

Risk Analysis of Infrastructure Development in the Megathrust Active Seismic Region of Southern Lombok Island

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Abstract: Southern Lombok combines active seismic conditions with expanding coastal infrastructure. This study compares six local zones using a semi-quantitative hazard-vulnerability-capacity index, an indicative SNI 1726:2019 building-function assessment, and district-scale exposure and loss inputs reported in the research summary. The earthquake catalogue covers 1969–2021. Composite vulnerability is calculated as $V = 0.4V_s + 0.3V_p + 0.3V_e$, and $R = (H \times V)/C$. The reported indices are 72.08, 61.77, 132.94, 88.80, 58.16, and 54.97 for Zones I–VI. Zone III ranks highest, followed by Zone IV. The original analysis labels five zones Low Risk and Zone III Moderate Risk, although the classification thresholds require documentation. SNI categories are indicative and require verification for individual buildings. A reported district loss reference of IDR 4,603,070 million is allocated proportionally as an illustrative scenario, giving Zone III 28.36%; the allocation is not a prediction of actual zonal loss. The results support screening priorities for further investigation and mitigation. Key limitations are incomplete indicator-level scoring documentation and missing metadata for the original exposure-and-loss extract.

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INTRODUCTION

Indonesia lies within an active tectonic setting where interactions among major plates generate frequent earthquakes and high seismic hazard. Southern Lombok is particularly important because it is influenced by the Sunda-Banda subduction system and has experienced rapid infrastructure growth associated with tourism and coastal development. National seismic-hazard mapping and post-2018 Lombok studies confirm that seismic demand in Lombok and the surrounding islands must be explicitly considered in development planning (Irsyam et al., 2017; Agustawijaya et al., 2020; Ananda & Pujiastuti, 2024).

Infrastructure risk is not controlled by earthquake hazard alone. The consequence of an earthquake also depends on building vulnerability, exposed population and assets, local site conditions, and the capacity of a region to prepare for and respond to disasters. Contemporary seismic-risk studies therefore combine hazard, vulnerability, exposure, and infrastructure-system characteristics rather than relying on a single hazard indicator (Poudel et al., 2023; Shirvani Harandi et al., 2024; El-Maissi et al., 2023). Building-level studies also show that structural typology, material quality, and local vulnerability strongly influence damage potential (Juliafad & Gokon, 2022; Pramesti et al., 2023; Weber et al., 2024).

In southern Lombok, this problem is especially relevant because the same seismically active environment contains zones with different land uses, concentrations of tourism assets, settlement patterns, and emergency capacity. SNI 1726:2019 provides the technical basis for earthquake-

resistant structural design according to building function and the consequences of failure, while BNPB's IRBI/InaRISK framework provides regional disaster-risk and loss information. However, these perspectives are often discussed separately. The novelty of this study is the integration of three complementary approaches at a six-zone local scale: (1) an H-V-C risk index for spatial differentiation, (2) SNI 1726:2019 for structural-risk category implications, and (3) IRBI/InaRISK BNPB for population exposure and economic-loss consequences. The study therefore aims to identify spatial differences in infrastructure-development risk and translate them into practical priorities for planning, structural design, mitigation, and financing.

RESEARCH METHOD

Data Sources and Study Zone Delineation

The study applies spatial and semi quantitative analysis using the geotechnical, infrastructure, geological, land-use, administrative, population, and earthquake information reported in the research dataset. The earthquake catalogue covers 1969–2021, with magnitude 2.5–10, hypocentral depth 0–300 km, and a search radius of 500 km. The catalogue provider is the United States Geological Survey (USGS), whose earthquake catalogue service supports temporal, magnitude, depth, and geographic filtering (United States Geological Survey [USGS], n.d.). These years describe the event-selection period, not the publication date of the catalogue. The study uses IRBI 2023 as regional risk context (Badan Nasional Penanggulangan Bencana [BNPB], 2024) and refers separately to the InaRISK portal for exposure and loss information (BNPB, n.d.).

IRBI 2023 is the assessment edition, whereas January 2024 is the publication date shown in the official volume. A citation to that volume does not, by itself, establish the year of the underlying population or asset data. For the exposure and loss inputs, the source record must distinguish the hazard layer, administrative unit, data vintage, and extraction date. These metadata are not interchangeable with the year appearing in the IRBI title.

The southern Lombok study area was digitized as six local polygons using Google Earth Pro. The zones cover the coastal-development corridor around Awang, Gerupuk, Seger, Kuta Mandalika, Mertak Barat, and Blongas. The zonation was used to capture local variation in topography, land use, settlement and tourism intensity, infrastructure distribution, and exposure that would be obscured by district-level aggregation.

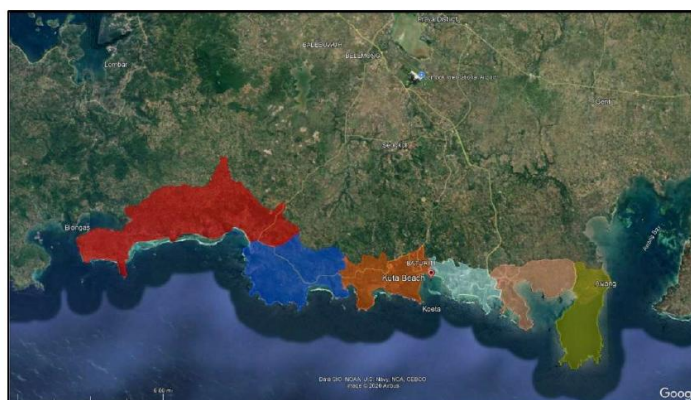


Figure 1. Spatial division of the six study zones in southern Lombok (source: thesis mapping using Google Earth Pro)

Risk Index Analysis

The H–V–C approach is a semi quantitative screening model. Individual indicators use ordinal scores from 1 to 5, whereas H, Vp, Ve, Vs, and C in the results table are aggregate component scores, not individual 1–5 ratings. Higher H and V scores represent greater adverse conditions. Because capacity appears in the denominator, higher C must represent stronger capacity and therefore lower calculated risk. A deficiency indicator must be reverse-coded before inclusion in C; for a five-point deficiency scale, the corresponding capacity score is 6 minus the deficiency score. This direction must be consistent across all zones.

Table 1. Interpretation of the ordinal scale and its direction in the model

Score	Hazard and vulnerability	Capacity
1	Very low adverse contribution	Very low protective capacity
2	Low adverse contribution	Low protective capacity
3	Intermediate adverse contribution	Intermediate protective capacity
4	High adverse contribution	High protective capacity
5	Very high adverse contribution	Very high protective capacity

Note: These labels clarify the mathematical direction of the scale; they do not establish indicator-specific measurement thresholds. The original scoring worksheet is needed to demonstrate which observation justified each assigned score. No new threshold or observed score is inferred from the aggregate totals.

Table 2. Indicator groups and evidence needed to reproduce the scoring

Group	Parameters reported in the study	Required scoring evidence
H	Soil and rock characteristics; fault conditions; groundwater depth	Geological/geotechnical observations, units, location and indicator-specific class limits.
H	Bedrock acceleration; short- and long-period spectral parameters	Mapped or calculated values, units, probability/return-period basis and original scoring intervals.
H	Magnitude; duration; depth; distance; MMI	Event selection and representative-statistic rule; source of duration and intensity; original class limits.
Vs	Population; age; education; occupation/income	Reference year, zonal counts or proportions, denominator and original scoring intervals.
Vp	Building and infrastructure types	Inventory, structural condition, typology and explicit category-to-score mapping.
Ve	Economic functions and assets	Asset or activity measure, units, reference year and original scoring intervals.
C	Land use; standards implementation; evacuation access; shelters; emergency facilities	Evidence of availability, condition and service coverage; coding in which a higher score means stronger capacity.
C	Health indicators and budget support	Reference year, relevant population/budget denominator and protective score direction.

The original article reports the component totals but does not provide the raw indicator-by-zone matrix, numerical cut-offs, or internal weighting rules. Consequently, the calculations below are reproducible from the reported totals, while the assignment of those totals remains a methodological limitation. The same parameter set and aggregation convention must be used in all zones for a fair comparison. The H-V-C index is study-specific and should not be equated numerically with the official IRBI index.

Vulnerability is separated into social (V_s), physical (V_p), and economic (V_e) components. Social vulnerability includes population characteristics, age, education, and occupation/income; physical vulnerability represents building and infrastructure types; and economic vulnerability represents the economic functions and assets present in each zone. The composite vulnerability value is calculated as:

$$V = 0.4V_s + 0.3V_p + 0.3V_e$$

Capacity represents the ability of the area to reduce disaster impacts. The reported capacity totals are 20 for Zone I and 23 for Zones II–VI. The vulnerability weights are retained from the study: 0.4 for social, 0.3 for physical, and 0.3 for economic vulnerability; they sum to 1. These weights are model choices rather than empirically calibrated damage probabilities. With C greater than zero, the risk index is calculated as:

$$R = (H \times V) / C$$

For Zone II, $H = 48$, $V_p = 13$, $V_e = 19$, and $V_s = 50$. Thus, $V = (0.4 \times 50) + (0.3 \times 13) + (0.3 \times 19) = 29.6$. With $C = 23$, $R = (48 \times 29.6)/23 = 61.7739$, reported as 61.77. For Zone III, $V = (0.4 \times 61) + (0.3 \times 21) + (0.3 \times 19) = 36.4$ and $R = (84 \times 36.4)/23 = 132.9391$, reported as 132.94. The same calculation was checked for all six zones. Classification labels are retained from the supplied analysis; their numerical class boundaries are not documented in the available scoring material.

SNI 1726:2019 Assessment

SNI 1726:2019 was used to identify building risk categories according to building function and the consequences of structural failure. This classification is distinct from the regional H-V-C risk index. For structural planning, the standard requires consideration of design spectral accelerations (SDS and SD1), site class, structural system, importance factor, and structural detailing (Badan Standardisasi Nasional, 2019).

IRBI and InaRISK Sources and Scenario Allocation

IRBI and InaRISK serve different roles in this analysis. IRBI 2023 provides regional risk context (BNPB, 2024), while InaRISK is the spatial risk-information portal (BNPB, n.d.). The supplied research summary attributes an exposed population of 912,737 people, physical losses of IDR 4,084,038 million, and economic losses of IDR 519,032 million to Central Lombok Regency. Their sum is IDR 4,603,070 million. These values are retained as reported study inputs; the original layer export or source table, underlying data year, and extraction date are not available in the supplied material. They therefore cannot be independently attributed to a specific IRBI table or InaRISK data vintage. They are not observations of actual earthquake losses.

The six local polygons do not constitute a demonstrated partition of the district exposure inventory. Allocating the entire district total to them cannot therefore establish actual losses within their boundaries. For continuity with the original analysis, an illustrative allocation is retained: $W_i = R_i / \sum R$ and $A_i = W_i \times L_{ref}$, where L_{ref} is the reported district total and A_i is a scenario allocation, not an independently modelled zonal loss. The denominator is 468.72, using the six displayed two-decimal R values. Monetary results are rounded only after allocation. This assumption preserves the reference total for comparison but does not correct differences in area, asset distribution, or administrative coverage.

RESULTS AND DISCUSSION

Risk Index Results

The reported H-V-C scores show spatial variation across the six zones. Under the classification labels used in the supplied analysis, five zones (83.33%) are Low Risk and Zone III (16.67%) is Moderate Risk. Zone III has the highest index (132.94), followed by Zone IV (88.80), Zone I (72.08), Zone II (61.77), Zone V (58.16), and Zone VI (54.97). The numerical ranking is reproducible from the reported component totals. The categorical labels remain conditional on verification of the original classification thresholds.

Table 3. Risk-index results for the six study zones

Zone	H	Vp	Ve	Vs	V	C	R	Classification
I	53	10	14	50	27.2	20	72.08	Low Risk
II	48	13	19	50	29.6	23	61.77	Low Risk
III	84	21	19	61	36.4	23	132.94	Moderate Risk
IV	69	18	14	50	29.6	23	88.80	Low Risk
V	49	16	15	45	27.3	23	58.16	Low Risk
VI	49	16	10	45	25.8	23	54.97	Low Risk

Zone III combines the highest hazard score ($H = 84$) with the largest composite vulnerability ($V = 36.4$), while its capacity remains $C = 23$; this combination produces the highest index and the only Moderate Risk classification. Zone IV ranks second because its hazard and vulnerability remain comparatively high. In contrast, Zones V and VI have lower vulnerability and lower development exposure, resulting in lower index values. This pattern supports the general finding that seismic risk is shaped by both the hazard environment and the characteristics of exposed infrastructure and communities (Poudel et al., 2023; Shirvani Harandi et al., 2024).

The regional ranking should be interpreted alongside studies that address different scales of seismic risk. Juliafad and Gokon (2022) examine building fragility, while Irsyam et al. (2017) provide the national seismic-source and hazard context. Local studies consider updated Lombok hazard and Mataram site characteristics (Agustawijaya et al., 2020; Septiadhi et al., 2024). These studies support attention to source, site, and building conditions, but they do not validate the numerical thresholds or weights of the present screening model. A Low Risk label in this model must therefore not be interpreted as an absence of strong-earthquake hazard.

Implications of SNI 1726:2019

The supplied analysis associates the dominant functions in Zone I with Risk Category I and those in Zones II–VI with Risk Category II. This is an indicative screening summary, not a formal category assigned to a geographic zone. Under SNI 1726:2019, the applicable category must be determined for each building from its actual function and consequences of failure (Badan Standardisasi Nasional, 2019). Small size or simple construction alone does not establish Category I. Buildings with essential functions or greater consequences of failure require separate assessment even when located within a zone dominated by ordinary residential or commercial uses.

Table 4. Indicative SNI building-risk categories reported for dominant area functions

Zone	Indicative category	Dominant Function	Structural Implication
I	I	Low-consequence facilities, subject to verification of actual use	Verify category for each building; $le = 1.0$ applies only where Category I is justified.
II-VI	II	Housing, hotels, villas, restaurants, commercial and tourism uses	Verify actual occupancy and function; $le = 1.0$ where Category II applies.

This distinction is important for practice. A zone can be classified as Low or Moderate Risk in the regional rating while the buildings within it still require the technical provisions of SNI 1726:2019. Consequently, site investigation, SDS and SD1, site class, structural-system selection, and detailing should remain mandatory for projects throughout the study area.

District Exposure and Illustrative Allocations

The exposure and loss values in Table 5 are presented once at the administrative scale stated in the supplied study summary. The population of 912,737 is a reported exposed population, not a count of casualties and not the population of each individual zone. The total of IDR 4,603,070 million equals IDR 4,603.07 billion. Until the original source extract is recovered, the geographic and temporal provenance of these inputs remains subject to confirmation. The publication date of IRBI 2023 alone cannot be used to date the exposure or asset inventory.

Table 5. District-scale exposure and loss inputs retained from the supplied study summary

Data Scale	Exposed Population	Physical Loss (IDR million)	Economic Loss (IDR million)	Total Loss (IDR million)
Central Lombok Regency	912,737	4,084,038	519,032	4,603,070

Applying the illustrative allocation to the reported reference total gives Zone III the largest share (28.36%; IDR 1,305,538.76 million), followed by Zone IV (18.95%; IDR 872,061.39 million). Zone VI has the smallest share (11.73%; IDR 539,833.50 million). The same ranking necessarily appears because each monetary allocation is a fixed positive multiple of R . The monetary column therefore provides no independent validation of the risk ranking. It should not be used as a predicted damage bill, insurance valuation, or project budget. Displayed percentages sum to 100.01% and displayed

monetary allocations to IDR 4,603,070.01 million because of rounding; the unrounded allocations sum to the reference total.

Table 6. Illustrative allocation of the district reference total by relative risk-index weight

Zone	Risk Index (R)	Classification	Risk Weight (%)	Scenario allocation (IDR million)	IDR billion
I	72.08	Low	15.38	707,862.45	707.86
II	61.77	Low	13.18	606,612.98	606.61
III	132.94	Moderate	28.36	1,305,538.76	1,305.54
IV	88.80	Low	18.95	872,061.39	872.06
V	58.16	Low	12.41	571,160.93	571.16
VI	54.97	Low	11.73	539,833.50	539.83

Integrated Interpretation and Development Implications

The three approaches answer different decision questions. The H-V-C rating identifies spatial priorities; SNI 1726:2019 defines structural safety requirements according to building function; and IRBI/InaRISK places the zonal findings within a broader exposure-and-loss context. This integrated interpretation is consistent with current infrastructure-risk literature that promotes multi-component assessment rather than single-metric screening (Amendola & Pitilakis, 2023; El-Maissi et al., 2023; Sousa & Tsionis, 2025).

Zone III is the first screening priority because its combination of hazard and vulnerability produces the highest reported index; Zone IV ranks second. Follow-up investigations should assess actual site response, building inventories, foundation conditions, and emergency access before project-level decisions are made. Zones I, II, V, and VI also require preventive controls because development can change exposure. Relevant studies examine near-fault hazard, residential loss modelling, building typology, and roadway vulnerability (Aglia et al., 2023; Lambang-Goro et al., 2022; Firmansyah et al., 2024; Yildirim et al., 2024). They provide methodological context rather than direct evidence of conditions within these six polygons.

Accordingly, the practical contribution of the study is not a single 'safe/unsafe' label. Instead, it provides a decision framework that links local risk zoning with SNI-based design control and a transparent economic-priority indicator. Such integration can support development permits, mitigation investment, emergency planning, and risk-informed infrastructure budgeting in a rapidly developing coastal tourism region.

Sensitivity and limits of interpretation

The equation also clarifies how assumptions affect the result. Holding other inputs constant, a 10% increase in H or V increases R by 10%. A 10% increase in C reduces R to 1/1.10 of its original value, a reduction of approximately 9.09%. These are algebraic sensitivity statements, not forecasts of the effect of a particular intervention. Improving an evacuation route or enforcing a building standard cannot be assigned a percentage reduction in risk without a documented change in the corresponding indicator and supporting evidence.

Uniform capacity totals across Zones II–VI mean that their ordering is driven by $H \times V$ in the current model. However, equal totals do not demonstrate equal service coverage or equivalent

emergency performance. Different combinations of capacity indicators can yield the same aggregate value. Likewise, a composite vulnerability index can obscure contrasting social, physical, and economic conditions. Future reporting should retain the disaggregated indicators so that mitigation measures can target the conditions responsible for each score.

The analysis has three principal evidence limitations: incomplete documentation of the original scoring rubric and class boundaries; missing source metadata for district exposure and losses; and the use of an ordinal risk index to allocate a monetary reference total. The 1969–2021 catalogue also represents a historical selection window rather than a current hazard model. These limitations constrain reproducibility and absolute loss interpretation. Future work should use archived data extracts, explicit scoring criteria, georeferenced asset inventories, and independently validated hazard and vulnerability models before estimating losses for individual zones.

CONCLUSION

The reported screening index is highest in Zone III (132.94) and lowest in Zone VI (54.97), with Zone IV the second priority (88.80). Five Low Risk labels and one Moderate Risk label are retained from the supplied analysis, pending confirmation of the original class boundaries. The indicative SNI summary must be verified at building level and must not be treated as a zone-wide structural designation. The reported district loss reference of IDR 4,603,070 million produces a 28.36% allocation to Zone III under the proportional scenario; this is not an independently estimated zonal loss. The study supports prioritization of further site investigation, structural assessment, construction quality control, and emergency-capacity review. Its results remain conditional on the reported aggregate inputs, and full reproducibility requires the original scoring worksheet and the exposure-and-loss source extract.

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