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IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Earthquake Risk Assessment of Sabah, Malaysia Based on Geospatial Approach

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DOI: https://doi.org/10.30880/ijie.2022.14.05.004
Received 21 February 2022; Accepted 01 July 2022; Available online 25 August 2022

Abstract: Sabah is located in the northeast region of East Malaysia and recognized as the most active seismic area in Malaysia. The scalability and frequency of earthquakes are growing due to the existence of both local and distant ground motions from active faults, with more than 67 earthquake occurrences with light to moderate magnitude (M_w larger than 3.5) recorded since the 1900. On the other hand, the skewed socio-economic development process associated with the rapid population growth and changes in the family structure, inequality issues, and the lack of adaptation measures would intensify the vulnerability of the earthquakes. Key elements linked to socio-economic vulnerability need to be addressed in order to reduce the risk of earthquake. Based on previous studies, we identified vulnerabilities from a multi-dimensional perspective consisting of exposure, resilience and capacity across districts. Subsequently, a holistic indicator system with 18 variables was constructed to assess the potential earthquake vulnerability in Sabah, Malaysia. The accumulated data will present an earthquake vulnerability classification using the Geographical Information System (GIS) approach. Finally, the earthquake risk was derived by integrating the earthquake vulnerability map with earthquake hazard map proposed by the Department of Mineral and Geoscience (JMG) Malaysia. The results of the analysis revealed that the highest level of earthquake risk, which accounts for 15.5 %, were concentrated in the eastern part of the Sabah region; the high-risk areas account for 7.7 %; the moderate-risk areas account for 11.3 %; and the low to very low risk areas account for 65.4 %. Accordingly, it is expected that the derived earthquake vulnerability and risk map will allow the policymakers and response teams to improve the earthquake disaster mitigation and management in Sabah.

Keywords: Earthquake, GIS, Sabah, seismic risk, vulnerability assessment

1. Introduction

Vulnerability refers to the susceptibility of populations to hazards. The conditions that occur including physical, social, and economic factors have affected the ability of the population to respond to hazard or catastrophic events [1]. Vulnerability is always associated with poverty, helplessness, weakness, limited capabilities and lack of resources. The main contributors are inappropriate use of technology, lack of building code enforcement, lack of construction design

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in considering disaster risk, lack of vulnerability analysis and unplanned urban settlement in high risk areas. In disaster risk reduction, preparedness and mitigation strategies are implemented in an effort to reduce the actual or possible impact of disasters on the human, structural, economic, and social systems and the environment. Thus, the Hyogo Framework for Action (HFA) 2005–2015 has highlighted the vulnerability indices as a guideline for a holistic vulnerability assessment by considering the adaptive capacity and the myriad of resilience factors. [2].

Research on earthquake or seismic vulnerability studies has gained attention in recent years [3]–[7]. There have been several attempts from previous studies to assess the level of earthquake vulnerability using methods based on indicator systems in various geographical scales (e.g. local, regional, national, international, etc). For instance, [8] developed the Earthquake Disaster Risk Index (EDRI) to assess earthquake risk at a metropolitan area by considering hazard and vulnerability components; [1] proposed the holistic MOVE framework to systematize and assess vulnerability in the context of exposure, resilience and adaptive capacity of a community towards natural hazards; while in Tehran, [9] and [10] introduced the relative seismic risk index (RSRi) and Integrated Earthquake Safety Index (IESI), respectively. RSRi proposed a new method for estimating urban structural risks by considering hazards, vulnerability, and response capacity indicators, while IESI evaluates the level of earthquake safety at urban fabrics using different physical and socio-economic criteria.

In brief, from the literature review on previous studies, despite many formidable challenges, some constraints have been underlined such as the limitations of its implementation across locations and conditions and the requirement of comprehensive and appropriate data to assess earthquake vulnerability and risk. Under the current circumstances, the situation has become more complex and challenging due to differences in local geography, ecology, and socio-economic environment. The method in developing vulnerability index is based on a prevailing theory which defines the disaster risk as a product of three major elements comprising the frequency or severity of the hazard, vulnerability and the capacity. The aim is to measure vulnerability and risk through selected comparative indicators in a quantitative way and to be able to compare different regions or communities [1], [11]–[13].

In Malaysia, the research on earthquake vulnerability and risk are still in the early stages [14]. The focus of earthquake-related studies is on seismic hazard assessment, with only a handful of studies conducted on seismic vulnerability and earthquake risk assessment. Amongst them are the evaluation of earthquake threat in Sabah considering the rate of earthquake events, the distribution of various magnitude quakes and the level of ground shaking [15]; the preliminary seismic vulnerability assessment of existing buildings using the simplified method that focus only in particular areas of Kundasang, Sabah [16]; evaluation of earthquake vulnerability in the context of physical (buildings only) components on Ranau, Sabah [17]; and the Earthquake Vulnerability Assessment (EVA) [14] to assess the earthquake vulnerability in terms of environmental and social characteristics. However, this study is only focused on the district of Ranau, which is one of the most prone areas to earthquake hazard in Malaysia. Recently, the seismic vulnerability assessment method and framework for Malaysia has been proposed [18] and part of the framework has been conducted in Pahang, Malaysia to assess the social vulnerability to the earthquake hazard at local districts [19]. Alternatively, the introduction of holistic risk components would be of great value for Malaysia, due to the provision of preliminary information on disaster preparedness and planning [20]. The proposed approach depicts an instrument for identifying cost-effective risk reduction initiatives by providing a scientific method for regional risk planning and management strategies.

In this study, risk is viewed within the framework of hazards and vulnerabilities [21]–[24]. Accordingly, vulnerability is expressed in separate components of exposure, resilience and capability, in other words, a cumulative of those characteristics will measure the vulnerability level of a population. An integrated method to construct a composite vulnerability index based on an unequal weighting scheme is developed. This method has been selected as it enables socio-economic and environmental factor incorporation to assess earthquake vulnerability. Generally, the composite index has been used in various disciplines to measure complex multidimensional theories that cannot be directly observed or evaluated [25]. Its advantages are highlighted through the ability to synthesize large amounts of diverse information into easy-to-use forms. The indicators that contribute to disaster risk are identified and implemented in the earthquake risk model. Multiple ranges of indicators are scaled using mathematical calculations. Subsequently, we utilized the analytical ranking or scoring approaches to prioritize the different types of indicators of risk. Next, the combination of scaled indicators could generate earthquake risk indices which can be implemented in seismic risk analysis [11].

In order to present the vulnerability and risk of earthquakes at the local districts of Sabah in the form of maps, the advantages of a geospatial approach were applied. In particular, geoprocessing tools in the ArcGIS software were employed to perform the spatial analysis (e.g. overlay, reclassify, weighted sum, raster calculator, tabulate area, etc.). The expected benefits of mapping the distribution of an earthquake vulnerability and risk at the regional level, is as an alternative tool for local governments to guide the reduction of social vulnerabilities and the preparation of appropriate mitigation plans.

2. Materials and Methods

2.1 Study area

This study is conducted in the Sabah region, which is located in East Malaysia with an estimated area of 73,904 km^2, bounded by coordinates of 115° through 119° E and 4° through 7° N as shown in Fig. 1. The overall area of Sabah is rugged with a major high hilly landform type concentrated in the west with Mount Kinabalu, at an altitude of 4,101 meters, dominating the surrounding landscape. The territory of Sabah is divided into 25 districts with an estimated population of approximately 3.91 million in 2020 [26]. The region has been rocked repeatedly by both near and far-field earthquakes of small to moderate magnitudes. The most notable earthquake was the 6.0 magnitude earthquake that occurred in Ranau, Sabah in 2015 with a huge impact on Malaysians, both locals and the authorities [27].

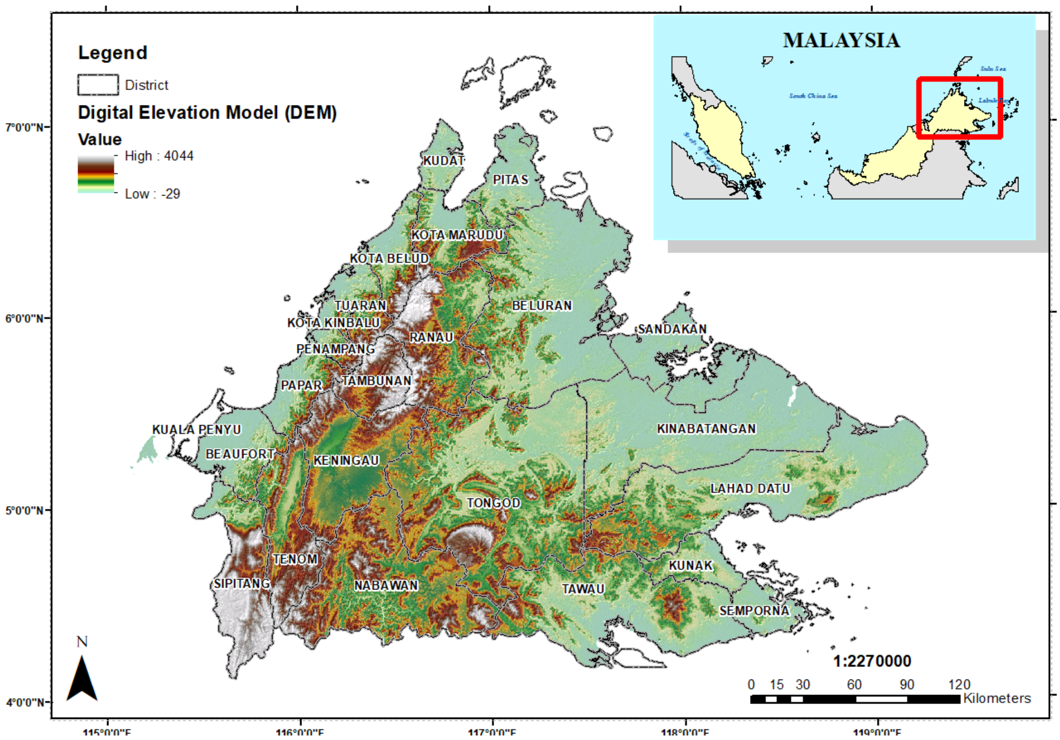

Fig 1 - The study region of the present research

2.2 Data Collection and Processing

2.2.1 Data Sources and Details

Data from related federal government agencies were collected and organized according to the application of the modules in the GIS database. The list of agencies consists of the Malaysian Geospatial Data Infrastructure Center (MaCGDI), the Malaysian Meteorological Department (MET Malaysia), the Malaysian Department of Minerals and Geosciences (JMG) and the Department of Statistics Malaysia (DOSM). Details on seismic center data were obtained from local agencies (MET Malaysia), and international online earthquake monitoring websites that refer to the Institute of Seismic Research Incorporated (IRIS) and The United States Geological Survey (USGS). The list of entities, formats and sources is shown in Table 1. Data is the most important component in determining the success of GIS applications. Accordingly, the data required for this study were identified according to the data type, either spatial or data attributes, and data format (vector or raster).

Table 1 - List of data sources and details

Module	Entity	Format	Source	Year
Hazard	Fault	Line- vector	JMG	2012
	Epicenter	Point- vector	MET Malaysia/IRIS/USGS	2016
	Seismic zone	Polygon- vector	JMG	2016
Cadastral layer	State map	Polygon- vector	MaCGDI	2010

Module	Entity	Format	Source	Year
	Country	Polygon-vector	MaCGDI	2010
	District	Polygon-vector	MaCGDI	2010
	Road	Line - vector	MaCGDI	2012
	Administration Boundary	Line - vector	MaCGDI	2012
	Slope (DEM)	Raster image	MaCGDI	2012
Potential risk zones	Land use	Polygon- vector	MaCGDI	2015
	Building	Polygon- vector	MaCGDI	2011
	Residential	Polygon-vector	MaCGDI	2010
	Public facilities (police station, fire station, and others)	Point / polygon - vector	MaCGDI	2012
	School	Point / polygon - vector	MaCGDI	2012
	Hospital	Point / polygon - vector	MaCGDI	2012
	City	Point- vector	MaCGDI	2012
	Population / Census	Polygon-vector	DOSM	2010

2.2.2 Selection of Indicators

Identification of indicators and sub-indicators are important to define the factors that contribute to earthquake vulnerability and earthquake risk. Groups of indicators are classified into hazard and vulnerability modules. A vulnerability module consists of indicators of exposure, resilience, and capacity. Each group of the indicator will be assigned with sub-indicators. The development of the indicator list is determined based on the data availability, previous studies, and expert opinions. Exposure is an important element of vulnerability risk that defines the extent of societies and properties being assessed within the geographical context of a risk occurrence [1]. Meanwhile, the lack of resilience or coping capabilities to society is measured by the limitations of access and mobilization of community or social-ecological capital to respond to predetermined hazards [28]–[31]. Therefore, the selection and characterization of the respective data were collected and gathered from responsible agencies to identify and develop the vulnerability indicators at a municipal scale. The functional relationship between composite indicators and vulnerability is distinguished by representing indicators with positive and negative correlations. A positive sign indicates that the contribution of the indicator increases the level of vulnerability, while a negative sign is vice versa.

The exposure indicator is commonly related to characteristics of a population and physical properties to predict the vulnerability. These characteristics include the socio-economic demographic data, such as age structure, gender, disability condition, household composition and residential distribution [22], [23], [32]–[36]. Most of the information is retrieved from the national census. In detail, the resilience indicator incorporates the existing community resources including economic capital (e.g. GDP, income, poverty, etc.) and communication facilities (e.g. telecommunication services, transportation, etc.) in order to respond to a threat or hazard [26], [30], [36]–[38]. while quantifying adaptive capacity to vulnerability related to critical public facilities with high occupant density and transportation network. Public facilities like police station, fire station, healthcare services, school and road networks that are subjected to collapse or fail during the disaster will exacerbate the impact of the disaster [10], [28], [39]–[42].

2.2.3 Calculation of Indicators Weight and Earthquake Vulnerability Index

There are two broad approaches to vulnerability calculations which empirically refer to conventional and indicator-based methods [11]. In this study, we aggregate the exposure, resilience and capacity indicators following [43] and [44]. First, normalization was performed for the purpose of rescaling the indicators using min-max Eq. (1) and Eq. (2) [45]. Therefore, the standardized indicators were dimensionless with an identical range between 0 and 1. The use of mathematical formulas depends on the functional relationship indicator to vulnerability: (i) Eq. (1) for positive functional relationship and (ii) Eq. (2) for negative functional relationship.

$$X_{ij} = \frac{\left(x_{ij} - \text{Min}\, x_{ij}\right)}{\left(\text{Max}\, x_{ij} - \text{Min}\, x_{ij}\right)}, \quad \left(0 \le x_{ij} \le 1\right) \tag{1}$$

$$X_{ij} = \frac{\left(\text{Max}\, x_{ij} - x_{ij}\right)}{\left(\text{Max}\, x_{ij} - \text{Min}\, x_{ij}\right)}, \quad \left(0 \le x_{ij} \le 1\right) \tag{2}$$

where, X_{ij} = normalized value of the indicator i of the component j, x_{ij} = value of the indicator i, $Max\ x_{ij}$ = the maximum values of the indicators i of the component j respectively, $Min\ x_{ij}$ = the minimum values of the indicators i of the component j respectively. Subsequently, the linear sum of dimensionless x_{ij} were calculated using Eq. (3).

$$\bar{y}_j = \sum_{j=1}^{K} w_j x_{ij} \tag{3}$$

where, K = indicators of vulnerability, x_{ij} = normalized scores (i = 1, 2, …,n; j = 1, 2, ….., K) , w_j= weight of indicator variable ($0 < w < 1$) and $\Sigma w_j = 1$. Weights should vary inversely, as the difference between regions is a measure of their respective characteristics. Contributions or weight (wj) for different indicator variables are defined by Eq. (4) and Eq (5) where c represents a constant normal.

$$w_j = c \Big/ \sqrt{\operatorname{var}\left(x_{ij}\right)} \tag{4}$$

$$c = \left[\sum_{i=1}^{j=K} 1 \Big/ \sqrt{\operatorname{var}\left(x_{ij}\right)}\right]^{-1} \tag{5}$$

The resulting weight values calculated for each variable are shown in Table 2.

Table 2 - Weight of vulnerability indicator variables

Group Indicator	Variable Indicator (unit)	Functional Relationship	Weight
Exposure	Age structure (less than 15 years old) (%)	+	0.1059
	Age structure (more than 65 years old) (%)	+	0.1043
	Gender (female occupant) (%)	+	0.1101
	Disabilities occupant (%)	+	0.1333
	Population density (per hectare)	+	0.1270
	Household density (per hectare)	+	0.1339
	Household residence density (per hectare)	+	0.1359
	Building (residential) density (per hectare)	+	0.1496
Resilience	Telecommunication equipment and services (%)	-	0.2193
	Gross income (%)	-	0.1788
	Poverty incidence %	+	0.2028
	Gross Domestic Product (GDP) – agriculture (per capita)	+	0.2215
	Population growth (%)	+	0.1777
Capacity	Police station (%)	-	0.1847
	Fire station (%)	-	0.1859
	Healthcare services (%)	-	0.2306
	School (%)	+	0.1812
	Road network density (per hectare)	-	0.2177

In this method, the selection of weights would ensure that the contribution of the remaining factors would not be excessively influenced by significant differences in any of the variables and would mislead inter-regional comparisons. Appropriate selection of measured weights must be ensured so that the large variation indicator will not dominate the overall composite index and distort comparisons. The calculated earthquake vulnerability index is between 0 and 1, where the transition from 0 to 1 indicates a change in the minimum value of vulnerability (not vulnerable at all) to the maximum level (most vulnerable) following Eq. (6) with generally skewed Beta distributions and beta function $\beta(a, b)$ (Eq. (7)).

$$f(z) = \frac{z^{a-1}\left(1-z\right)^{b-1}}{\beta\left(a,b\right)}, \quad 0 < z < 1 \text{ and } a,b > 0 \tag{6}$$

$$\beta(a,b) = \int_0^1 x^{a-1}(1-x)^{b-1}\,dx \tag{7}$$

According to [44] or using the software, both parameters ‘a’ and ‘b’ are estimated. Then, a significance linear intervals of $(0,z_1)$, (z_1,z_2), (z_2,z_3), (z_3,z_4) and (z_4,z_5) with the same probability of 20% were used to classify the vulnerability categories as follows;

- Very low vulnerability if $0 < \overline{y}_i < z_1$
- Low vulnerability if $z_1 < \overline{y}_i < z_2$
- Moderate vulnerability if $z_2 < \overline{y}_i < z_3$
- High vulnerability if $z_3 < \overline{y}_i < z_4$
- Very high vulnerability if $z_4 < \overline{y}_i < z_5$

2.2.4 Preparation of Earthquake Vulnerability Index Map and Earthquake Risk Map

This section described the process that have been carried out in phases to produce the earthquake vulnerability and risk map. The GIS approach is applied to support effective decision-making by managing, constructing, and utilizing comprehensive data for disaster prevention. Firstly, the data layers representing the indicators for each vulnerability component are overlaid to produce a composite index map of their respective exposure, resilience, and capacity. Subsequently, those composite index maps were combined to produce the total earthquake vulnerability map. This process is simplified by building GIS models using the ModelBuilder function in the ArcGIS software. Finally, we overlaid the derived thematic map with the earthquake hazard map to produce an earthquake risk map. The seismic or earthquake hazard map (Fig. 2) proposed by the JMG has been underpinned as the guideline and reference to all parties in conducting construction in earthquake-risk areas. Classification of earthquake hazard zones is based on the historical earthquake occurrences, Peak Ground Acceleration (PGA) value and local geological characteristics.

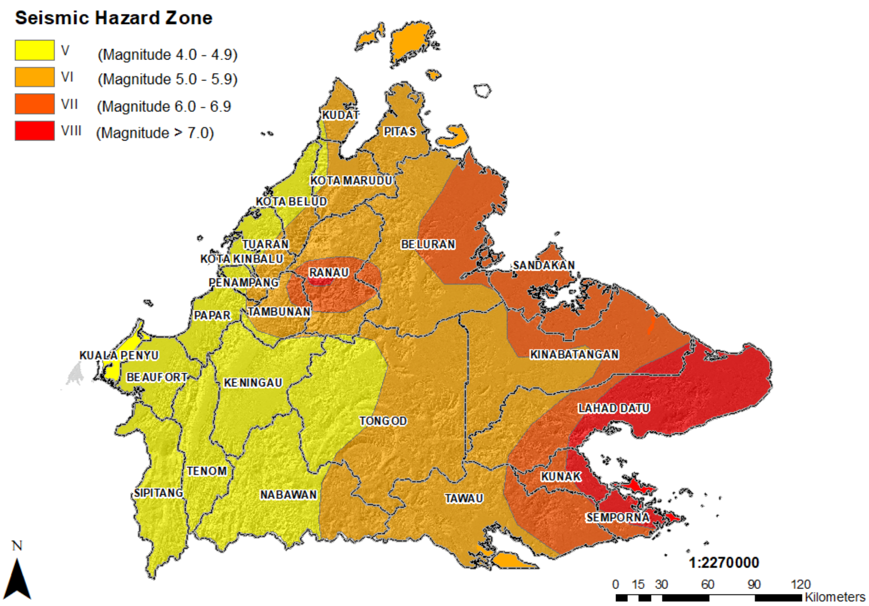

Fig 2 - Seismic hazard map of Sabah

3. Results and Discussion

3.1 Earthquake Vulnerability Index Map

The cumulative index for exposure, resilience and capacity component of Sabah districts are illustrated in Fig. 3. The standard deviation or the Z-value method was opted to classify the pixel values of the generated maps into five levels of vulnerability, namely Very low, Low, Moderate, High, and Very high. The district denoted with red color represents the highest level; orange accounts for high level; yellow accounts for moderate level and green color accounts for low to very low levels. It is important to understand the theory of correlation with vulnerability before interpreting maps of exposure, resilience, and capability. Exposure factors are directly proportional to vulnerability, in other words, any increase in the amount of exposure to a community or environment to disasters will also increase the level of vulnerability or vice versa [46]. Contrarily, both resilience and capacity component correlations are non-linear with vulnerability. An increase in resilience or capacity index will decrease the degree of vulnerability or vice versa [1], [29], [34], [47].

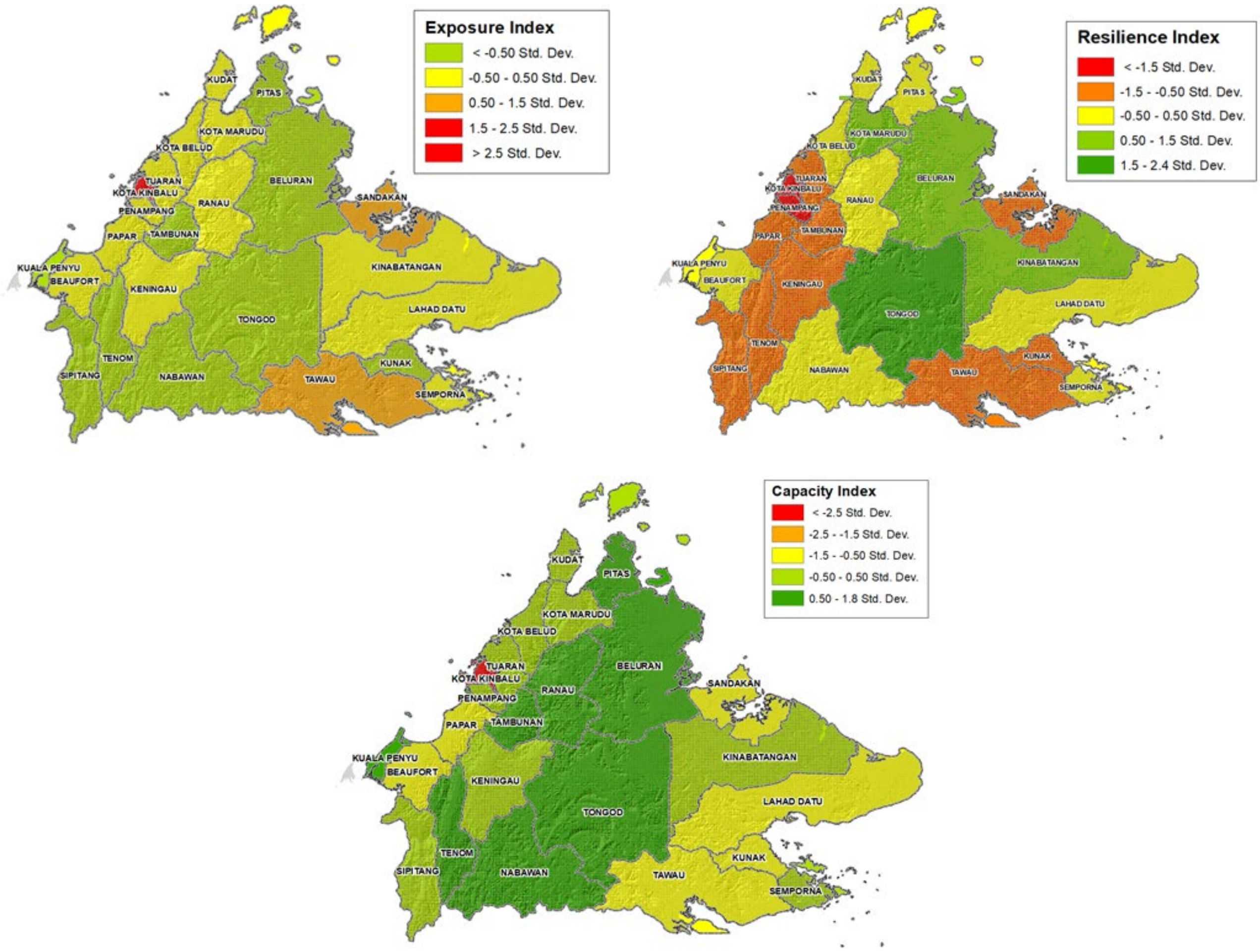

Fig 3 - (a) Exposure index map; (b) resilience index map and; (c) capacity index map

Exposure measured the integration of population and built environment indicators, such as age structure, female occupants, disabled occupants, household structure and residential building density. The exposure index for Sabah in all 25 districts in Sabah is relatively low and moderate. However, a few districts are among the major cities in Sabah with high and very high exposure index. Overall uniformity in the exposure level throughout the region of over 85 % (21) of the district are in the range of less than +0.5 standard deviation. Only 8 % (2) of the district fell in the red zone as their standard deviation is larger than 1.5, which are the Kota Kinabalu and Penampang areas. Correspondingly, only 8 % (2) of the district is in high-level zone (orange) between +0.5 and +1.5 standard deviation (Sandakan and Tawau parishes). Based on the available data, most of the districts have moderate to low exposure levels indicating a moderate or low level of vulnerability.

The resilience modeling encompasses five indicators, such as gross income, poverty incidence, percentage of occupants with telecommunication equipment and services, gross domestic product (GDP) of agriculture activities and population growth. Kota Kinabalu and Penampang are classified as the lowest resilience index in Sabah, which accounts for only 8 % of the total district. The highest resilience index was concentrated in the central region involving Tongod, Beluran, Kota Marudu and Kinabatangan representing 16 % of the area. The remaining 76 % of the district has a relatively moderate to high resilience index. To this end, the majority of the districts in Sabah have moderate to high level of resilience or moderate to low level of vulnerability.

Capacity represents the potential of the public facilities comprising safety and health services, school and road network systems to reduce its vulnerability and thus to minimize the risk associated with a given hazard. Police station, fire station, healthcare services, schools and road networks are classified as critical facilities that are necessary for effective response and recovery activities during a disaster. Only Kota Kinabalu (4 %) has the lowest capacity level as there are many elements at risk, which refer to the critical facilities that could be affected during an earthquake. Similar to resilience, low capability levels indicate high rates of vulnerability. Interestingly, 96 % of the regions displayed a moderate-to-high capacity index indicating that almost all of the areas in Sabah are less vulnerable to earthquakes.

In summary, the findings obtained from the vulnerability component analysis are presented in Table 3. The analyses of exposure, resilience and capacity components show various patterns of vulnerability index values.

Table 3 - Proportion of vulnerability level according to exposure, resilience and capacity component

Vulnerability Component	Vulnerability level (%)				
	Very low	Low	Moderate	High	Very high
Exposure	0	36	48	8	8
Resilience	8	16	44	24	9
Capacity	36	36	24	0	4

Based on Fig. 4, the total vulnerability assessment results revealed that districts with relatively moderate to high vulnerability rankings correspond to areas with considerable moderate to high levels of exposure on losses caused by earthquakes. The higher exposure could be attributed to the larger number of occupants residing there, which includes children (age less than 15 years old), elderly (more than 65 years old), female, people with disabilities; population density, and residential building density. Furthermore, the low levels of resilience in the central part of the region, particularly in districts that have the combination of the following factors: lowest gross income, high poverty incidence, and high rate of population growth. Most of the districts with high level vulnerability are influenced by adaptive capacity level, which are interpreted through a number of safety and health facilities and also the limitation of access to road networks that were affected by earthquakes, especially in the central part of the region.

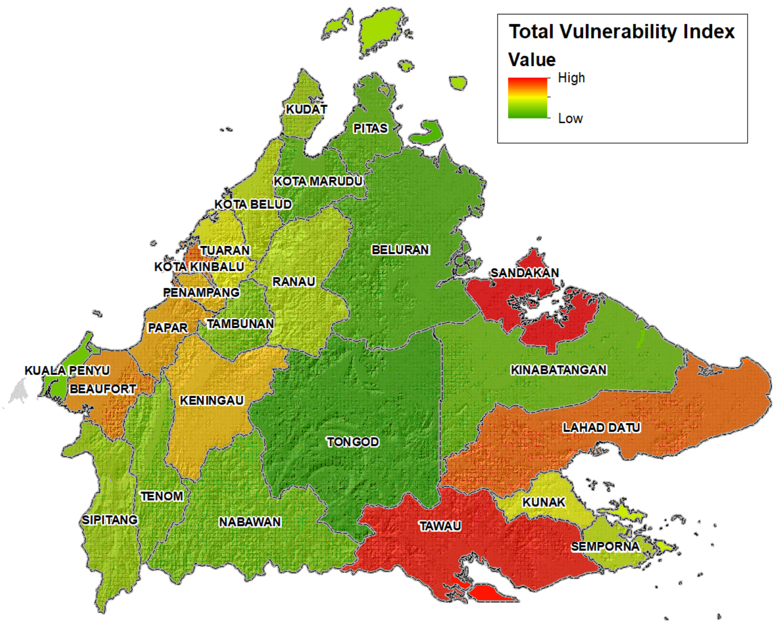

Fig. 4 - The total vulnerability index map for Sabah region

In particular, 8 % from the overall districts, comprising Sandakan and Tawau denoted with red indicate the high level of vulnerability. The higher level of exposure and the low resilience level for both districts contributed to the highest total vulnerability index recorded. Majority or over 56 % of the districts have a relatively low-to-moderate level of vulnerability, which refers to Tongod, Beluran, Kinabatangan, Pitas, Kota Marudu, Kudat, Kota Belud, Ranau, Tambunan, Kuala Penyu, Sipitang, Tenom, Nabawan and Semporna. The remaining 36 % of the districts (Lahad Datu, Kunak, Tuaran, Kota Kinabalu, Putatan, Penampang, Papar, Beaufort, and, Keningau) lies in the moderate to high vulnerability zone range.

3.2 Earthquake Risk Map

The results of potential earthquake risk map for Sabah were obtained by integrating the total vulnerability index map with the seismic hazard map (Fig. 5). The total area according to the earthquake risk classification is presented in Table 4. The combination of districts with high levels of vulnerability and hazard may indicate high levels of earthquake risk, while the same logic also applies in opposite conditions. Most areas in Lahad Datu, Sandakan, Semporna, Tawau and Kunak accounted for 15.5 % or 1,137,192 ha of the area with the highest earthquake risk. Followed by 7.7 % of high-risk areas in parts of Ranau, Penampang, Tawau, Kunak, Lahad Datu and Semporna. On the contrary, a total of 65.4 % of the regions were classified as low to very low risk, which refers to Tongod, Nabawan, Tenom, Sipitang, Kuala Penyu, Pitas, Kota Marudu, Beluran, Keningau, Beaufort, Papar, Putatan and part of Kota Kinabalu, Tambunan, Kota Belud and Tuaran. Moderate-risk areas in Sabah are estimated at about 11.3 %, including parts of Ranau, Kinabatangan, Kudat, Kota Belud, Tuaran, Tambunan, Lahad Datu and Papar.

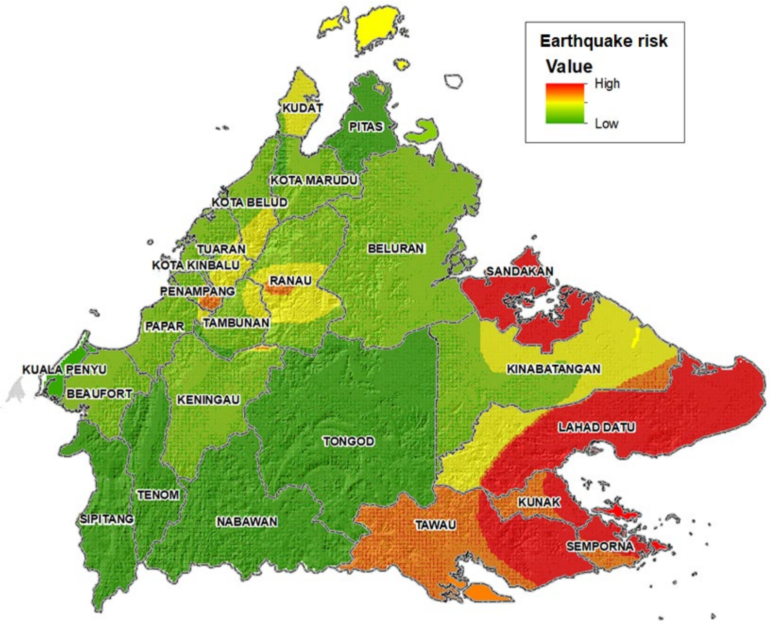

Fig. 5 - Combination of total vulnerability map and earthquake hazard map for Sabah

Table 4 - Total area based on earthquake risk classification for Sabah

Risk level	Actual area (ha²)	Proportion of total area (%)
Very Low	2334948	31.9
Low	2451372	33.5
Moderate	827512	11.3
High	565068	7.7
Very High	1137192	15.5

4. Conclusions

This study measured the earthquake vulnerability and risk in the local district of Sabah, Malaysia using the geospatial approach. In addition, the combination of appropriate indicators (i.e., exposure, resilience, and capacity) and their relative contribution towards earthquake vulnerability were also determined. The analysis used the socio-economic and residential area characteristics with hazard component to understand the implication of the population in society towards earthquake vulnerability and risk. Based on the result of this study, the main conclusions obtained are as follows:

- The final output indicated the disproportionate impact of earthquake vulnerability on the population from exposure, resilience, and capacity factors to seismic hazard. Thus, influenced the risk classification in the study area.
- The potential highest risk area is 15.5 % (1137192 ha) and high-risk area is 7.7 % (565,068 ha) from the total area, where it is predominantly seen in the southeast and a small part at the center (Ranau district) of Sabah. The area is associated with a high level of vulnerability and doubled by seismic hazard rendering it to be the riskiest area, except for Ranau (exhibits low vulnerable level).
- The moderate-risk area accounts for 11.3 %, which is 827,512 ha from the total area. The spatial distribution of a high possibility of earthquake occurrence together with certain high-level vulnerabilities contributed to the present risk level for the area, otherwise referring to the parts of Ranau, Kinabatangan, Kudat, Kota Belud, Tuaran, Tambunan, Lahad Datu and Papar.
- Interestingly, over 65.4 % of the total area exhibited low to very low risk levels covering 4,786,320 ha of Sabah region, which is mainly distributed in the western area, apart from the Ranau, Kota Kinabalu and Penampang areas that are classified as moderate-risk areas. The low level of earthquake risk is attributed to the low level of seismic hazard and vulnerability.

Acknowledgement

The authors would like to thank the editors and reviewers for their thoughtful and useful comments on an earlier draft of the paper. Special thanks to the Ministry of Higher Education Malaysia for the financial support through UTHM TIER1 grant (Vot: H810) and HLP Doctoral Scholarships (This research is carried out as part of the PhD study). Thanks also to the government agencies namely, MaCGDI, JMG, DOSM and MET Malaysia for providing important data in the preparation of this paper.

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