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The Role of Geospatial Technologies in Earthquake Disaster Management for Malaysia

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The paper discusses the application of Geographical Information System (GIS) technology for earthquake disaster preparedness and mitigation strategies and activities to minimise the earthquake consequences in Malaysia. The strategies highlighted the preparedness plan and hazard mitigation plan during disaster response. The earthquake preparedness plan focuses on continuous and integrated risk reduction measures to reduce the vulnerability and increases the capacity to lives, livelihoods and property of the affected region. Earthquake mitigation plan used the structural and non-structural approaches to prevent or decrease the effects of disaster to life, property, social and economic activities, and environmental. The GIS tools application provides a platform to handle disaster dataset and produce maps of seismic hazard, seismic vulnerability, and seismic capacity for preparedness and mitigation plan. Group of multiple layers are organised into three modules, such as hazard layer, cadastral layer, and potential risk layer. Cadastral layer supports both hazard and potential risk layer analysis. Hazard layer consists of fault line, historical earthquake, geology, seismic zones for hazard analysis benefit in land-use planning, mitigation, and emergency plan. The potential risk layer outputs are seismic vulnerability maps (social, economic, physical, and environmental) and seismic risk maps for determination of earthquake risk level of populations and constructions. It helps in planning the need for building retrofit or identify new construction location and population relocation if necessary.

Keywords: Earthquake disaster; GIS; mapping; preparedness and mitigation; vulnerability

I. INTRODUCTION

Based on the demographic-economic projection of urban population growth by 2050, the risk of earthquakes in developing countries will increase more than doubled in the present day (Brecht, Deichmann, & Wang, 2013). Earthquakes are natural catastrophe frequently occurring unexpectedly and often cause great destruction and casualties. Though it is difficult to avoid earthquakes completely, suffering can be minimised by creating and raising awareness of these disasters and their impact by developing appropriate warning systems, disaster preparedness, and disaster management through the application of information technology tools (MOSTI, 2009). Unplanned and unlimited land use, lack of environmental control, and the poor application of building standards are among the major contributors to loss due to earthquake vulnerability. Therefore, disaster management and mitigation are needed to predict the hazards and risks of future earthquakes.

Earthquake disaster management in Malaysia is still in its early stages (Tongkul, 2021). Over the last 50 years until 2015, there has been no formal awareness program and formal education for earthquakes introduced to the public, schools, and universities as well as the lack of an effort to develop an earthquake warning system by responsible agencies (Adnan, Ramli, & Abd Razak, 2015). Despite the lack, efforts that have been done by the authorities to address the issue of the

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earthquake management either by structural or non-structural methods (Adnan *et al.,* 2015).

The structural methods approach involves improving construction practice and retrofit critical structures and lifelines to reduce or avoid possible impacts of hazards, thus to apply the engineering techniques or technology to improve hazard resistance and resilience in structures or systems. Meanwhile, the non-structural method involves studies and research on identifying seismic impacts, seismic hazard analysis and modelling (Marto, Tan, Kasim & Mohd Yunus, 2013), organising public education and awareness campaigns (Zainal *et al.*, 2011), upgrading of earthquake and tsunami warning systems, producing seismic hazard map and developing Malaysian Standards (MS) for design of structures that are earthquake resistance. Nationally Determined Parameters are the standards reference which contains information used for the construction of building design, and civil engineering works in Malaysia. However, there are unproportioned disaster management planning between structural and non-structural approach. Less focus is given to non-structural methods to manage disaster (Adnan *et. al.,* 2015; Chan, 2014).

In managing earthquake disaster preparedness and mitigation for a prone-earthquake region, data from various agencies are required to support the analysis. Therefore, information system technology approach in disaster management enables the information sharing across organisations such as National Disaster Management Agency (NADMA), Mineral and Geoscience Department Malaysia (JMG), Malaysian Meteorological Department (MET Malaysia), and other federal or district level disaster response agencies (Chong & Kamarudin, 2017). Technologies should support effective disaster management, tools and practices that allow the disaster response organisation to efficiently manage information from various sources and collaborate systematically to help victims, mitigate loss and assist the community during pre-disaster and post-disaster situations.

In the current literature, several initiatives have been done by the government for mitigation and preparedness to the earthquake disaster. However, there is still lack of an integrated system to manage the earthquake disaster efficiently. Therefore, this paper will focus on the application of Geographical Information System (GIS) in earthquake management to assist the planners, decision-makers, and administrators in disaster preparedness and mitigation. Globally, GIS is the preferred information system technology used in managing disaster management. The capability of GIS to integrate spatial and attribute data and handle complex spatial analysis benefit in mapping the seismic hazard and risk analysis (Van Westen, 2013).

II. TECTONIC SETTING OF MALAYSIA

Malaysia is located outside the Pacific Ring of Fire between longitudes 90°E to 140°E and latitudes of 12°S to 20°N. It lays on the Eurasian plate, with neighbouring of the Australian Plates in the west and the Philippines Plate in the east (Marto *et al.,* 2013). Although the nation was considered as a moderate seismic region, the tremors due to surrounding high seismicity areas of Sumatra and Andaman Sea are felt several times (Adnan, Marto, & Irsyam, 2005). Most of the time, earthquake and tremors occurred in Malaysia caused by both local earthquake and regional earthquakes.

During the 84-year period from 1923 to 2007, 65 earthquakes (magnitude 3.3 to 6.5 Richter scale), with the Maximum Mercalli Intensity (MMI) scale VIII were recorded in Sabah (Adnan *et al*., 2015) (Figure 1). The location lay within active subduction zone of Manila Trench, Negros Trench, Sulu Trench, Cotabato Trench, and North Sulawesi Trench make it the most prone-earthquake region in Malaysia (Koh *et al.,* 2012). The most significant earthquakes event was the 5.9 magnitude earthquake that occurred in Ranau, Sabah in 2015 with a massive impact on Malaysians, whether local residents and authorities. Earthquakes in Sabah caused by thrust faults, strike-slip faults, and normal faults. Observation on fault scarps, road damages, mud volcanoes, and hot springs in several places associated with earthquake shown that thrust and strike-slip faults occurred in the Lahad Datu-Tawau (southeast Sabah) and normal faults around Ranau area (Tongkul, 2017).

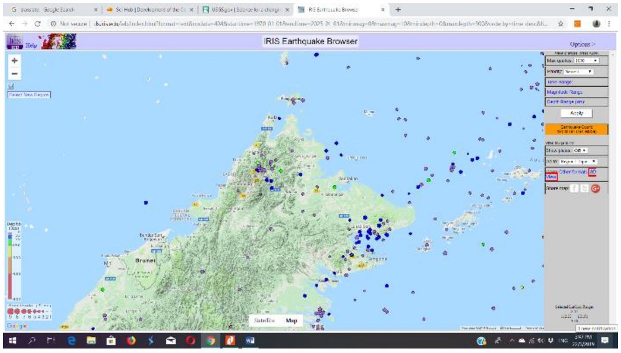

Figure 1. Earthquake distribution in Sabah (IRIS, 2019)

Three most significant earthquakes recorded in Sabah were in July 1976 at Lahad Datu-Kunak area, 26 May 1991 and 05 June 2015 at Kundasang-Ranau area (Tongkul, 2015) (Table 1). Ranau district is a prone-earthquake region as it is located in the hilly geographical structure of West Coast Division of Sabah, Malaysia. Besides, numerous faults distribution lay within the region known as Mensaban Fault, Kibbas Fault, Mamut Faults, Kihunut Fault, Kimolohong and many more are triggering the seismic activity.

Table 1. Significant earthquakes in the Sabah area

Year	Location	Mag	Damage	Casualties
1976	Lahad Datu-Kunak	6.2	- Ground floor walls of Lahad Datu police complex badly cracked - Telekom building cracked - Low-cost house cracked - Rubber factory steel rails buckled, snapped and displaced - Kunak jetty cracked - Water pipes burst - Five houses collapsed - Tawau's hospital cracked - Resident's office cracked	Two people injured
1991	Kundasang-Ranau	5.1	- Brick walls at teacher's quarters at SMK Mat Salleh, Ranau collapsed - Some building in Ranau and Kundasang cracked - Landslide at Kg Perapot triggered	One death, several injured
2015	Kundasang-Ranau	5.9	- Public building (schools, hostels, teacher's quarters, hospital, police quarters, temple) damaged - Utilities (water tanks, water intakes, drainage pipes) damaged - Private building (shops, houses, banks and others) damaged. - Facilities at Kinabalu Park (hostels and climbing trails) damaged - Landslide at Kg Kiau Nulu triggered - Liquefaction at Poring hot spring area triggered - Rockfalls and landslide at Mount Kinabalu area - Debris flow at Sg Mesilau (east and west), Sg Kadamaian, Sg Tohabang, Sg. Kilambun, Sg Penataran	18 death, several injured

Table 2 shows the earthquake occurrences recorded for Sabah between 1991 to 2021 (IRIS, 2021; USGS, 2021). Local earthquake ranging from 3.5 to 5.3 Richter scale also recorded in Sarawak since 1874 (Alexander Y, 2011). In January 2010, mild tremors with 3.5 Richter scale had been reported hit Batu Niah, Sarawak (Alexander Y, 2011). Major active faults refer to Tubau Fault, Bukit Mersing Fault, Kelawit Fault, Tinjar Fault, and West Baram Fault.

Therefore, the state is threatened by local earthquakes due to intraplate seismicity. According to Prof. Nelson Lam (JURUTERA, 2015), Sabah's potential seismic hazard is higher as the seismic activity dominated by the active faults in local faults and surrounding seas of state and The Philippines as compared to Sarawak.

Table 2. Earthquake catalogue (1991 - 2021) in the Sabah area
(Sources: IRIS earthquake browser and USGS earthquake catalogue)

Date	Time UTC	Mag	Lat	Long	Location
2020/06/30	1:58:30	4.9	6.9303	116.3824	Kudat
2020/4/14	20:04:23	4.2	4.9074	118.6333	Lahad Datu
2019/08/03	15:31:05	4.5	6.2913	117.1841	Ranau
2018/03/08	13:06:13	5.2	6.0370	116.6059	Ranau
2017/03/26	09:30:48	4.6	4.9334	118.7791	Lahad Datu
2016/03/04	00:43:35	4.1	4.9182	118.4359	Lahad Datu
2015/06/04	23:15:45	5.9	6.0439	116.6651	Ranau
2015/06/12	18:29:18	5.2	6.0674	116.6210	Ranau
2015/06/06	05:45:15	4.6	6.1880	116.7836	Ranau
2015/06/23	09:32:33	4.5	6.0491	116.5472	Ranau
2015/6/12	18:25:39	4.4	6.0390	116.5783	Ranau
2015/06/05	15:13:35	4.4	6.2153	116.8726	Ranau
2015/03/19	21:56:04	4.1	5.6182	118.6962	Sandakan
2014/02/01	11:35:10	4.6	6.1136	116.5807	Kota Belud
2014/09/05	01:15:53	4.3	4.5819	118.3607	Semporna
2012/05/28	16:44:14	4.8	4.8168	118.2948	Sabah
2010/08/21	19:43:33	4.2	5.1917	118.1427	Sabah
2008/5/18	06:26:46	5	4.5980	118.1668	Sabah
2008/04/9	00:51:46	4.5	4.9453	118.7655	Sabah
2006/09/28	15:11:40	4.5	5.9690	117.2976	Sabah
2006/04/22	02:01:31	4	6.3029	117.9956	Sabah
2005/05/23	19:58:08	5.4	6.2531	117.7553	Sabah
1996/12/06	12:42:27	4.4	4.9130	118.6437	Sabah
1995/08/11	06:21:00	4.1	6.3761	117.1542	Sabah
1994/11/02	01:43:55	5.7	5.0941	118.6441	Sabah
1992/07/04	22:33:02	4.6	4.9948	118.5595	Sabah
1992/07/04	18:19:33	4.3	4.5640	118.0255	Sabah
1991/05/26	11:17:03	5.1	5.8632	116.7875	Sabah

1991/05/26	10:59:51	5.1	5.8792	116.7124	Sabah
1991/05/26	11:14:32	4.7	5.7412	116.8027	Sabah
1991/05/26	07:02:41	4.6	6.0304	116.9541	Sabah

In Peninsular Malaysia, Bentong Fault Zone is the main active seismic feature that consists of the Bukit Tinggi Fault and the Kuala Lumpur Fault (Marto *et al.,* 2013). Table 3 shows the local earthquake events occurred in Peninsular Malaysia recorded between 2007 to 2010 (Zainal *et. al.,* 2011; Alexander. Y, 2011).

The Bukit Tinggi earthquakes were felt around the Bukit Tinggi area, Kampung Janda Baik, and Kampung Chemperoh. A series of weak earthquake magnitude 1.7 to 3.5 Richter scale was detected between 2007 and 2009 at depths of 2.3 to 6.7 km at Bukit Tinggi, Pahang (Figure 2). The impact has caused hairline cracks to a few houses in Kg. Janda Baik and Kg. Chemperoh; minor damage to Sekolah Menengah Bukit Tinggi and the Bukit Tinggi police station (Noorliza Lat & Ibrahim, 2009). The first wave movement recorded at several seismic stations shows faulting and suspected re-activation of Bukit Tinggi Fault with strike-slip movement (Alexander Y, 2011). Currently, there is ongoing research done by JMG and collaboration team, focusing on the geological study of seismic activities in the Bukit Tinggi area.

Table 3. Local earthquake occurrences in Peninsular Malaysia

Year	**Location**	**Case**	**Magnitude**
2007 – 2009	Bukit Tinggi, Pahang	24	1.7-3.5
2009	Kuala Pilah, Negeri Sembilan	4	2.6-3.2
2009	Jerantut, Pahang	1	3.2
2009	Manjung, Perak	1	2.8
2010	Kenyir Dam, Terengganu	1	2.6

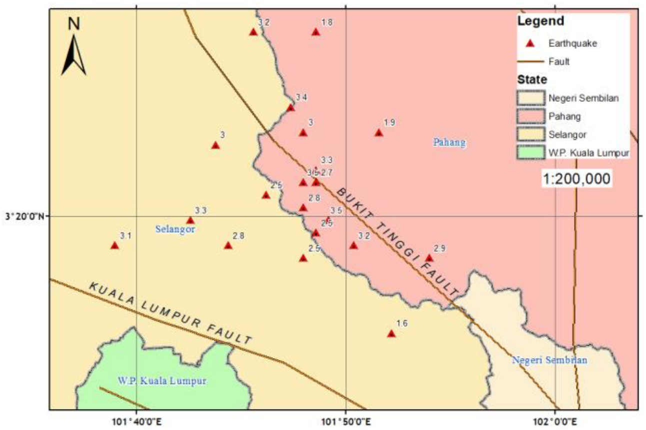

Figure 2. Earthquake distribution in Bukit Tinggi, Pahang

III. EARTHQUAKE DISASTER PREPAREDNESS AND MITIGATION PLAN DEVELOPMENT

The technical development of earthquake disaster management plan is divided into two main phases;

Phase 1:

Identification and acquisition of essential GIS datasets for preparedness and mitigation activities. The basic cadastral layers to describe the administrative boundaries, built structures, relief, residential settlement, transportation network, facilities, and others.

Phase 2:

The implementation of GIS tools for preparedness and mitigation purposes with reference to the assessment of seismic hazard, seismic risk analysis and evacuation route planning. The fault line, geology, soil, historical earthquake data layers are vital to produce geological and geophysical map. In order to produce seismic risk map, the seismic hazard, vulnerability and exposure or capacity analysis are performed. Data layer on built structures and population are essential to assess and define the vulnerability level of a region.

The earthquake disaster management refers to preparedness and mitigation actions and strategies to reduce the vulnerabilities and increase the capacity of a community either in short-term or long-term plan (Nazir, Bajwa & Khan, 2006). The GIS functions that support the disaster activities for earthquake management are shown in Table 4.

In non-emergency circumstances, the earthquake disaster preparedness plan assists the city planners to consider the land-use policies for the high-risk area; the enforcement of construction code for building and other structures (bridges, roads and others) (Standards Malaysia, 2017); the public works departments to identify the location of infrastructure and utilities that lay within the risk area and disaster response agencies to improve their response plans (Zainal *et al.,* 2011).

In the case of mitigation plan during and after the disaster, its helps the emergency teams to identify the most vulnerable area that require more attention; to recognise and decide the safe location for evacuation process and to estimate the limited emergency sources (tent, shelter, aid, food, water supply and others) allocation based on priority of the affected region. After the disaster, reassessment of the property can be determined by the insurer; contingency plan by the authorities; distribution allocation for the recovery process; and many other benefits of effective preparedness and mitigation plan.

Disaster risk reduction measures are related to national risk reduction program; incentive programmes improvement; effective risk communication strategies; earthquake hazard maps production; research and development programmes; implementation of earthquake early warning systems; and enforcement of earthquake risk legislation and policy (UN-ISDR, 2017). Typical uses of GIS for planning and preparedness in disaster management are development of evacuation route planning, evacuation zone planning and scenario modelling, and simulation to answer what-if questions for developing disaster capacity and readiness (Mili, Hosseini, & Izadkhah, 2017; Tomaszewski, 2015; Walker *et. al.,* 2014; Hashemi & Alesheikh, 2011).

Table 4. The relation of earthquake management strategies, disaster activities and GIS functions

Earthquake management strategies	Disaster activities	GIS functions
The earthquake preparedness plan	- to identify the location of infrastructure and utilities that lay within the risk area - to consider the land-use policies for the high-risk area - to create and improve building code/regulation for design and construction practices - to improve disaster response plans in terms of public awareness to public and training of rescue teams (historical earthquake to learn from lesson)	- to map the distribution of earthquake epicentre, fault line, geological, infrastructure, public facilities and administrative boundary - to create buffer zones for identified and ranked hazard areas (low to high-risk). - to find the shortest routes in evacuation activities based on demographics and capacity of existing transportation networks. - to create database on historical earthquake information and related entity (fault line, seismic zone, critical facilities and others)
The earthquake mitigation plan	- to identify the most vulnerable area that requires more attention - to recognise and decide the safe location for evacuation process - to estimate the limited emergency sources such as shelter, medical facilities, food, water supply and others for allocation based on priority of the affected region	- to produce spatial indexes for vulnerability and risk using site selection technique (weighted and combined parameters scores) (Al-Dogom, Schuckma, & Al-Ruzouq, 2018; Erden & Karaman, 2012; Mohanty *et. al.,* 2007; Raduan, Daud, & Kaamin, 2018).

	- reassessment of the property by the insurer - contingency plan by the authorities	- the modelling of risk scenarios to identify potential social, economic, physical and environmental vulnerabilities and classified according to vulnerability level. - creating the building inventories characteristics including residential database and relation with fault line to determine the potential losses and casualties caused earthquake (FEMA, 2018; M. N. Alam, Tesfamariam, & Alam, 2013; Hassanzadeh *et. al,* 2013; Mili *et al,* 2017).

IV. GIS APPLICATION

The 'what' and 'when' aspect of a map is particularly important to represent the processes during a disaster. For example, what is the extent of the disaster?; when will the disaster rescuer team arrive at the disaster area if they leave from a disaster centre?. The 'why' and 'how' aspect focuses on how maps can assist in disaster management decision making and reasoning. For example, basic operation by controlling the data layer (on and off) enables the user to make comparisons and understand how a disaster evolved (Tomaszewski, 2015). The interaction between the user (map reader) and the map itself will develop insight, reason, and make decisions on 'how' and 'why' about a disaster. GIS provides functions that quickly modify the statistical display of data to produce a thematic map in helping the user to understand 'how' and 'why' a disaster situation developed (Tomaszewski, 2015). The application of GIS technologies for earthquake management are explained according to essential component comprises of data, software and hardware, and organisation perspectives.

A. Data

Data sources from different federal government agencies are gathered and organised according to the module application. The list of agencies is Malaysian Centre for Geospatial Data Infrastructure (MacGDI), Malaysian Meteorological Department (MET Malaysia), Mineral and Geoscience Department Malaysia (JMG), and Department of Statistics Malaysia (DOSM). Details on the epicentre of earthquake data are obtained from a local agency (MET Malaysia), and international online earthquake monitoring website refers to Incorporated Research Institutions for Seismology (IRIS) and The United States Geological Survey (USGS). List of entities, format, and sources are arranged as in Table 5. The data layer scale depends on the level of application either in federal or district level.

Seismic hazard module refers to sources of the potential level of ground shaking during earthquakes that cause the loss of life, injury, property damage, social, and economic disruption or environmental degradation (USGS, 2018). Cadastral layer refers to baseline data related to administrative boundary, land cover, roads, streams, transportation, and utility network system. The capacity or exposure assessment require those data mentioned. Potential risk layer comprises facility and building structures, demography (census, population distribution, density) and economic value of the asset of various sectors for vulnerability assessment (Sauti, 2020a; Sauti, 2020b). It measures the physical, social, economic vulnerability level of a community that adversely affect its ability to respond to hazards or disaster events. (Leon, 2006; Sauti, 2021a; Sauti, 2021b;). The flowchart of seismic risk map production is illustrated in Figure 3.

Table 5. List of module, entity, format and data sources

Module	Entity	Format	Source
Hazard layer	Fault	Line- vector	JMG
	Epicentre	Point- vector	MET/MET/IRIS /USGS
	Seismic zone	Polygon- vector	JMG
	Geology	Polygon- vector	JMG
Cadastral layer	State map	Polygon- vector	MacGDI
	Country	Polygon-vector	MacGDI
	District	Polygon-vector	MacGDI
	Road	Line - vector	MacGDI
	River	Line - vector	MacGDI
	Administration Boundary	Line - vector	MacGDI
	Contour	Line - vector	MacGDI
	Slope (DEM)	Raster image	MacGDI
Potential risk zones layer	Land use	Polygon- vector	MacGDI
	Building	Polygon- vector	MacGDI
	Residential	Polygon-vector	MacGDI
	Public facilities (hospital, school, prison, hotel, bank, and others)	Point/ polygon - vector	MacGDI
	City	Point- vector	MacGDI
	Population/ Census	Polygon-vector	DOSM

B. Software and Hardware

Implementation of GIS requires careful planning and significant investment in computer equipment, network technology, database connection, and other necessary tools. Software and hardware are vital for handling spatial and attribute data in variety of applications of disaster management. Combinations of (vector, raster, attribute, and image) depend on GIS software types. Most of the spatial data sources gathered from related agencies are in *shapefile* format which means ArcGIS software compatible. ArcGIS by Environmental Systems Research Institute (ESRI) capabilities to perform ranging of GIS task including mapping, spatial analysis, data management, 2D and 3D visualisation, geoprocessing, data editing and updating, and many more (ESRI, 2004). In terms of hardware, wide range of centralised computer servers to desktop computers application used in stand-alone or networked configurations.

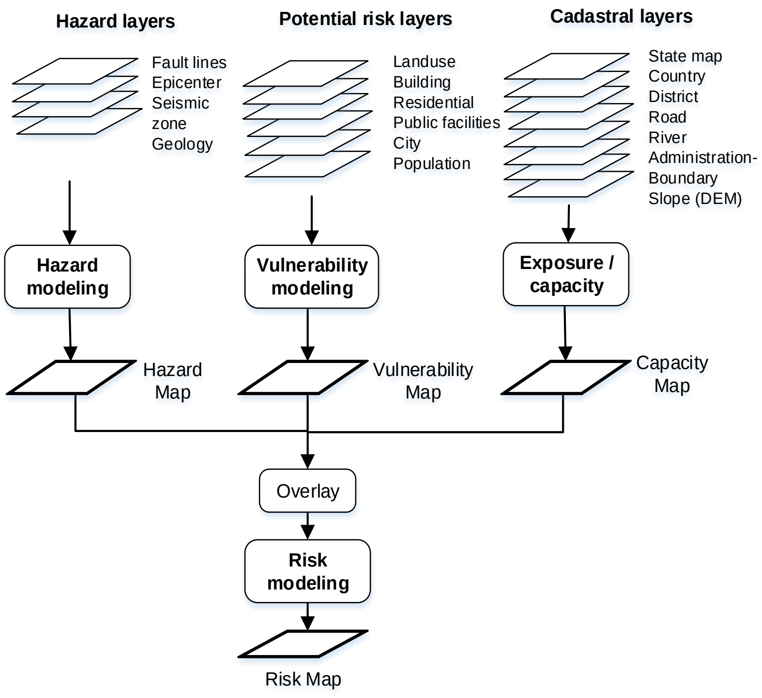

Figure 3. Methodology of seismic risk map production using GIS

C. User and Organisation

This component refers to the end user and professional that utilise GIS in preparedness and mitigation activities. The user and organisation are able to collaborate and share data, people, tools, and other resources to support disaster management activities. For example, JMG and MET Malaysia gathered data resources and shared with NADMA to disseminate the information on earthquake to the communities. The example of final output using GIS application for earthquake mitigation plan is illustrated in Figure 4 (Raduan, Daud & Kaamin, 2018).

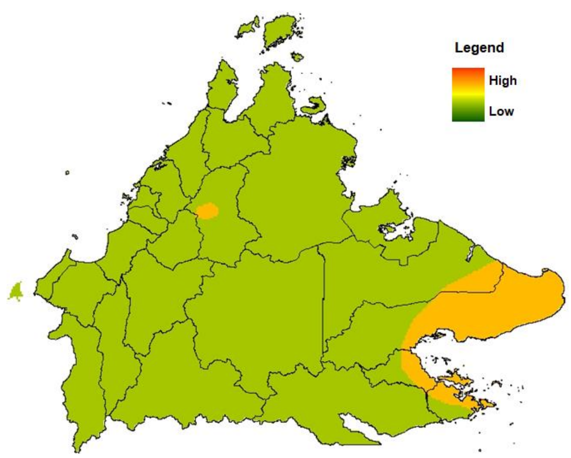

Figure 4. Earthquake threat map with potential threat level for the affected area

Earthquake threat map or hazard map classified the potential threat levels based on the peak ground acceleration (PGA) value by location of the affected area. The similar concept is applied to produce seismic risk maps with GIS tools to identify the most vulnerable areas and population groups in order to get assistance from the disaster response teams in the aftermath of the earthquake disaster. The combination of seismic hazard map, seismic vulnerability, and capacity maps through seismic risk analysis will produce seismic risk map.

V. CONCLUSION

The initial step to reduce the likelihood of losses and support disaster preparedness and mitigation decisions is the assessment of earthquake risk (N. Alam, Alam & Tesfamariam, 2011). Malaysia should focus on strengthening the building design and code regulation enforcement; enhance the public preparedness and awareness on the earthquake risk; develop an effective earthquake risk management system to define the vulnerable structure and population for particular region for retrofitting of build structures and community relocation; and produce seismic risk map as reference for contingency plan. Spatial information system plays an essential role in earthquake risk assessment to support the spatial modelling that enables models to be created and displayed to reflect hazards and depicted hazard implication in terms of risk and planning. Spatial information refers to maps which help to understand the geo-graphical context of a disaster in answering the fundamental aspect of disaster situation (who, what, where, why and how). GIS provides tools to established and updates maps of vulnerable areas easily in seismic risk assessment. The earthquake risk or damage potential of an area due to a combination of seismic hazard, and vulnerability of the built environment and its expo-sure using GIS is amenable to convenient graphical inputs and outputs.

The effectiveness of GIS application depends on the quality of the data and analysis to support operational preparedness and mitigation activities. Hazard and potential risk are dynamic and changing over time depending on the development and design of built structure and number of populations; the availability of new information; and the evolution of disaster risk reduction measures. Periodic mapping of hazard or potential risk zones for emergency and evacuation plan ensure the accurate information to minimise the damage and casualties caused an earth-quake. For future work, the combination of GIS technology together with remote sensing approach is useful in obtaining comprehensive data on building inventories such as building type, age, number of floors, and building quality (Ghafar *et al.,* 2015). More accurate assessments can be made on the vulnerability of a building that needs to retrofit and to determine the suitable location for the new construction which is far from the high-risk area. The use of radar images is also useful in detecting the movement of tectonic plates for better seismic hazard assessment.

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