A novel model for comparing Peak Ground Acceleration derived from three attenuation laws using an integrated GIS technique in Sabah area, Malaysia

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Abstract- Ninety percent of major earthquakes of the world directly indicating the sources of subduction and collision zones with shallow, intermediate, and deep focus earthquakes. The state of Sabah not indicating a high seismic risk zone and not directly associated with the Ring of fire. Nevertheless, it is positive towards seismic risk as the state experienced more than *65* earthquakes. However, no attention of researchers on comparative analysis of PGA map recorded in literature. Therefore, this study conducted; 1) to analyze the earthquake hazard and active tectonics of Sabah using PGA map derived from three methods and; 2) to understand the intersection of faults that can create isoseismic elongation. More than ***90%*** of earthquakes are shallow and focused at a hypo-central distance of **(*0 ~ 100)*** km as resulted from this research. Therefore, Sabah had been experienced a highest magnitude of ***~6.3***, which can create the maximum PGA values of **~ *(0.075, 0.06 and 0.08)*** based on three different attenuation equations proposed in this study. These earthquakes can produce a maximum intensity of ***(MMI~7)*** that is derived from the resulted PGA values. The study on active tectonics explains about the major ***12*** active faults and their intersection relationship. Therefore, this whole study has been conducted based on three attenuation relation to find out the best method for preparing the PGA map and the stereo net plotting using an integrated GIS technique.

Index Terms- Earthquake; PGA; attenuation model; active tectonics; GIS

I. INTRODUCTION

The generation of seismic waves are due to earthquakes that can be resulted from the fault movement or from any other sources. There are many ways to measure various earthquake aspects. However, magnitude is the most common one that has been used for size measurement. There are many scales used for the magnitude measurement out of which, four magnitude scales popularly used to calculate magnitude that are globally accepted such as; Mb, Ms, Ml and Mw. Because of the limitations of all three-magnitude scales (ML, Mb, and Ms) more uniformly applicable magnitude scale, known as the moment magnitude or **Mw** was developed. Nevertheless, Mw is mostly used in various countries to find out the exact magnitude of an earthquake. In general, damages to buildings are depends upon PGA (Peak ground acceleration) and PGV (Peak ground velocity). Therefore, it has been recognized that the frequency of ground motion significantly depends on the characteristics of lithology of the site (Bazzurro and Cornell, 2004; Borcherdt, 1994).

Many scientists and researchers have investigated from various perspectives about the problem of amplification of ground motions by using probabilistic approaches (Lee et al., 1998; Tsai, 2000). Seismic amplification due to ground motion is the important and fixed problem can be found in every seismically active zones. Therefore, equations of ground-motion prediction has been developed for the classification of sites (Fukushima et al., 2007). Campbell found that the intensities resulting from reverse faults are more than that of normal and strike slip faults (Dowrick 1992; 1999). (Chavez & Presttley, 1985) proposed the Mo Versus Ml relationships for the (1980) Mamoth Lakes, California Earthquake as a base for conversion of magnitudes. However, It is described that the body waves originally contributes the seismic damage and ground amplification resulted by multi reflection formed due to SH-wave (Von thun et al., 1988; Sato et al., 2004). For the soil classification, the important parameter is the average shear velocity on the top 30 m of the ground surface (Barani et al., 2008; Akkar and Bommer 2007; Choi and Stewart 2005). Therefore, due to loose sedimentary deposits shear waves amplification happens, that causes the strong ground motion.

Malaysia is a country coming under low seismic zone. However, in the state of Sabah, local earthquakes can be found in various parts originated from large local faults. It was reported by USGS (US geological survey) that Sabah had experienced some earthquakes with highest magnitude of 6.5 on a Richter scale. Malaysia is located on a stable block called Sundaland and that is the southern edge of the major Eurasian plate (Simons et al., 2007). Continental collision between Indian subcontinent and Eurasian plate genuinely affecting the block (Simons et al., 2007). However, this block includes not only Vietnam, Thailand and Malaysia but also the Sunda shelf, Borneo, Sumatra and Jawa. The major faults that can be found in western Sabah (MOSTI, 2009) are mostly responsible for high magnitude of

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Recent studies have shown that earthquakes in Ranau area are attributed to the two intersecting faults i.e. Mensaban and Lobou-Lobou (Mohammed 2012). These fault zones are active as an evidence from past earthquakes and ground deformation has resulted in extensive damage to infrastructures in this area, specifically to schools and teachers quarters (Mohammed 2012). Peak ground acceleration (PGA) is defined as the maximum ground acceleration that occurred during earthquake shaking at a location. Therefore, this is the big problem in Sabah to categorize the site based on the ground motions and there is no comprehensive analytic model for PGA map preparation and comparison. Therefore, we proposed a novel model to choose the best method for the PGA mapping that could provide good quality results. The designed model is also able to model the fault plane solution of large regional faults of Sabah.

In this study, we have ensemble various attributes to investigate ground motion from the probabilistic point of view. Our study focusing on the PGA map preparation for the Sabah. Nevertheless, our proposed method is to make an effective comparison between various attenuation models to derive the PGA map. This model tests three global attenuation models for PGA mapping. Comparative assessment of the PGA mapping is reliable and effective to find out the accuracy, quality of PGA maps and to understand the strength, limitations of all the models. The aim of this research is to identify the best model for PGA mapping and the focal mechanism analysis in Sabah.

II OBJECTIVES

•Graphical investigation of events to find out the relationship between depth, distance and magnitude.
•To develop PGA map according to three attenuation laws and comparative analysis.
•To execute MMI calculation from the PGA values resulting from the three attenuation laws.
•To analyze active fault mechanism and tectonics from fault data using stereo net and beach ball diagram.

III. STUDY AREA

Sabah is located in the north of the isle of Borneo. In Sabah, between Ranau and Mount Kinabalu there are at least two active regional fault zones exist that intersect each other. Sabah of Malaysia has experienced more than 65 earthquakes with the highest magnitude of 6.3. The state of Sabah is the highly hazardous region for earthquakes as compared to other parts of the country. It is lying at a lat. and long. of 40 to 70 and 1150 to 1200, respectively. The tectonics of Sabah pointed out that variety of faults and a large number of lineaments, which can be found in different parts of the state. However, not all the local faults that can be found in Sabah are active. Nevertheless, 12 major and large active faults can be found in the hilly regions that are intersecting to each other. Various types of lithological soils and rocks such as volcanic sediments, basin sediments, limestones, sandstones, philitic rocks, gneiss and granites characterize the study area.

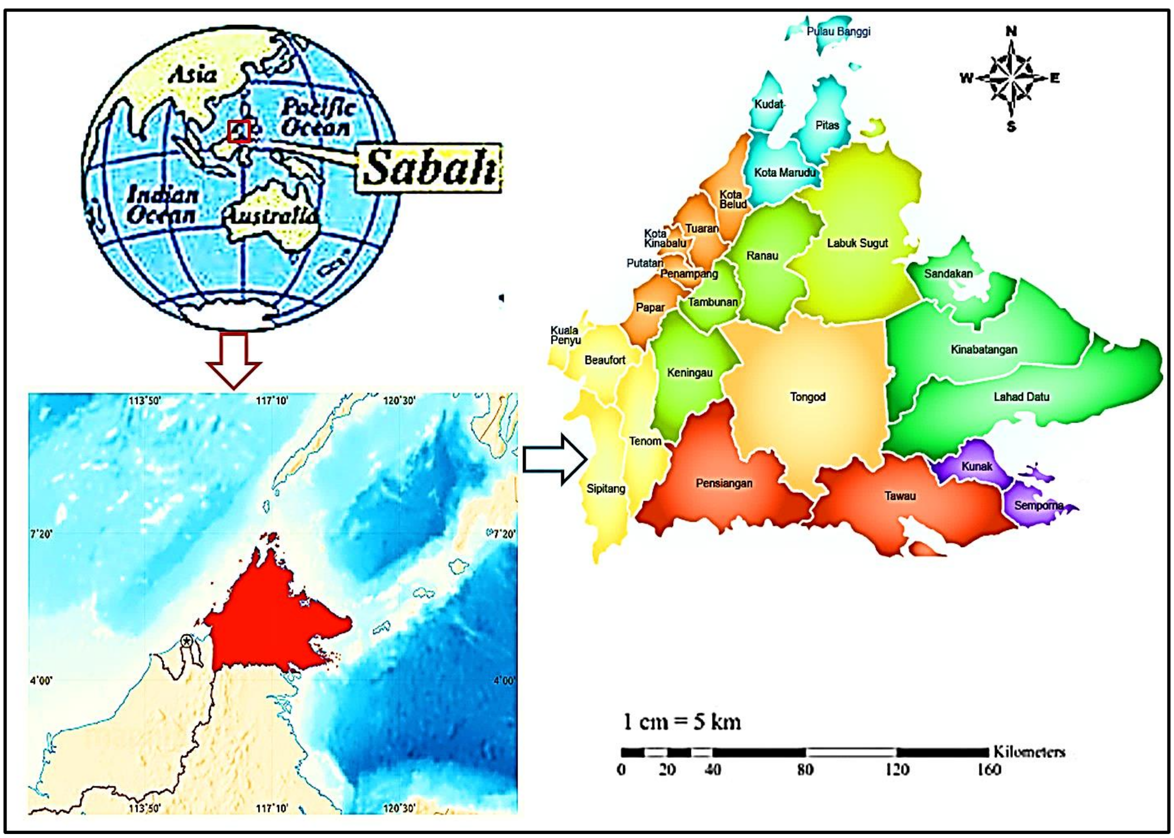

Figure 1. Represents the study area of Sabah, Malaysia

IV. MATERIALS AND METHOD

Earthquake data has been collected from the USGS (US geological survey) and ISC (International seismological center) in a proper way. Geological data has been collected from the geological map published in the journals. Firstly, data were arranged in a proper scientific manner in excel sheet. In next step, various calculations has been outperformed to apply in three attenuation models. Those earthquakes with magnitude below 3 were not considered for the PGA calculation. Because low magnitude earthquakes cannot shake the ground through which, destruction can happen. PGA map can be prepared by using the designed methodology as well as the comparative analysis can be outperformed. The proposed methodology inclusively used three attenuation equations. The distance (D) can also be calculated to apply in attenuation models for PGA calculations. Therefore, D value can be calculated by the formula;

D= (E^2+7.3^2) ^0.5 Eq (1)

Where, E = Epicentral distance

M = Earthquake Magnitude

Table 1. Types of attenuation models used for PGA analysis.

ID	Source	Laws
1	Joyner & Boore-1981	10^(0.249*M-Log(D)-0.00255*D-1.02, D=(E^2+7.3^2)^0.5
2	Campbell- 1981	0.0185*EXP(1.28*M)*D^(-1.75), D=E+0.147*EXP(0.732*M)
3	Fukushima & Tanaka- 1990	(10^(0.41*M-LOG10(R+0.032*10^(0.41*M))-0.0034*R+1.30))/980

The estimation of (PGA) peak ground acceleration by using the event magnitude, source-to-site distance, environment and tectonic sources will be reliable. Various types of attenuation relationships are developed for the major research of seismic hazard analysis. Such relationships have been proposed as well as the comprehensive reviews also been published in peer reviewed journals (Boore and Joyner (1982), Campbell (1985), Joyner and Boore (1988), Abrahamson and Letihiser (1989), Fukushima and Tanaka (1990)). Most of them are well developed by using various regional and worldwide data acquired through the arrays of strong motion. We applied the general equation of regression models proposed by Campbell (1985), Joyner and Boore (1988) and Fukushima and Tanaka (1990).

The MMI (Modified Mercali Intensity) can be calculated by using the formula,

$$MMI = 1/0.3 * (log10\ (PGA * 980) - 0.014 \qquad \text{Eq (2)}$$

Where PGA unit is G.

It is feasible to understand the changes in values of MMI resulting from three attenuation models. The whole process has been working out as per the designed methodological flowchart. In the first step, graphical investigation of various attributes of earthquakes need to perform. In next step, by using the attenuation laws, PGA and MMI need to be calculated. From there, PGA density map can be prepared. By using the geological map, different lithological units have been extracted and assigned factor values to each units. Developing the amplification factor map from geological map and amplification values are also performed. By multiplying the amplification factor map with the PGA density map, the PGA map can be derived. In next step, using the data of active faults and stereo net the fault plane mechanism can be understood and types of faults can be identified.

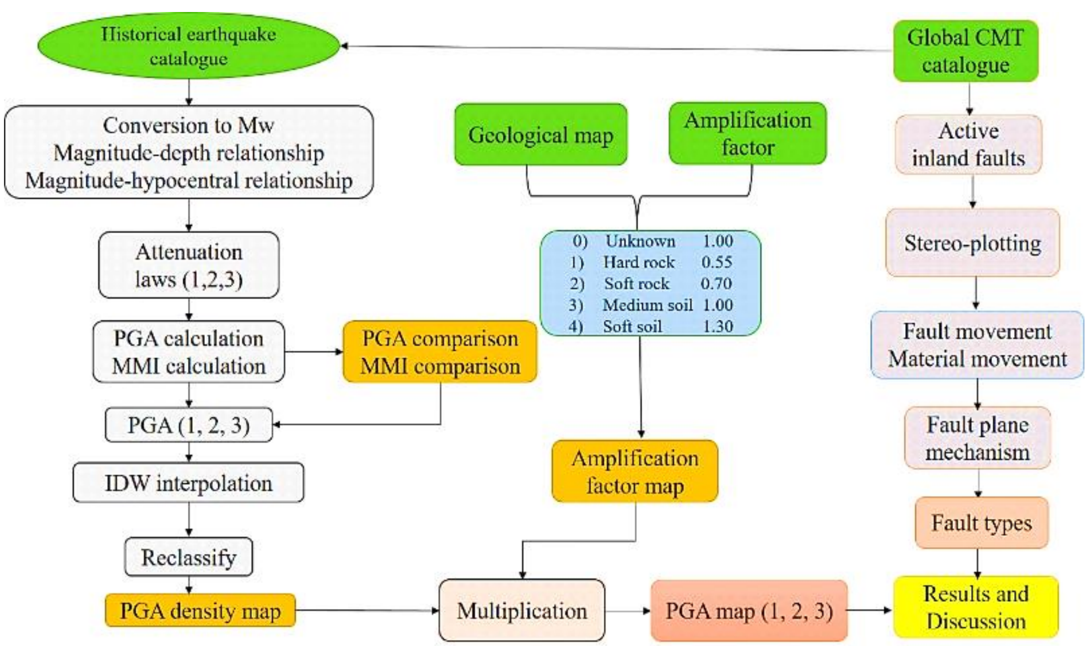

Figure 2 represents the overall methodological flowchart of the study.

V. RESULT AND DISCUSSION

The earthquakes experienced in Sabah, Malaysia recorded by the three seismic stations are resulted because of local active faults. The magnitude of all the earthquakes were recorded in Mb. However, it is not effective and good magnitude to estimate the size of earthquakes. Nevertheless, Mw is the moment magnitude, which is much reliable to estimate the size of earthquakes. Therefore, conversion of Mb to Mw is important to find out the changes in magnitude value. Because it is inclusively, evaluate the values based on the fault length, depth and slip. The model derived between magnitude and depth explains that more than 90% of earthquakes experienced in Sabah are shallow focus earthquakes and these earthquakes are happening at a depth of 0 to 60 kilometer. Nevertheless, in this area very less intermediate or deep focus earthquakes have been experienced. The second model clearly shows that most of the earthquakes happening at a particular hypocentral distance of 0-200 km. Therefore, very less earthquakes happened at a distance of approximately 100 km from the site.

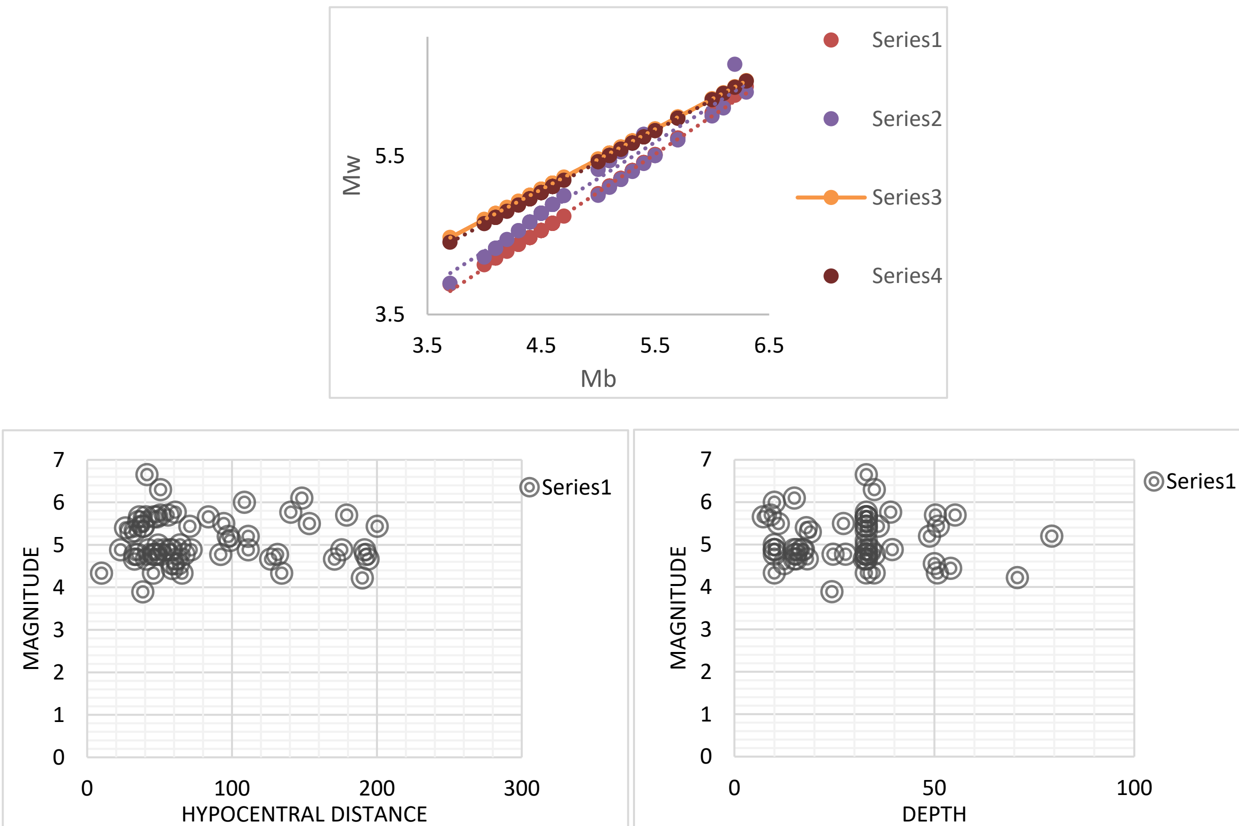

Figure 3 Graphical relationship between various attributes of earthquakes.

A. PGA calculation and comparison

As we know, the applicability of the distance to Sabah from the surrounding seismic sources as well as the events magnitude and the depth information for the PGA calculation. Therefore, it possible to make an estimation of the Peak Ground Acceleration of rocks in Sabah as a result of these events. Generally, Input parameters for the earthquake scenario are location, depth, magnitude and occurrence time. The relationship between PGA, epicentral or hypocentral distance and magnitude can be estimated by using an attenuation function. In the RADIUS method, PGA can be calculated using three attenuation formulas: Joyner & Boore (1981), Campbell (1981) or Fukushima & Tanaka (1990). All the results are presented in the figure 4.

All these three models have been compared by plotting in a single model, which clearly explains that there is a huge difference between series one and the series two. At a particular time period, these two methods developed but in between these two methods, the series one is much better for the PGA analysis. Series three can be found in between the series one and two. However, it follows other two attenuation series. Therefore, third method is also effective for the preparation of PGA map.

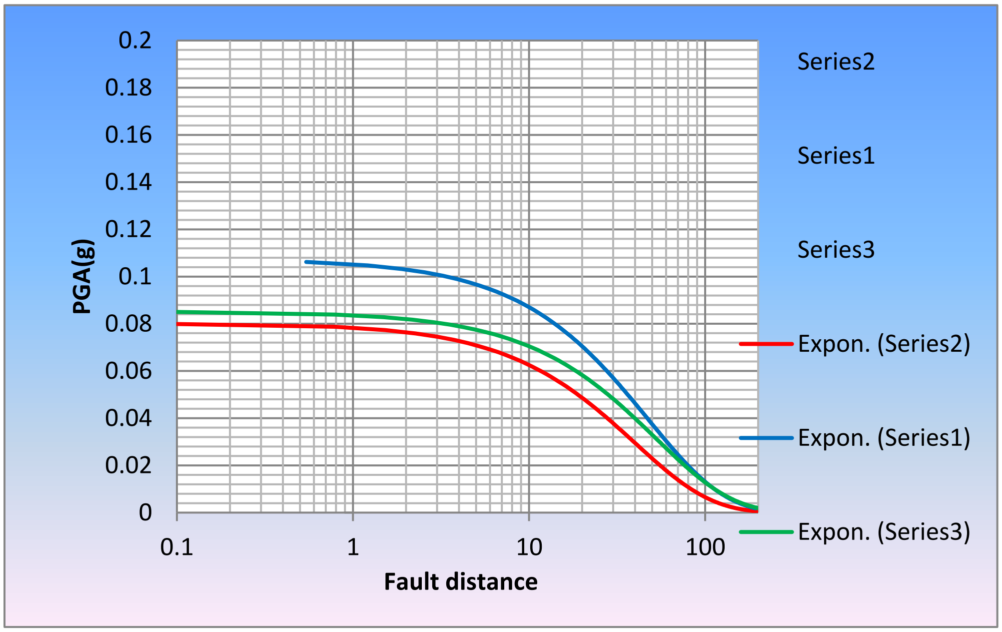

Figure 4. PGA calculation and plotting with fault distance.

***B**. Comparison of MMI calculated from PGA*

It was important to investigate the intensity or the level of destruction that can be possibly happened due to an earthquake of four or more. In order to convert the PGA values to (MMI) Modified Mercalli Intensity, the general relationship of Trifunac & Brady (1975) is applied, which is reliable for the study. Therefore, the level of destruction can be understood clearly from the MMI map. Nevertheless, only MMI calculation has been outperformed to investigate
the quality of results. Therefore, the models are presented graphically. PGA to MMI conversion can be done from the above method and applied as the intensity map for the study area. These three models explain about the PGA and Intensity relationship. MMI-1 and MMI-2 are almost looks similar and the values are approximately equal but the results of MMI-3 is quite different from the other two models.

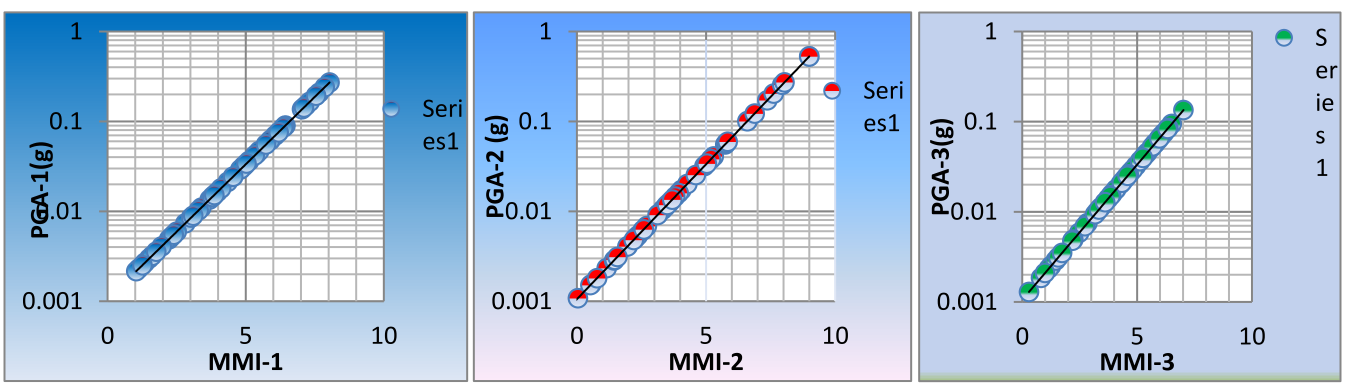

Figure 5. Represents graphically the PGA vs MMI.

C. *PGA density Comparison*

PGA density map has been derived by using the IDW interpolation method and used for the comparative analysis. PGA density map represents the density of PGA values resulted from the attenuation models by using the earthquake events and site distance from the source of faults and earthquakes surrounding Sabah. PGA-1 and PGA-2 density map seems to be similar while the PGA-3 density map looks quite different from others. Therefore, by considering the entire factors PGA-1 density map seems to be better than other two. Red color of the maps shows highest PGA values and the yellow, green color shows the medium and lowest PGA values. These PGA interpolations have been performed by IDW interpolation technique because of appropriate results than the Spline interpolation.

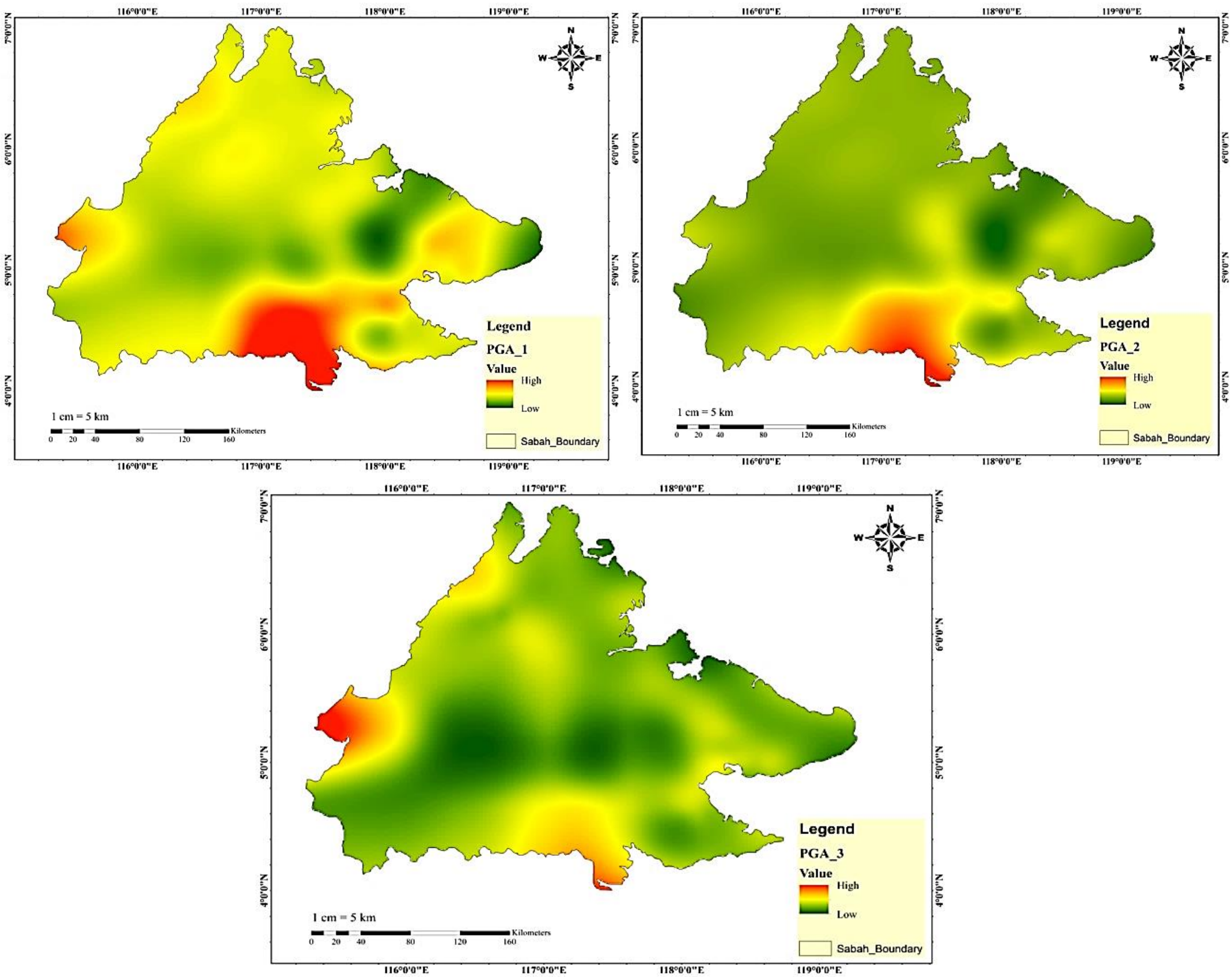

Figure 6. PGA density map for the Sabah using three attenuation models.

D. *Amplification factor map*

In order to verify the reliability of the amplification factors calculated in this study, shaking maps are derived for the destructive earthquakes occurred. The dynamic character of ground due to seismic waves simply depends on various types of lithology. Seismic waves amplify the ground if the materials are recent sedimentary deposits (mostly soils and loose sedimentary rocks). Firstly, Preparation of lithological map from the geological map of Sabah was performed.

In the next step, assigning some particular values to different rocks based on amplification types and rock types. These values called as amplification factor values. Then reclassifying the map according to the amplification factor values to make the amplification factor map, which is very much useful to prepare the PGA map. Therefore, in the figure 8. total area is divided into four classes based on amplification factors. Classified map is characterize by (0.5-V.low, 0.5-0.7-Low, 0.7-1-Medium, and 1-1.3-High).

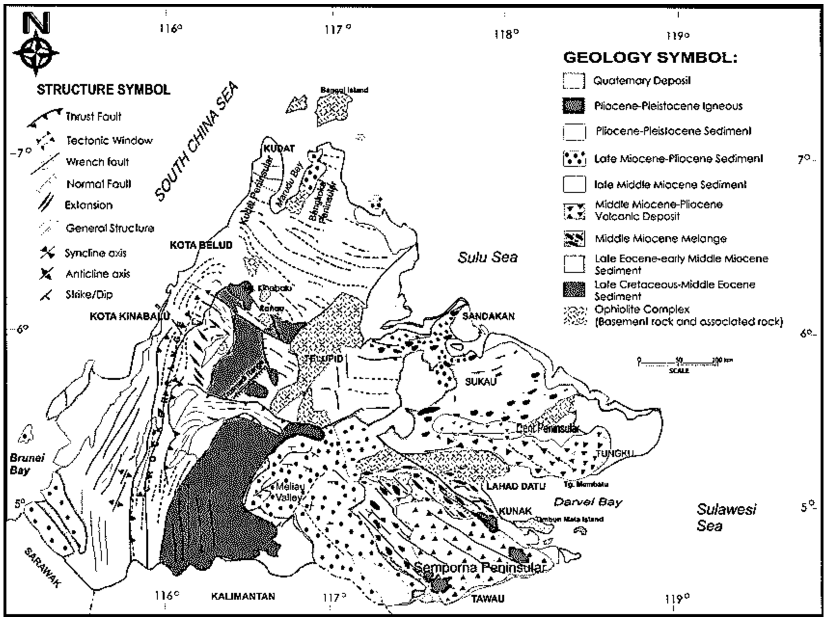

Figure 7. Geological map of Sabah, Malaysia

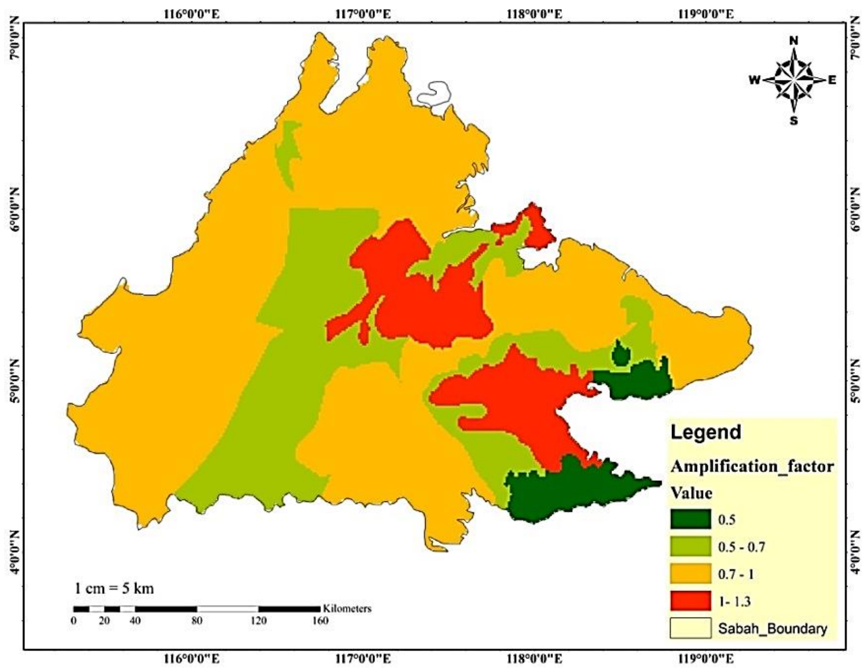

Figure 8. Amplification factor map from lithology

E. Comparative analysis of PGA maps

A simple method, followed by the RADIUS methodology, in which Peak Ground Acceleration is calculated for a scenario earthquake and the amplification of soil, is treated by simple multiplication values. PGA map have been prepared using three attenuation laws presented in the methodology. PGA density map was prepared first and then the PGA map by using the amplification factor value for various rock types. PGA-1 and PGA-2 are approximately similar but there is a very big difference in between the PGA-3 with the other two. The red areas in the map shows the high PGA values while the yellow one shows medium. Derived PGA map generally depends on the amplification factor of various lithology of the study area. The

PGA map resulted from the third equation is much better than other two because of effective values. Producing earthquake ground-shaking scenarios has become a common practice in earthquake research and development in the last decade. These PGA maps, which can be found within a few minutes of an experienced earthquake via the various Web portals or communication sites, are useful for public and scientific consumption. PGA maps are most important, for planning of emergency response, recovery and assistance during a destructive earthquake. Generally, the reliability of PGA maps depends on several factors such as, the ground-motion equation used to estimate the shaking attenuation laws as a function of event magnitudes and distance. The geological map used to provide an estimation of the average shear wave velocity *V*S, in the upper 30 m, and site correction factors adopted to account for amplification effects produced by particular soil conditions. Based on types of soil and rocks the amplification factors are categorized and added into the database to apply for the preparation of factor map, which was finally used for the PGA map development in next step. Therefore, the models are derived here by proposing the PGA comparison model are correct with good accuracy and effective.

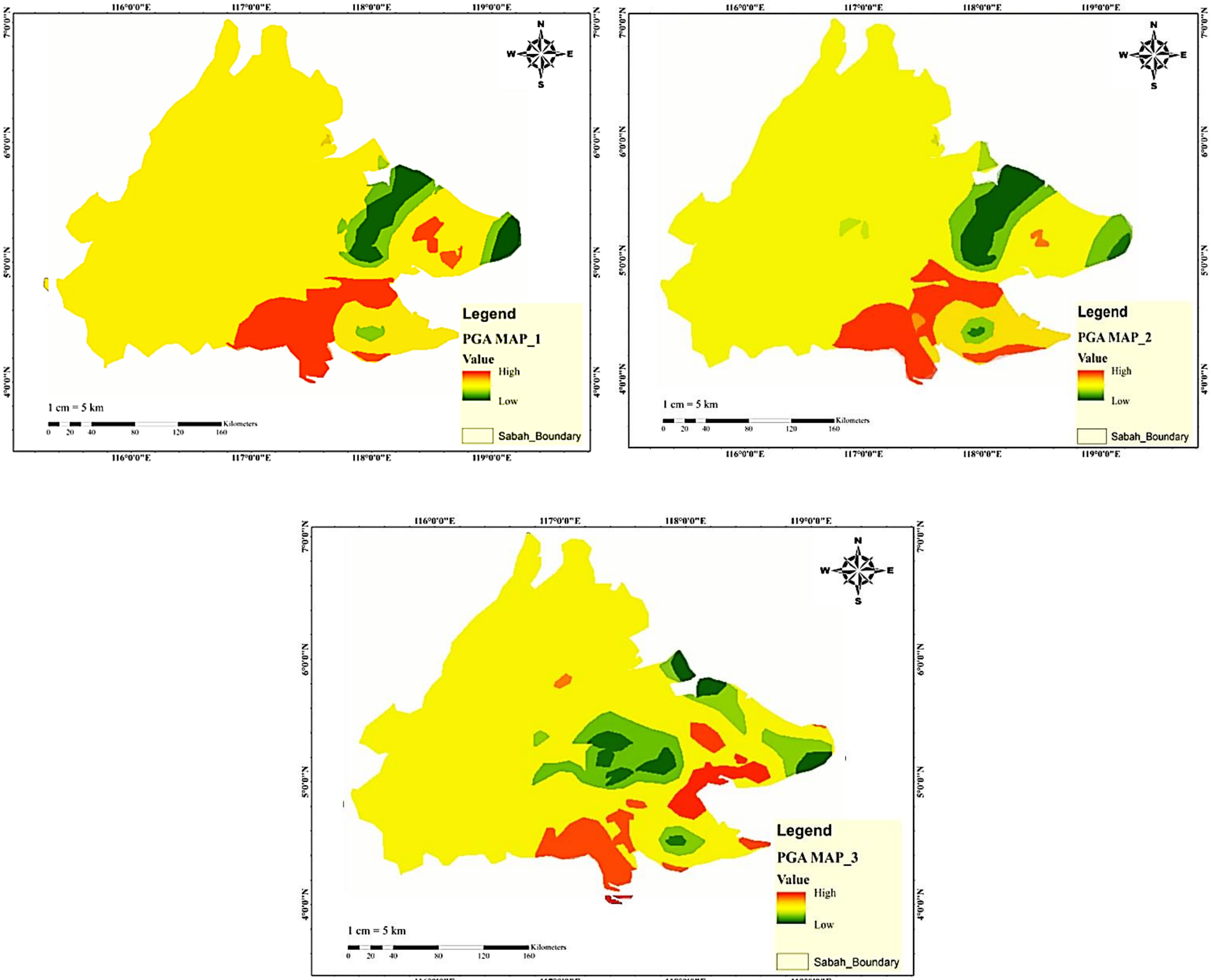

Figure 9. Comparative analysis of PGA maps.

Table 2. Represents the PGA and MMI values resulted from the study.

PGA Values	MMI Values	Remarks
PGA-1(0.075)	**MMI-1(7)**	Damageable
PGA-2(0.06)	**MMI-2(6)**	Negligible damage to well-developed infrastructure
PGA-3(0.08)	**MMI-3(7)**	Damageable

***F**. Stereo plot of twelve active faults of Sabah, Malaysia*

Faults can be represented through the stereo net for a better understanding. Therefore, almost 12 active faults are plotted in the stereo net with dip and strike of all faults. All the faults are active in Sabah resulting medium magnitude of seismicity and these are major local faults, which are very much responsible for most of the earthquakes. All the 12 active major faults plotted in stereo plot representing the fault mechanism. Most of the earthquakes can be found at the intersection of faults and lineaments. All the 14 faults explains about the fault movements, strike, slip, compression, tension and it also describe about the kind faults are present in Sabah. Most of the faults are reverse faults that are producing high magnitude of earthquakes**.** Fault plane solutions are derived for all the faults to understand the active mechanism in Sabah. Material movements can be clearly understood from all the fault plane solutions presented in the figure 10. All the solutions derived using stereo net and to validate the resulted beach ball diagrams from the stereo net plotting the details of information can be found in the Global Centroid-Moment-Tensor (CMT) Project (http://www.globalcmt.org/). Again, the same models are also derived from Arc-GIS, which are plotted at the right side down of each model to confirm the results are correct. These models are useful to understand the tectonics of the study area. This modelling of fault plane solution can also be performed by using the first P-wave motion, which is not our main interest in this project. Our main interest is to understand the tectonics of the active faults in Sabah that can be clearly understood from these fault plane solutions.

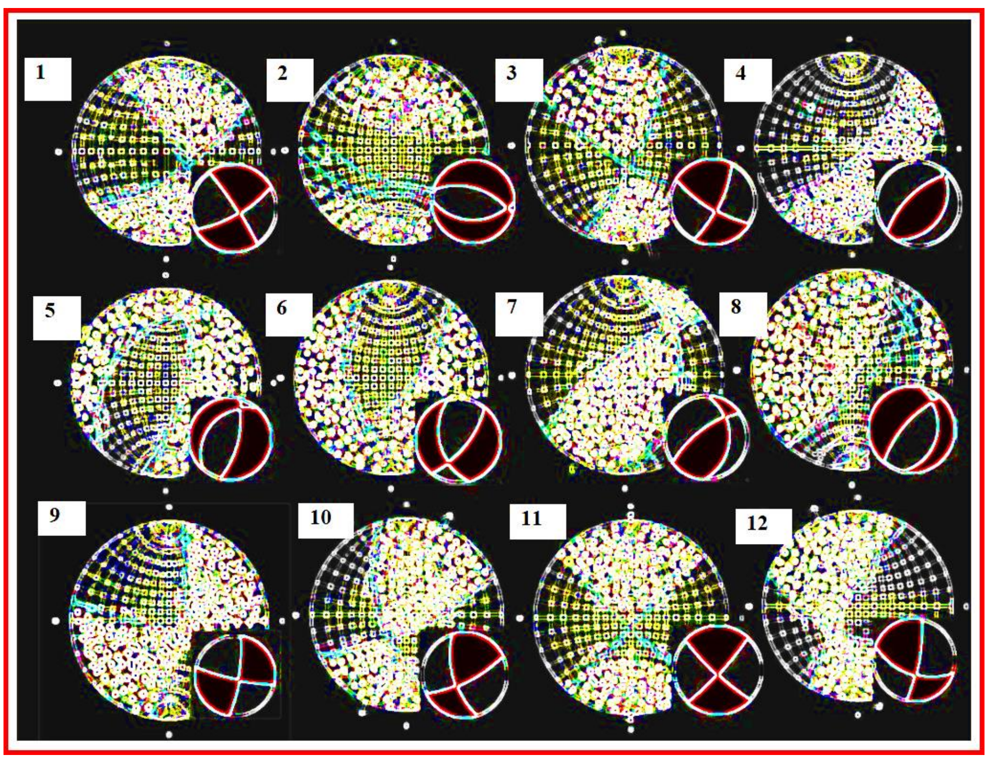

Figure 10. Fault plane solution for 12 active inland faults of Sabah.

VI. CONCLUSIONS

All the earthquakes experienced in Sabah area are mostly shallow focus as resulted from the analysis of magnitude and distance relationship. Generally, the earthquake magnitudes are converted to the best size measuring magnitude to make an effective result, while applying in the attenuation laws. PGA values resulting from the three attenuation laws are well expressed in graphs. The results interpreted from the graphs shows the best method that can be applied for the Sabah. PGA maps are resulted using all the three attenuation models and compared to find out the best one. PGA map prepared from equation 3 is the best method for this study based on, (a) Lithology and amplification factor (b) Magnitude of earthquakes and (c) Fault System. By analyzing the results of PGA map it is quite clear that equation 1 and 2 are almost similar, while the results from equation 3 is different from others. The patches of intersection of faults, earthquake magnitudes, and the types of lithology clearly indicates that possible area of highest ground acceleration. Therefore, by analyzing and considering all the factors it is clear that the equation 3 is the best one for the PGA map preparation in Sabah. By making a very effective analysis on faults using stereo net plotting fault movement, compression and dilation can be clearly understood. Beach ball diagrams are presented to understand the fault mechanism as well as the types of active inland faults that are present in Sabah. The overall design of the method is unique and effective for the PGA comparison. The strength and limitations of the developed model is totally depends on the types and completeness of data used. The model is providing very realistic results to make a useful comparison between PGA models. The method is cost effective, feasible and accurate.

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