DEVELOPING A SEISMIC LAND CAPABILITY FRAMEWORK FOR EARTHQUAKE-RESISTANT HOUSING BASED ON GIS APPROACH: A CASE OF SUKABUMI DISTRICT

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ABSTRACT.

The majority of fatalities in an earthquake are those caused by collapsing buildings. The ability of the land to endure seismic activity, Seismic Land Capability (SLc), has a significant impact on this catastrophe. Therefore, the primary objective of this research is to create a comprehensive framework for SLc and its impact on the vulnerability of built-up areas (BV). This objective aligns with the Indonesian government's initiative to promote earthquake-resistant housing in regions susceptible to seismic threats. The selection of Sukabumi District in West Java, Indonesia, a region renowned for its high seismic activity, as the primary focus of this study, highlights its significance. Distinctively, this research transcends conventional analyses of earthquake vulnerability by incorporating a diverse array of factors that contribute to land instability and the potential for residential area collapse. It employs a sophisticated spatial model, evaluated through the application of a weighted score method and multi-criteria analysis within a Geographic Information System (GIS) framework. The findings reveal that the majority of communities reside within zones of moderate vulnerability, characterized by an unstable to moderate SLc level. The validation of the spatial model, conducted through an empirical validation method, demonstrated a high degree of accuracy, with a score of 0.87 according to Guilford scale. Crucially, the study identifies a multitude of parameters as pivotal in the construction of an effective SLc and BV spatial model. These parameters include seismic history, soil type, and the structural and geological features of the land, as well as the slope/topography, the land use of built-up areas, and socio-economic data such as types of buildings and the readiness of disaster infrastructure. Through its comprehensive analysis, this research furnishes essential insights for augmenting disaster preparedness and informing efforts to build earthquake-resistant housing, thereby significantly contributing to the mitigation of earthquake-related risks and enhancing the safety and resilience of vulnerable communities

Key-words: *Spatial analysis, Earthquake, Earthquake resistant houses, GIS, Seismic Land Capability*

1. INTRODUCTION

Indonesia is situated in the Pacific Ring of Fire, an area with intense tectonic activity that makes it one of the most seismically active regions on Earth. However, many buildings and infrastructure in Indonesia have not been designed with adequate earthquake resistance standards. This increases the risk of building damage during an earthquake, thereby compromising population safety. As Markušic et al. (2020) stated, the majority of the casualties in an earthquake have been revealed to be fatalities due to building collapse. This means that settlements, either in rural or urban areas, are prone to disaster when an earthquake strikes.

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As part of the disaster mitigation efforts, the Indonesian government is initiating the construction of earthquake-resistant buildings in seismic-prone areas. To properly address this issue, it is essential to evaluate the land capability conditions of the area. Because, the physical characteristics of rocks and the arrangement of rock strata can act as an excellent medium for seismic wave transmission, causing the building above to quake (Pratt et al. 2017; Sekac et al.2016). Similarly, the type and structure of the soil can have an effect on ground shaking during an earthquake (Fu et al. 2021; Liu et al. 2020). The condition of land that is capable of transmitting an earthquake wave is classified as unstable. As a result, land capability in the presence of earthquakes is a critical problem that should be investigated further in order to avoid casualties.

Investigations concerning Seismic Land Capability (SLc) have been undertaken in the city of Palu (Erwindy et al., 2021). In the context of spatial assessment of land stability, a rudimentary overlay technique is employed, contingent upon variables such as geological characteristics, geological hazards, land use, and hydrology (Erwindy et al., 2021). The Ministry of Public Works (2007) has additionally promulgated directives concerning the seismic land capability matrix. This framework encompasses several factors, including geological parameters, Ground Peak Acceleration (GPA), and fault lines. However, geological parameters, such as rock type is not a single factor affecting the level of lands capability to withstand earthquake shakings that may have a destructive effect on life above it. Other factors, such as soils (Liu et al. 2020; Taghizadeh 2021; Munirwansyah et al. 2019), land use (Barua et al. 2020) and slope (Kahandawa et al. 2018) may be used to determine the extent of the capability of the land to withstand the shakings and transmit seismic waves. The integration of rock and soil traits is crucial in ascertaining their resilience against seismic activities; hence, incorporating this aspect into the research is indispensable. Therefore, the objective of this study was to develop a comprehensive framework for Seismic Land Capability (SLc) and its impact on Built-up Area Vulnerability (BV) based on a spatial model, which is expected to facilitate the implementation of corrective measures, improve disaster preparedness, and encourage the development of earthquake-resistant housing. The components consist of seismicity, including peak ground acceleration (PGA), geological and soil characteristics, geological structure, slope and land use. The methodology for spatial analysis has been enhanced through the formulation of a model that originates from the Analytical Hierarchy Process (AHP) analysis. For the case study, the district of Sukabumi in West Java Province, Indonesia, was selected due to its pronounced vulnerability to seismic disasters.

2. STUDY AREA

The issues of SLc and (BV) hold particular importance for the Sukabumi District in West Java (**Fig**.1). This district is situated above the Benioff subduction zone between the Indo-Australian and Eurasian plates, rendering it an active seismic zone vulnerable to ongoing earthquake hazards (Saputra et al, 2018; Simanjorang et al, 2020; Wallansha, 2020). Latuconsina et al. (2019) revealed that there are two earthquake sources in Sukabumi, namely the southern West Java Megathrust and several onshore faults, including the Cimandiri and Citarik faults that run through its center (Abidin et al, 2009) (see **Fig. 2**).

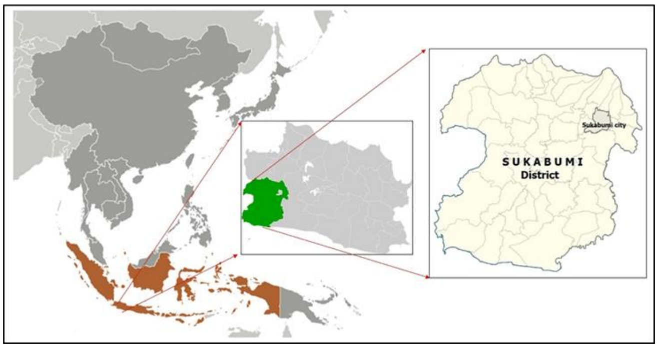
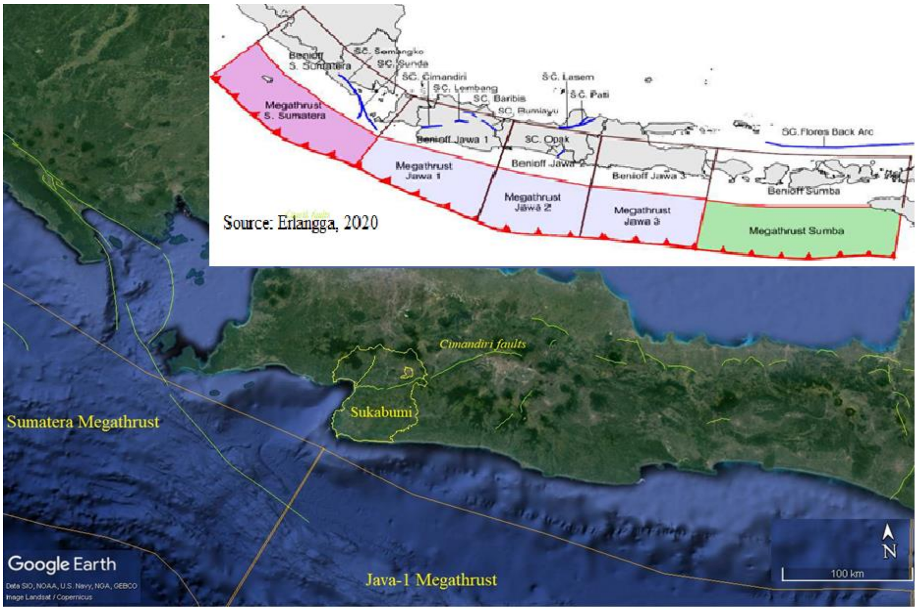
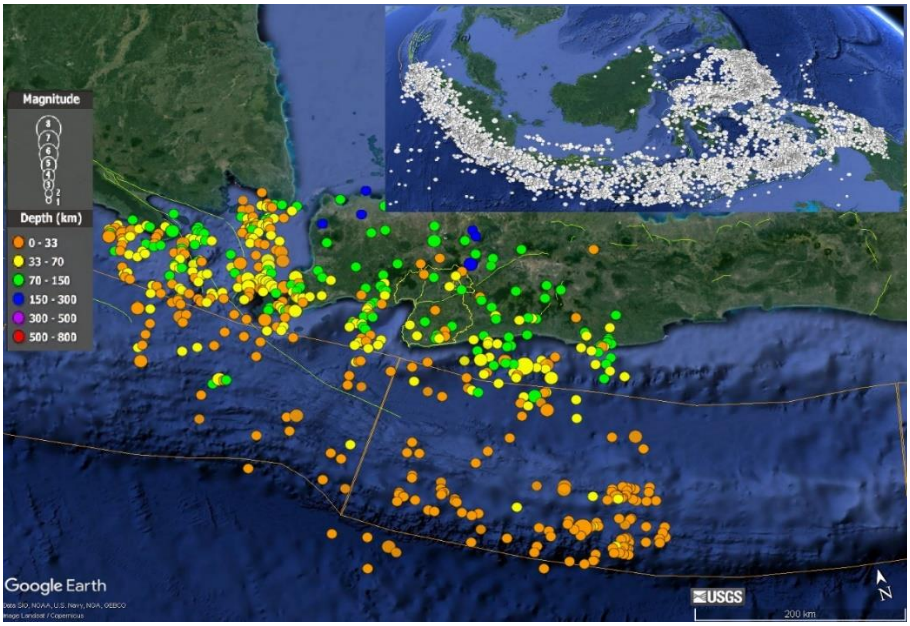


Fig. 1. The Study area Sukabumi District, West Java, Indonesia (Gunkarta, 2021; Mandamaruta, 2017).



(a)



(b)

Fig. 2. (a) Threat of megathrust in Sukabumi along with the Cimandiri active fault. Insert Benioff and megathrust along the Java Island (Erlangga, 2020); **(b)** Historic of Sukabumi's earthquakes with a magnitude of 5 to 9 in the Benioff zone and Sunda Megathrust area from 1923 to 2023. Insert occurrences of earthquakes with a magnitude of 5 to 9 in Indonesia (1923 - 2023) (USGS, 2023).

Over the last two decades, these faults have been sites of numerous shallow earthquakes (Safitri et al., 2018). At least 14 destructive earthquakes have occurred in the area. Notable earthquakes occurred on March 14, 2020, resulting in damage to 202 homes and the displacement of 173 individuals (Idhom, 2020). The last devastating earthquake occurred on December 14, 2023, leading to the complete destruction of 61 residential buildings (BMKG, 2023). **Fig. 2-b** illustrates the magnitude of the earthquakes that transpired within the Benioff zone and megathrust in the Sukabumi region. This depiction elucidates the potential hazards confronted by the communities in this area.

3. DATA AND METHODS

In this study, the assumption of SLc in the context of earthquakes refers to the capacity of a land area or region to withstand or respond to seismic activities.

The added value of this research beyond previous analyses lies in developing a formulation based on the Analytic Hierarchy Process (AHP) and augmenting the formula by incorporating influential parameters, such as soil and land use, particularly for built-up areas. So, various factors such as seismic history indicating a region's vulnerability to earthquake occurrences, geological structures signaling the presence of active faults, soil types and geological characteristics influencing the intensity of seismic vibrations at the earth's surface during an earthquake, slope attributes that play a role in systemic disaster outcomes, and variables such as land use such as built-up area and its density that contribute to the understanding that densely populated and extensively urbanized areas are more prone to significant casualties in the event of an earthquake and type of the houses and disasters infrastructures that contributes to the fatalities of the earthquake event were analyzed in this study.

3.1. Data

The necessary data, focusing on the study area of Sukabumi District, includes the following:

(1) Spatial data points pertaining to earthquakes spanning a hundreds-year interval were obtained from sources USGS Earthquake Data (Earthquake Hazard Program 2023). The points were subject to interpolation analysis to ascertain the spatial distribution of earthquake occurrences as polygons, measured on the twelve-scale of Modified Mercalli Intensity (MMI). Subsequently, the accuracy of these data was validated against the reference map provided by Supartoyo et al. (2013);

(2) Secondary data on Peak Ground Acceleration (PGA) were obtained from a study by Sunardi et al. (2012), presented as polygons at a 1:50,000 scale. The data are categorized into four classes: <0.05, 0.05-0.15, 0.15-0.30, and >0.30.

(3) Secondary data pertaining to the Sukabumi fault were obtained from Kabupaten Sukabumi (2020c), depicted at a scale of 1:50,000. Buffer analysis was utilized to categorize the vulnerability zones into three polygon classes: within the fault zone, within 100 meters of the zone, and beyond 100 meters of the zone.

(4) Secondary data related to the Sukabumi Geological map were sourced from the study conducted by Padmanegara (1990). These data were subsequently analyzed in conjunction with the soil map as per **Table 1** and then categorized into five polygon classes;

(5) Secondary data of the soil at a scale of 1:50,000, were obtained from Kabupaten Sukabumi (2020b). These data were subsequently analyzed in conjunction with the geologic map as per **Table 1** and then categorized into five polygon classes;

(6) The Digital Elevation Model (DEM) was analyzed at a scale of 1:50,000, sourced from (https://tides.big.go.id/DEMNAS, 2020).

(7) Data pertaining to built-up area and land use were extracted from the Rupabumi (topography) maps at a scale of 1:25,000 (Kabupaten Sukabumi 2020a) and subsequently generalized to a scale of 1:50,000.

All of these data were in polygon spatial data base format.

(8) Field data on Sukabumi District were collected for observation and data validation purposes.

3.2. Methods

The procedural phases of the SLc spatial model for analyzing vulnerability in built-up areas are illustrated in **Fig. 3** and can be described as follows:

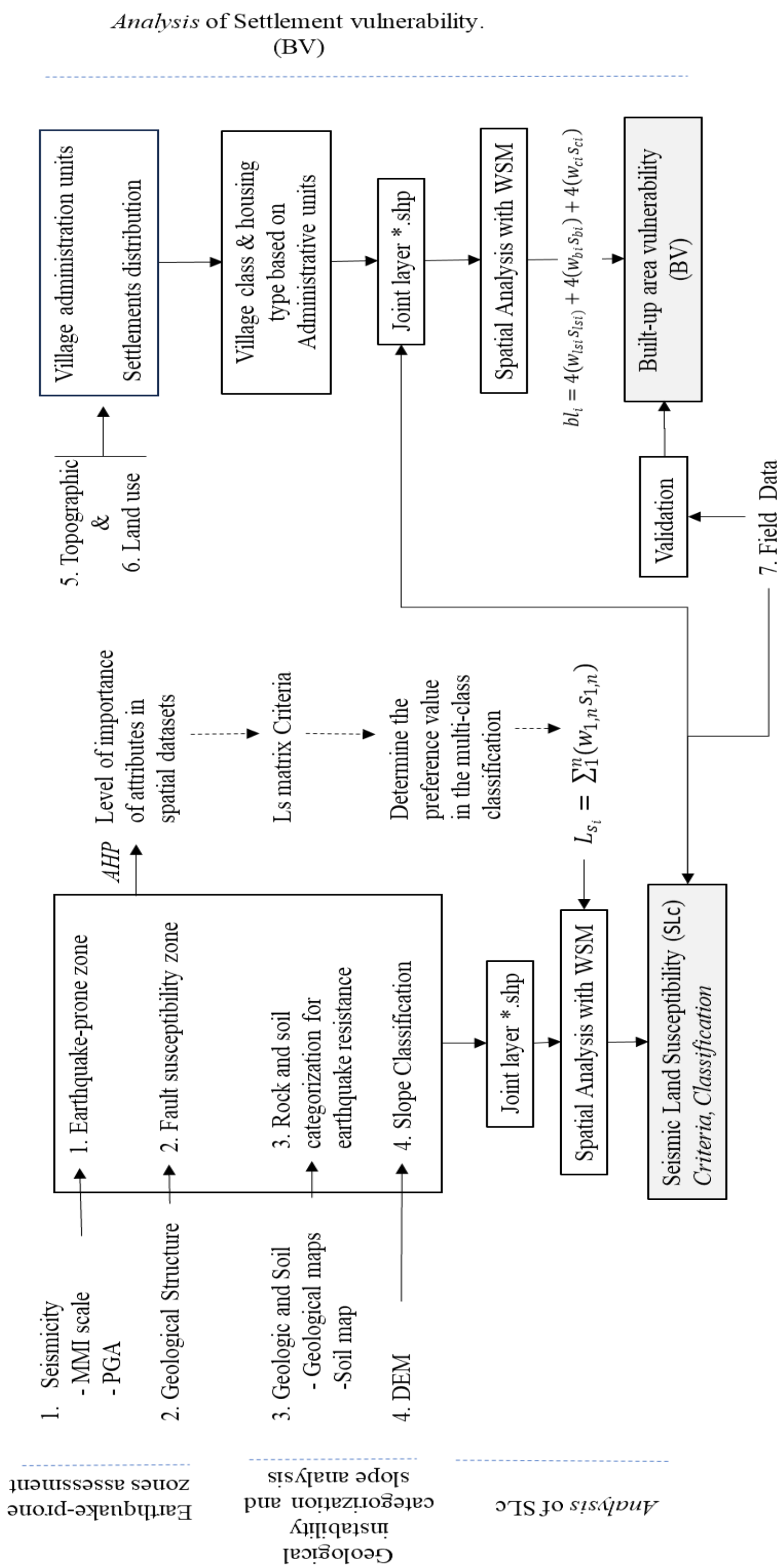


Fig. 3. Steps of the study.

3.2.1. Spatial data preparation

a. Earthquake-prone zones assessment

Seismic zones were analyzed based on secondary data derived from USGS earthquake data (1923 – 2023) and classified the areas into 12 vulnerability zones based on the Modified Mercalli Intensity (MMI) scale (Novikova & Trifunac, 1993). The scale is categorized as I-III= very weak, IV–V= weak, VI–VII= moderate, VIII= strong, and IX-XII = very strong to extreme. PGA was classified into five classes according to MMI: <0.05g, 0.05-0.15g, 0.15-0.30g, >0,30g (The Ministry of Public work Affair, 2007). The geological structure's classification was based on proximity to an active fault, with areas closer to the fault zone being more earthquake-prone. Spatial buffer analysis identified susceptibility zones in (Kabupaten Sukabumi, 2020c) categorizing them as highly susceptible within the fault zone, vulnerable within 100‑1,000 m, and moderately to lowly susceptible beyond 1,000 m (Gupta & Trifunac, 2018; Nejad et al, 2021; The Ministry of Public Work Affairs, 2007).

b. Geological instability categorization and slope analysis

Geological instability categorization was assessed by examining the rock composition, rock characteristics, and soil type based on its resistance to earthquakes and the speed of seismic waves, represented by Vs30, using the Sukabumi geologic map (Padmanegara, 1990) and Sukabumi soil map (Kabupaten Sukabumi, 2020b). Vs30 is an effective indicator of soil stiffness and strength characteristics, and is considered one of the elements affecting the speed of seismic wave propagation through the physical properties of rocks (Amri et al, 2020). To identify rocks related to Vs30, we modified the National Earthquake Hazards Reduction Program (NEHRP) method (Holzer et al, 2005), as summarized in **Table 1**.

A slope map was analyzed using DEM raster data (DEMNAS, 2021). The categories are modified from the U.S. Department of Agriculture's (USDA's) soil gradient classification: 0–3%, 3–8%, 8–15%, 15–30%, 30–45%, and >45%.

Table 1. Classification of rock types modified from the NEHRP based on Vs30.

Site Condition	Rock Class	Rock/Soil Characteristic	Vs30 (m/s)	Earthquake-resistance
SC I	A	Hard Rock	>1.500	Very High
SC II	B	Rock	760-1.500	High
SC III	C	Very Dense Soil and Soft Rock	360-760	Medium
SC IV	D	Stiff Soil	180-360	low
SC V	E	Soft Soil	<180	Very low

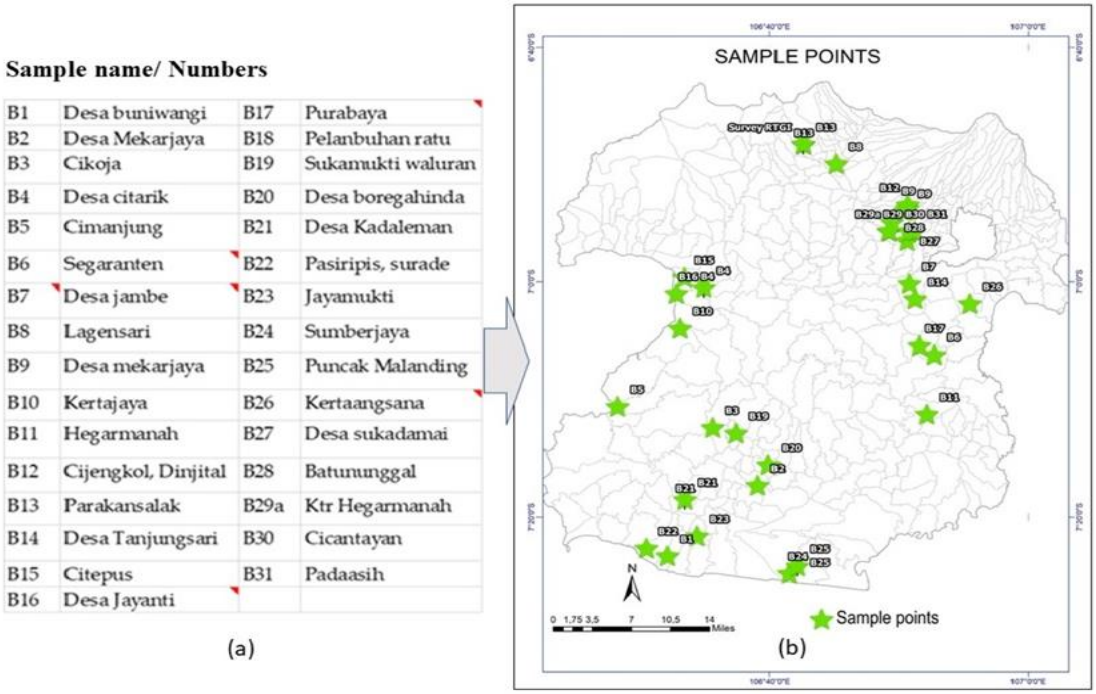
3.2.2. Field Data

To verify ground truth, field observations were conducted in carefully chosen villages, particularly those recently affected by an earthquake, using a purposive sampling strategy (**Fig. 4**). Data collection encompassed interviews and direct observations. Fifty local residents were interviewed to obtain detailed insights into the earthquakes' occurrence, its magnitude, and the resulting damage. Field observations also assessed local building conditions, geological and geomorphological characteristics, soil properties, topography, and rural living conditions.

3.2.3. Analysis of SLc and Settlement vulnerability

a. Seismic Land Susceptibility (SLc)

The SLc spatial analysis employed the Weighted Score Method (WSM) derived from the Analytic Hierarchy Process (AHP), utilizing the aforementioned spatial data (**Fig. 5**):



Sample name/ Numbers

B1	Desa buniwangi	B17	Purabaya
B2	Desa Mekarjaya	B18	Pelanbuhan ratu
B3	Cikoja	B19	Sukamukti waluran
B4	Desa citarik	B20	Desa boregahinda
B5	Cimanjung	B21	Desa Kadaleman
B6	Segaranten	B22	Pasiripis, surade
B7	Desa jambe	B23	Jayamukti
B8	Lagensari	B24	Sumberjaya
B9	Desa mekarjaya	B25	Puncak Malanding
B10	Kertajaya	B26	Kertaangsana
B11	Hegarmanah	B27	Desa sukadamai
B12	Cijengkol, Dinjital	B28	Batununggal
B13	Parakansalak	B29a	Ktr Hegarmanah
B14	Desa Tanjungsari	B30	Cicantayan
B15	Citepus	B31	Padaasih
B16	Desa Jayanti		

Fig.4. Ground-truth and fieldwork sampling.

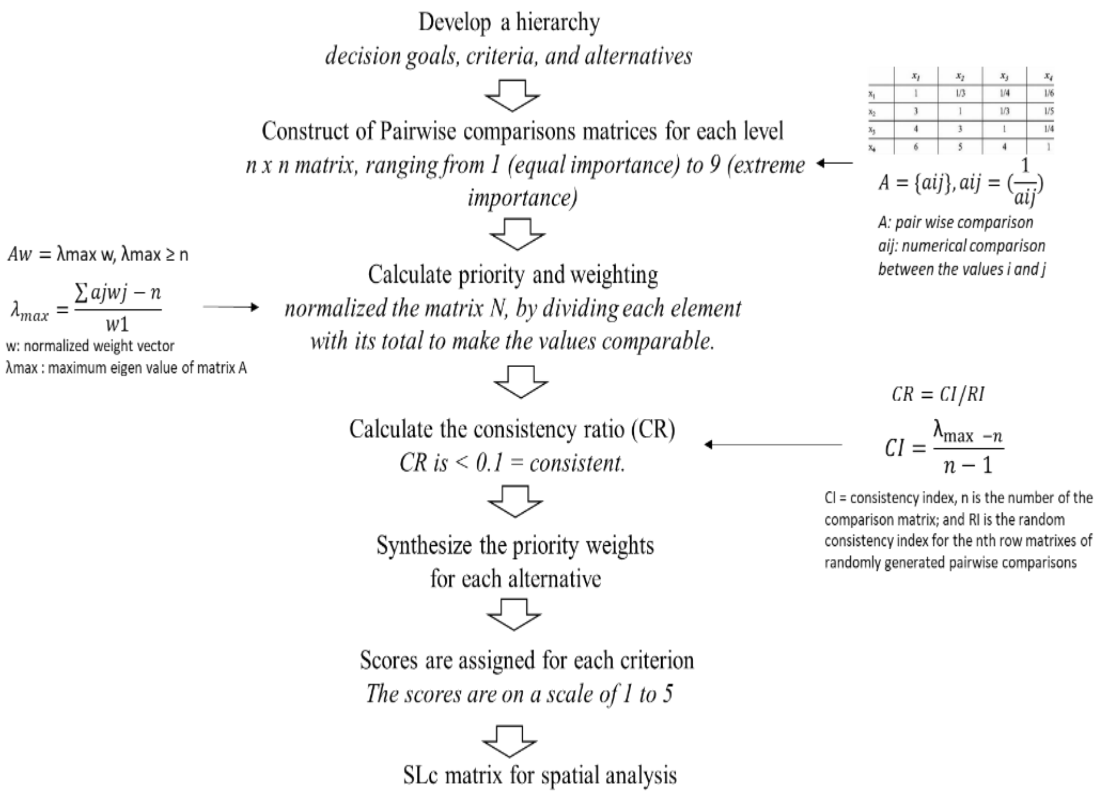


Fig. 5. The steps of WSM based on AHP for SLc analysis.

The SLc was classified into five categories: stable, slightly unstable, moderately unstable, unstable, and highly unstable. The WSM was used for spatial analysis and its formula is as follows:

$$SLc_{s_i} = \sum_1^n (w_{1,n} s_{1,n}) \tag{1}$$

$$SLc_{s_{I,m}} = \sum 1.029 \left(s_1^j\right) + 0.279 \left(s_2^j\right) + 0.095 \left(s_3^j\right) + 0.08 \left(s_n^j\right) \tag{2}$$

where:

$Slc_{s_i,m}$ is the land instability for classes i–m,
s is the score for classes 1–j,
n is the number of parameters (**Table 2**).

The classification interval was computed using the median value between two adjacent categories. While the median values of SLc_{s1} and SLc_{s2} are med_1, the median values of SLc_{s2} and SLc_{s3} are med_2,…. med_n. Therefore, the interval value of the SLc_i classes can be determined as $SLc_{s1} > med_1$; SLc_{s2} is med_1 - med_2 and SLc_{sn} is med_{n-1} - med_n. Then, SLc the overlaid with the density and settlement distribution to indicate community vulnerability.

Table 2. SLc Matrix.

No	Parameters	Categories	Value	Weight	Score
		Modified Mercalli Intensity (MMI)	PGA (∝ (g))		
1	Seismicity	I, II, III	<0.05	1.029	1
		IV, V	<0.05		2
		VI, VII	0.05-0.15		3
		VIII	0.15-0.30		4
		IX, X, XI, XII	>0.30		5
2	Geologic structure	Far/ outside fault zone		0,279	1
		close the fault zone (100 - 1000 m)			2
		nearby to fault zone (0 -100m)			5
3	Geological characteristics based on NHERP	stiff soil, consolidated		0.095	1
		rocks, consolidated			2
		very dense soil and soft rock			3
		very dense soil and soft rock,			4
		Soft soil, unconsolidated			5
4	Slope	0-3%		0.008	1
		3-8%			1
		8-15%			2
		15-30%			3
		30-45%			4
		>45%			5

b. Built-up Area (BV) analysis

A BV analysis was performed to evaluate the susceptibility of these locations to SLc. This was accomplished by extracting data from built-up areas in Sukabumi topographic maps at a scale of 1:25,000 (Kabupaten Sukabumi, 2020c). The analysis then focused on the proportion of land covered by settlements and their distribution across the smallest administrative units, specifically villages, relative to the villages' total area (**Table 3**).

Table 3. Village classification based on ratio percentage of settlement area versus village area.

No	Classes	Built-up' density	Categories
1	Class 1	0-10%	very sparse settlements
2	Class 2	10-20%	sparse settlements
3	Class 3	20-30%	partially dense
4	Class 4	30-40%	moderately dense
5	Class 5	>40%	dense village/ urban

Ancillaries were gathered from sub-districts in the study area to determine the prevalent types of houses, such as permanent, semi-permanent, and traditional wooden houses (**Fig. 6**).

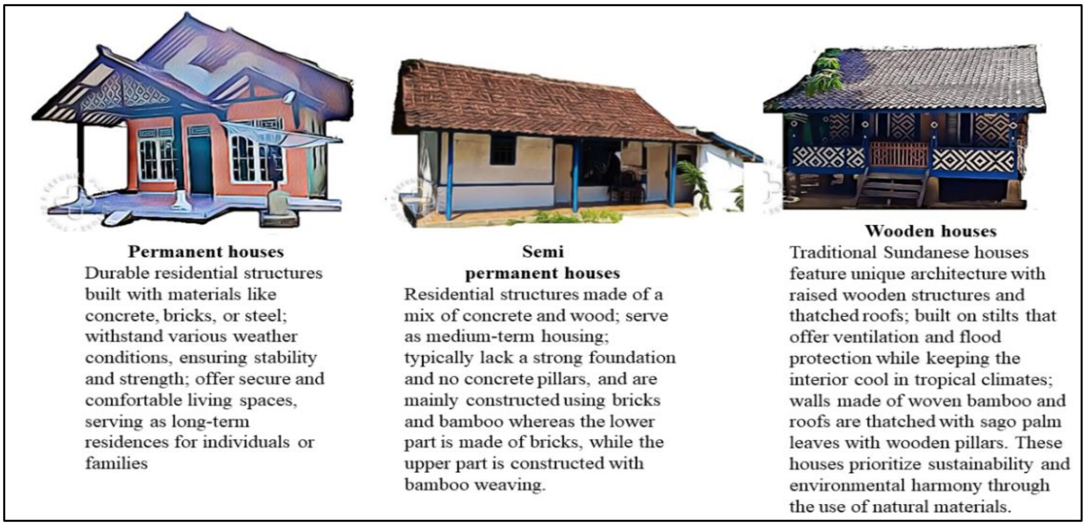


Fig. 6. The type of the houses in the area, nearly all of the permanent houses in the area do not meet the standard for earthquake resistance.

It is hypothesized that densely populated areas with mostly non-earthquake-resistant buildings are likely to have a lower land capacity. By contrast, while sparsely populated areas may have a lower risk of widespread damage, the impact of disasters can be severe because of limited access to resources and emergency services.

Following ancillary data collection, a database was developed for each administrative unit, encompassing details on common building types and disaster infrastructure. This facilitated the assessment of BV to SLc through spatial analysis using three parameters: SLc, built-up area density, housing types, and disaster facilities. Each factor was assigned equal weight and score, as expressed by the following formula:

$$bl_i = 4(w_{lsi}s_{lsi}) + 4(w_{bi}s_{bi}) + 4(w_{ci}s_{ci}) \quad (3)$$

where:

bl_{i_i} is the settlement for class *i*,
w_{lsi} is the weighted factor of parameter *l* for class *i*
s_{lsi} is the score of parameter *l* for class *i*,
w_{bi} is the weighted factor of parameter *b* for class *i*,
s_{lsi} is the score of parameter *b* for class *i*,
w_{ci} is the weighted factor of parameter *c* for class *i*,
s_{ci} is the score of parameter *c* for class *i*.

The classification of settlement vulnerability to SLc was categorized into five levels: invulnerable, slightly vulnerable, moderately vulnerable, vulnerable, and very vulnerable.

3.2.4. Validation

This study used the empirical validation method to validate the research findings for the BV model and SLc factors. Validation was accomplished by comparing the results of the BV spatial model to the ground check/field data. If the instruments' criteria for the spatial model match the reality in the field, then the instrument has a high degree of validity (Sutrisno et al., 2019), and the equation;

$$if\,(x,y)_1 = (x,y)_n, then\ (x,y)_1\ is\ true \tag{4}$$

$$if\ (x,y)_1 \neq (x,y)_n, then\ (x,y)_1\ is\ false \tag{5}$$

where: $(x,y)_t$ is the BV model criteria and $(x,y)_n$ is reference field data.

The total validation V_{vev} is

$$BV = {}^{(t_t - t_n)}/_{t_t} \tag{6}$$

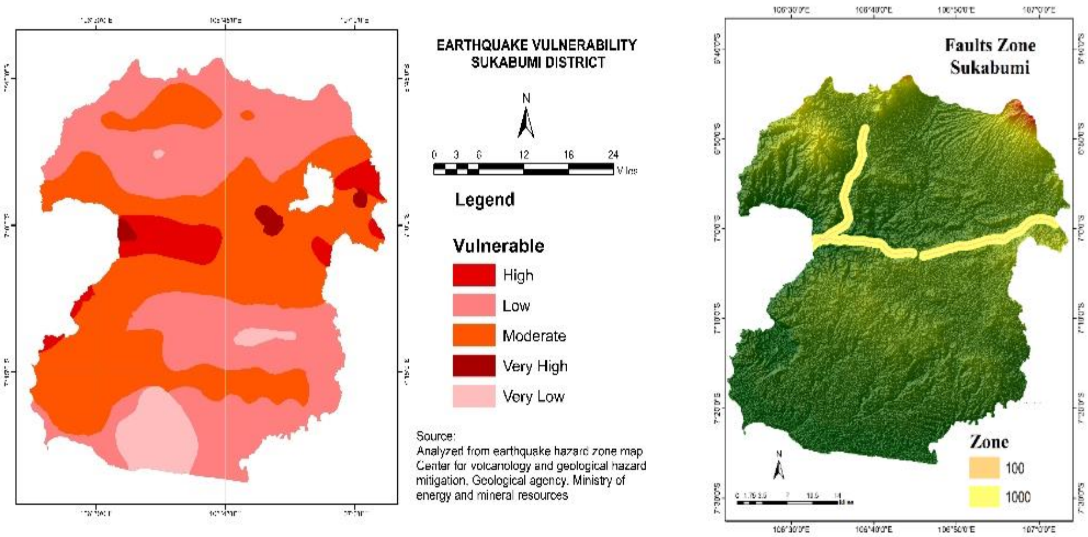
where: t_t is the total value and t_n is the false values total.

Expanding on the methodological frameworks set in this sections, subsequent subchapters present our key findings, demonstrating how the methodologies employed directly to obtain SLc and BV spatial model and validate the results.

3. RESULT AND DISCUSSION

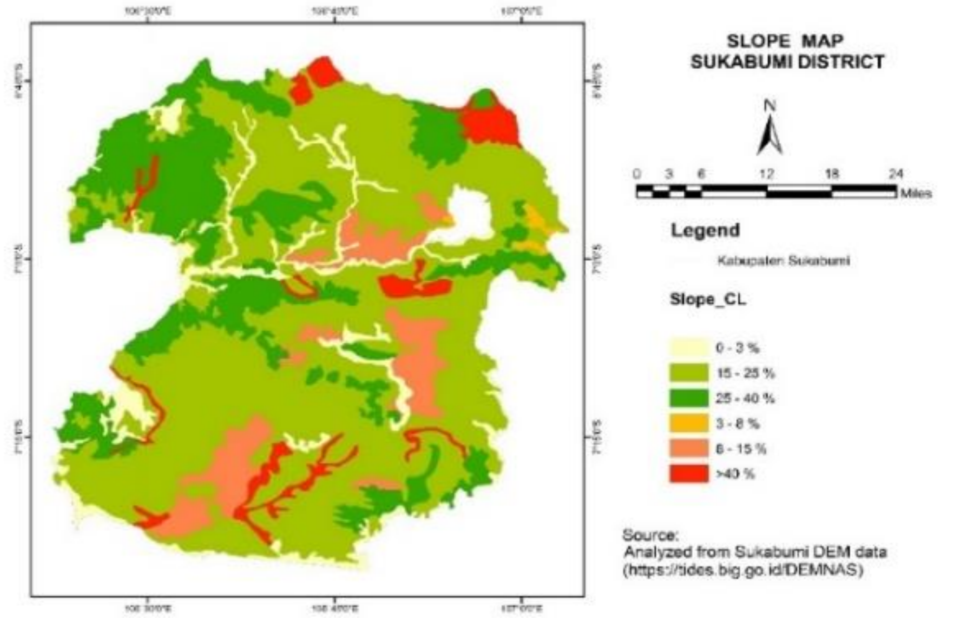
3.1. Results

By leveraging data obtained from the analysis of parameters pertaining to earthquake-prone zones (refer to **Fig. 7**) and geological instability categorization along with slope analysis (see **Fig. 8**), insights into land stability (SLc) were acquired, as depicted in **Fig. 9.**

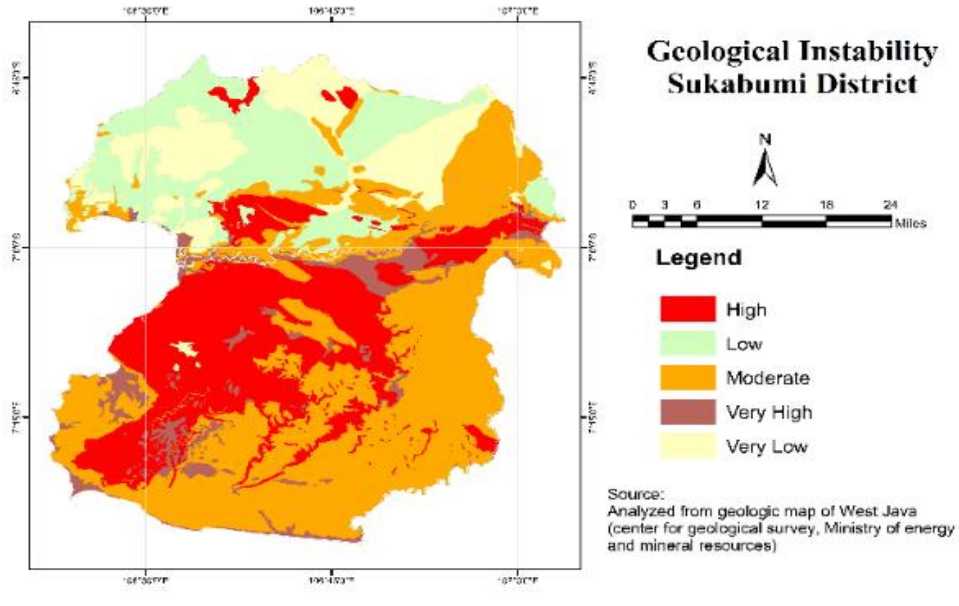


(a) (b)

Fig. 7. The earthquake-prone zones **(a)**, the categorization is I-III= very low, IV-V= low, VI-VII= moderate, VIII= high, and IX-XII = very high **(b)** and faults zone categorizations.



(a)



(b)

Fig. 8. The geologic instability, represent by the characteristic of rock composition and soil type to withstand earthquake **(a).** It categorized from very low to very high instability; and the slope categorization **(b).**

The SLc spatial analysis revealed that the majority of the Sukabumi area was controlled by an unstable to moderate level to withstand seismicity (**Fig. 9)**. Meanwhile, the highly unstable land was concentrated in the vicinity of the Cimandiri and Citarik Faults (**Fig. 9**). This is because the rock types along the fault zones include alluvium and coastal deposits, Cianglar Beach sediment, and young terrace deposits, which provide the area with the lowest capacity to endure earthquake shaking.

In the case of moderate and unstable zone categories, which typically comprise soft alluvial soil and soft terrestrial soil, the MMI falls within the range of VI to VIII, denoting earthquake shaking that is very strong to moderate in intensity (**Table 4**).

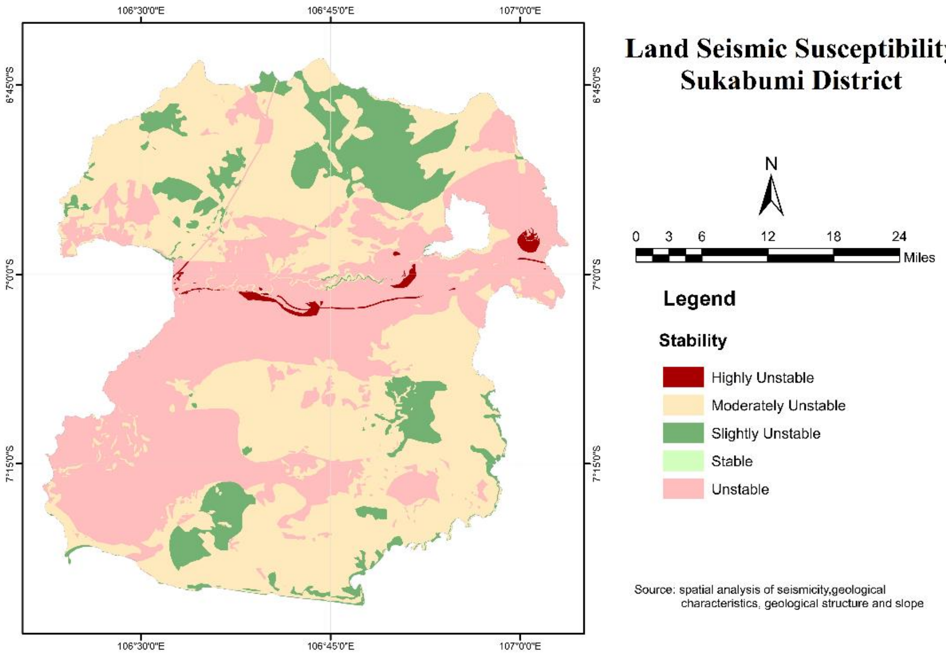


Fig. 9. The land susceptibility, indicated by the level of stability to withstand the earthquake tremors.

Table. 4. Description of SLc's Categories.

Instability Classes	Description of SLc classes
Stable	Stiff soil; majority formed by tertiary deposits such as coarse polymict, breccia, old lava deposits; consolidated rock type; not-resistant to earthquake, <IV MMI; distant from faults; PGA < 0,04g; no earthquake shaking and potential damage; flat to slightly flat slope
Slightly unstable	Stiff soil; generally formed by tertiary deposits such as coarse polymict, breccia, lava, Limestone, sandstone, claystone; generally consolidated rock types; moderately resistance to earthquake; MMI V; distant from faults; flat to undulating area, PGA > 0,04g; very light to light shaking; no potential damage; flat to moderately steep slope
Moderately unstable	Partly consist soft alluvial soil and soft terrestrial soil; generally formed by tertiary and quaternary deposit such as medium sandstone, marl, sandstone, breccia, conglomerate and intermediate polymict, lava deposits; unconsolidated to consolidated rock types; moderately resistant to earthquake, MMI VI; near the fault zone; PGA > 0,15g; moderate shaking and potential of light to moderate damage; flat coastal area to hilly
Unstable	Generally, consist of soft alluvial to soft volcanic soil; formed by quaternary deposits such alluvium, coastal deposits and young volcanic lava; generally unconsolidated rocks type; low resistance to earthquake; VII-VIII MMI; near the faults zone; PGA > 0,15g; very strong to moderate earthquake shaking; light to moderate potential damage; flat coastal area to hilly
Highly unstable	Formed by soft alluvial soil by quaternary deposits such as alluvium, fluvial and coastal deposits, young terrace deposits; unconsolidated rock types; lowest resistant to earthquake; VIII MMI; inside or near faults; PGA > 0,15g resulting in very strong earthquake shaking and potentially moderate damage; flat coastal area to hilly; flat to steep slope; possibility of liquefaction

The findings of the spatial analysis, which categorized BV based on SLc conditions, are illustrated in **Fig. 10**. This indicates that most communities are situated within a zone of moderate vulnerability. This is evident in areas located on moderately unstable land, characterized by a moderate sparsity of settlements. These areas feature a mix of permanent, semi-permanent, and wooden houses with the potential for light-to-moderate damage. Residential areas classified as highly vulnerable are primarily situated in coastal regions near the Cimandiri and Citarik faults, as depicted in **Fig. 10** and **Table 5.**

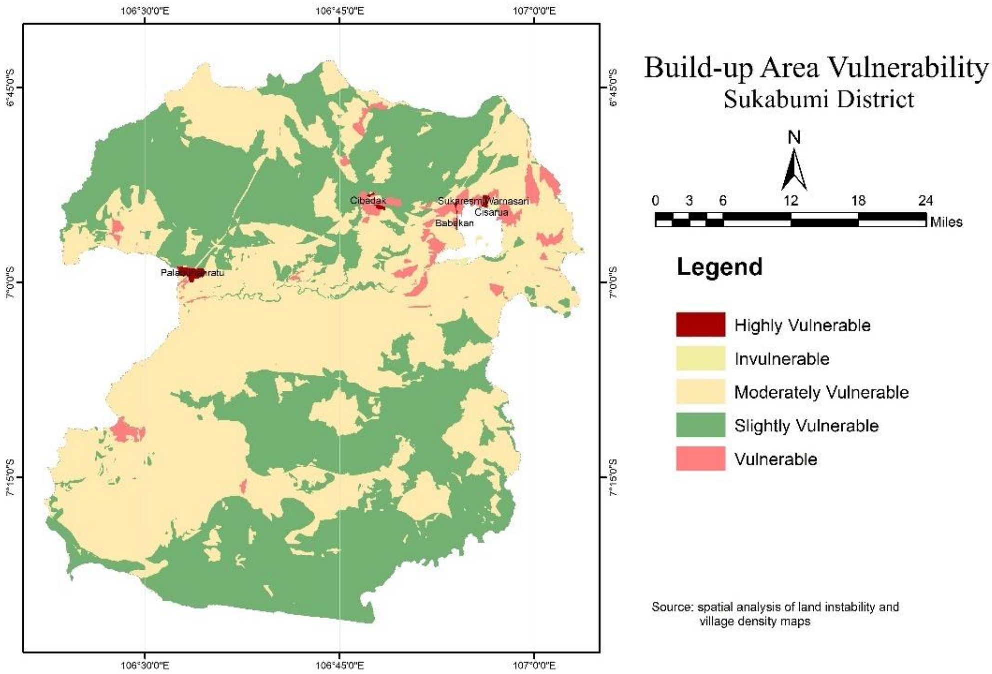


Fig. 10. Vulnerability of built-up area, assess from SLc, built-up area density, majority type of houses and disaster infrastructures.

Table 5. Built-up area vulnerability Categories-based on village administration.

Categories	Criteria
Invulnerable	Located in stable land, very sparce to sparse and mix of permanent, semi-permanent and wooden houses with the majority are concreted.
Slightly vulnerable	Locate on the slightly unstable, a sparse settlement, a mix of permanent, semi-permanent and wooden houses with the majority are concreted
Moderately vulnerable	Located on the moderately unstable land, generally has the moderate to sparse settlement, a mix of permanent, semi-permanent and wooden houses; moderate earthquake shaking and potential of light to moderate damage.
Vulnerable	located on unstable type of land, moderately dense settlements, the majority is permanent and semi-permanent, a very strong to moderate earthquake shaking and light to moderate potential damage.
Highly vulnerable	located on the highly unstable land, adjacent to the subduction zone, or inside an active fault zone, moderate dense settlements, a town or tourism area, mostly permanent concrete houses, very strong earthquake shaking and potentially moderate damage, disaster infrastructure is available

These areas are located on highly unstable land adjacent to the subduction zone or inside an active fault zone, featuring dense settlements, sub-districts, or urban villages, and mostly permanent concrete houses. Although disaster infrastructure is available, these areas are prone to very strong earthquake shaking and potentially moderate damage.

By assessing the BV spatial data with the field sample data (**Fig. 4**), the BV spatial model validation test yielded an accuracy of 0.871. This validation was on the high validation scale according to Guilfords scale (Mahendra et al., 2020), who stated the range of 0.80‑1.00 is excellent (**Table 6**). This value indicates that the VEVI model is valid.

Table 6. Guilford validation scale (*Mahendra et al., 2020*).

Value	Interpretation
0.80 - 1.00	Very High
0.60 - 0.80	High
0.40 - 0.60	Moderate
0.20 - 0.40	Low
0.00 - 0.20	Very Low
< 0.00	Not valid

3.2. Discussion

Parameters such as seismic history, soil types, structural and geological characteristics, Peak ground acceleration, slope/topography, land use, especially in built-up areas, building types, and disaster infrastructure readiness data serve as crucial inputs for constructing an SLc and BV spatial model. The results presented above indicate a link between the SLc and BV spatial models in relation to past earthquake occurrences. For instance, earthquakes that occurred on March 10, 2020, and December 14, 2023 (Idhom, 2020; BMKG, 2023) resulted in moderate damage. Similarly, a highly vulnerable zone is typically found in proximity to fault lines or regions exposed to the megathrust zone. Previous studies conducted by Gunawan & Widiyantoro (2019), Supartoyo and Solikhin (2013), and Febriani (2016) provide further evidence of high vulnerability along these subduction and active fault zones. Nevertheless, the research conducted by those three researchers was limited to assessing disaster vulnerability and did not explore land stability or its effects on the overlying settlements. This gap underscores a notable strength of this study.

While the spatial models for BV and SLc are consistent with references and on-site observations, limitations in these models persist, especially regarding housing types that frequently involve a mix of three distinct kinds of dwellings (**Fig. 6**). Most buildings, particularly in rural areas, remain permanent structures without reinforced concrete pillars and are semi-permanent. The issue of building type has become a significant concern because 75% of fatalities are caused by structural collapse (Hancilar et al, 2020). Traditional wooden houses that are more earthquake-resistant than concrete houses (Dutu, 2021; Kurnio et al, 2021) are almost extinct (**Fig. 6**). Therefore, the development of a building code is critical for disaster resilience (Hancilar, 2020; Ahmed et al, 2018; Srividhya et al, 2020) for future earthquake-resistant house initiatives. Moreover, this research is specifically designed to support government initiatives, particularly in prioritizing the establishment of earthquake-resistant housing in the highly vulnerable areas. For example, within the Pelabuhanratu Town and Ciletuh tourism village (**Fig. 9**). As a part of the UNESCO Pelabuhan Ratu-Ciletuh Geopark, recognized in the Global Geopark Network and as a tourist destination, Pelabuhanratu Town and Ciletuh show inconsistent construction practices in adhering to earthquake resistance house criteria. In addition, this region is susceptible to tsunami catastrophes (Nugrahia et al, 2020). On September 2, 2009, a recorded earthquake with a magnitude of 7.3, struck the Pelabuhanratu area (Indira & Manesa, 2023), causing severe damage, with 5,545 residential buildings collapsing.

4. CONCLUSIONS

This study underscores the importance of various parameters, including seismic history, soil types, geological structure and geological characteristics, topography, land use, building types, and disaster infrastructure readiness, in constructing SLc and BV spatial models. The model has the potential to significantly contribute to disaster preparedness and initiatives for constructing earthquake-resistant houses. Homeowners residing in instability zones identified by the SLc and BV spatial models can offer opportunities for safer construction. Comprehensive data can provide accurate inputs for decision makers in implementing outreach and assistance in the construction of earthquake-resistant houses. Understanding land capability concerning earthquakes has emerged as a vital aspect of urban planning and disaster management, enabling better preparation for potential seismic events in certain areas.

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