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# Seismic Risk Assessment in Malaysia: A Review

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**ABSTRACT**

Earthquakes are among the most disastrous natural hazard that affects the economy and livelihood of the population around the world. Understanding the risk by assessing the hazard and vulnerability beforehand is vital to lessen the impact of the earthquake event. Although the seismic hazard in Malaysia can be considered at a low to moderate level, however, the existence of the local fault line and historical seismic data in Malaysia should be considered in preparing the future risk for such region. Therefore, this study aims to review the trend of seismic risk assessment in Malaysia. The review is important to see the current approaches in conducting the seismic risk assessment that will incorporate in the Disaster Risk Reduction (DRR) strategies to reduce the future impact of earthquakes. Additionally, several issues and challenges in assessing the seismic risk particularly in this region also have been highlighted in this review. In conclusion, the trend of seismic risk assessment in Malaysia shows some enhancement in the methodology and reliability of the outcomes especially in terms of assessing the seismic hazard and vulnerability level in an earthquake-prone region. However, some further improvement is needed to obtain a more comprehensive risk understanding for developing seismic risk resilience in Malaysia.

***Keywords:***
Seismic risk assessment; earthquake; disaster risk reduction

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## 1. Introduction

Disaster risk assessment (DRA) is a key to determine and understand the character and extent of the potential risk by evaluating the future hazards and assessing the vulnerability level of the exposure element such as population, property, and critical infrastructure as well as the environment [3]. The Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) outlines one of the priority for action of the framework is an understanding of the disaster risk [4]. This is also in line with the vision of the 2030 Agenda for Sustainable Development Goals (SDGs) which highlight the importance of risk understanding as a requirement for achieving the visions especially on the underlying drivers of risk issues on climate changes, poverty, and inequality as well as weak institutions [3, 5]. It shows

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the importance of risk assessment in terms of hazard and vulnerability in the high-risk region that should be taken into account for disaster risk management. Disaster risk can be defined as the probability of loss of life, injury including the potential of destroyed or damaged assets which could occur to a system, society, and community in an explicit period. In addition, the risk factor can be determined and controlled depending on the function of hazard, exposure, vulnerability, and the capacity of the society to cope with, in order, to reduce the risk. The probability function of disaster risk can be translated in Eq. 1 [3].

$$Disaster\ Risk = \frac{Hazard\ \times Vulnerability\ \times Exposure}{Resilience\ or\ coping\ capabilities} \quad (1)$$

Amongst of the most natural catastrophic that affect the economic losses and people around the world is 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 earth [6]. Earthquake disaster will cause surface rupture and radiated the seismic wave which can trigger a cascading effect such as tsunami, landslide, liquefaction effect as well as damaging the structural building due to tremors impact. Silva *et. al*., [7] found that earthquake disaster contributes to an average of 20,000 fatalities worldwide every year. Malaysia is not excluded from this type of disaster since several epicenters were recorded in the region. In terms of tectonic setting, Malaysia is underlain by the relatively stable tectonic plate namely Sunda Plate and semi-stable South China Sea area which is exposed to the seismic activity originated from Sulawesi and the Philippines particularly in Sabah and Sarawak [8]. In general, seismic hazards in Malaysia can be considered as at low to a moderate level which the seismic source is from both regional and local intraplate movement. For Peninsular Malaysia, the seismic source is mostly induced by tectonic activity in Sumatra. [2] stated that, a series of high magnitude earthquakes including the 2004 Sumatra Earthquake, 2005 Nias Earthquake, and 2007 Bengkulu Earthquake had reactivated the local ancient fault system in Peninsular Malaysia. On the other hand, the seismic activity in East Malaysia is considered moderate, particularly in Sabah which is mostly generated from the local sources. The magnitude 6.0 Ranau Earthquake incident in 2015 was originated from a local active fault namely Lobou-Lobou Fault located within the area [9]. Furthermore, the seismic activity in Malaysia shows a significantly frequent trend together with the increasing strength of the earthquake magnitude as well. Therefore, conducting the risk assessment and risk analysis is important to understand the seismic risk by covering all related factors including the hazard characteristic, capacity, vulnerability and the threat of the element at risk. Hence, this paper will review and discuss the current approaches and challenges in conducting the seismic risk assessment focusing on hazard and vulnerability valuation in Malaysia.

## 2. Methodology

In this review, the approach is to review the related published paper on the seismic hazard assessment and seismic vulnerability assessment related to seismic risk assessment which is our particular interest in Malaysia. Disaster risk assessment is a key to determine and understand the character and extent of the potential risk by evaluating the future hazards and assessing the vulnerability level of the exposure element. The vulnerability assessment finding can be translated and visualized in the form of maps or figures for certain indicators as communication tools for the decision-making process in disaster management. From the literature review, the analysis will be focusing on identifying the current practice, its challenge, and gap, thus provides some recommendations for improvement to the seismic risk assessment hence lessen the future earthquake impact in Malaysia.

## 3. Results

### *3.1 Seismic Hazard Assessment in Malaysia*

Seismic hazard assessment (SHA) refers to the estimation of potential hazards due to the earthquake initiated within the geographic region at a specific site [10]. Dealing with seismic hazard assessment involved multi background expertise such as engineering, seismology, geology, and geodetic. Each discipline plays an important role to produce reliable and comprehensive hazard understanding. For example, the geologist will provide an insight into the earthquake source and its behavior whereas the seismologist will study the mechanism of ground motion during an earthquake. Next, the information will be used by the engineer to predict and simulate the effect of seismic waves on the population, infrastructure, and critical facilities for better understanding [11]. Most of the studies related to the seismic hazard assessment were focusing on analyzing the peak ground acceleration and producing the seismic hazard map. Generally, there are two methods commonly used by the researcher to conduct the SHA which are Probabilistic Seismic Hazard Assessment (PSHA) and Deterministic Seismic Hazard Assessment (DSHA). PSHA is a method that focuses on estimating either frequency of the event, the probability of exceedance, and ground motion level based on some parameters that reflect on the uncertainty of earthquake factors such as size and location. This method has become a standard to derive the seismic building code for ground motion estimation analysis [12]. On the other hand, DHSA implements the seismic source modeling by using the historical seismic record in terms of magnitude, distance to the source, geological and velocity model information to generate the estimated ground motion in the specific area [10, 13]. Additionally, the ground motion prediction equation (GMPE) is used as a key component in both methods to calculate the ground motion level of the area [14].

In Malaysia, the SHA has been evolved significantly due to the increase of the seismic activity in the region which also enhanced the seismic data and catalogue. In the early stage, the assessment was only concentrated from the far-field sources such as Sumatra and the Philippines, however, the Ranau earthquake 2015 has been an eye-opener to all the stakeholders to carry out a detailed assessment on the seismic hazard by considering both regional and local seismic sources. The preliminary attempt was initiated by Adnan *et. al.,* [15] to develop the first macro zonation of seismic hazard map for Peninsular Malaysia based on the regional sources from Sumatra Subduction Zone and Sumatra Fault Zone using Gumbel's method statistical theory. It found that the Peak Ground Acceleration (PGA) values range from 10 gals to 25 gals and 15 gals to 35 gals for 10% and 2% of 50 years hazard level respectively. However, this result indicates around 65% lower PGA value compared to the previous analysis using a deterministic approach in the same region. After a series of tremors were recorded within the Bukit Tinggi area between 2007 to 2008, Nabilah and Balendra [16] in their study have attempted to consider the local seismic source to analyze the seismic hazard by developing the suitable GMPE of the Kuala Lumpur area. From the study, it is difficult to identify the seismicity of the local sources due to certain data limitations of the seismic catalog, hence, the parameter was omitted in the analysis. As a result, it found that the maximum PGA for the Kuala Lumpur area is in the range within 16.5 gals to 23 gals for 10% and 2 % probability respectively. Consequently, a large-scale study on PGA and classifying the seismic zone for Peninsular Malaysia was also conducted by Manafizad, Pradhan *et al*., [17] using the deterministic approach based on the data from 1900 to 2014. The result shows the PGA value of peninsular Malaysia produced from the far-field earthquake is ranging from 1-191 gal. Nevertheless, these methods were derived only based on the far-field sources from Sumatra Subduction Zone and Sumatra Fault Zone without taking into account the source from local intraplate movement. For this reason, Shoushtari, Adnan et al. [18] in their study attempted to produce a new Seismic Hazard Map of Peninsular Malaysia by considering the local faults and far-field sources. As a result, the estimated PGA values across Peninsular Malaysia for 10% and 2 % probabilities of exceedance in 50 years are ranging from 1.0% to 10.0% g and 2.0% to 20.0% g respectively. Figure 1 shows the development of PGA map based on seismic hazard assessment in Peninsular Malaysia from previous researcher.

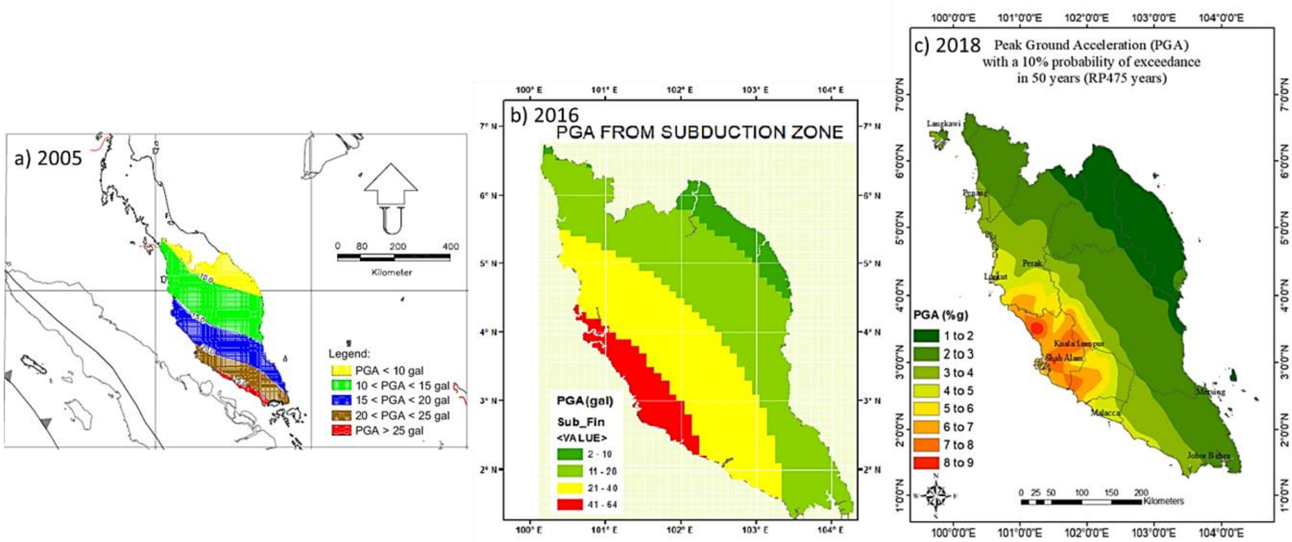


**Fig. 1.** Development of PGA map in Peninsular Malaysia a) PGA map produced by Adnan *et. al.*, [15] b) PGA map from Sumatra Subduction Zone by Manafizad, Pradhan *et al.*, [17] c) PGA map derived from far field sources and local sources by Shoushtari, Adnan *et al.*, [18].

Apart from that, the SHA study has been done in the Sabah area on both regional and localize scales particularly in active seismicity zone based on past epicenters records like in the Ranau area. The seismic hazard analysis in Sabah using the DSHA through the integration of GIS technique and triangular critical analysis revealed that all of the seismic activity in Sabah are mostly originated from the intersection of the local active fault movement. This fault intersecting zone may produce PGA up to 0.7 g specifically in the central and southern part of the state which is expected to experience more than 6 magnitudes of an earthquake in the future [19]. A different method using PSHA was applied by Khalil *et. al.,* [20] in their study to produce the probability of ground acceleration in Sabah. The analysis was carried out for six cities in the state which prone to earthquakes. As a result, the uppermost ground motion values are expected in Lahad Datu and Ranau area due to its nearest distance to the seismic sources. A framework for site-specific of PSHA was introduced by using a case study for a specific area in Kuching, Sarawak. The result shows that the PGA value for the scenario of 10% Probability of Exceedance in 50 years will be 0.002 g and classified as a low seismic zone. The output from this study and its methodology framework then contributed in preparing the seismic hazard map of Sarawak [21].

On the other hand, the first edition of the Seismic Hazard Map of Malaysia was published by the Department of Mineral and Geoscience Malaysia [22]. It found that Ranau and Lahat Datu area in Sabah is located at the high hazard zone with the peak ground acceleration value (PGA) 12% to 16%. Whereas, Niah in Sarawak, Bukit Tinggi, Kuala Lumpur, Kuala Pilah, Klang, Manjung and Tasik Kenyir sited at medium hazard zone with PGA value 6% to 12%. This map was adopted as a national reference on the Malaysia Standard document for the first national code of practice for the seismic design of buildings namely as Malaysia National Annex to MS EN 1998-1: 2015, Eurocode 8: Design of Structures for Earthquake Resistance-Part 1: General Rules, Seismic Actions and Rules for Buildings. Since the first seismic hazard map was produced, there was a significant improvement in the methodology and data input to enhance the reliability of the map as a reference for the stakeholders in translating into a local policy for disaster risk reduction strategy.

#### *3.1.1 Local Seismic Source Identification*

The SHA methods require inclusive information of the seismic sources, otherwise, the modelled level of hazard will always be showing a higher value compared to the previous analysis. In reality, the hazard level can be very low and it depends on the comprehensiveness of seismic sources identification including active fault sources [23]. The seismic activity in Peninsular Malaysia can be divided into two main sources which are far-field sources and local intraplate sources [10,24]. The far-field seismic source was initiated by two origins which are the Sumatra Subduction Zone (SSZ) and Sumatra Fault Zone (SFZ). On the other hand, the local intraplate seismic was initiated from the local fault system in Peninsular Malaysia including Sabah and Sarawak. Several major fault systems in Peninsular Malaysia were mapped by the Department of Mineral and Geoscience including Bok Bak Fault, Bukit Tinggi Fault, Kuala Lumpur Fault, and Mersing Fault. Some of the faults were believed to be reactivated which can be related to the minor seismic activity in the region. An active fault identification study was conducted by Shuib *et. al.,* [25] in Manjung, Perak area to delineate the fault line responsible for the seismic activity in the area. From the evidence of Quaternary movement in the field, it suggests that the active fault in the area is characterized by the North East and North-South trend of the fault line which able to produce huge earthquake in the future. Besides that, the same research was also carried out in the Bukit Tinggi area which focuses on the geomorphic features to identify the active fault. It found that several fault line in Bukit Tinggi fault zone is active based on the onsite evidence such as geomorphic feature related to recent fault movement (Figure 2), displacement and also the pattern of the epicenters [2].

For the Sabah area, the previous study by Tongkul [1] has categorized the active fault into two different groups based on the type of fault movement which is thrust and strike-slip fault resulted from compressional force structure and also normal fault originated from extensional force structure. Both thrush fault and strike-slip fault are mostly oriented in East North West – West South West (ENW-WSW) and North West-South East (NW-SE) respectively whereas the normal fault dominated in the orientation of North East – South West (NE-SW) (Figure 3). Apart from that, the government agency also plays its role to assess the seismic hazard and risk in the region. Department of Mineral and Geoscience Malaysia under the Ministry of Water, Land, and Natural Resources was given the responsibility to carry out the study on the Active Fault and Earthquake Risk Area Mapping in Malaysia under the 11$^{th}$ Malaysia Plan (2016-2020) and to be continued in twelfth Malaysia Plan (2021-2025). The project area has been identified based on the historical earthquake data and potential earthquake areas including in Ranau and Lahad Datu, Niah, Bukit Tinggi and Janda Baik, Batang Kali -Ulu Yam, Kuala Pilah, Kenyir, Manjung, and Temenggor with the total study area around 10,000 km$^2$. The finding of this ongoing research will be used as one of the parameters in the seismic hazard analysis for updating the Seismic Hazard Map of Malaysia.

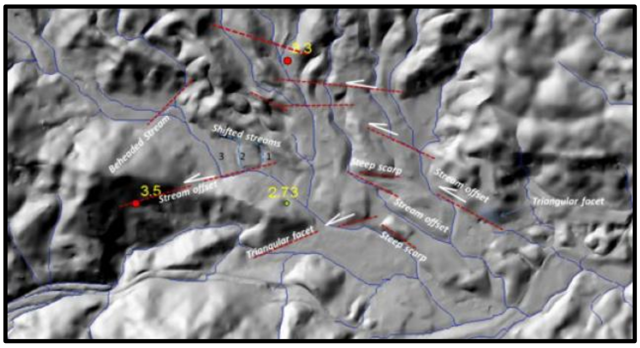


**Fig. 2.** Some examples of the geomorphic features related to the active fault movement in the Bukit Tinggi area [2]

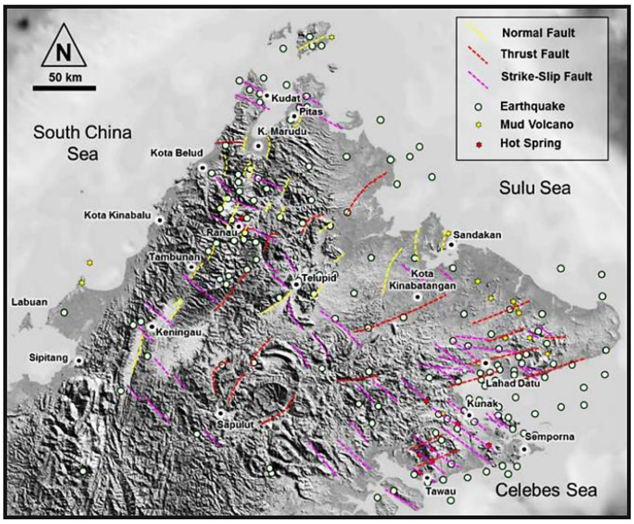


**Fig. 3.** Map of an active and potentially active fault in Sabah [1]

### 3.2 Seismic Vulnerability Assessment

To understand the seismic risk, the vulnerability of the exposure element is one of the important factors in the measurement framework to assess the level of risk in the specific region. It is crucial to estimate the possible consequences and impact of the population and assets exposed to natural hazards including earthquakes [26]. The seismic vulnerability can be assessed based on the physical, social, economic, and environmental factors or processes that can increase the susceptibility of an individual, a community, assets, or systems from the impact of hazards [3]. The result can be translated and visualized in the form of a map or figures for certain indicators as communication tools for the decision-making process in disaster management. Furthermore, vulnerability assessment requires several criteria and its specific indicator to measure the vulnerability level in the specific area. In Malaysia, the Seismic Vulnerability Assessment (SVA) can be considered as a new approach in assessing the seismic risk of the area [27]. Several methods are commonly used in assessing seismic vulnerability. A review from Kassem *et. al.,* [28] on the methodology used by the previous researcher to evaluate the vulnerability can be divided into two methods which are empirical assessment in example Rapid Visual Screening (RVS) and Vulnerability Index Method (VIM), and also analytical assessment approach which involves linear and non-linear static as well as linear and non-linear dynamic analysis. From the literature review, most of the research focusing on physical vulnerability by assessing the vulnerability degree of building structures in earthquake-prone areas [27, 29-31]. In regards to Peninsular Malaysia, a study on SVA of the industrial building by taking the Sinagama building sample using Modified Acceleration Displacement Response Spectrum (MADRS) methods was found that the capacity of the Sinagama industrial building is considered in a safe condition due to an adequate seismic building design [31]. On the other hand, Ramly *et. al.,* [32] has carried out a study in SVA of building in the Bukit Tinggi area using RVS methods. A total of 1166 buildings were identified, inventory, and analyze qualitatively. Twenty-sixth percent (26%) of the building was classified as vulnerable to damage during an earthquake and need for detailed evaluation whereas 74 percent (74%) of the building can be considered as in a safe form. A recent study shows there was an improvement on the SVA methodology framework which involve multi-criteria and parameter such as physical, socio-economy and environmental. The Geographic Information System (GIS) software also has been introduced as a platform for the analysis in a systematic approach. Sauti *et. al.,* [33] have proposed a new holistic model using GIS spatial analysis to assess the seismic risk by suggesting an appropriate indicator and its contribution to the vulnerability together with the coping capacity parameter. A case study in Pahang state found that 45% of the area classified as low to very low vulnerable whereas 36% indicate moderate to highly vulnerable which shows Bentong district as the most vulnerable area for the seismic hazard.

For the Eastern part of Malaysia, the SVA study was numerous compared to Peninsular Malaysia especially in Sabah due to its active seismicity. A physical SVA on the public building structure in the Sabah area was conducted by Ismail *et. al.,* [34] using Finite Element Modelling (FEM) analysis. It found that most of the existing public buildings in the Sabah area will be affected with moderate damage levels during the earthquake which may show some non-structural damage. The same result was also revealed from the study by Roslee *et. al.,* [27] particularly in the Ranau area which indicates 60% of the area including building structures classified as moderate vulnerability. Besides that, an assessment using empirical assessment of RVS for the Building in Ranau township shows that 21 numbers out of a total of 245 buildings are expected to experience significant to severe damage on the structure during earthquake due to the inadequate structure design and material of the existing building [30]. Similar RVS methods were also applied by Jainih and Harith [35] to assess the vulnerability of existing buildings around Kota Kinabalu. The result shows 60.4% from the total 250 buildings are classified as highly vulnerable and in an unsafe condition which susceptible to collapse during an earthquake. However, this preliminary SVA using RVS methods may require a detailed investigation for future mitigation planning although it is proven as the most effective method for preliminary seismic evaluation tools and cost-effective. In addition, the SVA based on nine parameters of physical and environment in Ranau area using two different model frequency ratio (FR)–index of entropy (IoE) and a combination of (FR-IoE) with an analytical hierarchy process (AHP) was conducted by Abd Razak *et. al.,* [36] thru GIS platform. The result shows that the area located in very high seismic vulnerability in the FR-IoE model and (FR-IoE) AHP Model were 0.548% and 0.575% to the total area respectively. Instead of physical and environmental parameter, Sauti *et. al.,* [37] has researched in assessing the exposure vulnerability of the social parameter in Sabah which includes the density of population, condition of household and also vulnerable population. An analysis using GIS modeling shows that most of the districts in Sabah expose to low and moderate vulnerability except for Sandakan, Lahad Datu, Tawau, and Semporna which are categorized as the most at-risk area due to their high vulnerability exposure as well as situated in a high seismic hazard zone. However, for the Sarawak area, there is no such SVA has been done to date particularly at the state level by the researcher. This might be due to the least seismic activity and its impact from the previous earthquake in the area. The seismic vulnerability assessment involves a significant criterion that reflects on the current condition on-site together with the different methodology which will provide a different result. Although the seismic vulnerability assessment is considered a new method in the country, yet it is important to establish the standard methodology framework which suits the condition of this region.

### *3.3 Issues and Challenges*

The trend on the seismic risk assessment in Malaysia shows an improvement in terms of data analysis framework and reliable output, however it is still considered as in an early stage compared to other neighbouring seismic active regions such as Indonesia and the Philippines. This is due to the deficiency of available critical information related to the behavior of the seismicity in the country including the seismic source characteristic, ground response estimation, and also data related to the exposure element for vulnerability valuation [8]. Based on the review from the previous study in assessing the seismic risk, the list of issues and challenges raised in their research can be summarized as in Table 1.

**Table 1**
Summary of issues and challenges in Seismic Hazard Assessment and Seismic Vulnerability Assessment in Malaysia

| | Issues and Challenges | References |
|---|---|---|
| **Seismic Hazard Assessment (SHA)** | Lack of scientific data for local intraplate seismic sources for comprehensive analysis. | [10] [8] [20] [13] [38] |
| | Inadequate Peak Ground Acceleration (PGA) analysis in specific localize scale to predict the future earthquake | [11, 38] |
| **Seismic Vulnerability Assessment (SVA)** | Absence of national standard for seismic vulnerability assessment guidelines and methodologies | [33] |
| | Lack of essential data for the exposure element to assess its vulnerability | [33] [36] [37] |

In terms of SHA, poor scientific data for local intraplate seismic sources would affect the accuracy and reliability of seismic hazard analysis results. For example, the earthquake data before 1991 was not accurate due to lack of seismological stations and unavailable active fault information thus, made it difficult to determine the parameter for seismic source, hence, be omitted for the analysis [20]. Besides that, the current hazard assessment was carried out mainly on a regional scale except for some seismic active locations such as Ranau, Lahad Datu, and Tawau in Sabah as well as Bukit Tinggi in Pahang which has been conducted on the local scale. It is crucial to establish the local PGA values prior to the earthquake for each state level that can be used in implementing the mitigation measure for the vulnerable group and assets to resist against earthquake. For example, during the magnitude 4.1 earthquake in Perak, there was no such seismic hazard map available to predict the potential seismic hazard before the incident [38]. Additionally, no PGA information can be referred to for formulating the building code during the 2015 Ranau Earthquake. As a result, most of the building in the area was severely damaged due to inadequate building structure strength toward seismic wave [8]. From these case study, it shows the importance of evaluating the seismic hazard in local scale across the country even though in low seismicity area for the future earthquake preparedness. Besides that, the existing first addition of National Seismic Hazard Map may require an update version based on recent finding on the several seismic hazard parameters. For instance, lack of seismic source information from local intraplate such as fault location, fault slip rate and the ground behaviour in the present hazard map can be undertaken from the recent sighting by the local expert as well as researcher.

On the other hand, a national standard for SVA guideline should be established which suit with the local condition of this region. According to Sauti *et. al.,* [33], most of the methodologies used in the previous study were taken from existing models from another region such as Earthquake Disaster Risk Index (EDRI), Methods for the Improvement of Vulnerability Assessment in Europe, and Rapid Visual Screening (RVS). However, such framework requires a proper and inclusive data which is certainly insufficient in our country. Consequently, the lack of essential data for the exposure element to assess its vulnerability will produce inconclusive output which does not indicate the actual condition of the study area. An example of the crucial data for vulnerability analysis are the building stock and household inventory which may be unavailable or outdated including the structure and non-structure component and also the census data [33]. These could be undertaken by developing an accessible systematic database for fundamental data related to the exposure elements together with the coping capacity and resilience parameter for the comprehensive vulnerability indicator component. On the other hand, utilising the Geographic Information System (GIS) in assessing the seismic hazard and vulnerability will give an advantage in producing more reliable output. GIS platform have been proven as a tool which could efficiently analyse and display multi dimension data format including high resolution data such as remote sensing images for assessing the natural hazard and the expose element under threat [39].

## 4. Conclusions

Systematic seismic risk assessment is critically important to understand the risk level for implementing the Disaster Risk Reduction (DRR) strategies in the earthquake-prone area. Through the years, the trend on the seismic risk assessment in Malaysia has been significantly enhanced with the increasing of numerous studies related to the topic has been done particularly in the seismic active region. However, the SHA and SVA still facing several issues and challenges such as lack of scientific data, the inadequate state-level scale of hazard assessment, unavailability of the national standard for seismic vulnerability assessment guidelines and methodologies, and insufficient essential data for the exposure element to assess its vulnerability. Finally, the finding from this review might give an overall scenario of seismic risk assessment in Malaysia which certainly may need some further improvement to obtain a more comprehensive risk understanding for developing seismic risk resilience in Malaysia.

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