# Estimation of Peak Ground Acceleration (PGA) for Peninsular Malaysia using geospatial approach

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**Abstract**. Among the various types of natural disasters, earthquake is considered as one of the most destructive events which impose a great amount of human fatalities and economic losses. Visualization of earthquake events and estimation of peak ground motions provides a strong tool for scientists and authorities to predict and mitigate the aftereffects of earthquakes. In addition it is useful for some businesses like insurance companies to evaluate the amount of investing risk. Although Peninsular Malaysian is situated in the stable part of Sunda plate, it is seismically influenced by very active earthquake sources of Sumatra's fault and subduction zones. This study modelled the seismic zones and estimates maximum credible earthquake (MCE) based on classified data for period 1900 to 2014. The deterministic approach was implemented for the analysis. Attenuation equations were used for two zones. Results show that, the PGA produced from subduction zone is from 2-64 (gal) and from the fault zone varies from 1-191(gal). In addition, the PGA generated from fault zone is more critical than subduction zone for selected seismic model.

## 1 Introduction

Natural hazards' management is one of the most important applications of remote sensing and GIS technologies [1-3]. GIS as the technology of gathering, combining, analysis and manifesting spatial data [4], has a very significant role in improving the quality of studies related to natural hazards and possibility of prediction, management and mitigation of their disastrous consequences. Collecting and classification of historical data about a disaster makes it possible to have a relatively realistic estimation of its behavior and rhythm of occurrence [5]. Especially in developed countries, by utilization of modern communication technologies, GIS are used in the real-time manner for managing natural disasters.

Furthermore, modelling of calamities and evaluating of their risks provide a very strong tool for decision-makers to find the best options for land use and development of infrastructures. These models are beneficial for some businesses like insurance companies to evaluate and estimate the amount of risk in investments.

Among natural disasters, earthquake is considered as one of the most destructive and devastating phenomenon which seriously threatens the life of people, properties and infrastructures. This fact makes it a necessity to investigate various regions of the world to gain a scientific understanding about the mechanism of occurrence and recurrence of it. There are nearly daily reports about earthquakes in different parts of the world, but until now there is no way to predict the exact location and intensity of the next event. As earthquakes imposes a great deal of damages to societies, seismologists and engineers concentrate on studies to find out the rhythm of occurrence of seismic events and seismic hazard analysis to apply the results in construction standards and codes in order to mitigate the rate of losses related to earthquakes.

An earthquake is an amount of energy which is released because of crash and displacement of rocks under the surface of the ground. Although the rupture is usually originated tens of kilometres under the ground level, at the surface of the earth; earthquakes manifest themselves by shaking and displacing the ground [6]. In case the epicentre is located at offshore, the earthquake at seabed shows itself as a tsunami. The occurrence of earthquake can intensify happening of other natural disasters like landslides and occasionally volcanic activities [2].

It has been recognized that urban areas located at large distances from tectonic plate margins (broadly categorised as low- to moderate-seismicity regions), may also be affected by earthquake tremors [7]. This is explained as the "Bowl of Jelly" phenomenon which was exemplified in occurrence of a huge devastation in Mexico City in year 1985 resulted from the long period component of the shear wave of a distant earthquake (approximately 350 km far from the city). The mechanism of this type of energy transfer is illustrated in Figure 1.

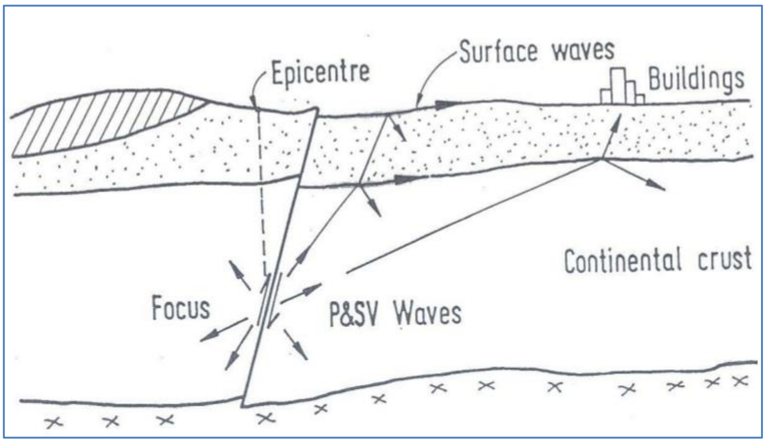


**Figure 1.** Schematic diagram for far-field effects of earthquakes [8].

Although Peninsular Malaysia is located in the stable Sunda Shelf with low to medium seismic activity level, the seismic risk, in terms of damage potential (to structures, loss of lives, assets, properties, businesses and services, as well as its psychological and cultural impacts), cannot be ignored since there is not a national code for building and structures for seismic loads.

Tremors due to Sumatra earthquakes have been reported several times [9]. Recent great magnitude earthquakes (Mw=9.1) which occurred in this area have resulted in extreme damages and death of lots of people. Especially 2004 Aceh earthquake was notably devastating, and was one of the largest to be recorded in the history. Fortunately, the rupture was not directed towards Malaysian territories, thus the level of ground shake on Malaysian grounds was insignificant [10]. Based on the findings of Bolt & Dreger [11] the directivity of rupture can intensify the ground acceleration more than 10 times. According to MMD [12], between years 1977 and 2014 more than 100 tremors have been felt in Peninsular Malaysia.

These findings besides to considering the rapid development of civic texture and construction of high-rise buildings and various infrastructures during recent decades make the necessity to study seismic events in this area. These studies usually are based on two stages. The first stage is estimation of peak ground movements using proper attenuation equations which is the subject of this research. The second stage (known as "Microzonation"), focuses on investigation of the impact of the type of local soil and other geological and geomorphological specifications of a site. The main aim of this stage is to achieve a very accurate estimation about the amount of earthquake waves' intensity that reaches to the surface of the ground and influences constructions and infrastructures.

Although there have been many attempts to investigate the issue of calculating PGA in this region during recent years, it is required to deal with it from different viewpoints and implementing various methods. Furthermore these types of research need to be updated for recently happened seismic events. Therefore, the objectives of this study are; to visualize important attributes of seismic events in the region; and to calculate PGA and prepare hazard maps based on deterministic method by using proper attenuation equations for two effective zones and evaluating the results.

## 2 Literature review

Many researches have been conducted by utilizing of GIS for manifesting spatial features combined with their various attributes as well as data integration platform [3, 13, 14]. Relating to seismicity, several application and tools for the analysis of geotechnical data and hazard mapping exist in a GIS platform. Furthermore, most GIS communicate easily with external modelling and simulation programs that are essential for seismic analysis. The results of an external analysis can be used by GIS as both graphic and non-graphic data for further interpretation and analysis. With these wide areas of application, GIS play a unique role for hazard preparedness and management.

Generally hazard mapping analysis is implemented in two macro and micro levels. Macro level which is the subject of this research, reports some general seismic characteristics of zones and sites like PGA, without considering the detailed specifications of the site under study. For this level the application of GIS is compiling the seismic data containing earthquake catalogues and maps of seismic sources which are compiled with site map and analysis.

Seismic micro-zonation is subdividing a region into smaller areas having different potential for hazardous earthquake effects. The earthquake effects depend on ground geomorphological attributes consisting of geological, geomorphology and geotechnical information. The parameters of geology and geomorphology, soil coverage/thickness, and rock outcrop/depth are some of the important geomorphological attributes. Other attributes are the earthquake parameters, which are estimated by hazard analysis and effects of local soil for a hazard (local site response for an earthquake). The Peak Ground Acceleration (PGA), amplification/site response, predominant frequency, liquefaction and landslide due to earthquakes are some of the important seismological attributes. These datasets are compiled and analysed to generate thematic maps based on assigning proper weightages to attributes. The Earth's outermost part (called the lithosphere) is not one continuous shell, but consists of several large (and some small) stable rock slabs adjoining each other which called tectonic plates. The way these plates interact with each other, provides a geological model that properly explains the occurrence of the majority of earthquakes. Each plate extends to a depth of about 100-200 km and includes the Earth's outermost rigid rocky layer, called the crust. The moving tectonic plates of the Earth's surface also provide an explanation of the various mechanisms of most significant earthquakes [11]. The collision of neighbouring plates that results in subduction of one plate beneath the other is the cause of fracturing of regional crustal rocks. Figure 2 provides a schematic global view of the arrangement of these plates.

The seismologic events occurring in these boundary regions are named "Inter-plate Earthquakes". The most devastating events all around the world that happened in shallow depths such as Chile, Peru, the eastern Caribbean, Central America, Southern Mexico, California, Southern Alaska, the Aleutians the Kuriles, Japan, Taiwan, the Philippines, Indonesia, New Zealand, the Alpine-Caucasian-Himalayan belt are of plate-edge type. The other sources to generate earthquakes are "Strike-Slip" or Transform Faults along them plates slide past each other.

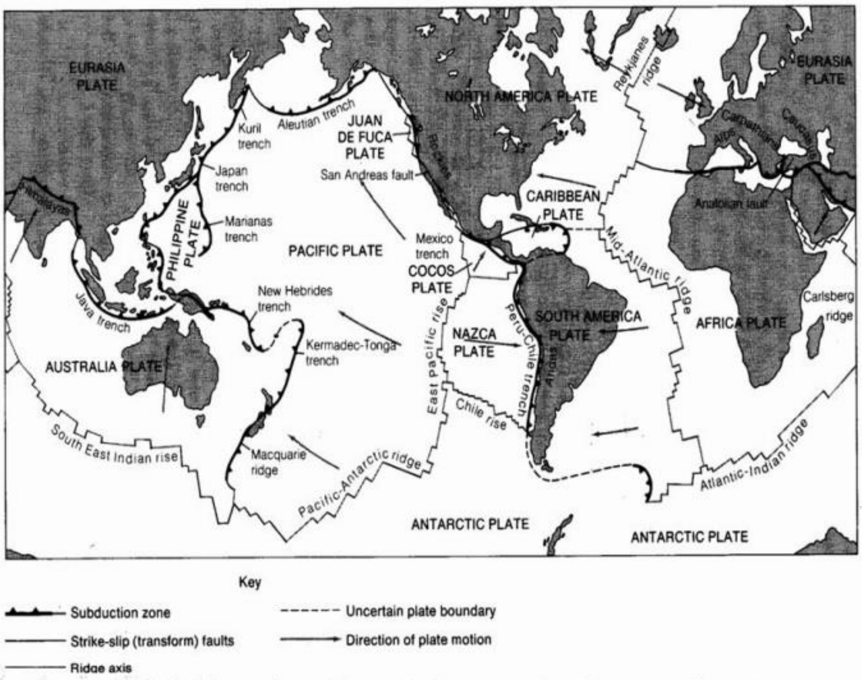


**Figure 2.** The major tectonic plates, mid-oceanic ridges, trenches and transform faults (Source: Bruce A. Bolt, Nuclear Explosions And Earthquakes: 1976).

However the plate tectonics theory explains the great part of seismic activities, some destructive earthquakes happen very far from plate boundaries within continents which are named" Intra-plate earthquakes". The general concept of how the earthquake sources interrelate with each other is demonstrated in Figure 3.

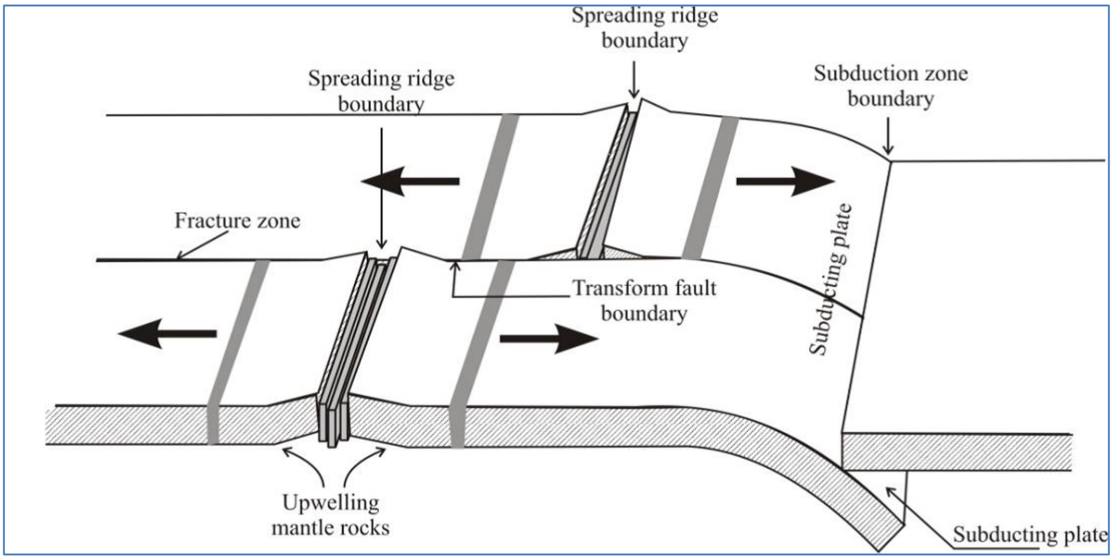


**Figure 3.** Interrelationship among spreading ridge, subduction zone, and transform fault plate boundaries [6].

Southeast Asia is a region of variable seismic hazard, ranging from high seismic hazard associated with the subduction process beneath the Indonesian and Philippine archipelagos to moderately low seismic hazard across a large stable region that contains the Peninsular Malaysia [15]. The concise introduction to the tectonic setting of the region is presented in Figure 4. It can be seen that three tectonic plates, Indian-Australian, Eurasian and Pacific plates are meeting each other in this region and the amount and the direction of convergence have been displayed as well. In addition to illustration of the tectonic texture of the region, the extent of active volcanoes as another source of earthquakes and the more earthquake-prone part of Malaysia are presented.

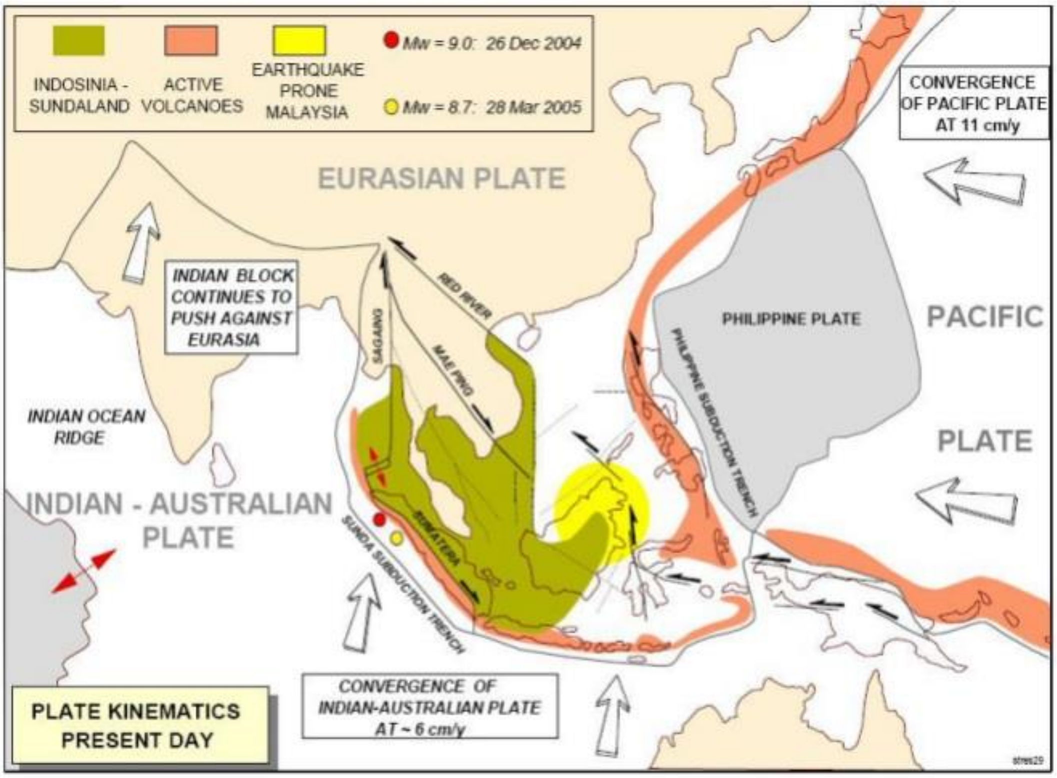


**Figure 4.** Earthquake-prone region of Malaysia [16].

In general, Malaysia is taken into account as a low- seismic activity country because of the fact it is situated on the stable part of Sunda crust and the nearest active source is located at least 350 km far from it. Until recently (before the occurrence of 2004 Sumatran giant earthquake), it was widely believed that West Malaysia will not be shacked because of activity of seismic sources inside the territory. According to Rosaidi [17] no earthquake had been originated from the area, although the flooding of the Kenyir Dam in Terengganu during 1984-1987 created some seismic activity (maximum magnitude was 4.6 on the Richter scale).

Considering the findings of Marto et al., [18] there have been records of more than 32 events that were originated from local sources during recent years. Although the magnitudes of these earthquakes are very small and there is not an official report and catalogue to refer, it seems inevitable to consider the reactivation phenomenon of inactive faults because of reformation in the core of the Sunda-land. According to Jeffery Chiang, the head of the group working on designing national building code in Malaysia [18], near field earthquake especially within the vicinity of 80km-long Bentong Fault should be given considerable attention.

Although East Malaysia and especially Sabah is tectonically more active and it is named earthquake-prone area of Malaysia, Peninsular has experienced some earthquakes as well. According to MMD [12], Peninsular Malaysia has felt tremors from local origin earthquakes (e.g. Bukit Tinggi Earthquakes, Kuala Pilah Earthquakes, Manjung Earthquake, Jerantut Earthquake and Terengganu Earthquake) and some of these local events had caused considerable damages to poorly built or badly designed building in the area. Table 1 depicts the maximum intensity and frequency of recorded earthquakes in various states of Malaysia.

**Table 1.** Earthquake Intensity recorded in Malaysia [12].

| State | Frequency | Maximum intensity (Modified Mercalli Scale) |
|---|---|---|
| **Peninsular Malaysia (1909-2010)** | | |
| Perlis | 3 | V |
| Kedah | 18 | V |
| Penang | 41 | VI |
| Perak | 24 | VI |
| Selangor | 52 | VI |
| Negari Sembilan | 14 | V |
| Melaka | 19 | V |
| Johor | 32 | VI |
| Pahang | 35 | III |
| Terengganu | 2 | IV |
| Kelantan | 3 | IV |
| Kuala Lumpur/Putrajaya | 38 | VI |
| Sabah (1897-2010) | | |
| Sabah | 41 | VII |
| Sarawak (1874-2010) | | |
| Sarawak | 17 | VI |

Based on historical records, the major part of earthquakes that influenced Peninsular Malaysia is originated from two external sources: Sumatran subduction zone and Sumatran strike slip fault. Only seismic source zones within a radius of 500 km from the site are considered. Those outside of this radius may not significantly influence the peak ground acceleration [19]. Large earthquakes that originated from these two active areas did create considerably ground motion over western part of West Malaysia [17].

## 3 Data and methodology

This study was conducted to estimate the peak ground acceleration in Peninsular Malaysia by using earthquake catalogue of the region from the year 1900 to 2014, and for an approximately 500 km distance from every side of this region which covers the longitude of 90°E to 110°E and latitude of 10°S to 10°N. The required data was collected from NEIC (USGS, 2014). There are more than 16000 recorded events for the mentioned time period. 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 Adnan et al. [9].

The methodology followed for (Deterministic Seismic Hazard Analysis) DSHA described as four steps and illustrated in Figure 5.

Data was shortened for records less than Mw=4, because this range of data has no impact for estimation of PGA. As the seismic sources were identified previously, the zonation model was generated (Figure 6) based on the model of Petersen et al. [20].

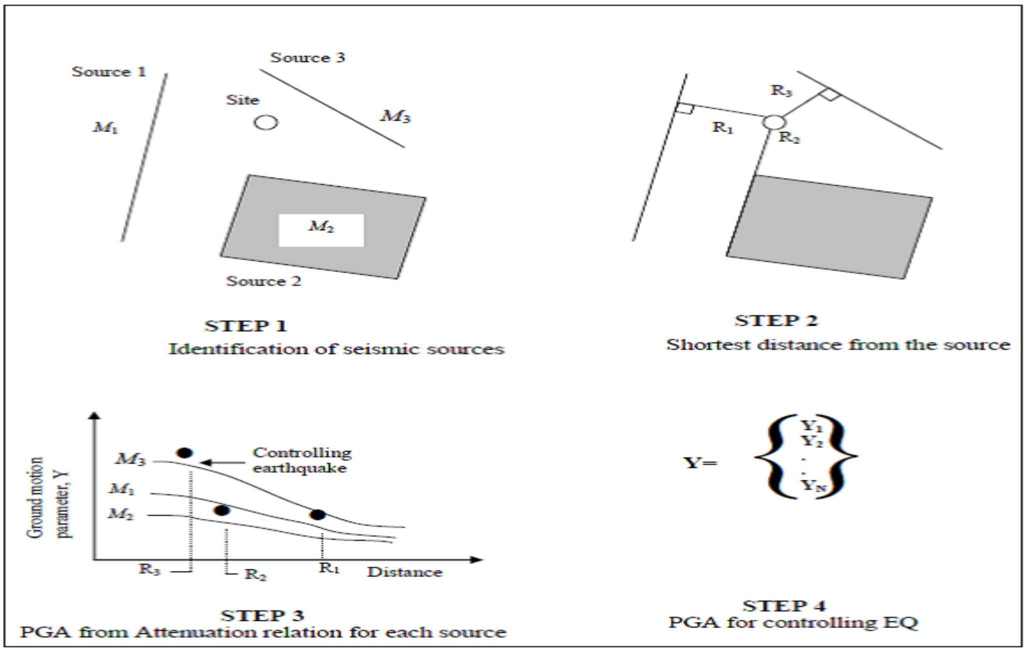


**Figure 5.** Different steps for deterministic seismic hazard analysis [6].

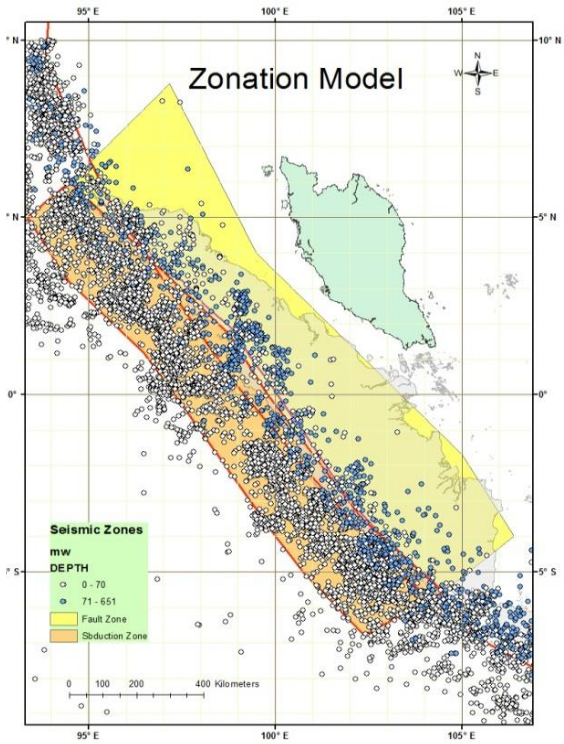


**Figure 6.** Zonation model of seismic sources.

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MCE was estimated in the way proposed by Gupta [21] by using an increment of 0.5 to the maximum recorded magnitude. Attenuation equation of Sadigh et al. [22] which has been developed for distances more than 200 kilometres by Petersen et al. [20], was implemented for calculation of PGA for subduction zone:

$$\ln y_{\text{Sadigh et al.}}(M,R) = C_1^* + C_2 M + C_3^* \ln\left[R + e^{C_4^* - \frac{C_2}{C_3}M}\right] + C_5 Z_{SS} + C_8 Z_t + C_9 H$$

Equation (1)

$$\ln y_{\text{Petersen}}(M,R) = \ln y_{\text{Sadigh et al.}}(M,R) + [-0.0038*(R-200)]$$

Equation (2)

For Fault zone, the equation of Campbell [23] was implemented:

$$\ln Y = c_1 + f_1(M_W) + f_2(M_W, r_{rup}) + f_3(r_{rup})$$

$$f_1(M_W) = c_2 M_W + c_3(8.5 - M_W)^2,$$

$$f_2(M_W, r_{rup}) = c_4 \ln R + (c_5 + c_6 M_W) r_{rup},$$

$$R = \sqrt{r_{rup}^2 + [c_7 \exp(c_8 M_W)]^2},$$

$$f_3(r_{rup}) = \begin{cases} 0 & \text{for } r_{rup} \leq r_1 \\ c_7(\ln r_{rup} - \ln r_1) & \text{for } r_1 < r_{rup} \leq r_2 \\ c_7(\ln r_{rup} - \ln r_1) + c_8(\ln r_{rup} - \ln r_2) & \text{for } r_{rup} > r_2 \end{cases}.$$

Equation (3)

Eventually rest of the analysis was done by using software ArcGIS 10.2.2.

## 4 Results and discussion

The findings of this work are based on the earthquake data collected from NEIC (USGS, 2014) which was accessible for years 1900 – 2014. Distribution of data which consists of 16150 recorded events for the region is summarized in Table 2.

**Table 2.** Number of earthquakes reported for study area from year 1900 to 2014.

| **MW** | Mw<4 | 4≤Mw<5 | 5≤Mw<6 | 6≤Mw<7 | ≤Mw<8 | Mw≥8 | Total |
|---|---|---|---|---|---|---|---|
| **EVENTS** | 4598 | 8339 | 2826 | 327 | 55 | 5 | 16150 |

Data distribution based on zonation model for fault zone and subduction zone are depicted in Figure 7 and Figure 8 respectively.

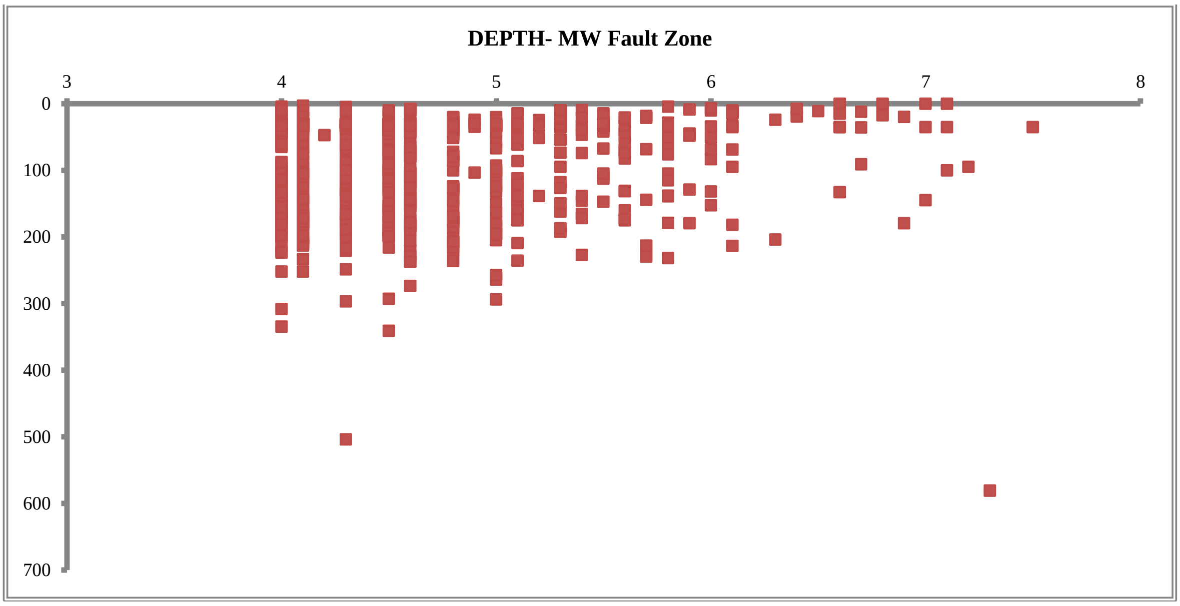


**Figure 7.** Distribution of events based on depth for Fault Zone.

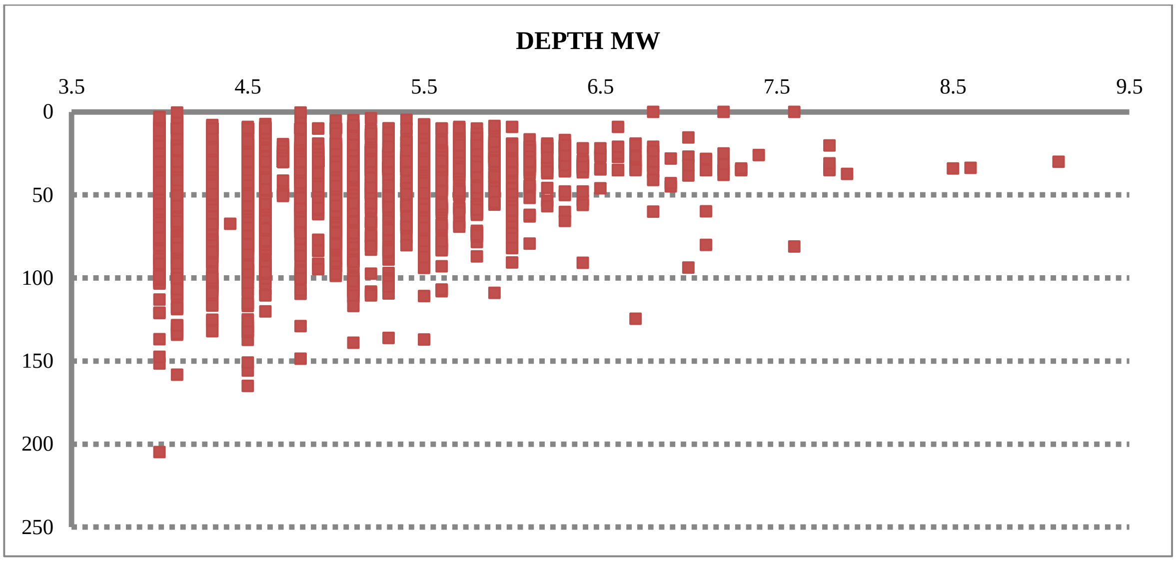


**Figure 8.** Distribution of events based on depth for Subduction Zone.

A comparison between two zones reveals that events in fault zone happen in depths deeper than subduction zone. Events smaller than Mw=4, because of having a very subtle effect in analysis are intentionally removed from report. The events in fault zone have occurred between 0 – 200 kilometres depth for Mw=4 to Mw=6, and for greater magnitudes the shallow events (lesser than 50 km) are more than deep events. The maximum magnitude recorded for this zone is Mw=7.5. On the other hand, for the subduction zone the majority of events are happened in shallow depths (lesser than 50 km) for whole range of magnitudes. Although for magnitudes greater than Mw=6 the events are restrained to 100 km, for greater magnitudes (Mw>7.5) events have happened within depths lesser than 35 km. The maximum magnitude recorded for this zone is Mw=9.1.

The results of PGA analysis for MCE= 9.6 for Subduction zone and MCE=8 for Fault zone are presented in Figure 9 and Figure 10 respectively.

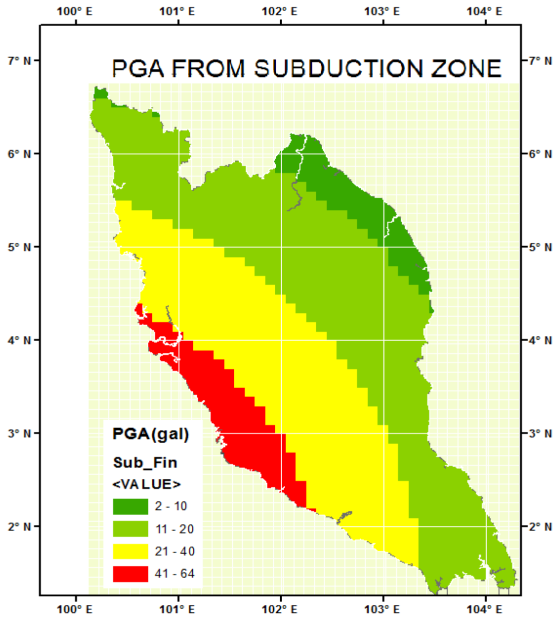


**Figure 9.** PGA for Subduction Zone using deterministic approach.

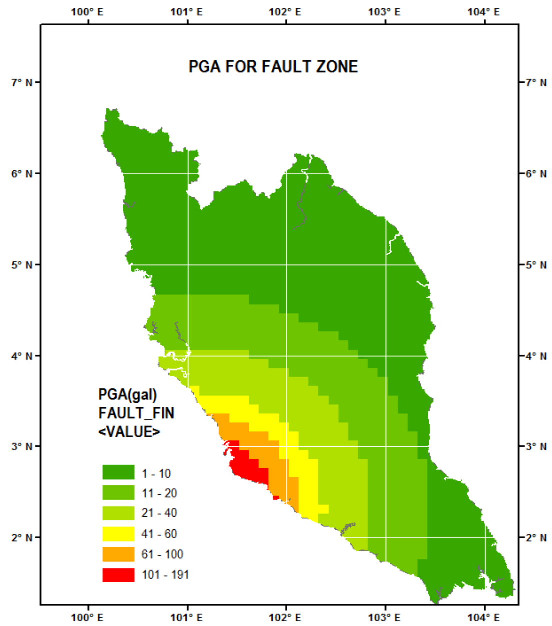


**Figure 10.** PGA for Fault Zone using deterministic approach.

There are some published results for estimation of PGA for Peninsular Malaysia which have been conducted using deterministic approach. Among them Adnan et al. [9] have published a result for deterministic approach and divided the PGA map of Peninsular into two zones, i.e. the zone for range between 30 and 50 gals on the east side of Peninsular Malaysia and the zone between 50 and 70 gals on the west side. The difference between results of that research and this work might relates to the zonation model of seismic sources, the estimation of MCE for each zone, and updating the earthquake catalogue as well.

## 5 Conclusion

GIS provides strong tools to visualize various attributes of seismic data and its analysis capabilities make it possible to estimate the PGA for a region accurately. Results from this research show the PGA from subduction zone fluctuates from 2-64 (gal) and from the fault zone varies from 1-191(gal). The results show the PGA generated from fault zone is more critical than subduction zone for selected seismic model. Finally, it can be concluded that, the amount of PGA for Peninsular Malaysia varies between 1 to 191 gals as per results of deterministic analysis.

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