GIS-BASED EARTHQUAKE DISASTER MANAGEMENT SYSTEM FOR SEISMIC RISK ASSESSMENT: A CASE STUDY OF SABAH AND PAHANG, MALAYSIA

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DEDICATION

For my beloved family

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ABSTRACT

Earthquake disaster management in Malaysia is still at the initial stages and faces multiple challenges. There is a dearth research on, and tools for, seismic risk assessment when estimating the impact of earthquakes for specific areas. Furthermore, the absence of a central authority to integrate earthquake disaster management and lack of coordination among organizations has caused crucial data related to the earthquakes to be managed separately and in different formats. Therefore, this research aim is to develop a GIS-based earthquake management system for seismic risk assessment that involves the development and verification of the seismic vulnerability index for Malaysia; the development of a GIS-based earthquake management system database for risk management planning; and an evaluation of the proposed seismic vulnerability and risk assessment modeling system. The methodology specifically relies on the development of a set of vulnerability index indicators using multivariate data analysis to identify the local characteristics that contribute to the vulnerability and risk of inhabitants at the district scale; and the development of GIS-based system with a modeling application to generate and map the spatial distributions of seismic vulnerability and risk. The study revealed the highest levels of seismic risk were concentrated in the centre-west of the Pahang region, namely the Bentong district, whereas in Sabah the riskiest areas encompassed the district of Lahad Datu, Sandakan, Semporna, Tawau and Kunak. Evaluation of risk assessment modeling systems through the integration of verification and validation processes demonstrates a reliable and robust modeling system to perform vulnerability and risk assessment. Finally, the contribution of this study offers an alternative methodology for developed countries, which often face the lack of comprehensive and readily available data for vulnerability assessment. The weighting scheme method has been extensively used in several disciplines, particularly the field of climate change and has yet to be applied for calculating weights for seismic vulnerability and risk indicators.

ABSTRAK

Pengurusan bencana gempa bumi di Malaysia masih di peringkat awal dengan pelbagai cabaran. Terdapat kurang penyelidikan dan alat penilaian risiko seismik untuk menganggarkan kesan yang disebabkan oleh bencana gempa bumi untuk kawasan tertentu. Selain itu, ketiadaan pihak berkuasa pusat untuk mengintegrasikan pengurusan bencana gempa bumi dan kurangnya koordinasi di antara organisasi menyebabkan data penting yang berkaitan dengan gempa bumi diurus secara berasingan dan dalam format yang berbeza. Isu-isu ini menyumbang kepada pembatasan maklumat yang tersedia mengenai maklumat zon risiko gempa bumi awal untuk tujuan kesiapsiagaan dan mitigasi. Oleh itu, tujuan penyelidikan ini adalah untuk membangunkan satu sistem pengurusan gempa berasaskan GIS untuk penilaian risiko gempa yang melibatkan pembinaan dan pengesahan indeks kemudahterancaman seismik untuk Malaysia; pembangunan pangkalan data sistem pengurusan gempa berasaskan GIS untuk perancangan pengurusan risiko; dan penilaian terhadap sistem pemodelan kemudahterancaman dan risiko seismik yang dicadangkan. Metodologi kajian secara khususnya melibatkan pembinaan satu set indikator kemudahterancaman menggunakan analisis data multivariat untuk mengenalpasti ciri-ciri tempatan yang menyumbang kepada kemudahterancaman dan risiko penduduk di skala daerah serta pembangunan sistem berasaskan GIS dengan aplikasi permodelan untuk menghasilkan dan memetakan taburan spatial kemudahterancaman dan risiko seismik masing-masing. Kajian menunjukkan tahap tertinggi risiko seismik tertumpu di kawasan tengah-barat Pahang, iaitu daerah Bentong, manakala di Sabah kawasan berisiko merangkumi daerah Lahad Datu, Sandakan, Semporna, Tawau dan Kunak. Penilaian sistem pemodelan penilaian risiko melalui penyepaduan proses pengesahan menunjukkan sistem pemodelan yang boleh dipercayai dan teguh untuk melaksanakan penilaian kemudahterancaman dan risiko. Akhirnya, sumbangan kajian ini menawarkan satu metodologi alternatif untuk negara maju yang sering menghadapi kekurangan data yang komprehensif dan tersedia untuk penilaian

kemudahterancaman. Kaedah skim pemberat telah digunakan secara meluas dalam beberapa displin, khususnya bidang perubahan iklim dan masih belum digunakan untuk mengira pemberat bagi petunjuk kemudahterancaman dan risiko seismik.

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LIST OF SYMBOLS/ABBREVIATIONS/TERMINOLOGIES

MET Malaysia	-	Malaysian Meteorological Department
JMG	-	Mineral and Geoscience Department Malaysia
NADMA	-	National Disaster Management Agency
DOSM	-	Department of Statistics Malaysia
IRIS	-	Incorporated Research Institutions for Seismology
USGS	-	United States Geological Survey
GIS	-	Geographical Information System
FEMA	-	Federal Emergency Management Agency
HAZUS	-	Hazards United States
RADIUS	-	Risk Assessment Tool for Diagnosis of Urban areas against Seismic disasters
GEM	-	Global Earthquake Model Foundation
MaCGDI	-	Malaysian Centre of Geospatial Data Infrastructure
DRM	-	Disaster Risk Management
SRA	-	Seismic risk assessment
Std. Dev	-	Standard Deviation
UNISDR	-	United Nations International Strategy for Disaster Reduction
ER-Diagram	-	Entity Relationship Diagram
Coping capacity	-	the ability of a society to absorb, cope, adapt, using available skills and resources, to manage adverse conditions, risk or disasters
Vulnerability	-	the susceptibility of a community to hazard resulting from the prevailing conditions including exposure, resilience and coping capacity factors to respond to earthquake events
Risk	-	the combination of hazard, exposure and capacity measures to seismic events
Hazard	-	the probability of occurance of earthquake hazard for a given area

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CHAPTER 1

INTRODUCTION

1.1 Background

Based on the demographic-economic projection of urban population growth by 2050, the risk of earthquakes in developing countries will increase more than double that of the present day (Brecht *et al.*, 2013). Earthquakes are natural catastrophes that frequently occur unexpectedly and often cause great destruction and many casualties. Though it is difficult to avoid earthquakes completely, the suffering caused can be minimized 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.

Malaysia is not excepted from the dangers of the earthquake. A series of tremors and earthquakes have been recorded by Malaysian Meteorological Department (MET Malaysia), Incorporated Research Institutions for Seismology (IRIS) and The United States Geological Survey (USGS) since 1874 with Richter scale measurements ranging from 2.7 to 6.5, especially in Ranau, Sabah, and several other areas that include Bukit Tinggi in Pahang (ASM & MMD, 2009). Unplanned and unlimited land use, a lack of environmental control, and the poor application of building standards are among the major contributors to losses 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. Over a 50-years period until 2015, there had been no formal awareness program; no formal education for earthquakes had been introduced to the public, schools, and universities;

and there had been a lack of an effort by the responsible agencies to develop an earthquake warning system (Adnan *et al.,* 2015). Despite this, efforts have been made by the authorities to address the issue of earthquake management, either by structural or non-structural methods (Adnan *et al.,* 2015).

The structural methods approach involves improving construction practices and retrofitting critical structures and lifelines to reduce or avoid possible impacts of hazards. Thus, engineering techniques or technology have been applied to improve hazard resistance and resilience in structures or systems. Meanwhile, the non-structural method involves studies and research to identify seismic impacts, seismic hazard analysis and modeling (Marto *et al.,* 2013); organize public education and awareness campaigns (Zainal *et al.,* 2011); upgrade earthquake and tsunami warning systems; produce seismic hazard map; and develop the National Annex of EC8 (NA-MS EN1998) as Malaysian Standards (MS) for the design of structures that are earthquake resistant. The standards of reference contain information on the Nationally Determined Parameters to be used for the design of buildings and civil engineering works to be constructed in Malaysia. However, there is a disproportionate element to disaster management planning with both the structural and non-structural approaches. Less focus is given to non-structural methods of managing disasters (Adnan *et al.,* 2015; Chan, 2014).

Various initiatives have been introduced by the government to manage earthquake disasters, but few approaches go beyond the earthquake or seismic risk management (Roslee *et al.,* 2018). Seismic risk deals with an integrated assessment of seismic hazard, the vulnerability of a region to the threat of earthquakes, and the capacity to deal with the threat (Carreño *et al.,* 2007). Economic, social, physical and environmental data define this level of vulnerability and the capacity of the populations and structures to deal with earthquake events (Leon, 2006).

In assessing the seismic risk for an earthquake-prone region, data from various agencies are required to support the analysis. Therefore, the information system technology approach to disaster management enables information sharing across organizations such as the National Disaster Management Agency (NADMA), the Mineral and Geoscience Department Malaysia (JMG), the Malaysian Meteorological Department (METMalaysia), and other federal or district level disaster response agencies (Chong & Kamarudin, 2017). Technologies should support effective disaster management, tools, and practices that allow disaster response organizations 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.

As the current literature shows, several initiatives have been undertaken by the government to prepare for, and mitigate the effects of, earthquake disasters. However, the existing system used in Malaysia to manage earthquake disasters only focuses on monitoring the presence of earthquakes and safety warning systems as an initial step in disaster preparedness and mitigation. In addition, only a handful of studies related to seismic risk assessment have been conducted and no integrated system has yet been developed to provide an alternate approach to managing earthquakes. Therefore, this study will develop an earthquake management system for seismic risk assessment using Geographic Information System (GIS) tools in an effort to assist planners, decision-makers, and administrators in disaster preparedness. Globally, GIS is the preferred information system technology used in managing disaster management. The capability of GIS to integrate spatial data, attribute data, and handle complex spatial analysis offers many benefits in mapping the seismic hazard and risk analysis (Van Westen, 2013).

1.2 Problem statement

The issue of earthquake risk management is a complex issue and needs to be addressed globally using appropriate systems. The management of earthquake disasters has become a significant issue. Earthquake risk management refers to the seismic hazard assessment of an area, its vulnerability to earthquake threats, and its capacity to deal with earthquake threats. These factors depend on the location, magnitude, and intensity of an earthquake that occurs. Preliminary information on the extent of the risk of earthquake threats refers to the potential number of people affected, the expected damage to property, and the expected disruption to economic activity due to an earthquake. Earthquake risk management needs to be taken seriously to facilitate the mitigation and preparedness phases for immediate, moderate, and extended term impacts of such a disaster.

The most significant Ranau, Sabah earthquake event in 2015, measuring 6.0 on the Richter scale, caused 18 deaths and many injuries; buildings also suffered considerable structural damage. Despite the experience of the 1991 (5.1 magnitude) earthquake in Ranau, the impacts of the damage and the greater loss of life associated with this incident (Tongkul, 2015) reflected poor practices in earthquake management. This shows the inadequacy of earthquake disaster management tools that are needed to identify the potential building and population losses in future disaster mitigation and preparedness in a particular earthquake area. Poor construction practices have increased the risk caused by an earthquake as the majority of buildings are designed with non-seismic resistance (Adiyanto & Majid, 2014; Ghafar *et al.*, 2015).

Bukit Tinggi, Pahang also recorded the highest number of earthquake activity of all time, which includes the Bentong Fault Zone and the Kuala Lumpur Fault Zone (Marto *et al.*, 2013). Due to its relatively close proximity to Malaysia's tourist and administrative centers, the position of this major active seismic fault has stimulated considerable interest and concern by disaster management agencies and relevant authorities. Therefore, both states, are considered as good study areas in conducting empirical assessment of seismic vulnerability and risk based on the history of regional earthquakes.

According to expert geologist Prof. Dr. Felix Tongkul, the next earthquakes are expected to occur in Ranau over the next 25 years, based on the seismic cycle. In 2039, there is the possibility of an earthquake of a similar magnitude (Abdullah, 2019). Therefore, Malaysia should learn from the lesson, as the long return period of damaging earthquake disasters enables regulatory bodies and society to take necessary action in terms of preparedness and awareness of the consequences of the damage and casualties associated with earthquake risk. According to local earthquake experts, namely Prof. Ts. Dr. Azlan Bin Adnan (Universiti Teknologi Malaysia) (personal communication, November 09, 2018) and Prof. Dr. Felix Tongkul (Universiti Malaysia Sabah) (personal communication, November 12, 2018), there is a dearth of research on seismic risk assessment for Malaysia that estimates the impacts of the fatalities and damage caused by an earthquake disaster on a particular area.

In order to estimate the impact of the consequences of an earthquake and identify the potential vulnerability of the built environment and population, an integrated seismic vulnerability index needs to be developed using specific statistical methods (Banica *et al.*, 2017). A vulnerability index refers to a set of variables or indicators related to social, economic, physical, and environmental factors and is used to determine the global patterns of vulnerability and risk potential of an area (Brecht *et al.*, 2013). The development of a vulnerability index would enable a better

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