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Analysis Of Settlements Affected by Earthquake Hazards (A Case Study: Kawasan Bandung Utara)

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ABSTRACT

Indonesia, as a country located along the Pacific Ring of Fire, faces a high risk of earthquakes due to intense tectonic activity. Kawasan Bandung Utara, with the presence of the active Lembang Fault, is one of the regions with significant earthquake risk. This study aims to evaluate earthquake hazards in the area using a methodology that integrates earthquake hazard maps and residential maps through GIS overlay analysis. The results indicate a variation in earthquake hazard levels across the Northern Bandung Area, classified into three categories: low, medium, and high. The population distribution in Kawasan Bandung Utara is divided into four administrative regions: West Bandung Regency, covering an area of 3,481.55 hectares; Bandung City, covering an area of 2,812.28 hectares; Bandung Regency, covering an area of 1,561.25 hectares; and Cimahi City, covering an area of 1,262.52 hectares.

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1. INTRODUCTION

Earthquakes are complex and destructive natural phenomena caused by the release of accumulated energy within the Earth. Indonesia, as an archipelagic nation located along the Pacific Ring of Fire, is highly susceptible to earthquakes. The country's high tectonic activity, the presence of numerous active faults, and its strategic geographical location make Indonesia one of the countries with the highest earthquake risk in the world (Haryono et al., 2022).

Earthquakes not only cause physical damage to buildings and infrastructure but also lead to significant social, economic, and environmental impacts. Material losses, casualties, and psychological trauma are inevitable consequences of these events. Furthermore, earthquakes can trigger secondary disasters such as tsunamis, landslides, and liquefaction, which exacerbate the extent of damage (Marzocchi & Woo, 2020).

The National Disaster Management Agency (BNPB) reported that in 2023, there were 12 earthquakes in West Java, resulting in damage to 3,244 homes. This is because West Java is the province with the highest number of disaster occurrences in Indonesia (BNPB, 2023).

The Northern Bandung area, with the presence of the Lembang Fault as one of the active faults, is among the regions with high earthquake risk. The Lembang Fault has the potential to generate earthquakes of considerable magnitude, which could impact the Greater Bandung area and its surroundings. Rapid population growth and uncontrolled infrastructure development in this region further increase the vulnerability to earthquake disasters (Susilo et al., 2021).

The vulnerability of buildings to earthquakes is a crucial factor that influences the extent of damage caused by seismic events. Many buildings in Indonesia, including those in Northern Bandung, do not meet earthquake resistance standards. Additionally, soft soil conditions and undulating topography can worsen the impact of earthquakes (Rahmawati et al., 2022).

Earthquake disaster mitigation is a vital effort to reduce the risks and negative impacts of such events. Mitigation efforts can be implemented in various ways, including the development of earthquake risk maps, improvement of building quality, dissemination of information and education to the public, and the development of early warning systems (BNPB, 2023).

Research on earthquake hazards in the Northern Bandung area is essential. The findings of such research are expected to provide accurate information on earthquake risk levels, identify vulnerable areas, and offer policy recommendations and effective mitigation measures. Consequently, it is hoped that the preparedness of the community and the government in facing earthquake threats will be enhanced.

2. METHODS

2.1. Research Location

This research was located in Kawasan Bandung Utara, West Java. Kawasan Bandung Utara has 4 (four) administrative regions, one of which is part of the Bandung Regency area. Bandung Regency is located at coordinates 107°14' - 107°56' E and 60°49' - 7°19' S located in the highland region.

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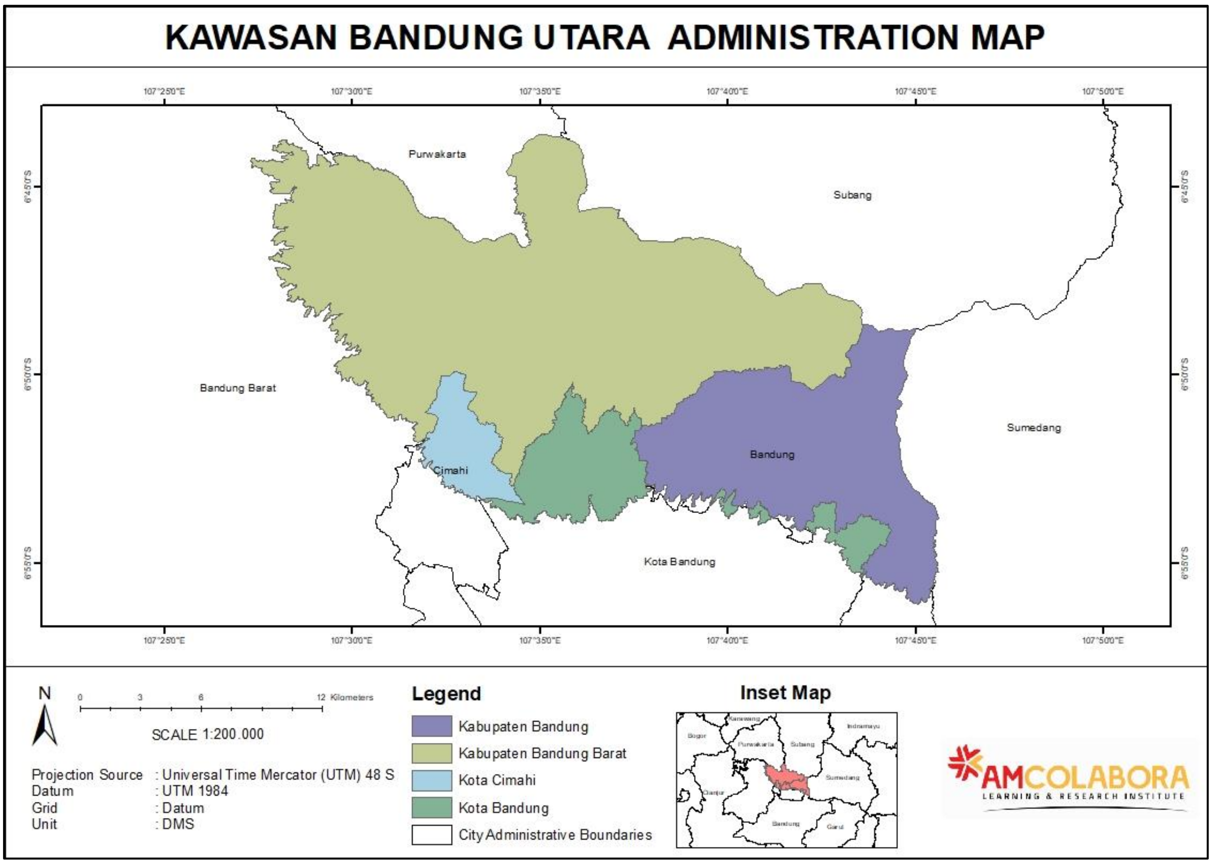

Figure 1. Administrative Boundaries Kawasan Bandung Utara

2.2 Tools and Materials

This research used several tools for data processing and materials consisting of imagery and spatial data. The tools and materials used are presented in Table 1 and Table 2. All available data were used in the creation of the earthquake hazard map affecting settlements in Kawasan Bandung Utara.

Table 1. Tools used in the research

Instrument Name	Function
ArcMap 10.8	Spatial data processing and map creation
Microsoft Excel	Processing results in the form of area

Table 2. Data used in the research

Data	Source
Administrative Boundary Shapefile of Kawasan Bandung Utara	BAPPEDA Jabar
Peak Ground Acceleration Map	PVMBG
Land Cover Map of Kawasan Bandung Utara	SPOT 7
Topographic Map	DEM
AVS30 Map	Conversion of Topography Class

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2.3 Data Processing and Analysis Phases

2.3.1 Data Processing and Attribute Data Entry

Earthquake hazard is based on the methodology developed by JICA (2015), which analyzes the intensity of surface shaking. The intensity of shaking at the surface is obtained by combining data on the intensity of shaking at the bedrock and data on the ground amplification factor. The bedrock shock intensity data (Earthquake Zone Map of 1.0" acceleration spectra response in SB for 10% probability of exceedance in 50 years) is derived from the Indonesian Earthquake Hazard Map (Ministry of Public Works, 2010), while the soil amplification factor data is obtained from the calculation of AVS30 (Average Shear-wave Velocity in the upper 30m) estimated based on the topographic class approach using DEM (Digital Elevation Model) raster data.

2.3.2 Classification

Based on the explanation of spatial definitions and the concept of earthquakes has been presented in the previous section, can provide an understanding that earthquake disaster studies can be conducted using spatial analysis methods. Then the data analysis techniques used in this research is image interpretation, buffering and overlay using arithmetic modeling. The value of each segment will be obtained by multiplying the weight and score. In order to obtain the zoning value, the following steps are required:

Table 3. Earthquake Intensity Rank Values

Earthquake Intensity	Level
VI – VII MMI	4
V- VII MMI	3
IV- V MMI	2
III – IV MMI	1

Source : Pusat Vulkanologi dan Mitigasi Bencana Geologi.

Table 4. The Topographic Class Conversion Table to become the value of AVS30

Topographic Class	AVS30 (m/s)	Topographic Class	AVS30 (m/s)	Topographic Class	AVS30 (m/s)
1	875	9	260	17	217
2	568	10	417	18	297
3	898	11	190	19	239
4	462	12	362	20	197
5	406	13	165	21	239
6	413	14	259	22	169
7	608	15	213	23	173
8	239	16	206	24	178

Source: JICA (2015)

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2.3.3 Overlay and Classification

This research begins by processing seismic data through topographic analysis using DEM data. Three topographic aspects are analyzed: slope gradient, slope texture, and slope shape. These characteristics are then used to classify the topography into 24 classes using semi-automatic techniques. These topographic classes are utilized as input to generate AVS30 data. The next step is to convert the AVS30 values into the Amplification Factor using the equation:

$$\mathbf{Log\ (G) = 1.35 - 0.47LogAVS30 \pm 0.18} \quad (1)$$

Where G is the ground amplification factor for peak ground acceleration (PGA). Subsequently, the surface shock intensity is calculated by multiplying the amplification factor with the shock intensity (peak acceleration) in the bedrock. The PGA/Peak Ground Acceleration value in the bedrock is used for the probability of exceeding 10% in 50 years.

The topographic characteristics are analyzed to create 24 topographic classes based on slope gradient, slope texture, and slope shape using semi-automatic techniques with DEM data. These classes are used as input to generate AVS30 data. The AVS30 values are then converted into the Ground Amplification Factor using the equation Log (G) = 1.35 – 0.47LogAVS30 ± 0.18, where G is the ground amplification factor for peak ground acceleration (PGA). This process involves calculating the surface shock intensity by multiplying the amplification factor value with the shock intensity in the bedrock. The PGA/Peak Ground Acceleration value in the bedrock for the probability of exceeding 10% in 50 years is obtained from the 2012 Indonesian Earthquake Source and Hazard Map. The final step is to create an earthquake hazard index based on the surface shock intensity. The hazard index is classified into three categories: Low ($H \leq 0.333$), Medium ($0.333 < H \leq 0.666$), and High ($H > 0.666$) according to SNI 8182: 2017.

The surface shock model is developed using a methodological approach based on geomorphological aspects depicted in the Digital Elevation Model (DEM). This data is then classified into topographic classes, which are subsequently converted into AVS30 classifications. The AVS30 classification results are used to calculate the Ground Amplification Factor, which is combined with the PGA value from the bedrock shock intensity map, resulting in the surface shock intensity value. The research flowchart is presented in Figure 2.

Land cover digitization is carried out using high-resolution SPOT 7 satellite imagery, enabling accurate identification and mapping of various land cover types. The digitization process begins with the downloading and preprocessing of SPOT 7 imagery, including geometric and radiometric corrections to ensure data quality and accuracy. Subsequently, the imagery is visually interpreted to identify land cover categories such as forests, agricultural land, urban areas, water bodies, and open land. Using ArcMap software, digitization is manually performed for each land cover category, ensuring that each boundary is clearly and precisely delineated.

Following the general land cover digitization, the next step is to specifically digitize the residential areas in Kawasan Bandung Utara. Utilizing ArcMap software, manually digitize the identified residential areas. Each building or group of buildings is marked, and their boundaries are meticulously drawn.

With the two obtained datasets, namely the earthquake hazard map and the residential map, the next step is to perform an overlay analysis to examine the relationship between these maps. This overlay process is conducted using GIS software, such as ArcMap, to combine the information from both maps into a comprehensive layer. Through overlay analysis, we can identify residential areas located within earthquake hazard zones. This

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information is crucial for disaster mitigation planning, as it allows authorities to develop more targeted risk reduction strategies, such as reinforcing structures in high-risk zones and planning efficient evacuation routes. Additionally, this overlay can be used to raise public awareness about earthquake risks and the steps they can take to protect themselves. By integrating earthquake hazard data and residential data, we can make more informed decisions to enhance the safety and resilience of communities in Kawasan Bandung Utara. The research flowchart is presented in Figure 2.

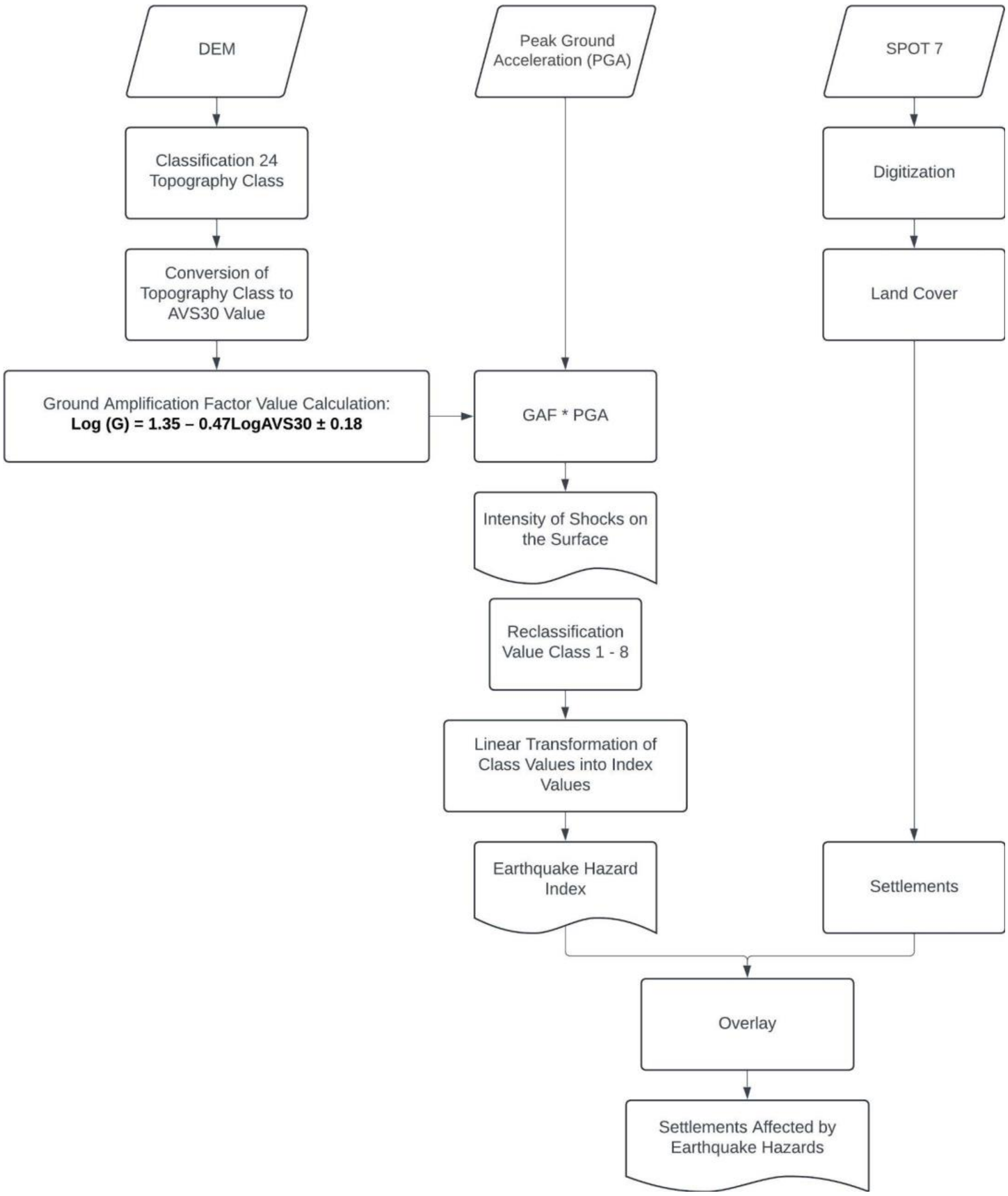

Figure 2. Research Flowchart

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3. RESULTS AND DISCUSSION

3.1. Peak Ground Acceleration

Table 5. Earthquake Intensity in Kawasan Bandung Utara, along with its Area

No.	Earthquake Intensity	Area (Ha)
1	VI – VII MMI	40.152,13

Source: Pusat Vulkanologi dan Mitigasi Bencana Geologi.

The analysis of Peak Ground Acceleration (PGA) values in Kawasan Bandung Utara indicates that the entire study area, encompassing 40,152.13 hectares, is classified as having a Modified Mercalli Intensity (MMI) of VI to VII. This classification implies a significant potential for the region to experience substantial ground shaking during seismic events (Figure 3).

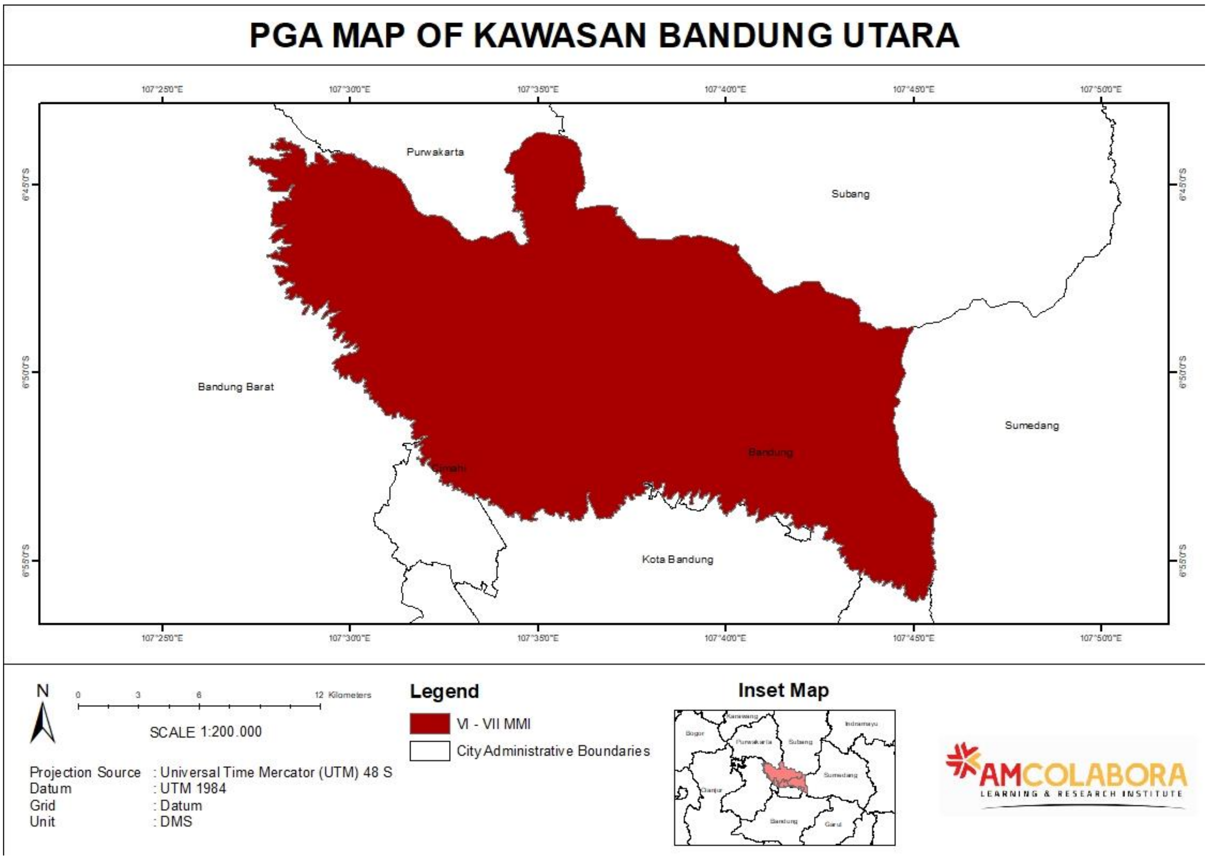

Figure 3. PGA Map of Kawasan Bandung Utara

3.2. Topography

Topographic class 7 covered the largest area at 8,438.30 hectares, followed by class 8 at 6,509.72 hectares. Classes 9 and 10 also had significant areas of 5,013.59 hectares and 6,826.35 hectares, respectively. Areas with higher elevations, represented by classes 11 to 14, had decreasing areas, ranging from 4,592.71 hectares to 1,613.92 hectares. On the other hand, classes 15 to 18, representing the highest elevations, covered only very small areas,

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ranging from 695.61 hectares to 6.33 hectares. The area of topography of each class in Kawasan Bandung Utara can be seen in Table 6.

Table 6. Topographic Class in Kawasan Bandung Utara, along with its Area

No.	Topographic Class	Area (Ha)
1	7	8.438,30
2	8	6.509,72
3	9	5.013,59
4	10	6.826,35
5	11	4.592,71
6	12	2.968,71
7	13	2.608,22
8	14	1.613,92
9	15	695,61
10	16	271,72
11	17	99,15
12	18	6,33

Source: Result of Topographic Map Processing, Kawasan Bandung Utara, 2024

The spatial distribution of topography in Kawasan Bandung Utara can be seen in Figure 4.

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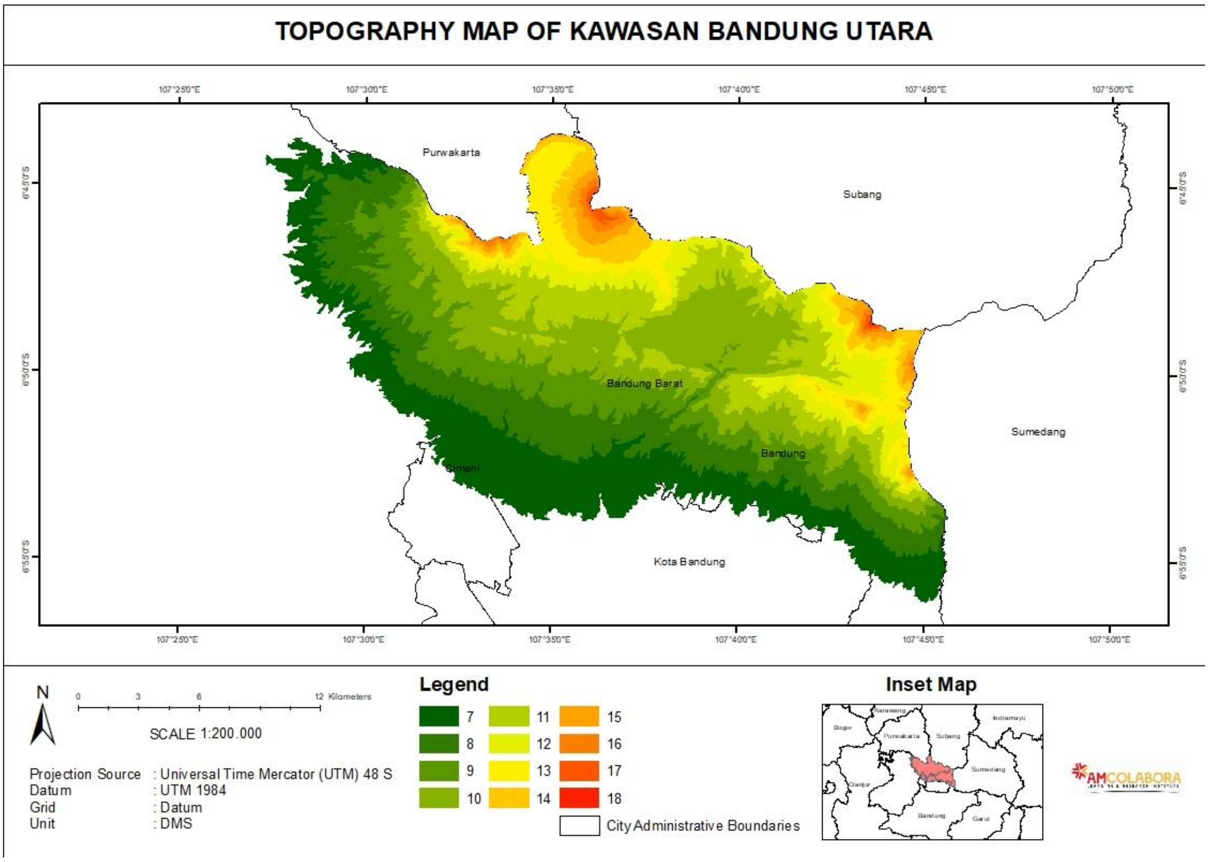

Figure 4. Topography Map of Kawasan Bandung Utara

3.3. AVS30

AVS30 values in the Northern Bandung area are categorized into twelve classes. The most extensive AVS30 class is AVS30 608, covering an area of 8,438.30 hectares, followed by AVS30 239 with a coverage of 6,509.72 hectares, and AVS30 417 with 6,826.35 hectares. On the other hand, the three classes with the smallest coverage are AVS30 206 with an area of 271.72 hectares, AVS30 217 with 99.15 hectares, and AVS30 297 with 6.33 hectares. These AVS30 values are derived from topographic class conversion.

Table 7. AVS30 in Kawasan Bandung Utara, along with their Area

No.	AVS30 Values	Area (Ha)
1	608	8.438,30
2	239	6.509,72
3	260	5.013,59
4	417	6.826,35
5	190	4.592,71
6	362	2.968,71

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No.	AVS30 Values	Area (Ha)
7	165	2.608,22
8	259	1.613,92
9	213	695,61
10	206	271,72
11	217	99,15
12	297	6,33

Source: Result of conversion of topography Class Map Processing, Kawasan Bandung Utara, 2024.

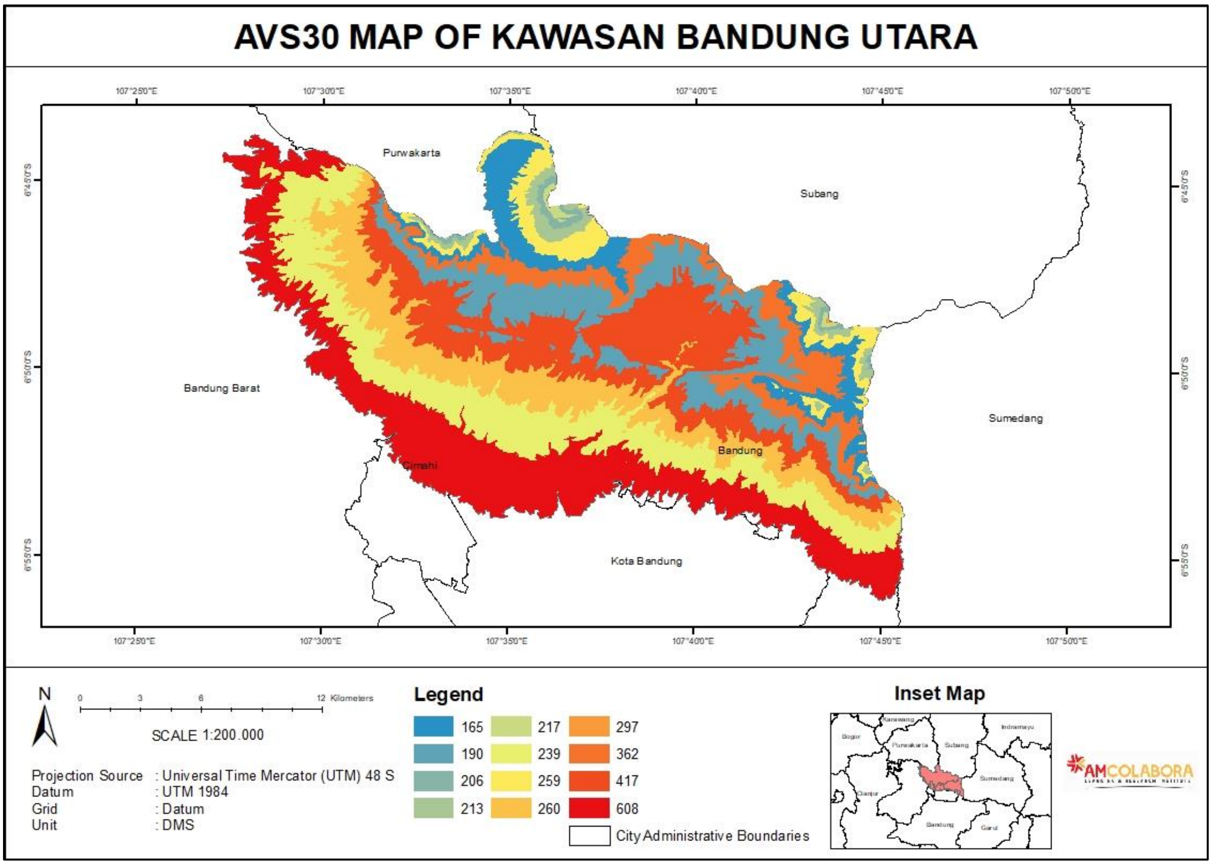

Figure 5. AVS30 Map of Kawasan Bandung Utara

3.4. Land Cover

There are nine land cover classes in the Northern Bandung area. The most extensive land cover in this region is Dry Fields, with an area of 15,386.31 hectares. The second-largest land cover is Settlements, covering 9,117.63 hectares, followed by Plantation Forests with 6,933.75 hectares. The land cover types with the smallest areas are Shrubs, covering 140.66 hectares, Paddy Fields with 66.90 hectares, and Water Bodies with 47.49 hectares.

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Table 8. Land Cover in Kawasan Bandung Utara, along with their Area

No.	Land Cover	Area (Ha)
1	Dry Fields	15.386,31
2	Dry Land Agriculture	3.729,72
3	Dryland Forests	3.499,29
4	Paddy Fields	66,90
5	Plantation	715,72
6	Plantation Forests	6.933,75
7	Settlements	9.117,63
8	Shrubs	140,66
9	Water Body	47,49

Source: Result of Land Cover Map Processing, Kawasan Bandung Utara, 2024.

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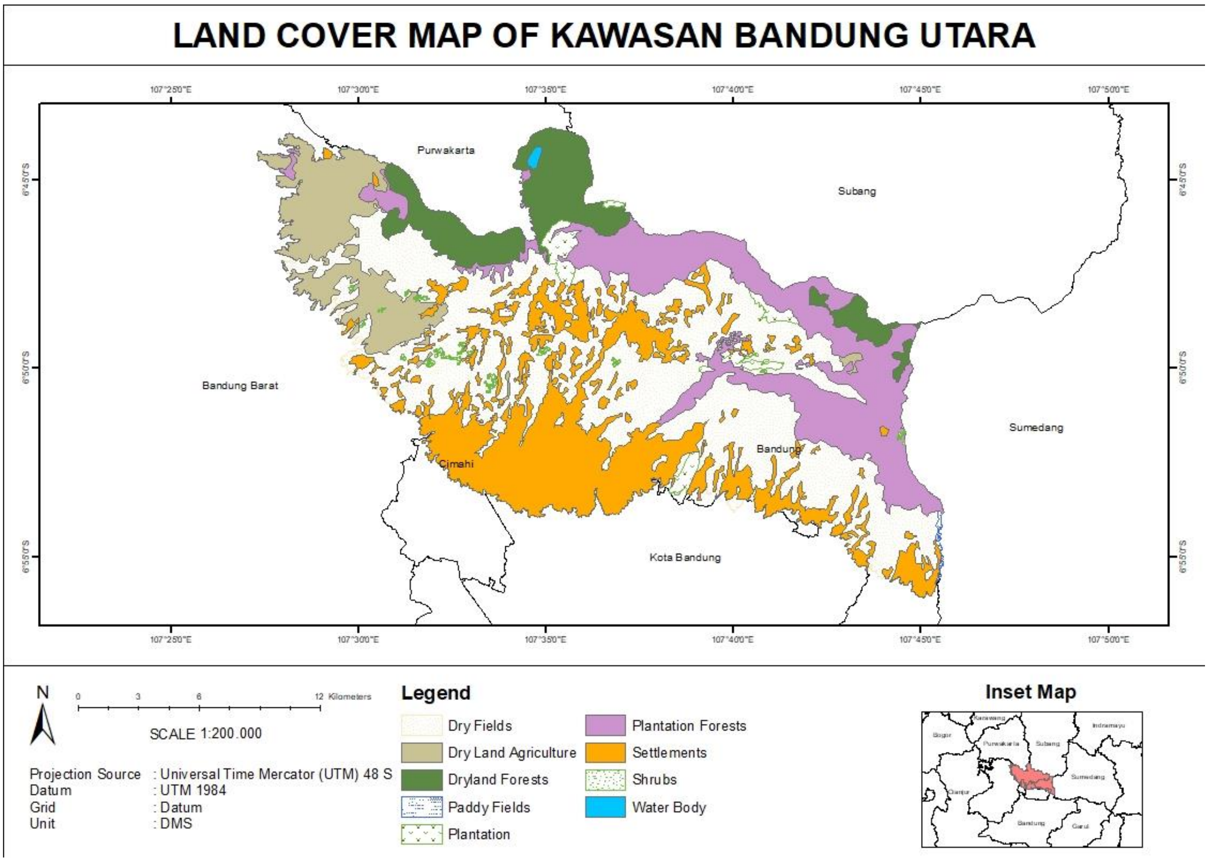

Figure 6. Land Cover Map of Kawasan Bandung Utara

3.5. Settlements Distribution

Distribution of settlements in the Northern Bandung area is administratively spread across four regencies and cities: Bandung Regency, West Bandung Regency, Cimahi City, and Bandung City, each with varying area sizes. The largest settlement distribution is found in the West Bandung Regency, covering an area of 3,481.55 hectares. This is followed by Bandung City, with the second-largest settlement distribution of 2,812.28 hectares. The third-largest settlement distribution is in Bandung Regency, covering 1,561.25 hectares, followed by Cimahi City, with an area of 1,262.52 hectares.

Table 9. Settlements Distribution in Kawasan Bandung Utara, along with their Area

No.	City/Regency	Area (Ha)
1	Kabupaten Bandung	1.561,25
2	Kabupaten Bandung Barat	3.481,55
3	Kota Cimahi	1.262,52
4	Kota Bandung	2.812,28

Source: Result of Settlements Map Processing for Kawasan Bandung Utara, 2024.

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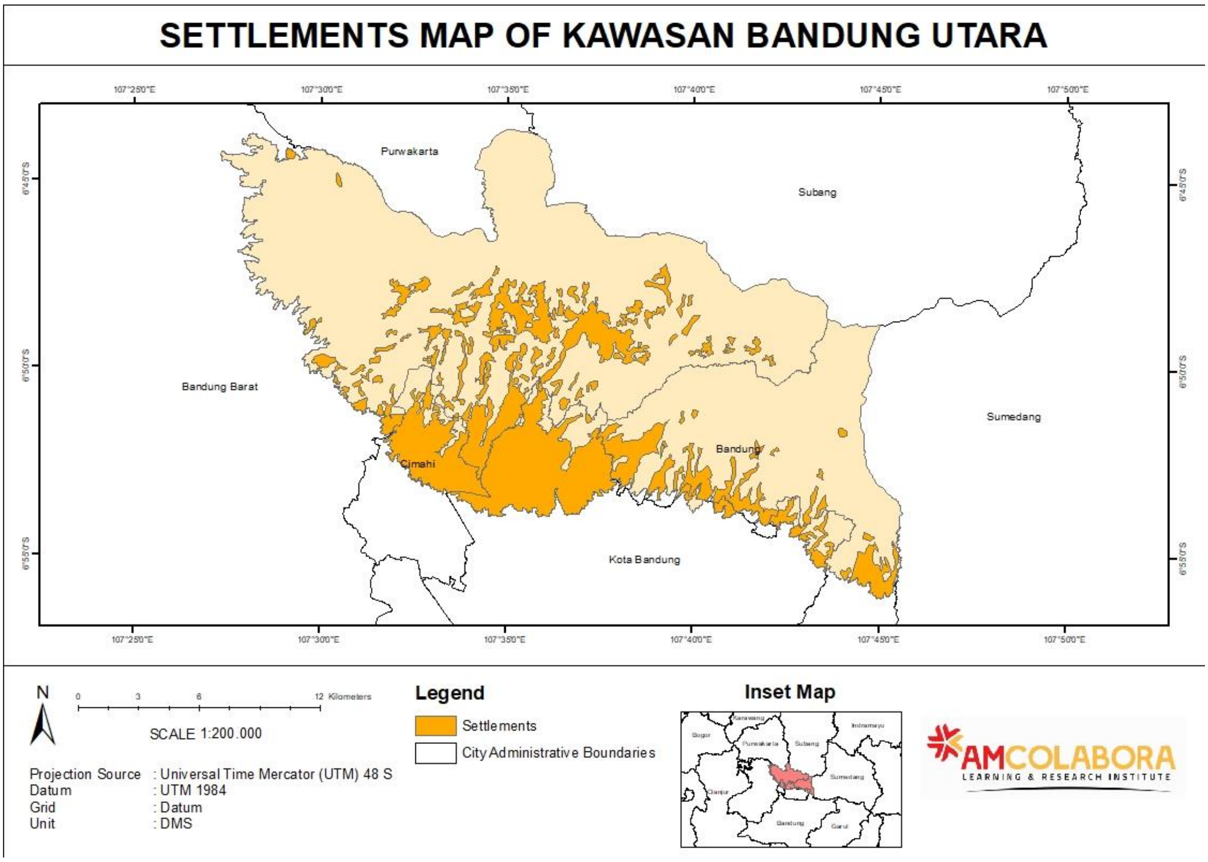

Figure 7. Settlements Map of Kawasan Bandung Utara

3.6. Earthquake Hazard

Earthquake hazard in the Northern Bandung Area is categorized into three classes, distributed across four regencies and cities. The Northern Bandung Area is predominantly classified as a medium hazard zone, covering an area of 23,043.51 hectares. This is followed by a low hazard zone, which spans 10,029.61 hectares. Additionally, there is a high hazard zone covering an area of 7,016.87 hectares.

Table 10. Earthquake Hazard Classes in Kawasan Bandung Utara, along with their Area

No.	Hazard Class	Area (Ha)
1	Low	10.029,61
2	Medium	23.043,51
3	High	7.016,87

Source: Earthquake Hazard Map Processing for Kawasan Bandung Utara, 2024.

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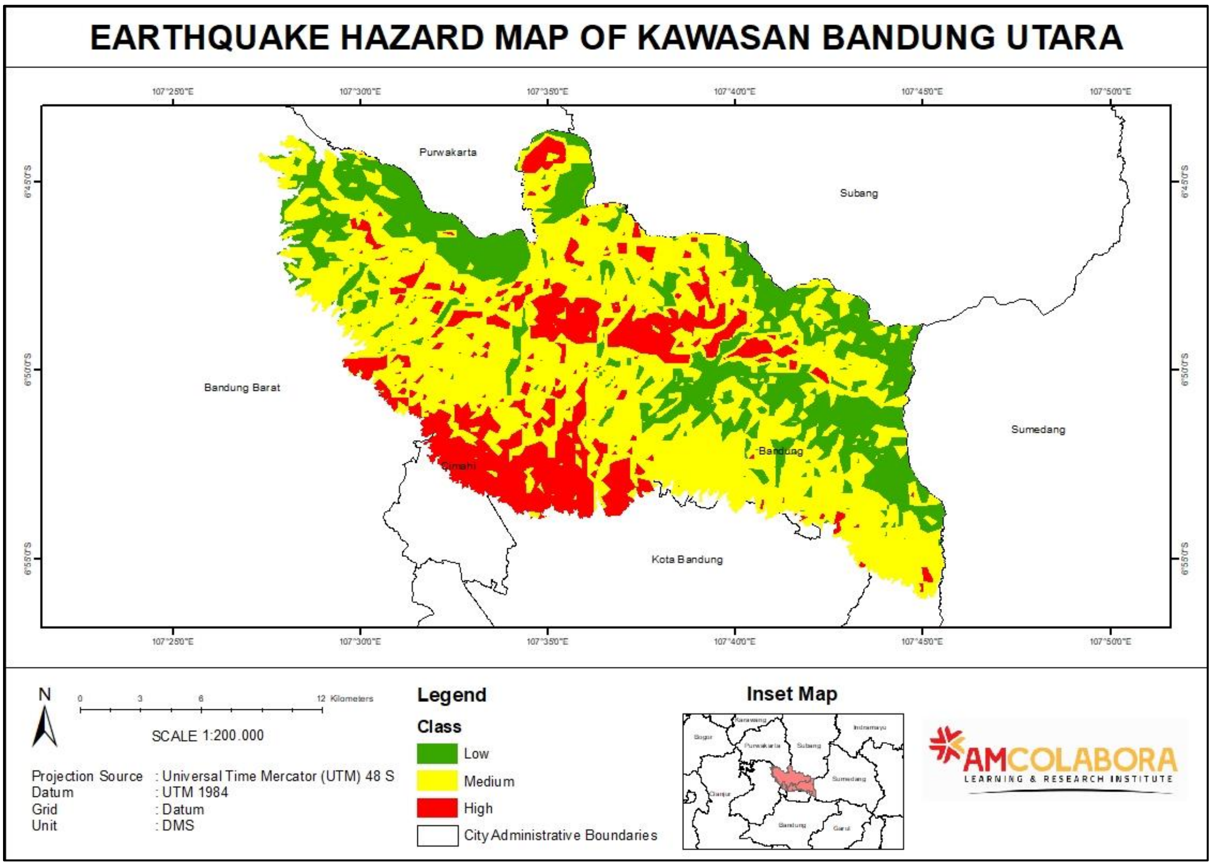

Figure 8. Earthquake Hazard Map of Kawasan Bandung Utara

3.7. Estimation of Settlements Affected by Earthquake Hazard

Estimation of settlements affected by earthquake hazards in the Northern Bandung Area was subsequently analyzed based on administrative regions. Bandung Regency is predominantly classified as a medium hazard zone, covering an area of 1,504.19 hectares, followed by a high hazard zone with an area of 33.85 hectares, and a low hazard zone with an area of 23.20 hectares. West Bandung Regency is primarily categorized as a high hazard zone, covering an area of 1,804.33 hectares, followed by a medium hazard zone with an area of 1,668.64 hectares, and a low hazard zone with an area of 8.58 hectares. Cimahi City is mostly classified as a high hazard zone, spanning 1,036.95 hectares, followed by a medium hazard zone with an area of 225.56 hectares. Bandung City is predominantly categorized as a high hazard zone, covering an area of 1,712.71 hectares, followed by a medium hazard zone with an area of 1,096.85 hectares, and a low hazard zone with an area of 2.72 hectares.

The administrative region with the largest high hazard class area is West Bandung Regency, which occupies an area of 1,804.33 hectares, ranking first. This is followed by Bandung City with an area of 1,712.71 hectares, ranking second. Cimahi City ranks third with an area of 1,036.95 hectares. Finally, Bandung Regency ranks fourth with an area of 33.85 hectares.

Table 11. Estimation of Settlements Affected by Earthquake Hazards in Kawasan Bandung Utara, along with their Area

No.	City/Regency	Hazard Class	Area (Ha)

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1	Kabupaten Bandung	Low	23,20
		Medium	1.504,19
		High	33,85
2	Kabupaten Bandung Barat	Low	8,58
		Medium	1.668,64
		High	1.804,33
3	Kota Cimahi	Medium	225,56
		High	1.036,95
4	Kota Bandung	Low	2,72
		Medium	1.096,85
		High	1.712,71

Source: Results of Estimation of Settlements Affected by Earthquake Hazards for Kawasan Bandung Utara, 2024.

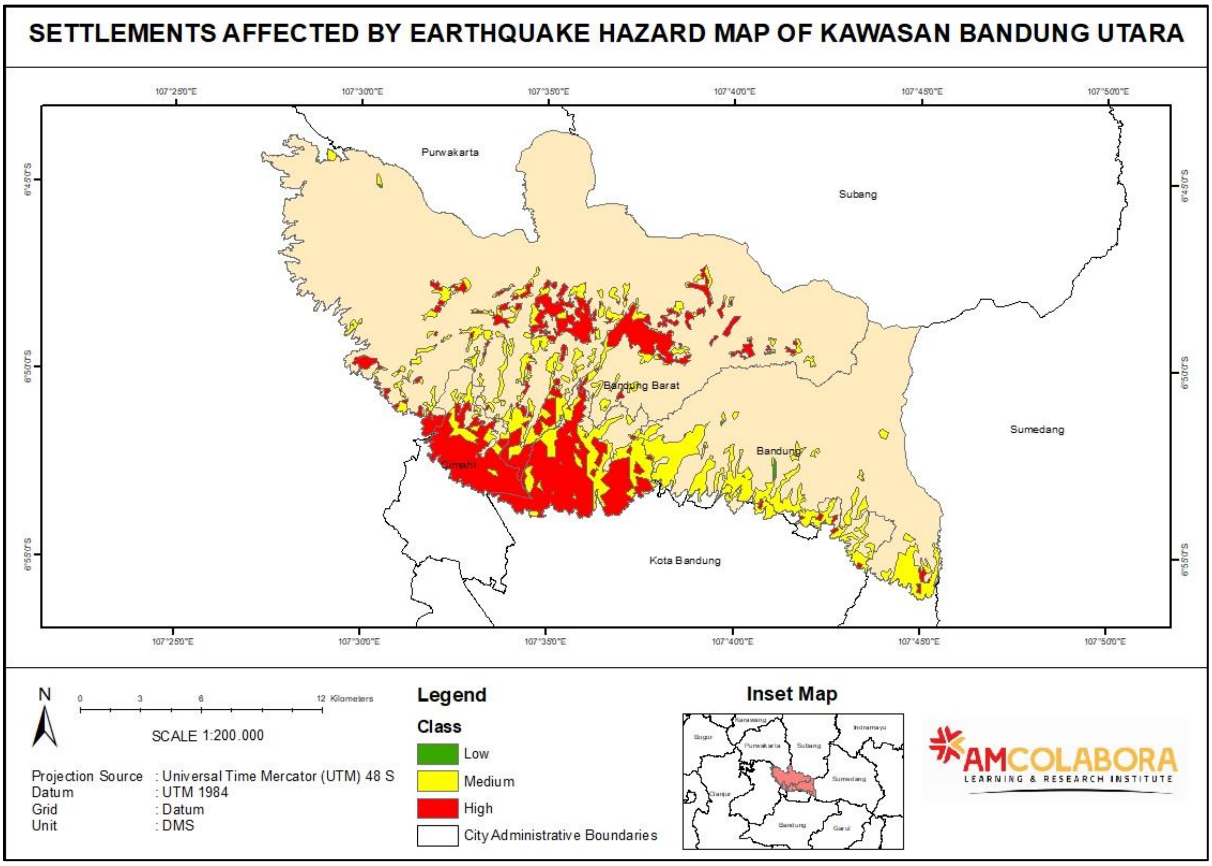

Figure 9. Estimation of Settlements Affected by Earthquake Hazards of Kawasan Bandung Utara

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3.8. Earthquake Hazard in Kawasan Bandung Utara

The variation in earthquake hazard levels across Bandung Utara necessitates a targeted approach to urban planning and disaster management. In high-risk zones, strict building codes and retrofitting of existing structures are crucial to minimize potential damage (Sun et al., 2021). Additionally, emergency response plans should be tailored to address the specific risks in these areas, including evacuation routes and public awareness campaigns (Fauzan et al., 2023).

Medium-risk zones should also be the focus of mitigation efforts, with particular attention to infrastructure that may be vulnerable to moderate seismic activity. In contrast, low-risk zones can serve as strategic locations for critical facilities and infrastructure, provided that they are designed with resilience in mind (Rahmawati et al., 2022).

Overall, the map underscores the need for a comprehensive earthquake preparedness strategy that considers the varying levels of risk within Bandung Utara. By integrating this hazard assessment into urban planning and disaster management efforts, the region can enhance its resilience to seismic events (Kusumawati et al., 2020).

Factors that influence earthquake hazard levels in Bandung Utara include the activity of active faults, soil type, and land slope. The Lembang Fault, one of the most prominent active faults in the region, has the potential to generate significant earthquakes that could impact the Greater Bandung area (Susilo et al., 2021). Soil type also plays a critical role, as soft and unconsolidated soils are more susceptible to amplifying seismic waves, increasing the risk of structural damage compared to hard and compact soils (Sun et al., 2021). Furthermore, the sloping and hilly terrain in parts of Bandung Utara increases the likelihood of landslides and ground movements during earthquakes, further exacerbating the hazards (Prakoso et al., 2022).

3.9. Settlements Affected by Earthquake Hazard in Kawasan Bandung Utara

The settlements affected by earthquake hazards in Bandung Utara are categorized into three hazard levels: low, medium, and high. The hazard levels are determined by overlaying maps of key variables, such as the Ground Acceleration Factor (GAF) map and the Peak Ground Acceleration (PGA) map, to produce an earthquake hazard map. This map is then overlaid with a map of settlements, resulting in a prediction of hazard levels for specific areas (Rahmawati et al., 2022).

Areas classified as high-risk, marked in red, indicate the highest potential impact from an earthquake, where settlements face significant risk of damage. Medium-risk zones, marked in yellow, represent areas with moderate potential impact, where settlements may experience moderate to severe damage. Meanwhile, low-risk zones, marked in green, indicate the lowest potential impact, though these areas are not entirely immune to seismic activity. The map serves as a basis for zoning and the development of strategies for controlling and monitoring the region, with the ultimate goal of minimizing the adverse impacts of earthquakes.

4. CONCLUSION

The population distribution in the Northern Bandung Area is divided into four administrative regions: West Bandung Regency, covering an area of 3,481.55 hectares; Bandung City, covering an area of 2,812.28 hectares; Bandung Regency, covering an area of 1,561.25 hectares; and Cimahi City, covering an area of 1,262.52 hectares.

The earthquake hazard in the Northern Bandung Area is classified into three categories: low, medium, and high. The medium hazard class dominates the Northern Bandung Area,

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covering 23,043.51 hectares, followed by the low hazard class covering 10,029.61 hectares, and the high hazard class covering 7,016.87 hectares.

The estimation of settlements affected by earthquake hazards in the Northern Bandung Area was analyzed based on administrative regions. Bandung Regency has 23.20 hectares in the low hazard class, 1,504.19 hectares in the medium hazard class, and 33.85 hectares in the high hazard class. West Bandung Regency has 8.58 hectares in the low hazard class, 1,668.64 hectares in the medium hazard class, and 1,804.33 hectares in the high hazard class. Cimahi City has 225.56 hectares in the medium hazard class and 1,036.95 hectares in the high hazard class. Bandung City has 2.72 hectares in the low hazard class, 1,096.85 hectares in the medium hazard class, and 1,712.71 hectares in the high hazard class.

The findings of this research underscore the importance of earthquake disaster mitigation efforts in the Northern Bandung Area. Both the community and the government must enhance earthquake preparedness by conducting evacuation drills, constructing earthquake-resistant buildings, and providing emergency equipment.

Local governments should incorporate the earthquake hazard map into regional spatial planning. High-hazard zones should be avoided when developing critical infrastructure, including residential areas.

The earthquake hazard map should be continuously updated and refined based on the latest data. Further research on active fault activities and soil characteristics in the Northern Bandung Area is also necessary to improve the accuracy of the earthquake hazard map.

5. ACKNOWLEDGMENT

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6. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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