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# Effect of Long-Distance Earthquake from Philippines and Sulawesi to Sabah Region

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**Abstract.** Sabah is known for its active earthquake activities, especially in Ranau, Kudat and Lahad Datu areas. The effects of local earthquake can reach  $M_w$  6.0. Furthermore, Sabah was also hit by earthquakes from neighbouring countries such as Sulawesi and Philippines. These countries produce highly active earthquakes that can reach as high as  $M_w$  8.6. The increase in the frequency of earthquakes is one of the concerns of the Sabah government for the safety of its people because most people live in concentrated areas near the coast. This study shows the effects of major earthquakes from the Philippines and Sulawesi which have been recorded between 1900 to 2020 and analyzed in terms of peak ground acceleration (PGA). The eastern region of Sabah is adopted in the analysis for the effect of long-distance earthquakes, as these areas are close to both countries. The analysis uses standard seismic hazard assessment procedure with compilation magnitudes greater than  $M_w$  5.0. In the final analysis, it is shown that the effects of large earthquakes from both countries are relatively small compared to the effects of local earthquakes.

**Keywords:** long-distance earthquake, active seismicity, Sabah vulnerable to seismic shaking.

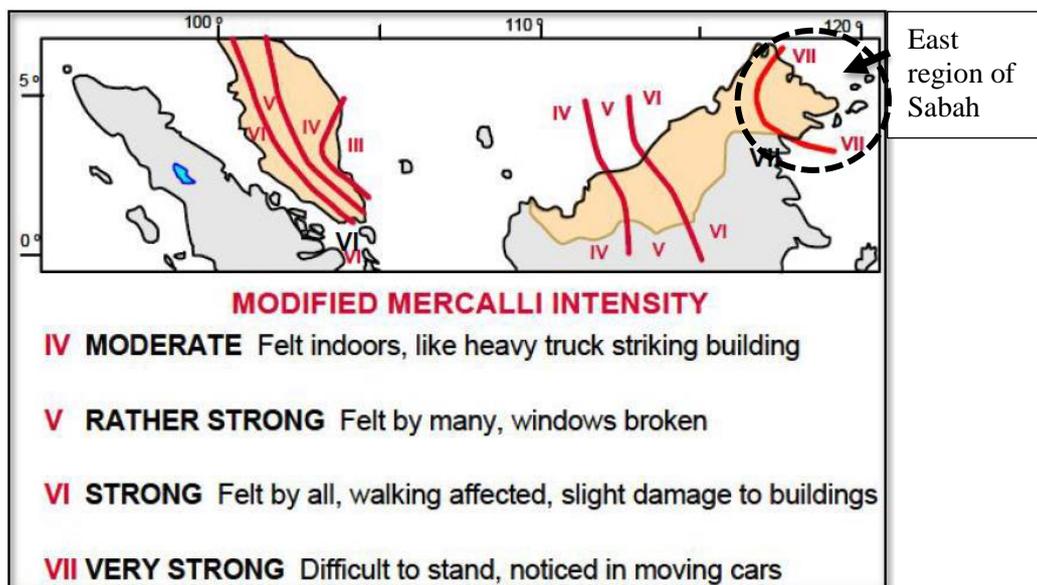
## 1. Introduction

Sabah is located in the eastern part of East Malaysia and is bordered by three seas: the South China Sea, the Sulu Sea, and the Celebes Sea. Sabah is the second largest state with the second largest population in Malaysia [1]. Most of the population lives in the city and spreads from the highly populated coastal zones to the inland zones. Activity in coastal zone areas is expected to continue to increase, due to growing urbanization, industry, and transportation. The demand for proper guidelines to address the new seismic design poses a significant challenge to the community of developers, engineers, and contractors. The scientific challenge is to leverage this progress into understanding the deep and practical phenomena of moderate earthquake activities in the region.

Figure 1 shows a qualitative map in terms of the Modified Mercalli Intensity Scale (MMI) of Malaysia. The MMI scale reflects 12 increasing severity level of the tremor where one single magnitude indicates the overall size and energy released by an earthquake. The map shows the earthquake intensity zone in accordance with MMI scale, east Sabah recorded category VII which indicated major damage to weak buildings. The high MMI scale in this area is due to several possible

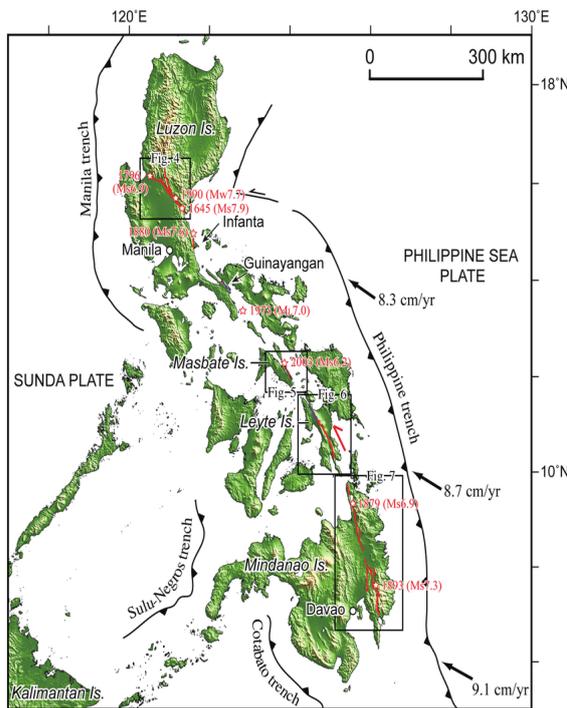


faults delineated, either local earthquakes, or active earthquakes from the Philippines and Sulawesi. In Sulawesi, it has a subduction zone in the northern region that occurs near the convergent boundaries where an oceanic plate is being subducted under an island arc (known as the Minahassa Trench). The Philippine Fault Zone can be seen across the Philippine archipelago behind the convergent boundary of the Philippine Trench as well as the subduction of the Philippine Sea Plate. Seismic source models are divided into shallow crustal fault sources and subduction zones including megathrust and Benioff. Each fault is considered for the analysis shown in Figure 2 for the Philippines region and Figure 3 for the Sulawesi region. Tsutsumi and Perez [2] and Cipta et al. [3] were used as a reference for possible seismic sources in the surrounding region within the study area. Tsutsumi and Perez [2] identified vast seismic zones in the Philippines; yet only the Southern Philippines is considered in this study. Cipta et al. [3] divided this region into 31 faults zones based on tectonic characteristic trend, predominant source mechanism solutions and epicentral distribution of past earthquakes. The average focal depth is taken as 25 km and constant throughout all shallow crustal faults. The value is considered reasonable since the depth characteristics for a shallow crustal earthquake are 70 km. Source-to-site in terms of hypocentral distance by taking the point at which the fault begins to rupture is considered in determining distance in each fault sources.

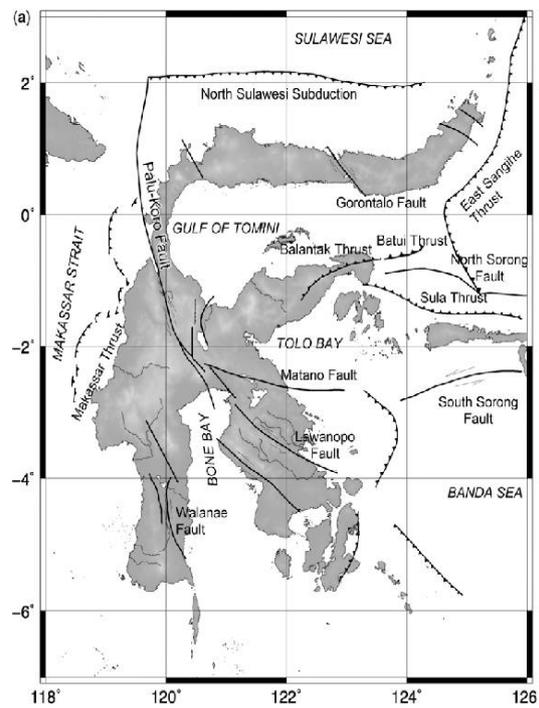


**Figure 1.** Location of eastern region of Sabah with the highest MMI scale [4]

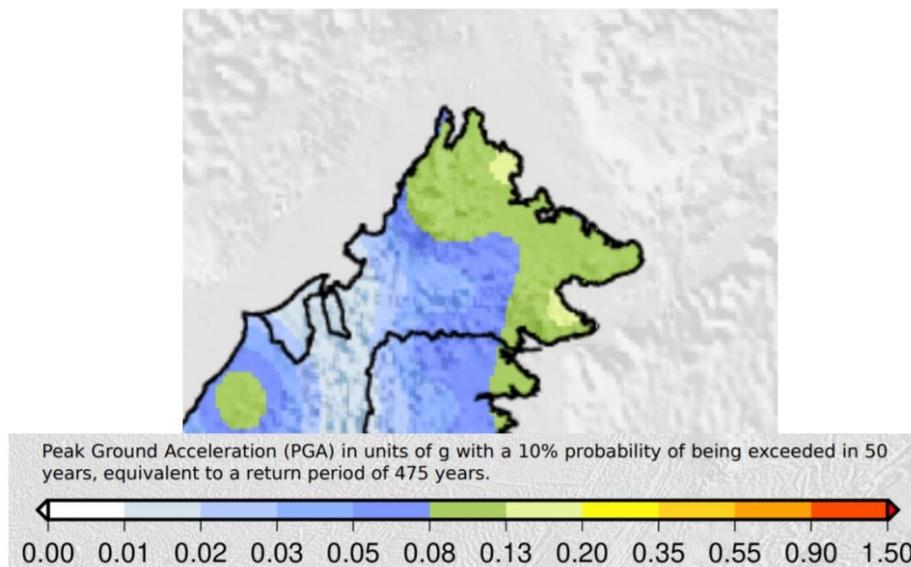
The latest Global Seismic Hazard Map [5] has developed by Global Earthquake Model (GEM) in terms of geographic distribution of the Peak Ground Acceleration (PGA) with a probability of 10% being exceeded in 50 years (Figure 4). Through the map, the PGA in eastern Sabah has the highest PGA between 0.08 and 0.20  $m/s^2$ . However, as stated by GEM, such information cannot be used for the earthquake design in buildings. Therefore, the PGA values for the use of seismic design can be referred to the Malaysia National Annex [6]. In this standard, the map also presents the Peak Ground Acceleration (PGA) distribution with a 10% probability exceedance in 50 years with values between 0.06 and 0.15  $m/s^2$ . The analysis is made based on the delineation of tectonic features from the source of the local fault.



**Figure 2.** Tectonic framework of the Philippine archipelago [2].



**Figure 3.** Tectonic framework of the Sulawesi archipelago [3].

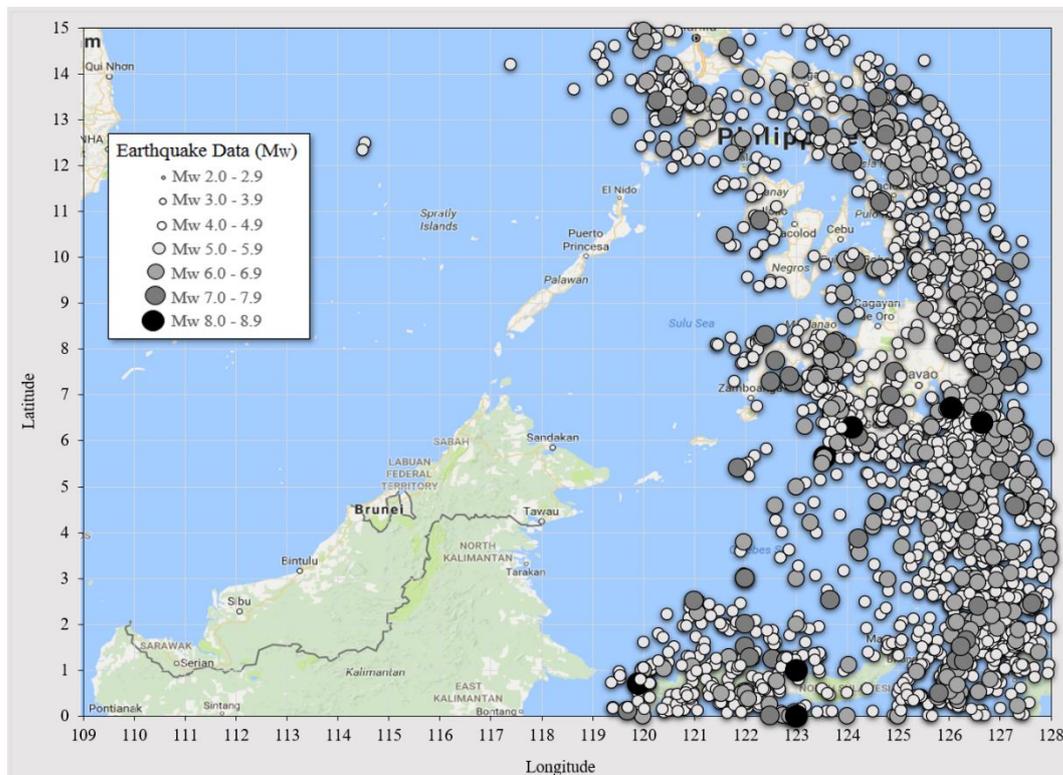


**Figure 4.** Earthquake seismic hazard map in Sabah region made by Global Earthquake Model (GEM) [5].

Large data sets provided by various national and international agencies have been collected. International agencies include the United States Geological Survey (USGS) [7], the International Seismological Centre (ISC) [8], the Global Centroid Moment Tensor (CMT) [9] and the Malaysia Meteorological Department (MET) [10]. The combination of international catalogs shown in Figure 5 with a magnitude of more than  $M_w$  5.0 since 1900 has accumulated earthquake events in more than 6000 earthquakes.

Seismotectonic settings around the region strongly indicate that large earthquakes of the Philippines and Sulawesi regions [4, 11, 12]. The catalog of earthquakes from the largest earthquake recorded from both countries is collected and listed in Table 1. In the record, the largest recorded earthquakes

occurred on 21st December 1939 with  $M_W$  8.6 followed by 15th August 1918 with  $M_W$  8.2 and 16th August 1976 with  $M_W$  8.0. The international catalog was originally compiled and analyzed by Harith [13] from 1900 to 2014 on a scale of  $M_W$  5.0 and above. Subsequently, this study extends data collection by adding earthquake records from 2014 to 2020.



**Figure 5.** Distribution of epicenters around the eastern region of Sabah from 1900 to 2020.

**Table 1.** List of largest earthquakes ever recorded from Philippines and Sulawesi.

Date	Latitude ( $^{\circ}$ )	Longitude ( $^{\circ}$ )	Depth (km)	Magnitude, $M_W$
02/03/1985	-1.96	119.73	43	6.9
13/02/1924	-2.50	122.00	35	6.6
31/03/1955	7.39	122.88	54.2	7.7
30/04/1949	6.50	125.00	130.0	7.3
15/08/1918	5.65	123.56	35.0	8.2
14/06/1978	8.29	122.40	30.1	7.0
21/12/1939	0.00	123.00	150.0	8.6
16/08/1976	6.29	124.09	57.7	8.0

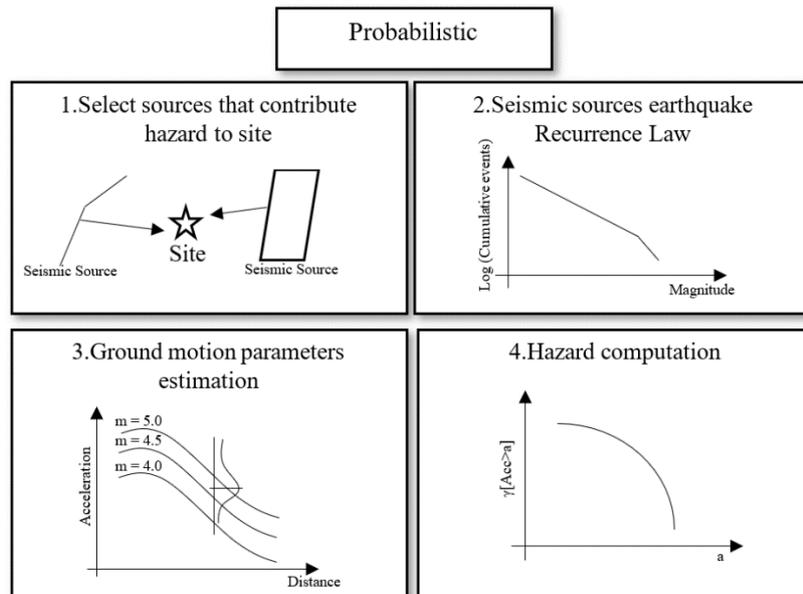
## 2. Methodology

Seismic hazard analysis has become more important in Malaysia for the safety needs of engineering structures and the public interest. Standard method for conducting seismic hazard assessments are required by performing Probabilistic Seismic Hazard Analysis (PSHA). This is a mathematical procedure involving probabilistic studies to evaluate the answers to uncertainties about seismic location, earthquake size and possible shaking in the future. In probabilistic studies, two main parameters are important namely the limit of magnitude and distance. Several ground motion prediction equations (GMPE) suitable for East Sabah are considered. The ground motion parameter considered in this assessment is peak ground acceleration (PGA). PSHA will be implemented using the approach below.

There are four steps to conduct PSHA:

1. Select sources that contribute hazard to site
2. Characterize seismic sources in terms of magnitude and distance using Recurrence Law.
3. Identifying the earthquake ground motion parameters
4. Computation of seismic hazard at selected locations.

The information required in this analysis is the hazard level at 10% probability of exceedance in 50 years corresponding to 500 years return periods of earthquakes. The flow chart for seismic hazard analysis performed in this study can be illustrated in Figure 6.



**Figure 6.** Flow chart of the probabilistic seismic hazard analysis methodology conducted for this study

Six areas located in eastern Sabah have been considered for analysis. The places are as depicted in Figure 7 which consists of Beluran, Sandakan, Kinabatangan, Lahad Datu, Semporna and Tawau. The position of these areas has been considered for analysis as these areas are close to the Philippines and Sulawesi.



**Figure 7.** Six locations from East of Sabah that have been considered for seismic hazard analysis

Seismic hazard analysis modelling should capture uncertainties about earthquake input parameters such as magnitude and earthquake distance. The concept of determining the level of seismic hazard has been very common in every country since first introduced in the 1960s [14]. In the development of design ground motion, its critical part is in the design of seismic structures, where it is required to perform PSHA. The seismic parameters for each source zone were calculated using the method by Gutenberg-Richter (G-R).

Aleatory uncertainty is often addressed by the distribution of probabilities with strong GMPEs to estimate earthquake ground motion parameters. Recently, a comprehensive and comparative study of the past GMPEs was compiled by Douglas [15]. For shallow crustal earthquakes, four models have been used in current studies including three GMPEs namely Abrahamson and Silva [16], Fukushima and Tanaka [17], Sadigh et al. [18]. In addition, the equation by Zhao et al. [19] was used to analyse PSHA for subduction zone. The PSHA will be calculated using the probability theorem developed by McGuire [20]. This theorem is based on the concept of probability developed by Cornell [21]. The study considered the magnitude,  $M$  and hypocenter distance,  $R$  as continuous independent random variables. The overall probability theorem can be represented in its most basic form as in equation (1).

$$P[I > i] = \int_r \int_m P[I \geq i | m \text{ and } r] \cdot f_M(m) \cdot f_R(r) dm \cdot dr \quad (1)$$

From the equation,  $f_M(m)$  is magnitude density function,  $f_R(r)$  is distance density function (hypocenter) and  $P[I > i | M \text{ and } R]$  is conditional probability of intensity  $I$  exceeding the value  $i$  at the location for the given magnitude,  $M$  and distance,  $R$ .

### 3. Results

In evaluating the seismic hazard analysis for East Sabah, the parameters such as the latitude and longitude of the start and end points of the fault, the number of earthquakes along the fault and the maximum magnitude for each source were then analysed. The fault source from each zonation model as well as Ground Motion Prediction Equations (GMPEs) are calculated. The mean annual rate is calculated from a combination of all input parameters. The results are compared in terms of peak ground acceleration (PGA) at bedrock level of 10% probability of exceedance in 50-year return period corresponds to 500 years between this study with Malaysia National Annex [6] and Global Seismic Hazard Map [5] (Table 2). As a result of these findings, the PGA values for six locations indicate that the impact of the long-distance earthquake towards eastern Sabah is much smaller than the impact of the local fault earthquake. Malaysia National Annex [6] shows a much higher value as studies incorporating local earthquake faults in their analysis. This is also found in Global Seismic Hazard Analysis [5], which predicts much higher value. The PGA results produced on these six areas show that Tawau and Semporna areas produce  $0.035 \text{ m/s}^2$  and  $0.038 \text{ m/s}^2$ , respectively higher than other areas since these two areas are close to Northern Sulawesi.

**Table 2.** PGA results at respective sites for 10% probability of exceedance in  $g$  ( $\text{m/s}^2$ )

Site Location	This study	Malaysia National Annex [6]	GEM [5]
1. Beluran	0.008	0.110	0.200
2. Sandakan	0.011	0.060	0.130
3. Kinabatangan	0.022	0.060	0.130
4. Lahad Datu	0.026	0.150	0.130
5. Semporna	0.038	0.070	0.130
6. Tawau	0.035	0.070	0.130

The different value obtained in the present study is mainly due to the seismic sources and earthquake catalogs. As in Malaysia National Annex [6], the PGA is particularly high for zone with the existence of fault for example at North and South of Sabah. The mostly contributed to the hazard level in Sabah is from the nearby active faults. Differences in acceleration hazard maps reflect the fact that the

distance from a particular close distance from the seismic source zone is an important factor rather than long-distance earthquakes. This study was analyzed to extract useful information about the earthquake source from the long-distance earthquakes' effects to Sabah. All effects are significantly related to local earthquakes has been analyzed in Malaysia National Annex [6] and GEM [5], proving that the effects of long-distance earthquakes are small.

#### 4. Conclusion

The results described in this research form the definition of PSHA by using the most recent earthquake data records between the years of 1900 and 2020. For seismic hazard analysis potentially caused by long-distance earthquakes, seismic source zones are identified and analyzed. The average focal depth is taken as 25 km and fixed throughout all shallow crustal faults and in subduction zones: less than 150 km for megathrust and more than 150 km for benioff. Peak Ground Acceleration (PGA) values from the effect of long-distance earthquakes, from Sulawesi and Southern Philippines were assessed. PGA values at bedrock level of 10% probability of exceedance in 50 years is calculated for the six eastern Sabah areas. As a result of this study, the PGA value is in the range of 0.008 to 0.038  $m/s^2$ . The highest PGA among six areas are Tawau and Semporna areas with a value of 0.035  $m/s^2$  and 0.038  $m/s^2$ , respectively. The PGA value pattern obtained from this study slightly lower with the results produced by Malaysia National Annex [6] and Global Seismic Hazard Map [5]. The values in this study are mainly due to the regional GMPE used followed by the definition of seismic source definition and earthquake catalog used.

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