ESTIMATING SEISMIC HAZARD USING GIS FOR THE STATE OF SABAH, MALAYSIA

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KEYWORDS: Earthquake; Active tectonic zone; Intensity map; PGA map; GIS

ABSTRACT: The state of Sabah, Malaysia is not forever immune to seismic risk from global tectonic boundaries but always under risk due to the local active faults. The patches of intersecting active faults can be found in the hilly regions of the Sabah that have resulted more than 65 earthquakes. Till date, researchers have not focused on the intersecting lineaments and faults of Sabah. Therefore, we have proposed the critical triangular analysis on these patches of intersection to find out the zone of risk where most of the earthquakes are happening. To the end, we prepared the PGA map and intensity map based on the historical earthquakes recorded. However, PGA and Intensity maps have been prepared using the Campbell attenuation model. The highest PGA and intensity values resulting from this study are 0.07 and 7, respectively. Our results shows that the critical zone of intersecting faults is the region coming under high intensity and PGA values. It is clearly pinpointing that the intersection of faults and lineaments lead to produce a large number of earthquakes, where the highest magnitude of earthquakes can be found due to the influence of intersecting fault movements.

1 INTRODUCTION

The main purpose of this paper is to investigate and analyse the seismic hazard for the state of Sabah in Malaysia that is characterized by low to medium seismic zones. This paper explains the active fault intersection, earthquake intensity modelling, PGA modelling, and interpreting the zones of high risk for population, properties and infrastructures due to earthquakes. The historical evidences reveal that the growing trend of earthquake analysis and research in Malaysia. Although several researchers have conducted various scientific studies that is significant and the damages can be happened within 100-200 km radius from the epicentre. A high magnitude earthquake can affect a large radius of an area same as Mexico earthquake 1985 (Megawati et al., 2005). Various seismic studies and hazard analysis have been proposed till date mostly based on ground motion acceleration due to earthquakes because of well-presented and correct database (Balendra *et al.*, 2002; Lam *et al.,* 2009; Megawati & Pan, 2010; Megawati *et al.,* 2005; Pan & Megawati, 2002; Pan *et al.,* 2007; Petersen *et al.*, 2004; Pappin *et al.*, 2011).

The two main zones that represent the Sabah are generally: (1) a low seismicity zone that can be found in between Sarawak border and the south-west of Kota Kinabalu, (2) the rest of Sabah, which is coming under medium seismicity zone. Zone (1) is within the Sarawak and some parts of the Sabah zone whereas the hazard for zone (2) is characterised by earthquake activities in other parts of the Sabah (Lam et al., 2016). Our research is mostly focused on zone (2) which comprises of the south-eastern and central parts of the Sabah. Researchers are focusing on the eastern part of the Sabah, which is attracting much of the attention during the last decades. However, researchers are also putting their interest in the central Sabah because of high magnitude earthquakes. There are many active faults can be found in the state of Sabah. The possibility of experiencing more than 6 magnitude of earthquake may rule the central Sabah (Lam et al., 2015b; 2016). Thus, necessitating the need for this research, which is aimed at estimation of seismic hazard in the state of Sabah in Malaysia by an integrated GIS technique.

2 STUDY AREA

Sabah is the state of Malaysia can be found at a lat. and long. of 4^0 to 7^0 and 115^0 to 120^0, respectively. East Malaysia and especially the Sabah is known to be tectonically much active and it is called as the earthquake-prone area of Malaysia. Peninsular Malaysia has experienced some earthquakes as well according to MMD (Malaysian Meteorological Department). Fifty percent of the state is characterised by hilly regions while others are plane lands. The state is lithologically characterised by granitic, schistose, gneissose, limestones, sandstones and philitic rocks. However, some kind of volcanic and loose sedimentary rocks can be found in different parts of the state. Therefore, due to tectonic stress many large active faults can be found in the east and central part of Sabah. The state is under risk due to some major earthquakes that happened in Ranau and other parts. Therefore, this part of the Malaysia was considered for the study to update and modify the research criteria.

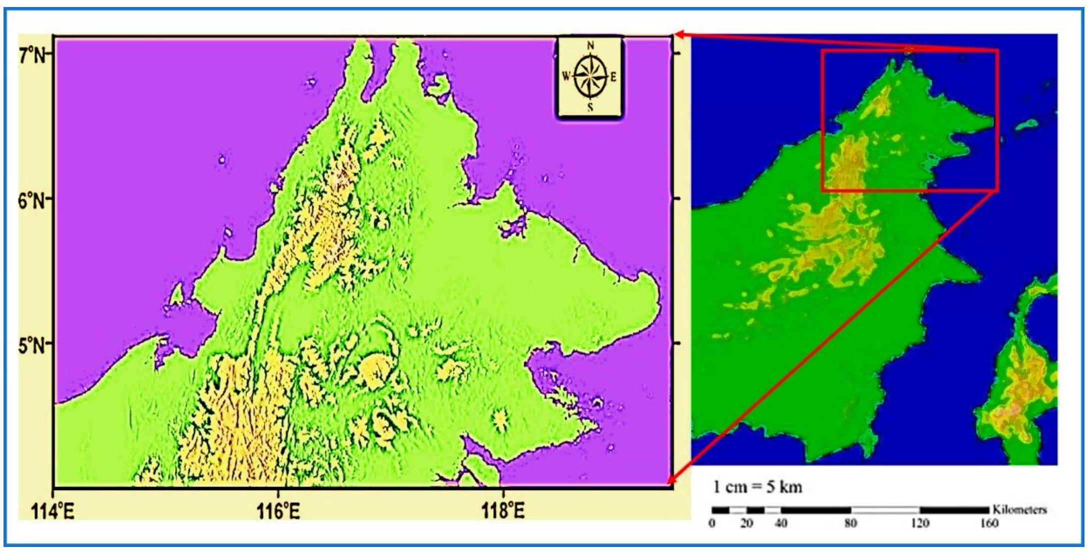

Figure 1 Study area of the state of Sabah.

3 DATA AND METHODOLOGY

This study has been conducted to estimate and analyse the PGA and Intensity map prepared using integrated GIS technique in the state of Sabah of Malaysia. The historical complete earthquake catalogue was used for the region. The required data was collected from NEIC (USGS). There are more than 65-recorded events for the limited period of 1966-2017. The catalogue contains more than 10 various types of magnitude scales; so the first step is unification of data scales by using equations of relation proposed by Boore, Campbell and Atkinson (2010). The methodology used for the study is (Deterministic Seismic Hazard Analysis) DSHA that has been described in four steps presented in the figure 2. Triangular critical analysis is a novel technique used for the intersecting active faults, which are most responsible for high magnitude earthquakes. Earthquakes of Mw=4 or less than that have not been considered in this research, because this range of magnitude has no effect for PGA calculation. Therefore, the sources are identified and used for the PGA calculation and Intensity calculation. In the next step, PGA density zonation model was generated. To the end, the triangular critical analysis was compared with the resulted PGA and intensity map to identify the zone of risk.

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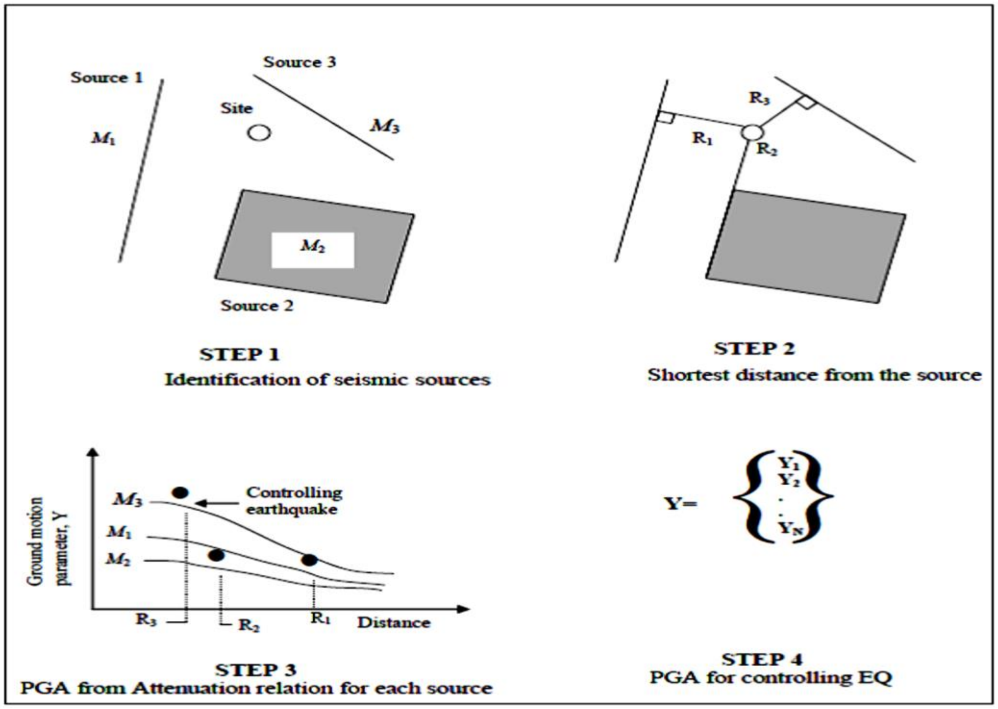


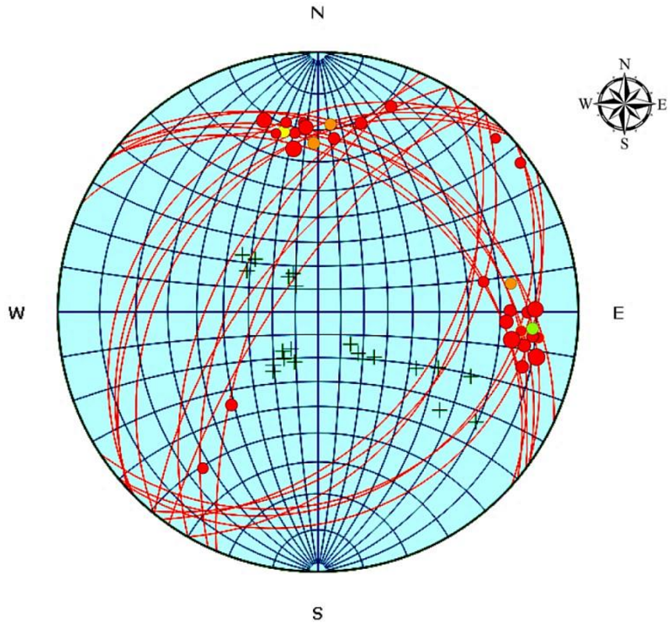
Figure 2 Overall methodological diagram for the PGA analysis of controlling earthquake (Kramer 1996).

Table 1 Listing of local *M*>5 events in *Central Sabah* and *Eastern Sabah* in the 50 year period 1966 – 2017. Adopted from the paper (Lam et al., 2016).

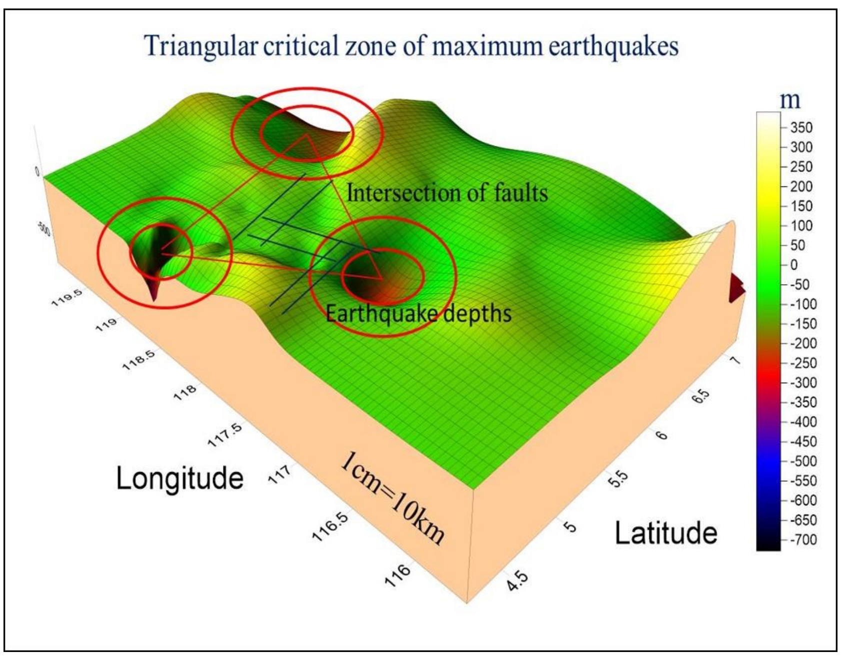
Region	Districts	Area (sq. km)	Magnitude of historical earthquakes	Approximate epicentral distance from *Kota Kinabalu* (km)	Year of occurrence
Central Sabah	Kota Kinabalu Ranau Tuaran Kota Belud Total area =	816 3556 1166 1386 6924	M5.3 M5.1 M5.9 M5.3	70 70 60 60	1996 1991 2015 2015
Eastern Sabah	Semporna Lahad Datu Kunak Total area =	1145 6501 1134 8780	M5.0 M6.2 M5.3 M5.6 M5.7	264 270 250 270 300	1976 1976 1976 1984 1994

4 RESULTS AND DISCUSSION

The findings of this work are based on the earthquake data collected from NEIC (USGS), which was accessible for years 1900 – 2017. Firstly, all the main faults data were collected from the Global centroid moment tensor catalog and plotted in the stereonet that is presented in figure 3a. Here in this figure, it can be seen that mostly faults are intersecting each other producing a triangular structure. However, more than 90 percent of earthquakes happened in these intersecting regions. Therefore, the triangular critical analysis has been performed to find out the zone of risk. The triangular analysis shows that all the earthquakes are happening in Sabah are mostly due to the



a)



b)

Figure 3a and 3b represents the triangular critical analysis for intersecting faults.

intersecting fault movements, which is influencing to the others for next generation of fault movement. In figure 3b, three earthquake regions are connecting by three straight-line creating a triangular zone within which the intersecting faults can be found. The models are depicted in figure 3a and 3b.

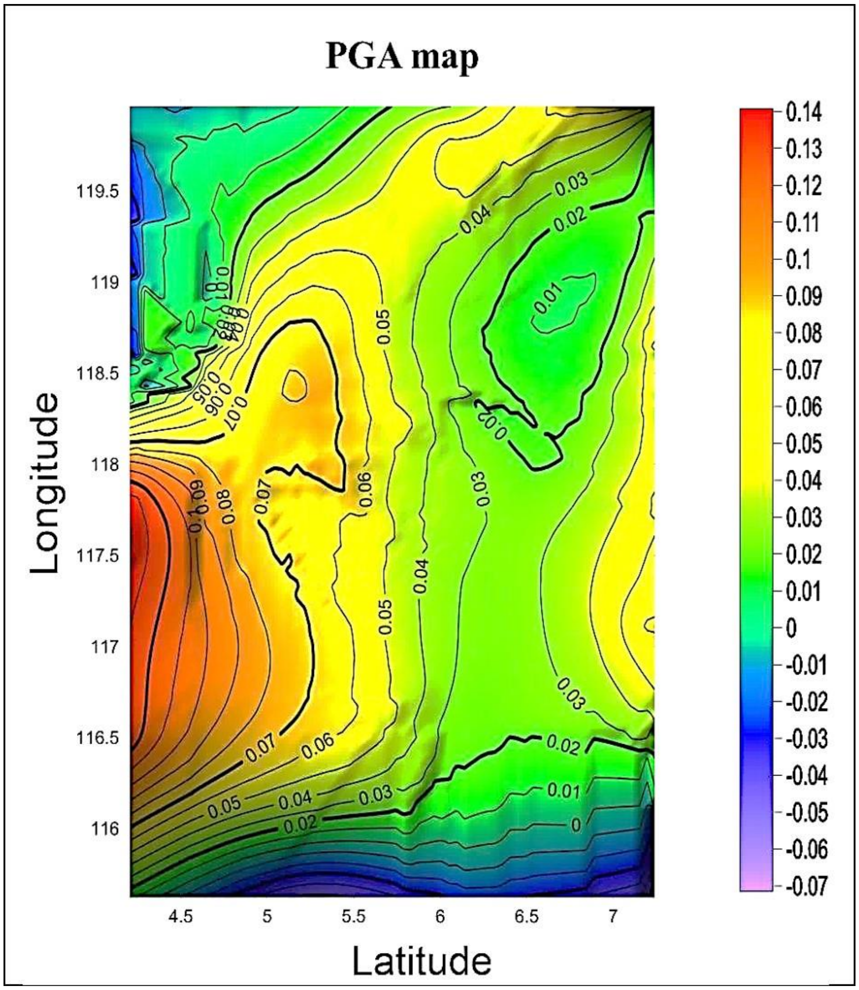


Figure 4 represents the PGA map of study area.

From the PGA analysis, it is clearly shown in figure 4 that the PGA values are ranging from 0.01 to 0.1. Moreover, the danger zone of PGA ranges 0.07 to 0.1. The controlling earthquake resulted from this study was 6.2. The triangular critical zone can be found in figure 3 which is falling in the zone of the PGA values ranging 0.7 to 0.1 (figure 4). Therefore, the results of PGA analysis and triangular critical analysis matched by providing the area of risk with highest PGA values. In the next step, the intensity analysis has been performed to prepare the Intensity map. The intensity values are calculated from the PGA values resulted from the study. Intensity map reveals the same zone of risk that match with the triangular critical zone of risk. Intensity map is depicted in the figure 5 with clear legends through which the zone of risk can be identified. Therefore, the results from this study clearly shows that the central and the southern region of the state is under high risk of experiencing more than 6 magnitude of earthquakes than other parts in future. The research reveals the important information about the region without identifying the particular regions of the state. The results from this research are presented in the table 2.

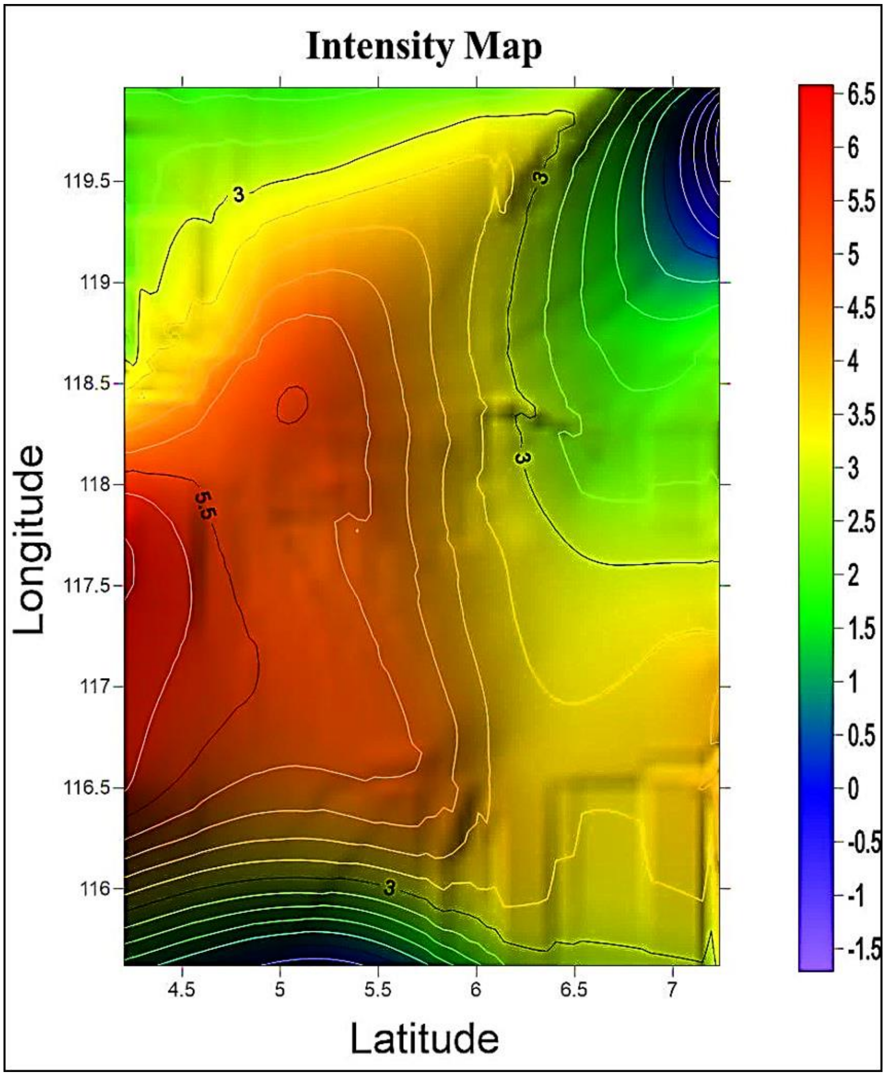


Figure 5 represents the intensity map of the state Sabah.

Table 2 presented results from this study.

Literature citations (LAWS)	Acronyms in legends	Research Remarks	PGA	Intensity	Triangular analysis
Boore, Campbell and Atkinson (2010)	BCA10d	BSSA article	0.7	7	Critical zone of risk with PGA 0.7 and Intensity 7 due to intersecting active fault movements.

There are some published research on the state of Sabah for the PGA estimation, which have been conducted by using deterministic seismic hazard assessment approach. However, the main difference between the published research and this study might relates to the zonation model of various seismic sources. This research on estimation of PGA and intensity for the study area updating the earthquake catalogue and providing good results. We have improved the method