GIS based seismic vulnerability assessment in tourist attractions area: a case study in Bukit Tinggi, Pahang, Malaysia

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Abstract

To decrease the impact of an earthquake, it is critical to analyse the risk by assessing the hazard and vulnerability ahead of time. The goal of this study is to examine the seismic susceptibility of the Bukit Tinggi area and then categorise it based on the degree of risk. Eleven indicators belonging to different group parameters were used in this study. Final seismic vulnerability maps of the Bukit Tinggi area demonstrate a pattern of vulnerability degree with 12% of the area designated as very low vulnerability, 26% as low vulnerability, 35% as moderate vulnerability, 25% as high vulnerability and 7% as very high vulnerability.

The findings of this research provide preliminary information on the seismic risk in the study region which may be useful to stakeholders in developing mitigation methods and risk-informed development plans for Bukit Tinggi's community resilience.

Keywords: Seismic vulnerability assessment, earthquake, disaster risk reduction.

Introduction

An earthquake, which refers to the phenomenon of sudden slip on a fault resulting in ground shaking and radiating the seismic energy triggered by the slip, volcano, magmatic activity, or other sudden stress changes in the earths[19], is one of the natural disasters that affects economic losses and people all over the world. Earthquake disasters produce surface ruptures and transmit seismic waves which can create cascade effects such as tsunamis, landslides and liquefaction as well as structural damage to buildings due to vibrations. From the record, earthquake disasters cause an average of 20,000 deaths worldwide each year[17].

Furthermore, natural disasters may have an immediate impact on the tourism industry, perhaps discouraging tourists from visiting the affected area due to concerns about their safety. The possibility of loss of life, injury including the potential for lost or damaged assets, which could occur to a system, society, or community in a specific period, is known as disaster risk.

Furthermore, the risk factor can be determined and regulated based on the function of hazard, exposure, susceptibility and society's ability to cope in order to lower the risk. Vulnerability is an important aspect in the measuring framework for assessing the level of risk in a certain place in order to comprehend disaster risk. Estimating the potential consequences and impact of the population and assets exposed to natural hazards is critical[3]. The findings of the vulnerability assessment can be translated and displayed in the form of maps or figures for specific indicators as communication tools for disaster management decision-making. The vulnerability of an individual, a community, assets, or systems can be determined based on physical, social, economic and environmental factors or processes that can increase their exposure to the impact of hazards[20] and can be divided into three progressive levels: root causes, dynamic pressures and unsafe conditions[22].

Furthermore, the vulnerability notion is a combination of direct and indirect catastrophe damage elements such as exposure, susceptibility and coping capacity[10]. It demonstrates that vulnerability assessment is an important component of disaster risk measurement tools for feeding the decision-making planning process, adapting methods and improving disaster preparedness policy.

In addition, previous researchers introduced several methodologies for analysing the vulnerability parameters including Analytic Hierarchy Process (AHP) and Global Information System (GIS) methods[11,13], Vulnerability Index Method (VIM)[11,14], a combination of Multiple Criteria Decision Analysis (MCDA), Multi-Criteria Evaluation (MCE), Logistic Regression (LR) Fuzzy logic regression[23] and Categorical Principal Component Analysis (CATPCA) in IBMSPSS 20 software[25].

Depending on the criterion supplied and suitability of the region of interest, each of these approaches has strengths and weaknesses in assessing vulnerability. As a result, utilising indicator-based methodologies and the combination of GIS and AHP methods, this study attempts to analyse the susceptibility of earthquake-prone areas with an emphasis on tourism attractions hubs.

Material and Methods

Study area: Bukit Tinggi is located in Pahang's Bentong District. Apart from the well-known Genting Highland,

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Cameron Highland and Frazer Hills, it is a popular highlands gateway. With a pleasant temperate temperature of 22°C and a green mountainside vista, the French-styled Colmar Tropical and Zen Japanese Village are Bukit Tinggi's most popular tourist destinations. The area is bordered on the north by Genting Highland, on the west by Selangor, on the south by Janda Baik and on the east by Bentong town. According to census data from 2010, it is located in the Bentong sub district and has a total population of 85,300 people. In general, between 2000 and 2010, the population of Bentong sub district increased by roughly 2.2 percent [7]. Agriculture and tourism are the main economic activities in the area and Bukit Tinggi and Janda Baik were the main suppliers of ginger in the region. In 2016, over 7.4 kilograms of ginger were produced, generating approximately RM64 million in revenue[4]. In addition, the state tourism bureau estimated that 1.06 million tourists would visit Bukit Tinggi between 2015 and 2020.

The Bukit Tinggi research region was chosen due to the presence of the Bukit Tinggi fault line which has shown signs of reactivation in earlier studies as well as the appearance of an epicentre in the area[18] (Fig. 1). Furthermore, the Bukit Tinggi area has been designated as one of the primary tourist attraction hubs and future residential zone extensions in Bentong District by the year 2035, according to the Bentong District Local Plan 2035. As a result, prior to any future development, the level of seismic risk and vulnerability in area should be examined in order to improve catastrophe resilience while also reducing damage.

Vulnerability Conditional Factor: The case study was chosen because of Bukit Tinggi's growing appeal as a tourist destination, which has prompted developers, local agencies and Government agencies to expand the study area's urbanisation. As a result, before expanding, more research into the area's preparation can be done by identifying the risk areas that are prone to seismic disasters. This study relied on five key sources of information to determine the danger area: 1) seismic data, 2) topographical data, 3) fault map, 4) land use map and 5) satellite imagery data.

The data was separated into three categories: physical, environment and coping, with each of these parameters containing many indicators. Based on a literature analysis of prior studies, a total of eleven indicators and their vulnerability indicators were found from a mix of physical, environmental and coping capability parameters that fit within the area of interest. Buffering, distance, overlay, slope, zonal and classification were used to analyse these factors utilising Geographical Information Systems (GIS) analysis tools.

Physical Parameters

(i) Land use: Land use activities contribute to the area's susceptibility with high-impact land uses such as residential, industrial and tourism giving the area a high level of sensitivity. By referring to prior research[10,25], the study area was divided into several types of land use such as residential, industrial, agriculture land and forest, based on restricted use, low effect use, medium impact use and high impact use (fig. 2a).

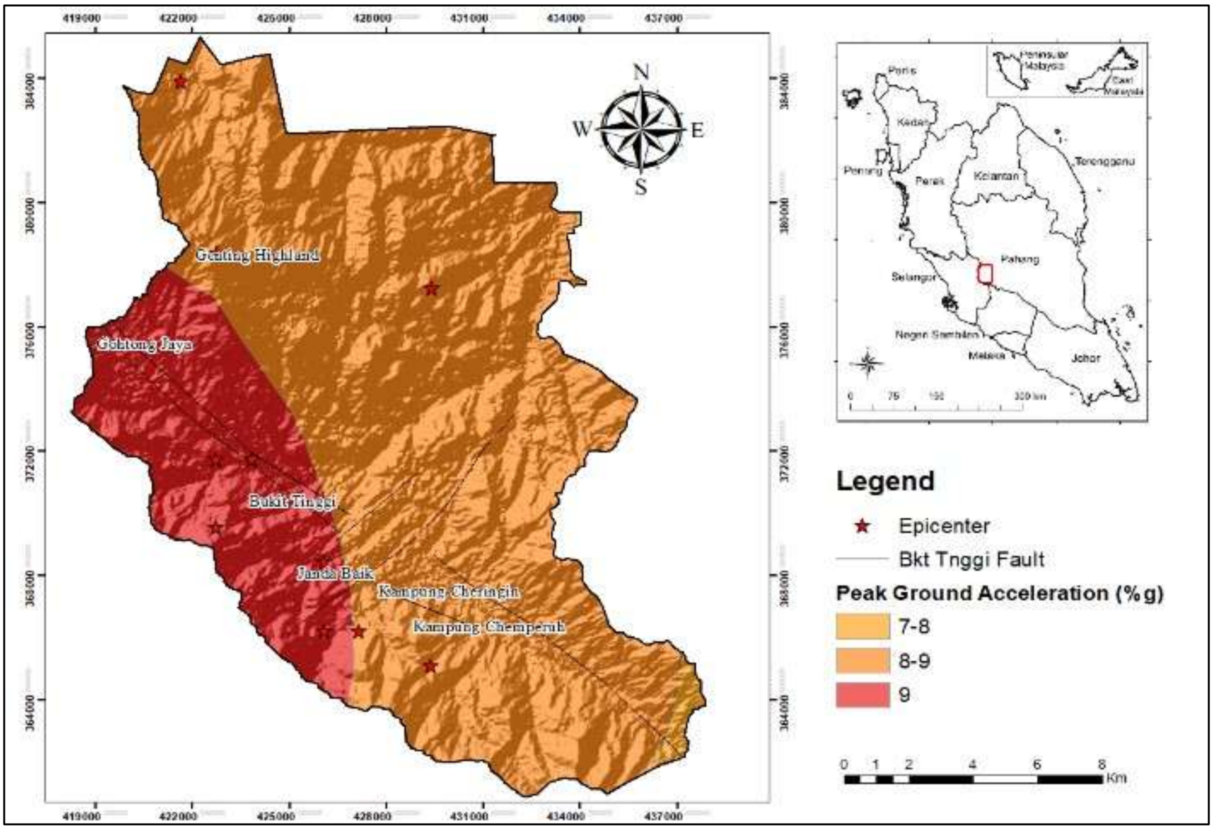


Fig. 1: Seismic hazard map of Study area in Bukit Tinggi, Pahang[13]

(ii) Building density: Areas with a high building density are more vulnerable because older buildings may collapse causing damage to residential areas[25]. The ratio of the number of buildings to the land area in a one-kilometre square region corresponds to the building density within the area. The building density was calculated using Kernel Density tools in ArcGIS software on a total of 1566 buildings (fig. 2b).

(iii) Building floor density: The number of floors in a building is a key factor in determining the area's susceptibility. This is owing to the fact that the higher are the number of storeys, the greater is the chance of the building collapsing due to ground shaking, which will produce structural instability[23,25]. The density of building floors in the research region was calculated using Kernel Density tools as shown in (fig. 2c).

Environment Parameters

(i) Distance from fault: Based on prior records, the Bukit Tinggi fault line could be a potential source of seismic hazard in the area[18]. As a result, the susceptibility degree can be determined by the distance from the fault, with the area closest to the fault line being the most vulnerable. Using Euclidean distance tools in ArcGIS software, the distance from the fault was separated into four classes (fig. 2d).

(ii) Slope degree: The study location is located in low to high hilly terrain with a steep incline. This topography will almost definitely feature a variety of steep to gentle slopes which could pose a landslide and debris flow threat if the earthquake occurs. As a result, the area with the most slopes is particularly vulnerable. Based on the vulnerability rating, slope degree was divided into five classes (fig. 2e).

(iii) Elevation: Bukit Tinggi which is over 1400 metres above sea level, is particularly vulnerable to landslides and debris flows due to its unstable slopes and inadequate geological elements with a high soil weathering profile. Based on earlier research[1] and current site suitability, elevations were classed into five different elevation intervals (fig. 2f).

(iv) Geology: Aside from that, the area's vulnerability can be estimated based on the type of geology since loose, unconsolidated geology material can create liquefactions triggered by earthquakes resulting in serious damage to structures above ground[16] (fig. 2g).

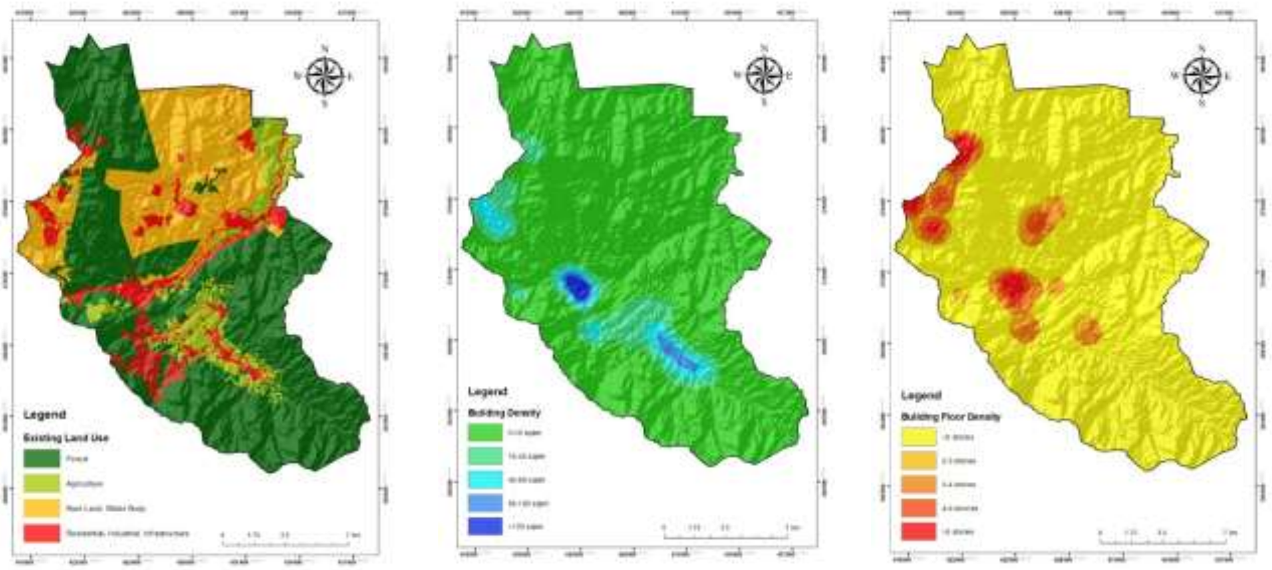
Coping Capacity Parameters

(i) Distance from road network: During an earthquake disaster, the road network component is critical in providing access to victims and rescue personnel for emergency and recovery operations[1,2]. As a result, it is projected that the area will be very vulnerable if the road network is inadequate (fig. 2h).

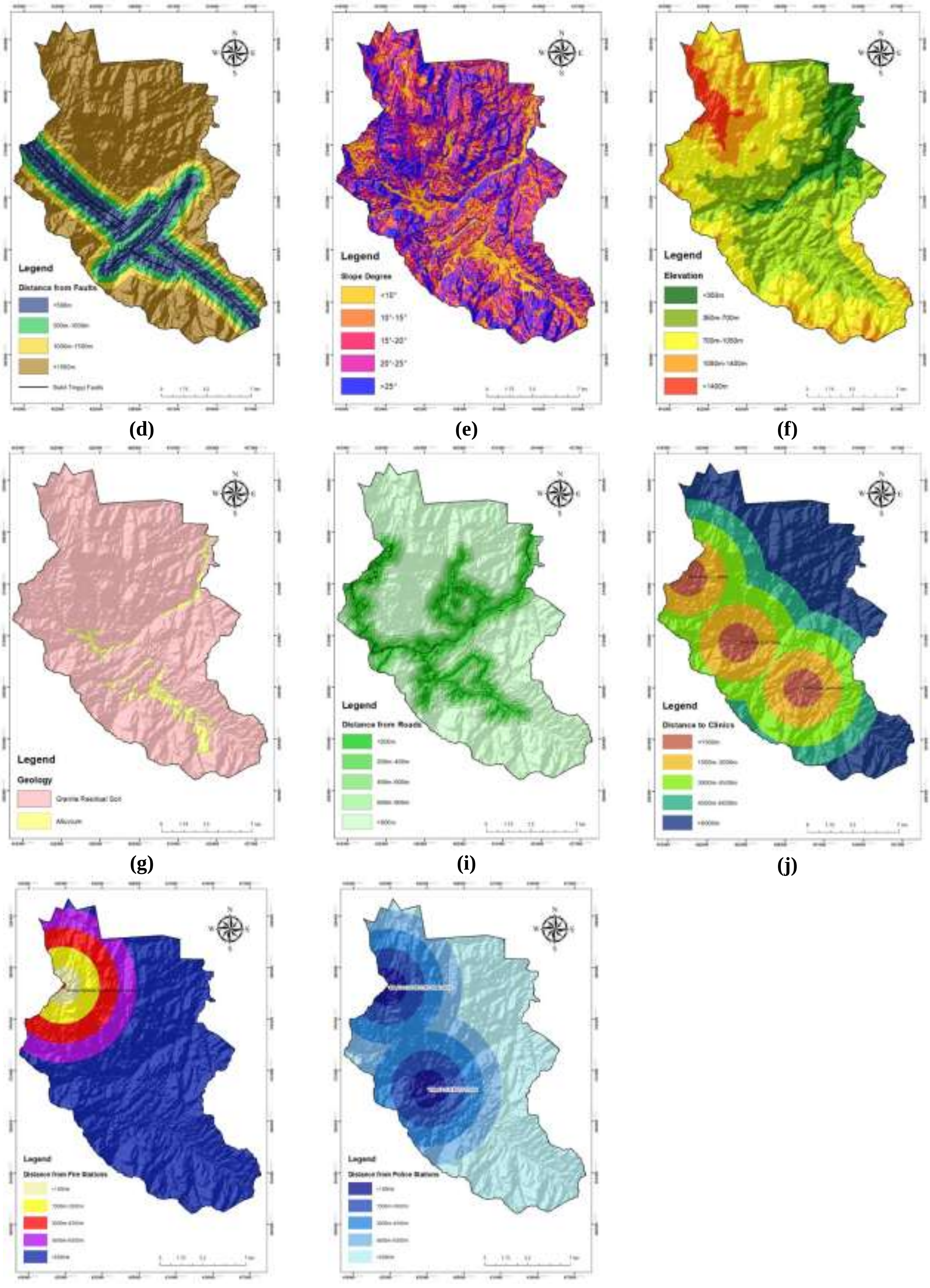
(ii) Distance from clinic: The ability to get to the nearest healthcare facility is critical in delivering post-earthquake treatment to the victims[23]. As a result, distance from the clinic will be taken into account in this study with the assumption that the region closest to the clinic facilities will be less vulnerable (fig. 2i).

(iii) Distance from Fire Station: Depending on the connectivity and distance to the fire station, the post-earthquake rescue effort could be expedited. For example, the further away a community is from a fire station, the more vulnerable it is due to a lack of response capacity, (fig. 2j).

(iv) Distance from Police Station: The responsibility of the police is not only to keep the population secure from criminals, but also to aid rescue operations in evacuating individuals to a safer location in the event of an earthquake. As a result, the distance to the police station affects the area's vulnerability in terms of coping capacity (fig. 2k).



(a) (b) (c)



(d) (e) (f)

(g) (i) (j)

(k) (l)

Fig. 2: Classification of each indictor (a) Existing land use, (b) Building density, (c) Building floor density, (d) Distance from faults, (e) Slope degree, (f) Elevation, (g) Geology, (h) Distance from roads, (i) Distance from clinics, (j) Distance from fire stations and (k) Distance from police stations

AHP Method for Weightage Calculation: The weight of each indicator and sub indicator in this study was calculated using a Multi Criteria Decision Making (MCDM) approach using the Analytical Hierarchy Process (AHP) method established by Saaty[15]. Previous researchers have used this strategy to solve multi-criteria and sub-criteria decision-making processes[5]. The first stage in the AHP methods is to create a hierarchical structure with the aim at the top followed by an indicator at the second level and a sub indicator at the third level. The next stage is to calculate each indication's score using a pair-wise comparison matrix and then give scoring to each indicator using the table of fundamental scale for pairwise comparison[15] as depicted in table 1.

The weightage of each indication can be computed from the score value of each indicator and the Consistency Index (CI) can be obtained from equation 1:

$$CI = \frac{\lambda max - n}{n - 1} \qquad (1)$$

where λmax is the matrix's eigenvalue and n is the number of indicators to compare. After that, using the formula in equation 2, the consistency ratio (CR) to measure the consistency of the judgmental pairwise comparison matrix will be calculated:

$$CR = \frac{CI}{RI} \qquad (2)$$

The consistency index is specified as CI and the random index is defined as RI. In order to calculate the RI value, Saaty[15] created a random consistency index table based on the number of indicators utilised in the study (n) as shown in table 2. Otherwise, the matrix judgmental and indicator scoring in the early steps should be altered if the CR value produced is less than 0.10. Through the weighted sum overlay options for Spatial Analyst in the ArcGIS software, the final weightage of each indication was then analysed to determine the vulnerability degree of the research area. Finally, based on each indicator input, the study's vulnerability degree was calculated and classified into five categories: very low vulnerability, low vulnerability, moderate vulnerability, high vulnerability and very high vulnerability. In conclusion, fig. 3 depicts the flowchart of the approach used in this study.

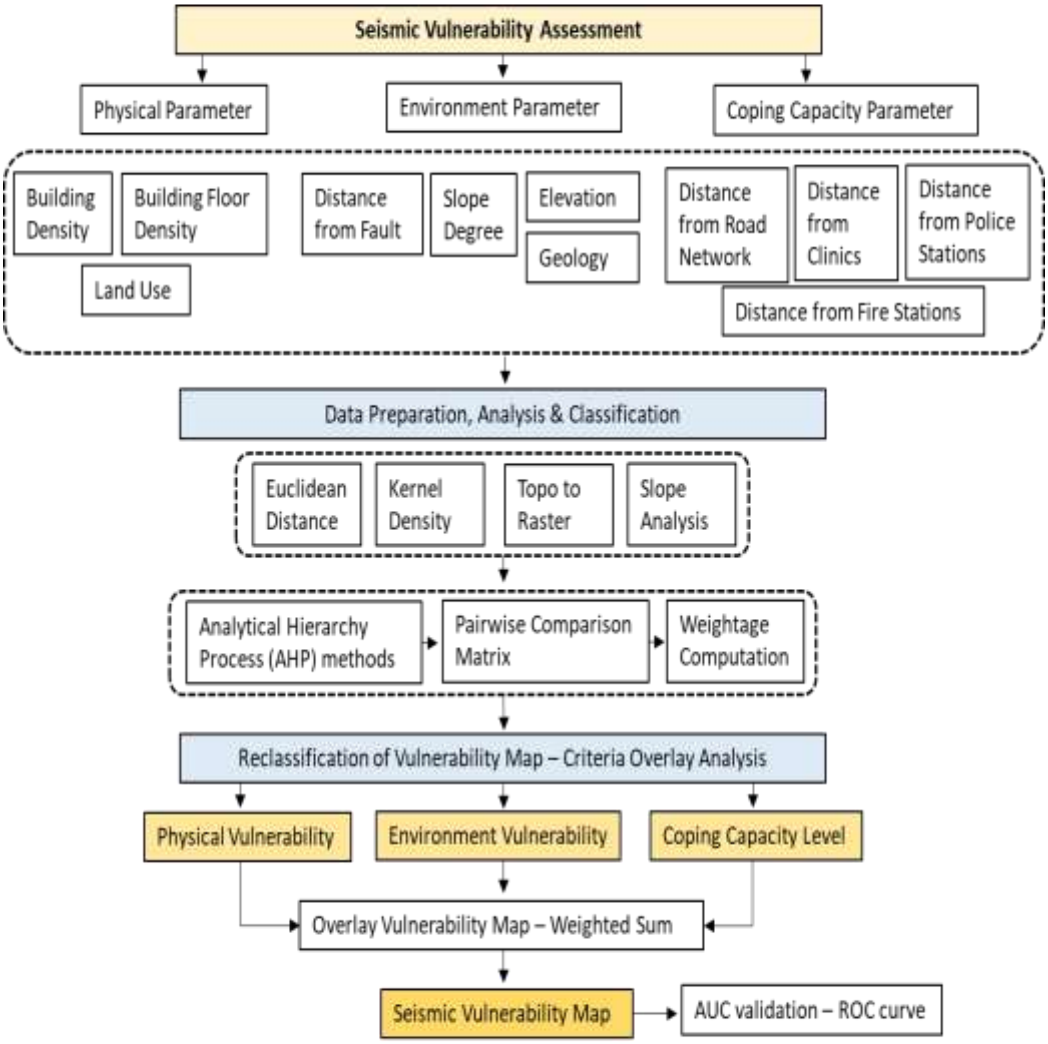


Fig. 3: Workflow of the methodology used in this study

Results and Discussion

Before overlaying each vulnerability parameter map to form the total seismic vulnerability map of the research area, the vulnerability map for each parameter, namely physical vulnerability, environment vulnerability and coping capability vulnerability, was generated individually. The pairwise comparison matrix methods based on the AHP approach by Saaty[15] were used to calculate the important weight for each indication. In the pairwise comparison of matrix table and total computed weight table 3, the findings of the assessment on the weightage indicator in relation to each parameter are shown.

Physical Vulnerability: Because of its consistency and effectiveness in describing the spatial pattern of the vulnerability classes, the vulnerability degree of the research region was classified into five classes using the Natural Break (Jenks) methodology in ArcGIS software. Very low vulnerability, low vulnerability, moderate vulnerability, high vulnerability and very high vulnerability were among the classifications.

According to the AHP results, the greatest criterion was building floor density which had a weight of 0.56 and had a significant impact on determining the physical vulnerability priority in the area. The next most influential factor was building density, which had a weight of 0.32 and the least influential criterion was land use, which had a weight of 0.12 of the total weightages.

As a result, the physical vulnerability of the research area was classified as very low vulnerability in 57 percent of the area, low vulnerability in 31 percent and moderate to very high vulnerability in 12 percent (fig. 4a, table 4).

Due to the high building density structure with large number of building floors, the moderate to very high vulnerability classes were concentrated in the residential and industrial areas, particularly in Genting Highland, Gohtong Jaya and Bukit Tinggi. Other areas with minimal building structure and low-impact land use, on the other hand, indicate low susceptibility.

Environment Vulnerability: According to the AHP results, distance from the fault had the highest weighting (0.32) in determining the degree of environmental vulnerability in the research area. This is because fault movement is thought to be one of the origins of local seismic intraplates, which can release seismic waves, causing ground tremors and landslides. Other criteria such as slope degree (0.28), elevation (0.13) and geology, have varied priority weightings (0.22).

As previously described, the environmental vulnerability map was constructed using the specified indicator and its priority weighting. According to the weighted sum overlay analysis results, the majority of the land along the Bukit Tinggi fault zone is vulnerable to seismic activity (fig. 4b, table 5). The percentages of the overall area for moderate, high and extremely high susceptibility are 34 percent, 20 percent and 10 percent respectively. Furthermore, a portion of these areas is situated near a steep slope and is underlain by unsuitable geological materials such as alluvium which can cause cascading hazards from earthquakes such as landslides and liquefaction.

Table 1
Fundamental scale for pairwise comparison[15]

Weight/Rank	Intensities	Definitions
1	Equal importance	Two indicators contribute equally to the objective
3	Moderate important of one over another	Experience and judgement strongly favour one indicator over another
5	Essential or strong importance	Experience and judgement strongly favour one indicator over another
7	Very strong importance	An indicator is strongly favoured and dominance in practice
9	Extreme importance	The evidence favouring one criterion is highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgements	When compromise is needed
1/3, 1/5, 1/7, 1/9	Reciprocals values for inverse judgement	

Table 2
Random consistency index table (RI)[15]

Number of indicators n	1	2	3	4	5	6	7	8	9	10
Random Index RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3
Summary of weightage indicator based on each parameter

Parameter	Indicator	Class	Vulnerability Rank	Weightage
Physical	Land Use	Forest	1	0.12
		Agriculture	2	
		Bare Land, Water Body	3	
		Residential, Industrial, Infrastructure	4	
	Building Density	<10 sq.km	1	0.32
		10-40 sq.km	2	
		40-80 sq.km	3	
		80-120 sq.km	4	
		>120 sq.km	5	
	Building Floor Density	<2 storey	1	0.56
		2-3 storey	2	
		3-4 storey	3	
		4-5 storey	4	
		>5 storey	5	
Environment	Distance from Faults	>1500m	1	0.32
		1000m-1500m	2	
		500m-1000m	3	
		<500m	4	
	Slope Degree	<10º	1	0.28
		10-15º	2	
		15º-20º	3	
		20º-25º	4	
		>25º	5	
	Elevation	<350m	1	0.14
		350m-700m	2	
		700m-1050m	3	
		1050m-1400m	4	
		>1400m	5	
	Geology	Granite Residual Soil	1	0.22
		Alluvium	2	
Coping Capacity	Distance from Road Network	<200m	1	0.39
		200m-400m	2	
		400m-600m	3	
		600m-800m	4	
		>800m	5	
	Distance from Clinic	<1500m	1	0.27
		1500m-3000m	2	
		3000m-4500m	3	
		4500m-6000m	4	
		>6000m	5	
	Distance from Fire Station	<1500m	1	0.20
		1500m-3000m	2	
		3000m-4500m	3	
		4500m-6000m	4	
		>6000m	5	
	Distance from Police Station	<1500m	1	0.14
		1500m-3000m	2	
		3000m-4500m	3	
		4500m-6000m	4	
		>6000m	5	

Table 4
Area percentage for each physical vulnerability degree

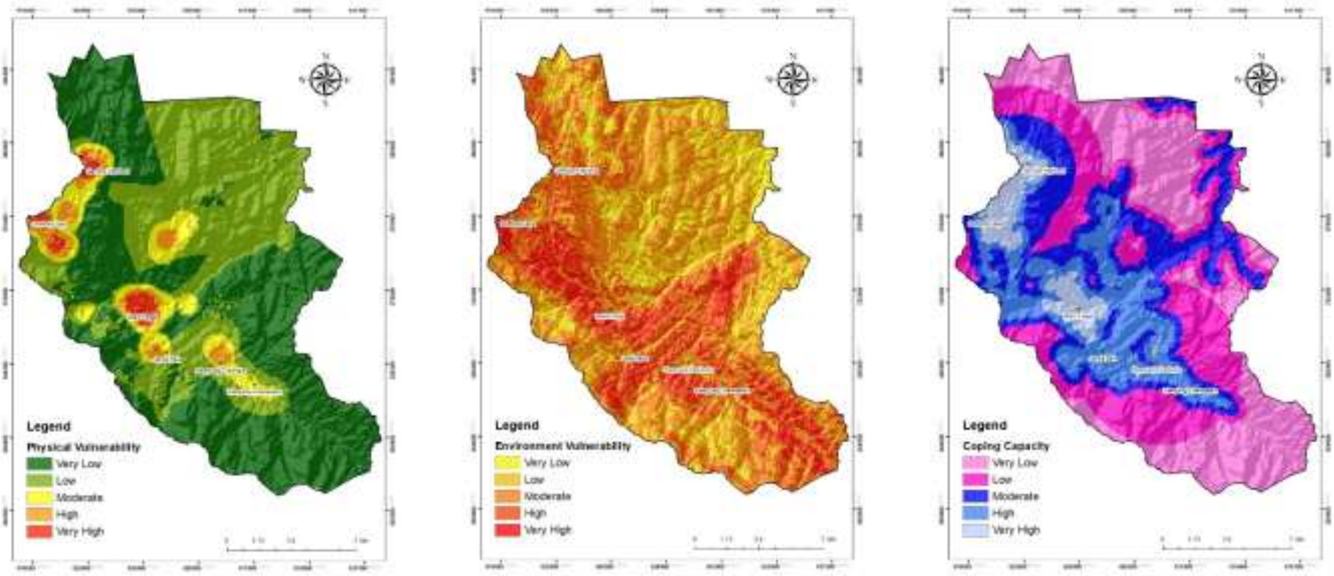
Vulnerability Degree	Area Percentage (%)
Very Low	57
Low	31
Moderate	7
High	3
Very High	2

Table 5
Area percentage for each environment vulnerability degree

Vulnerability Degree	Area Percentage (%)
Very Low	14
Low	21
Moderate	34
High	20
Very High	10

Table 6
Area percentage for each coping capacity level

Coping capacity level	Area Percentage (%)
Very Low	51
Low	21
Moderate	16
High	9
Very High	4



(a) (b) (c)

Fig. 4: Vulnerability map of each parameter (a) Physical vulnerability, (b)Environment vulnerability and (c) Coping Capacity level.

Coping Capacity Level: The distance from the road network has a significant influence in measuring the coping capacity of the research area, according to the AHP data, with the maximum weightage of 0.39. This is because the road network is crucial for the area's connectivity and it is used in search and rescue operations as well as providing escape routes in the event of an earthquake.

Distance to clinic (0.27), distance from fire station (0.20) and distance from police station (0.14) are the three key indicators. As a result, the research region's coping capacity map was created which classified the area into five classifications. The map in figure 4(c) shows that the areas of Bukit Tinggi, Gohtong Jaya, Genting Highlands and Janda Baik have moderate to very high coping capability, accounting for 13% of the total area.

These populous neighbourhoods are surrounded by a discernible road network as well as the proximity to health facilities and police stations, making the area more resilient than other parts of the city. Due to lack of infrastructure and facilities, the forest reserve and certain rural areas in the southern and northern parts of the research area (72 percent) have the lowest coping capacity (Table 6).

Generating the Seismic Vulnerability Map: The seismic vulnerability map was created by overlaying the three vulnerability parameters (physical, environment and coping capacity) that were previously determined. The AHP methods employing pairwise comparison matrix were also used to determine the priority vector which represents the weightage of each layer, in order to overlay those parameters.

Table 7 provides the pairwise comparison matrix results while table 8 shows the weightage computed for each parameter. The results suggest that the environment parameter (0.49) has the highest weightage followed by the physical parameter (0.31) and finally the coping capacity parameter (0.20). Apart from that, the computed CR value is 0.056, which is less than 0.1 indicating that the judgement is consistent. The results suggest that the environment parameter (0.49) has the highest weightage followed by the physical parameter (0.31) and finally the coping capacity parameter (0.31). (0.20). Apart from that, the computed CR value is 0.056, which is less than 0.1 indicating that the judgement is consistent.

Fig. 5 depicts the research area's seismic vulnerability map, which indicates five levels of susceptibility: very low vulnerability, low vulnerability, moderate vulnerability, high vulnerability and extremely high vulnerability. The graphic shows that the study area is dominated by low to high vulnerability levels which account for 81 percent of the total area. On the other hand, extremely low vulnerability accounts for 12% of total vulnerability whereas very high vulnerability accounts for only 7% of total vulnerability. However, most of the major towns in the research area including Bukit Tinggi, Gohtong Jaya and a portion of Genting Highland, are vulnerable to varying degrees. The percentage of each vulnerability degree in the research region is represented in table 9.

Table 7
Pairwise comparison matrix for each parameter

	Physical Parameter	**Environment Parameter**	**Coping Capacity Parameter**
Physical Parameter	1	0.5	2.
Environment Parameter	2	1	2
Coping Capacity Parameter	0.5	0.5	1
Sum ∑	3.5	2.0	5.0

Table 8
Weightage computation of each parameter

	Physical Parameter	**Environment Parameter**	**Coping Capacity Parameter**	**Weight**
Physical Parameter	0.286	0.25	0.40	0.31
Environment Parameter	0.571	0.5	0.40	0.49
Coping Capacity Parameter	0.142	0.25	0.20	0.20
	Consistency ratio (CR): 0.056			

Table 9
Area percentage for each seismic vulnerability degree

Vulnerability Degree	**Area Percentage (%)**
Very Low	12
Low	26
Moderate	30
High	25
Very High	7

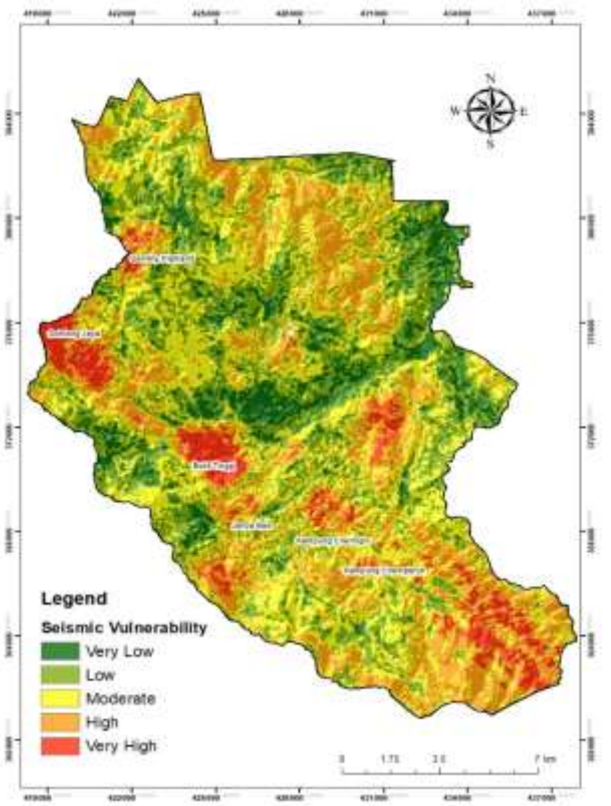


Fig. 5: Seismic vulnerability map of study area.

This vulnerability assessment used qualitative methodologies based on indicator-based approaches to conduct a holistic evaluation that included physical, environmental and capacity factors to produce a comprehensive result for the research area's vulnerability level[21]. Bukit Tinggi is situated in the Bukit Tinggi Fault Zone, a potentially active fault zone prone to future seismic activity[18]. According to vulnerability research, the majority of areas with densely packed high-rise buildings such as Gohtong Jaya and Bukit Tinggi town, are in an extremely vulnerable zone. According to the inventory, the highest building recorded has 30 stories while the densest building density is over 120 buildings per square kilometre.

In terms of the environment, the majority of Bukit Tinggi town is also underlain by an inappropriate geological material made up of an alluvium layer which has the potential to cause liquefaction.

As a result, in the event of a future earthquake, the study area's present building structure will be more vulnerable to catastrophic damage. In addition, the orange and red zones in the southern section of the research region suggest a high to extremely high sensitivity area. Despite the fact that the area is covered by a forest reserve, the location is vulnerable to seismic hazard due to the close proximity of the fault and the slope degree of more than 25 degrees, indicating that the area is prone to landslides.

Furthermore, due to its remote location from nearby facilities, this forest reserve is highly vulnerable in terms of environmental vulnerability which can result in cascading effects from earthquakes such as landslides and debris flows which can harm the nearby populated area as well as the destruction of the forest reserve's ecological zone and endangered species.

Moderate vulnerability, low vulnerability and extremely low vulnerability dominate the rest of the territory accounting for 30%, 26% and 12% of the total area respectively. The majority of these regions are in the vicinity of land use activities that have a low to moderate influence on the environment such as agriculture, forest and bare terrain with little building structure.

Other than that, the location is situated at a low to medium height, has a moderate slope and is located far away from the seismic source. Tolerable coping capacity accessibility such as proximity to health facilities and fire stations, also contributes to the lowering of vulnerability in this area.

Based on the findings of the seismic vulnerability assessment, stakeholders should begin planning and taking action for appropriate mitigation measures to reduce the impact of future earthquakes such as enforcing the building code and retrofitting work for earthquake resistance on the building structure. The most important target zone should be high to extremely high sensitivity areas, particularly those that include residential and tourism attractions areas that show the population extent in order to avoid any fatalities or injuries after an earthquake.

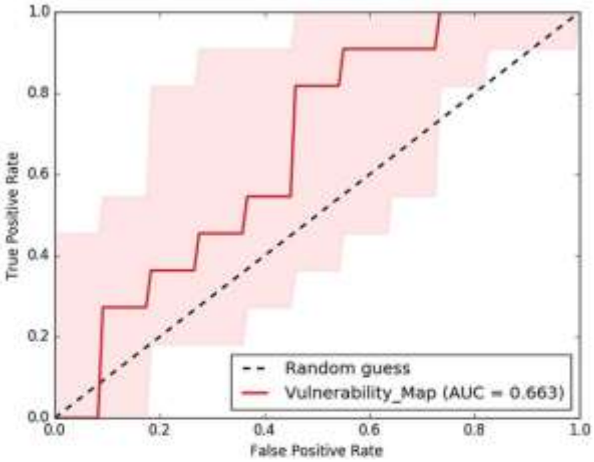


Fig. 6: ROC curve graph for validation of seismic vulnerability map.

Validation of Vulnerability Assessment: Validation of the developed seismic vulnerability map is required to establish the veracity of the vulnerability assessment outcome from this study. Apart from field observation and expert opinion, the previous researcher employed ROC curve methods to validate the vulnerability model[1,23,24]. As a consequence, the validation process was carried out using the ROC curve which compared the previous historical epicentre in the research area as a true positive rate input with the resulting seismic vulnerability map as a false positive rate data.

The area under the ROC Curve (AUC) is used to assess the validation results. It has a value range of 0 to 1 with a value near 0 indicating that the model is inaccurate and a value near 1 indicating that the model is entirely accurate[12,24]. The ROC curve was plotted in ArcGIS software using the ROC tool extension. The AUC value is 0.663, indicating that the map developed is satisfactory and can distinguish between the actual positive rate and false positive rate scenarios marginally (Fig. 6).

Although the AUC result is not perfect, the map can still be used for preliminary and conceptual vulnerability information in the area because the ultimate validation process is not possible due to a lack of specific data that represents the real scenario such as a building damage inventory and tremors incident witness record from a previous earthquake.

Conclusion

The seismic vulnerability assessment in the Bukit Tinggi area was based on spatial analysis using GIS and AHP methodologies. On the basis of each group of factors, namely physical, environmental and coping abilities, 11 indicators were chosen. The data was prepared by reclassifying each indicator into a new class based on the vulnerability rank assigned. A final seismic vulnerability map of the research region was developed and exhibited in the form of a GIS map that depicts the various patterns of vulnerability degree based on very low, low, moderate, high and very high classification areas.

This research study should be expanded to other earthquake-prone areas with high populations such as tourist hotspots, for a more accurate assessment of seismic vulnerability that can aid stakeholders such as local governments, urban planners and disaster managers in developing comprehensive DRR planning strategies for future resilience.

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