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Marc Lin F. Abonales

Department of Civil Engineering, Caraga State University

Robert A. Romero

Graduate School of Engineering and Architecture, Ateneo de Davao University

Stephanie Mae S. Albores

Department of Civil Engineering, Caraga State University

Sicenio D. Abera, Jr.

Department of Civil Engineering, Caraga State University

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Marc Lin F. Abonales^{1,2,3}, Robert A. Romero², Stephanie Mae S. Albores^{1,3}, Sicenio D. Abera, Jr.^{1,3},
Erwin D. Mendoza^{1,3}

¹Department of Civil Engineering, Caraga State University

²Graduate School of Engineering and Architecture, Ateneo de Davao University

³Caraga Center for Geo-Informatics (CCGeo), Caraga State University

Corresponding Author email: mlfabonales@carsu.edu.ph

Abstract:

On February 10, 2017, a 6.7 magnitude earthquake struck Surigao City, causing severe structural damage, unsafe airport runways, and collapsed bridges and roads. This event highlighted the city's lack of earthquake engineering and land-use planning. This study addresses the need for risk mitigation by creating a seismic microzonation map for Surigao City. Using seven thematic maps—Basement Topography, Geology, Geomorphology, Landslide Zonation, Site Classification, Spectral, and Peak Ground Accelerations—the study employs the Analytical Hierarchy Process (AHP) to assign weights with input from five respondents. Integrating these layers in QGIS, the resulting map classifies areas into Low, Moderate, and High vulnerability categories, emphasizing Peak Ground Acceleration (21.3%) in earthquake hazard assessment. The map indicates that most of Surigao City's mainland is in the moderate seismic hazard category.

Keywords: Analytical Hierarchy Process, Geographic Information System, Seismic Microzonation

1. INTRODUCTION

Surigao City, an urban area and known to be a 3rd class city, has 245.34 square kilometers land area and is populated by 154,137 people based on the 2015 Census of Population [10]. The city is classified as a 3rd Class Component City with a population density of 573 per sq. km. based on the 2010 NSO census [10]. Situated at the northeastern part of Mindanao, the city is surrounded by main earthquake generators, and it is known to be a seismically active area which experiences small to large magnitude earthquakes from the past.

Last February 10, 2017, a 6.7 magnitude earthquake shook the city where the epicenter at a depth of 10 kilometers is located 16 kilometers from the shore northwest of Surigao City [11]. The magnitude 6.7 earthquake is one of the most destructive earthquakes ever recorded in the city and it caused significant damage to buildings and other structures. Damages like large cracks in buildings and airport runways, some bridges and roads are no longer safe for land travel, and even a schoolhouse had collapsed [12]. Since the earthquake had damaged many structures, all of these may have led to a lack of concern in earthquake engineering in the design of structures and in land-use planning management both are principal approaches to earthquake loss mitigation [1]. Because of this, the City Government must prepare risk mitigation instruments to mitigate future damages due to earthquake.

The city is experiencing earthquakes recently and there must be an immediate action to lessen the loss of lives caused by earthquakes and these are one of the most damaging geological hazards. Hazards associated with earthquakes are called seismic hazards and one of the fields of civil engineering that involves the mitigation of these hazards is earthquake engineering. During and after an earthquake, source and path characteristics, local geological and geotechnical settings, and kind of structures are the main factors of earthquake damage [2][9]. To mitigate this type of hazard, a useful tool must

be considered which will be used for seismic hazard assessment and risk evaluation. Seismic microzonation represents a highly useful tool for land management, design of structures and for emergency planning. Seismic microzonation divides a city or a region into smaller zones having different potential for seismic hazards [3]. This is the first step in mitigation study for earthquake hazards and it requires other multidisciplinary fields like geology, geotechnical and structural engineering [1]. A first grade seismic microzonation will be prepared since only existing documents will be utilized in making the desired map.

To lessen future damages due to earthquake, the goal of this study is to prepare a first grade seismic microzonation map of Surigao City to be used in urban planning and building design especially for the future projects and constructions in the area.

2. METHODOLOGY

2.1 Preparation of the Thematic Maps

Seven thematic maps will be used in the creation of the seismic microzonation map of Surigao City. These are: Basement topography – A representation of the Earth's surface that illustrates the variations in height or elevation of the terrain. This will serve as the base map on the GIS platform.

1. Geology – This shows the distribution of different types of rock and surficial deposits and the locations of geologic structures [13].
2. Geomorphology – The form or surface features of the landscape [14].
3. Landslide zonation – This shows the distribution of the severity of landslide hazard potential in an area [6][15].
4. Site classification – This describes or represents the variety of soil types.
5. Spectral acceleration – This represents the acceleration response of either a structure or the

ground at a specific frequency in the event of an earthquake. This pivotal parameter plays a crucial role in the assessment and efficient design of structures to endure seismic forces [8].

6. Peak ground acceleration – This depicts the level of ground motion based on the magnitude of a certain earthquake.

2.2 Reclassification of each Thematic Map

Before the integration of maps, each thematic map must be reclassified to represent data in a way that is more meaningful for a particular purpose. It is the process of assigning new values to the pixels or features of a raster or vector dataset based on predefined criteria. This is a fundamental operation in GIS analysis that allows for the transformation of original data into a format that better suits the analysis or visualization goals. It involves assigning vulnerability classes to different areas based on their susceptibility to seismic hazards, thus contributing to the development of a seismic microzonation map.

For thematic maps where the criterion is a given range, the equal-interval classification method will be implemented which is used to segment the range of attribute values into subranges of uniform size. In this classification approach, the number of intervals (or subranges) will be defined, and the data is automatically divided accordingly [16]. While the other thematic maps where the criteria are defined by different descriptions, it will be reclassified by a Geologist.

2.3 Assigning Weights to the Thematic Maps

Saaty's Analytical Hierarchy Process (AHP) will be used and performed in assigning weight for each thematic map. It is a decision-making process which is based on the discernment of the user. To conduct pairwise comparisons, a questionnaire is crafted and distributed to gather opinions from various respondents. The scale used in this process spans from one to nine, where a rating of one signifies that the two elements are considered equal or equally significant. In contrast, a rating of nine indicates that one element is significantly more important than the other in the pairwise matrix [21][22]. When employing the AHP method, the typical range of experts involved in the analysis falls between 2 and 100. There isn't a stringent minimum sample size requirement for AHP, though some research has utilized sample sizes within the range of 4 to 9, with only a limited number of studies employing samples exceeding 30 individuals. In general, interviewing more than 7 to 10 experts can lead to redundant information collection [7].

A total of five respondents will participate in completing the AHP form, representing diverse roles within the relevant domains. These include one member from the City Disaster Risk Reduction and Management Office (CDRRMO), a Civil Engineer from the City Engineer's Office (CEO), a Civil Engineer from the Department of Public Works and Highways – Surigao del Norte 2nd District Engineering Office (DPWH-SDN 2ND DEO), a Civil Engineer and Geologist from the academic sector. The data analysis procedure comprises several key steps. Initially, a pairwise comparison matrix, referred to as matrix *A*, is derived from the interview data. Subsequently, the eigenvector of matrix *A* is calculated and denoted as '*w*' [4].

The geometric mean method will be used in calculating the eigenvector. Applying the geometric mean method involves initially computing the geometric mean of each

row in the pairwise comparison matrix. This resulting geometric mean serves as the priority value for the factor corresponding to that row. Subsequently, normalize these priority values by dividing each of them by the total sum of priorities obtained from the geometric means. It is essential to ensure that the cumulative sum of all priorities equals 1. In the subsequent phase, to verify the outcomes of the AHP, the consistency ratio (*CR*) is computed utilizing the formula $CR = CI/RI$, wherein the consistency index (*CI*) is assessed through the following formula:

$$CI = \frac{\text{principal eigenvector} - n}{n - 1} \quad (1)$$

Where *n* is the dimension of the matrix and to get the principal eigenvector, a matrix multiplication will be performed for pairwise comparison matrix and eigenvector. Then, from the multiplication result, a new eigenvector will be calculated by dividing a cell value of the matrix multiplication result vector by the corresponding priority vector cell. The principal eigenvalue can be obtained by the average of the resulting vector. The value of *RI* is associated with the matrix dimension and it is important to highlight that a consistency ratio below 0.10 confirms the acceptability of the comparison results.

2.4 Integration of Maps on GIS Platform

After obtaining the weights and reclassifying each thematic map, the values are then incorporated on a GIS platform using QGIS. The integration of seven thematic layers is done by union and overlay operations in QGIS to obtain the seismic microzonation map of Surigao City [5].

3. RESULTS AND DISCUSSION

3.1 Preparation of the Thematic Maps

The maps were obtained from different agencies for the creation of the seismic microzonation map of Surigao City. The following are the obtained maps to be used.

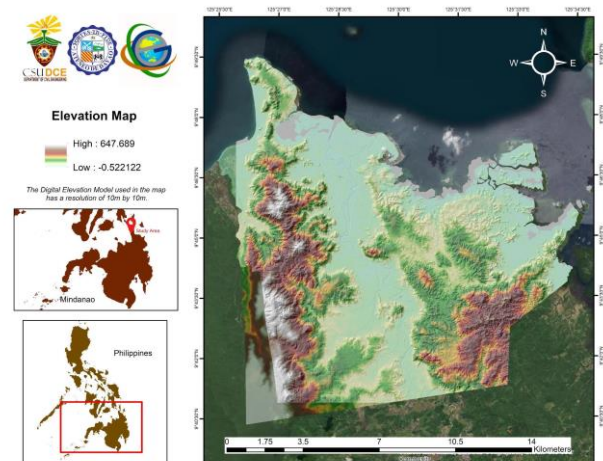


Fig. 1. Basement Topography/Elevation Map

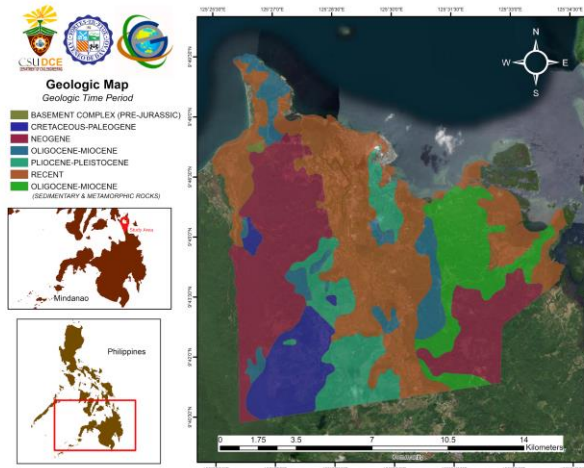


Fig. 2. Geologic Map

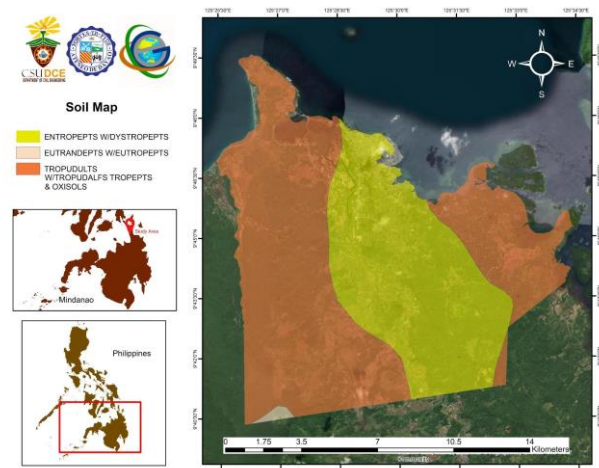


Fig. 5. Site Classification/Soil Map

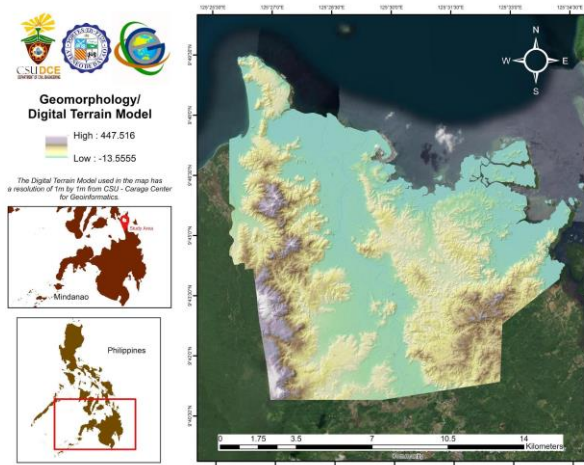


Fig. 3. Geomorphology/Digital Terrain Model Map

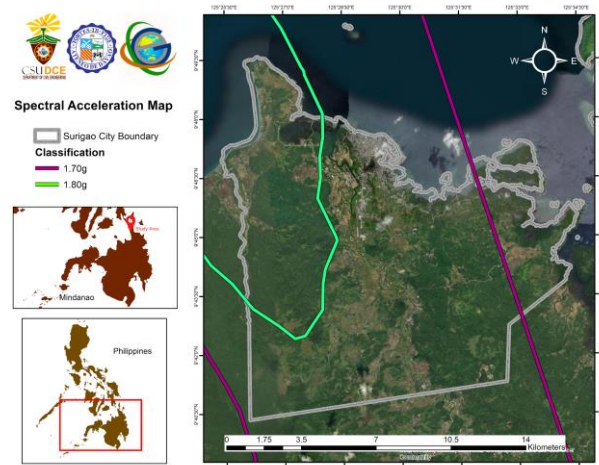


Fig. 6. Spectral Acceleration Map

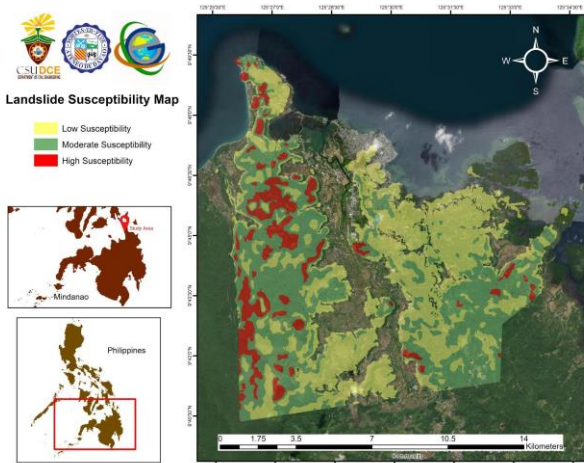


Fig. 4. Landslide Zonation/Susceptibility Map

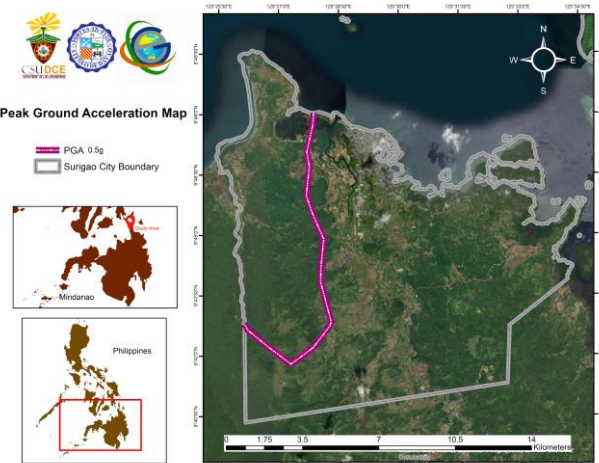


Fig. 7. Peak Ground Acceleration Map

3.2 Reclassification of each Thematic Map

The maps, sourced from various agencies, underwent reclassification, a process that involves assigning new values to the pixels or features of a raster or vector dataset according to predetermined criteria. Three specific criteria—Low, Moderate, and High—were considered, forming the basis for assigning vulnerability classes to different areas or criteria based on their susceptibility to seismic hazards. Table 1 provides the outcomes of the reclassification applied to each thematic map.

3.3 Weight of each Thematic Map

The weight of each thematic map was computed using the Analytical Hierarchy Process (AHP) based on a survey answered by five respondents. The ratings provided by the respondents were analyzed to determine the respective weights for each thematic map, which are crucial for the development of the seismic microzonation map. The computed weights reflect the relative importance of each map as assessed by the experts. The analysis also included a consistency check to ensure the reliability of the responses. The Consistency Ratio (CR) values from five respondents is shown in Table 2.

Table 1. Reclassification of each thematic map

Thematic Map	Criteria	Reclassification
Basement Topography	0 to 575	0 to 191.667 – Low
		191.668 to 383.334 – Moderate
Geology	383.335 to 575 – High	
	Basement Complex (Pre-Jurassic)	Low
	Cretaceous-Paleogene	Low
	Oligocene-Miocene (Sedimentary & Metamorphic Rocks)	Low
	Oligocene-Miocene	Moderate
	Neogene	High
	Pliocene-Pleistocene	High
	Recent	High
Geomorphology	-12.9 to 445.51	-12.9 to 139.903 – Low
		139.904 to 292.706 – Moderate
Landslide Zonation	Low Susceptibility	292.707 to 445.51 – High
	Moderate Susceptibility	Low
	High Susceptibility	Moderate
	Tropudults w/ tropudalfts & oxisols	High
Site Classification	Eutrandepts w/ eutropepts	Low
	Entropepts w/ dystropepts	Moderate
Spectral Acceleration	0.1g to 2.13g	0.1g to 0.78g – Low
		0.79g to 1.46g – Moderate
		1.47g to 2.13g – High
Peak Ground Acceleration	0.1g to 0.6g	0.1g to 0.267g – Low
		0.268g to 0.434g – Moderate
		0.435g to 0.6g – High

Table 2. Consistency Ratio (CR) Values from the respondents

Respondent	CR value
CDRRMO Member	9%
Civil Engineer from CEO	9%
Civil Engineer from DPWH-SDN 2ND DEO	8%
Civil Engineer from the academic sector	3%
Geologist from the academic sector	8%

These values indicate that the judgments were consistent, and the derived weights are reliable which is below 0.10 or 10% confirms the acceptability of the comparison results [4].

The following are the results of the computed weights of each thematic map using AHP:

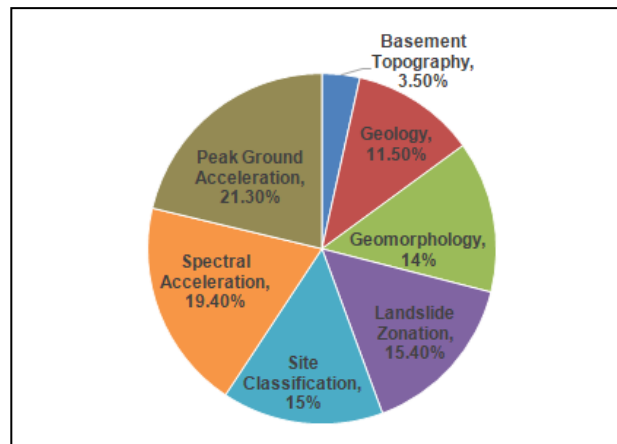


Fig. 8. Weight of each Thematic Map

3.4 Seismic Microzonation Map of Surigao City

After reclassifying each thematic map and computing the weights, the values are then incorporated on QGIS to obtain the seismic microzonation map of Surigao City. Two versions of the map were made with different color schemes or legends.

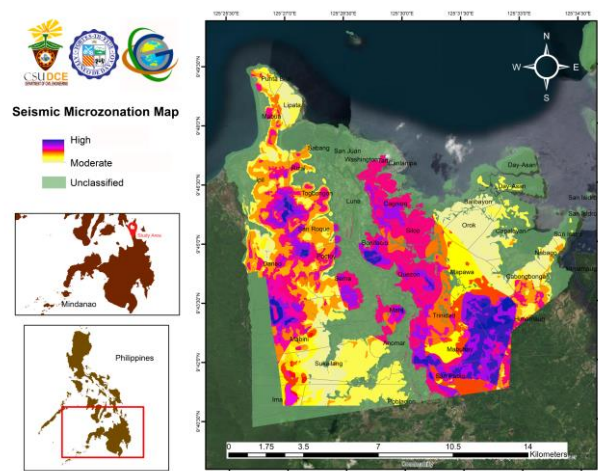


Fig. 9. Seismic microzonation map of Surigao City using a color gradient.

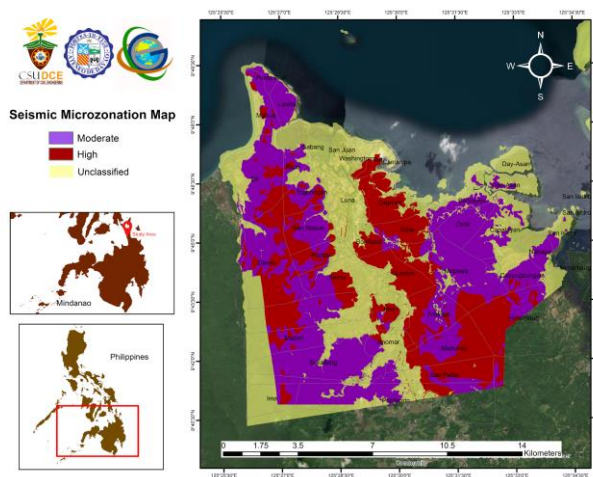


Fig. 10. Seismic microzonation map of Surigao City using two color legends.

Upon combining all the maps with their respective weights, the resulting map indicates a range from moderate to high, as the data points are predominantly high. It also indicates that the "Unclassified" category was used which refers to areas where the level of seismic activity has not been assessed or categorized. This is due to insufficient data in certain areas of the mainland of Surigao City for several thematic maps, making it impractical to include them in the process of creating the seismic microzonation map. Figure 9 shows the detailed representation of the different zones based on variations in seismic hazard and ground shaking characteristics. Typically, a color gradient is employed, where lighter or warmer colors indicate higher levels of hazard, and darker or cooler colors represent moderate levels of hazard. This color scheme helps visually distinguish areas with varying degrees of susceptibility to seismic activity. The map is predominantly represented by cooler colors which represent moderate level of seismic hazard. Based on Federal Emergency Management Agency (FEMA), this indicates that an area is susceptible to earthquakes, but the expected ground shaking and potential damage are not as high as in regions with higher levels of seismic hazard [20]. On the other hand, Figure 10 shows a simple visualization of moderate and high levels of seismic hazard. By computing the area for each hazard level, moderate level is much larger with 61.197 sq. km. than high level with 43.081 sq. km.

It indicates that most of the mainland area of Surigao City is moderate level where the term "moderate" in the context of seismic hazard is typically associated with a mid-range level of risk. This indicates that an area is susceptible to earthquakes, but the expected ground shaking and potential damage are not as high as in regions with higher levels of seismic hazard.

For the design of structures, regions with moderate seismic hazard must follow established building codes that include seismic design provisions. These codes provide guidelines for designing structures to resist the forces generated by moderate seismic events. Areas with a high seismic hazard must have more stringent building codes and standards. These codes often require structures to meet higher levels of seismic resistance, considering the increased risk of strong ground shaking. High seismic hazard areas may incorporate base isolation or damping systems.

Derived from Figure 10, Table 3 is crafted to pinpoint barangays positioned in high and moderate-risk areas. Among these, five barangays fall within the high-risk zone, and nine barangays fall within the moderate-risk zone. Additionally, twenty-one barangays are situated within areas ranging from high to moderate risk.

Table 3. List of barangays situated in high and moderate risk zones.

Seismic Susceptibility	Barangays
High	Bonifacio, Cagniog, Quezon, Silop, Taft Anomar, Cabongbongan, Danao, Himamaug, Ima, Ipil, Mabini, Mabua, Mabuhay, Mapawa, Mat-I, Poblacion, Poctoy, Quezon, Rizal, San Pablo, San Roque, Serna, Taft, Togbongon, Trinidad
High to Moderate	Balibayon, Capalayan, Day-Asan, Lipata, Nabago, Orok, Punta Bilar, San Isidro, Sukailang
Moderate	

As reported by PHIVOLCS, Surigao City encountered ground shaking recorded at PHIVOLCS Earthquake Intensity Scale (PEIS) VII, indicating a destructive level [19]. Destructive means that destruction entails widespread fear, prompting people to flee outdoors. Maintaining balance on upper floors becomes challenging, as heavy objects and furniture may tip over. Large church bells may chime, and older or poorly constructed buildings often experience significant damage. Even some well-built structures may sustain minor damage. Cracks may emerge in dikes, fish ponds, road surfaces, or concrete hollow block walls. Limited occurrences of liquefaction, lateral spreading, and landslides are evident. Trees are forcefully shaken during this seismic event [17].

Based on PHIVOLCS Special Report on 10 February 2017 Ms 6.7 Surigao del Norte Earthquake [18], significant ground shaking resulted in widespread damage, with reports indicating severe impacts on both government and private structures, facilities, and infrastructures. Non-engineered houses, in particular, bore the brunt of the destruction. The range of damages varied from complete to partial collapses of structures, as well as minor cracks on floors or walls and shear cracks on column-wall or column-beam joint failures.

Investigations revealed that many severely damaged buildings had utilized substandard materials or demonstrated poor construction quality. Likewise, signs of liquefaction were noted to cluster around the surface rupture zones or near them, as well as along coastal and floodplain areas. In contrast, earthquake-induced landslides were scarce, modest in size, and had shallow seating. These hazards had a moderate impact, which could be linked to the relatively brief duration of ground shaking, lasting between 10 to 15 seconds during the Ms 6.7 seismic event. The effects of the earthquake, as indicated in the reports from PHIVOLCS, correlate with the generated seismic microzonation map.

4. CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

In conclusion, the comprehensive analysis of seismic hazards in Surigao City involved the integration of various thematic maps obtained from reputable sources. The maps covered aspects such as Basement Topography/Elevation, Geologic composition, Geomorphology/Digital Terrain Model, Landslide Zonation/Susceptibility, Site Classification/Soil types, Spectral Acceleration, and Peak Ground Acceleration. The reclassification process, based on vulnerability criteria (Low, Moderate, and High), provided valuable insights into the seismic susceptibility of different areas. The weights assigned to each thematic map, determined through the Analytical Hierarchy Process (AHP) with input from relevant experts, revealed that Peak Ground Acceleration held the highest priority (21.3%), signifying its crucial role in assessing earthquake hazards. The resulting seismic microzonation map, combining all thematic maps and their respective weights, indicated moderate to high susceptibility, with a notable emphasis on the "Unclassified" category due to data limitations in certain areas. The visualization of seismic hazard levels demonstrated that most of Surigao City's mainland area falls within the moderate seismic hazard category. In summary, the seismic hazard assessment for Surigao City provides a nuanced understanding of the city's vulnerability, enabling informed decision-making for city planners, engineers, and residents to mitigate the potential impact of earthquakes.

4.2 Recommendations

The following recommendations are proposed to further improve the seismic microzonation map of Surigao City in future research:

1. **Prioritize Peak Ground Acceleration (PGA):**
Given its identified significance as the most crucial factor in assessing earthquake hazards, special attention should be directed towards monitoring and understanding Peak Ground Acceleration. Continuous updates and refinements of PGA data will contribute to a more accurate assessment of seismic vulnerability.
2. **Enhance Data Collection in Unclassified Areas:**
Acknowledging the challenges posed by insufficient data in certain mainland areas categorized as "Unclassified," efforts should be intensified to gather relevant information for a more thorough assessment. Additional surveys, monitoring, and collaboration with relevant agencies can help fill these data gaps, ensuring a more comprehensive seismic microzonation map. Also, inclusion of clustered islands must be considered in the creation of seismic microzonation map as it will be used in the design and construction of structures in this area.
3. **Public Awareness and Preparedness Programs:**
Irrespective of the seismic hazard level, it is imperative to implement robust public awareness and preparedness programs. Communities in both moderate and high hazard areas should be educated on earthquake risks, evacuation procedures, and the importance of adhering to building codes. This proactive approach can significantly reduce the potential impact of seismic events.
4. **Collaborative Decision-Making:**
City planners, engineers, and relevant stakeholders should engage in collaborative decision-making processes. By considering localized seismic hazard information, critical infrastructure, including schools,

hospitals, and emergency services, can be strategically located to minimize potential damage and ensure the safety of residents. The seismic microzonation map must also be presented to key stakeholders, including the Surigao City Local Government Unit, the City Disaster Risk Reduction and Management Office, and the City Engineer's Office. The presentation of the map serves as a vital step in conveying valuable insights into the seismic vulnerability of specific zones within Surigao City, enabling informed decision-making and strategic planning for disaster preparedness and mitigation measures. It is imperative to ensure that the information is clearly communicated and easily comprehensible to facilitate collaborative efforts in enhancing the city's resilience against seismic events.

5. Structural Design Considerations:

Emphasize the importance of tailored structural design based on seismic hazard levels. Structures in regions with moderate seismic hazards should adhere to established building codes, while those in high hazard areas should incorporate more stringent standards, potentially utilizing base isolation or damping systems to reduce seismic forces.

6. Continued Research and Collaboration:

Foster ongoing collaboration between academic institutions, government agencies, and engineering professionals to continually advance research in seismic hazards. Regularly update and refine seismic microzonation maps based on the latest data and technological advancements.

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