a **cumulative process.** The longer an area is exposed to certain types of disasters, the greater the damage over time:

- **High Winds**: The impact of high winds on buildings will increase if the buildings are repeatedly exposed to strong winds without efforts to repair or strengthen the structure [16]–[18].
- **Landslides**: Land exposed to repeated landslides will experience degradation of its quality and stability, increasing the potential for damage to the buildings in that area.
- **Earthquakes**: Frequent seismic activity in a given area can reduce the structural resilience of buildings over time, eventually leading to greater damage in the future.

The correlation between **damage** and **disaster potential** (high winds, landslides, and earthquakes) can be explained through these theories, which show that each of these types of disasters exerts **dynamic loads** that can cause damage to buildings, especially if those buildings are not designed to withstand them. In the context of Manggis and Karangasem, their exposure to various hazards—either simultaneously or consecutively—increases the potential for damage to infrastructure and housing in these areas.

4 Conclusion

This study underscores the significant vulnerabilities of educational facilities in Karangasem Regency due to environmental factors such as seismic activity, unstable soils, and extreme weather conditions. The findings reveal that a substantial portion of these facilities suffers from light to moderate damage, primarily in areas with high exposure to natural hazards like strong winds, landslides, and earthquakes. The integration of structural assessments with GIS-based environmental analysis has proven effective in identifying high-risk zones and understanding the spatial relationship between environmental conditions and building damage. Topographical challenges, particularly slope instability, were identified as key contributors to the severity of damage.

To improve the resilience of educational facilities in Karangasem, disaster-resistant construction should be prioritized, along with regular maintenance and inspections. Local authorities must incorporate disaster risk assessments into land-use planning to avoid high-risk areas. Additionally, disaster preparedness programs for staff and students are essential to ensure safety during natural disasters.

5 Acknowledgement

This study was funded by Hibah Penelitian Universitas Warmadewa. The authors also appreciate the support from Karangasem District authorities and contributors.

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