SEISMIC HAZARD MAPPING FOR YOGYAKARTA DEPRESSION AREA, INDONESIA

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Abstract

The probabilistic seismic hazard maps are developed for Yogyakarta depression area. The earthquake catalog of ANSS (1970-2007) is taken into account. On the basis of seismicity of the area, tectonics and geological information, the seismic source zones are characterized for this area. The seismicity parameters of each seismic source are determined by applying the classical Gutenberg-Richter recurrence model, regarding the historical records. The attenuation relation for Yogyakarta depression area cannot be evaluated since the sufficient strong ground motion records are not available for this region. Therefore the attenuation relations which were developed for other territories as Europe and Japan are used for the present hazard calculation by validating, using the aftershocks records, modeling the peak ground acceleration maps for the recent event, 27 May, 2006, Yogyakarta earthquake inserting the damage area distribution pattern. The probabilistic seismic hazard maps are finally developed by using EQRISK computer program by modifying for the present purpose. The seismic hazard maps expressed in term of peak ground acceleration (PGA) are developed for the recurrence intervals of 10, 50, 100, 200 and 500 years.

Keywords: Attenuation, PGA, Seismicity, Yogyakarta

Introduction

The earthquakes can cause the hazardous effects such as: those effects resulting directly from a certain level of ground shaking and those effects on the land surface resulting from faulting or deformations. In the estimation of seismic hazards for a specific area or region, the two approaches as the deterministic and the probabilistic method can be traditionally used. The deterministic method attempts to determine a maximum credible intensity of ground-motion at a given site through estimation of a maximum credible earthquake likely to take place in the proximity of that site. The probabilistic seismic hazard analysis is defined as the probability that the ground-motion amplitude exceeds a certain threshold at a specific site. For the present work we used and calculated the peak ground acceleration (PGA in cms^{-2}) which is the most commonly used parameter in earthquake engineering. We will construct the probabilistic seismic hazard [1, 2] maps of the certain return interval for the Yogyakarta depression area.

Seismotectonics of Yogyakarta Depression Area

With 3,200 sq kilometers, Yogyakarta is one of the second smallest Indonesian provinces, however it is densely populated with more than 3 million people. According to the historical and instrumental records, the Yogyakarta depression area was affected by some considerable high magnitude earthquakes in the last century. The strongest event with magnitude 8.1, at July 23, 1943, at the coordinate of 8.6^o S and 109.9^o E and the depth of 90 km. This earthquake caused about 213 people deaths and over 3,900 people injuries and

12,603 houses collapsed, 166 houses heavily damaged and 15,275 houses damaged [3]. The second largest event is 7.2 M_s, September 27, 1937 earthquake, struck at 8.88^{o} S and 110.65^{o} E. This event caused one death and 2,526 houses collapsed in Yogyakarta province [4, 5]. The most resent one is a magnitude 6.3 M_w earthquake struck on Saturday, May 27, 2006, at 5:54 am local time with the duration of shaking of about 57 seconds. The epicenter was located at 7.962° S, 110.458° E (USGS), 20 km SSE of the Yogyakarta, at a depth of 10km. This earthquake caused 6,234 deaths, while 36,299 people have been injured, 135,000 houses damaged, and an estimated more than 600,000 left homeless (Indonesian Social Affairs Ministry). Bantul in Yogyakarta Province and Klaten in Central Java Province are the main two districts affected by the strong ground shaking.

Geologically, Yogyakarta depression area is mostly covered by the alluvium and the young volcanic deposits of Merapi volcano. This area is also located in the region between the volcanic arc of the Central Java, and the Java Trench, and is surrounded by several fault zones. This subduction zone is one of the most active plate margins in the world and was formed by the convergence between the Indian-Australian and Eurasian plates.

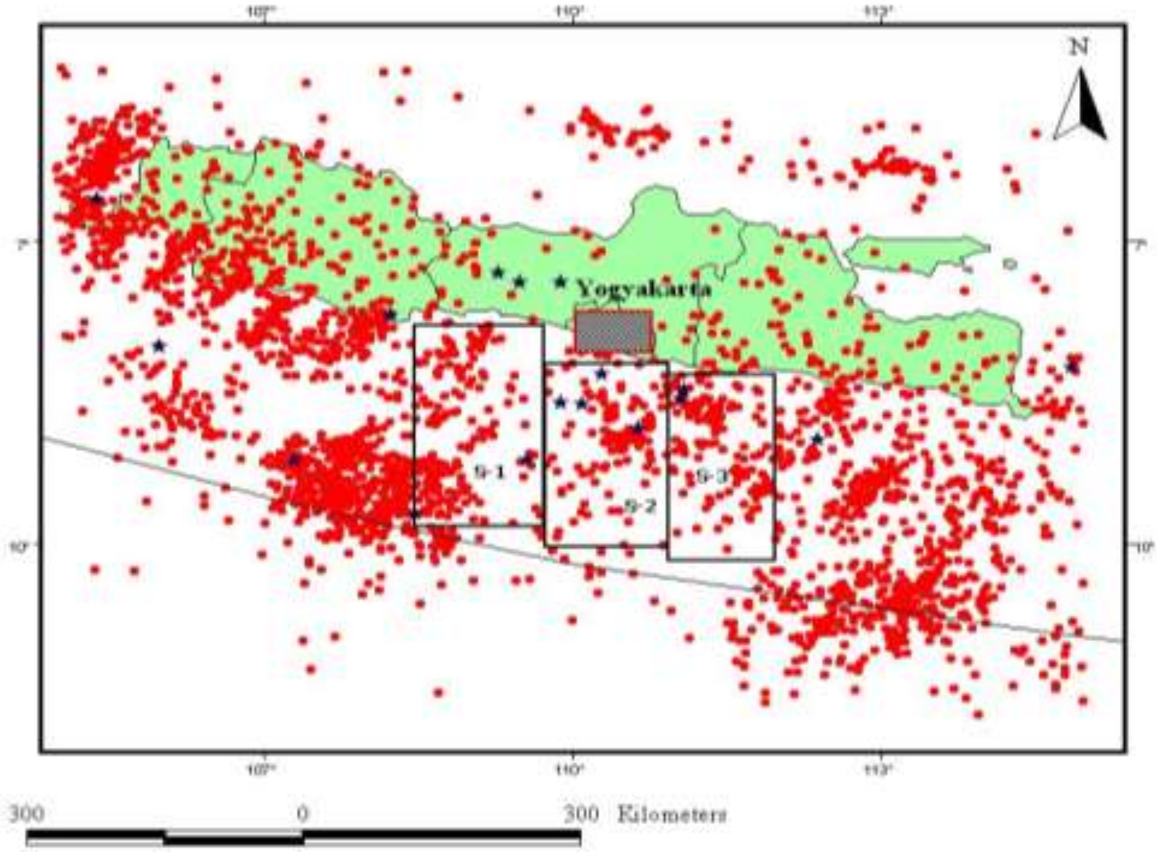


Figure 1. Map of areal seismic sources for Yogyakarta depression area depicting the historical earthquakes (dark blue colored stars) and the earthquakes of instrumental records in red colored circles that was taken from earthquake catalog of ANSS (1970-2007)

Estimation of Maximum Magnitude of Earthquake Potential

The maximum magnitudes of earthquakes which are expected to be caused by each fault specific seismic source are estimated by using the following empirical relation [8];

$$0.5\boldsymbol{M} = \boldsymbol{Log\ L} + 1.9 \qquad (1)$$

where $\boldsymbol{M}$ = earthquake magnitude, and $\boldsymbol{L}$ = the fault length. The maximum magnitude of earthquake potential from each fault specific sources is represented in Table1. However, to determine the $\boldsymbol{m_{max}}$ for the area seismic sources the following three relationships described below are handled.

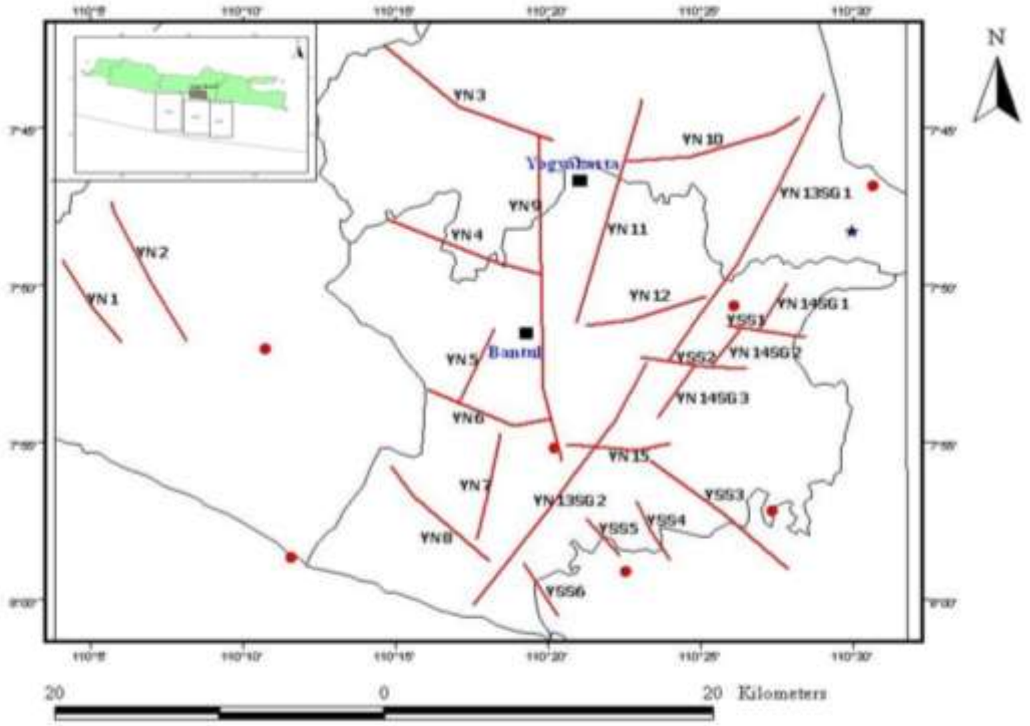


Figure 2. Map of fault specific seismic sources for Yogyakarta depression area depicting the historical earthquakes (dark blue colored stars) and the earthquakes of instrumental records in red colored circles [6, 7]

$$m_{\max} = m_{\max}^{obs} + \frac{E_1(n_2) - E_1(n_1)}{\beta \exp(-n_2)} + m_{\min} \exp(-n) \qquad [9] \qquad (2)$$

where, $\boldsymbol{m_{max}}$ = the maximum earthquake magnitude,

$m_{\max}^{obs}$ = the observed maximum earthquake magnitude

$\boldsymbol{m_{min}}$ = threshold of the completeness of the earthquake catalog,

$\boldsymbol{n}$ = the number of earthquakes greater than or equal $\boldsymbol{m_{min}}$,

$\boldsymbol{\beta} = \boldsymbol{b}\ \boldsymbol{ln}(10)$,

$n_1 = n / \{1 - \exp[-\beta(m_{\max} - m_{\min})]\}$,

$n_2 = n_1 \exp[-\beta(m_{\max} - m_{\min})]$ and $E_1(z) = \dfrac{z^2 + a_1 z + a_2}{z(z^2 + b_1 z + b_2)} \exp(-z)$

in which a_1= 2.334733, a_2 = 0.250621, b_1 = 3.330657, and b_2 = 1.681534.

$$m_{\max} = m_{\max}^{obs} + \frac{1}{n}\,\frac{1 - \exp[-\beta(m_{\max}^{obs} - m_{\min})]}{\beta \exp[-\beta(m_{\max}^{obs} - m_{\min})]} \qquad [10] \qquad (3)$$

$$m_{\max} = -\frac{1}{\beta} \ln\left\{ \exp(-\beta m_{\min}) - [\exp(-\beta m_{\min}) - \exp(-\beta m_{\max}^{obs})]\,\frac{n+1}{n} \right\} \qquad [11] \qquad (4)$$

a- and ***b***-value for the Yogyakarta depression area are determined as 5.3528 and 1.045 by using the Gutenberg and Richter's classical relation and the earthquake catalog of ANSS (1970/01-2007/07) with the independent earthquakes greater than magnitude 4 Mw. The maximum magnitude of earthquake potentials expected from the area sources are taken into account by the average of the results calculated using the above mentioned three equations Table 2.

Table 1. The Assumed Fault Parameters and the Estimated Maximum Magnitude Model of the Earthquake Potentials of Fault Specific Seismic Sources

Fault Specific Sources		Fault Length	Max. Magnitude
Normal Faults	**YN1**	6.1	5.4
	YN2	10	5.8
	YN3	12.5	6
	YN4	10	5.8
	YN5	5	5.2
	YN6	7.2	5.5
	YN7	6.5	5.4
	YN8	8.5	5.7
	YN9	20.5	6.4
	YN10	10.5	5.8
	YN11	14.5	6.1
	YN12	7.5	5.6
	YN13SG1	19.7	6.4
	YN13SG2	19.3	6.4
	YN14SG1	2.7	4.7
	YN14SG2	2.9	4.7
	YN14SG3	4	5
	YN15	6.3	5.4
Strike-slip Faults	**YSS1**	4.5	5.1
	YSS2	6.5	5.5
	YSS3	10.5	5.8
	YSS4	3	4.8
	YSS5	2.9	4.7
	YSS6	3	4.8

Table 2. The Estimated Maximum Magnitude Model of the Earthquake Potentials of Three Area Seismic Sources

Area Source	m_{max}(obs)	m_{min}	n	b	$^{1*}m_{max}$	$^{2*}m_{max}$	$^{3*}m_{max}$	Average m_{max}
S-1	8.1	4.04	36	0.809	8.163	8.116	8.325	8.2
S-2	8.1	4.16	37	0.809	8.089	8.116	8.319	8.2
S-3	8.1	4.04	50	0.809	8.07	8.112	8.262	8.1

$^{1*}m_{max}$- by using [9], $2^{*}m_{max}$- by using [10] and $3^{*}m_{max}$- by using the equation of [11]

Attenuation Relations

For present study, we applied four different attenuation formulae to carry out the comparative study of the results. The attenuation relations are applied for estimation of ground motion for Yogyakarta depression area [12, 13, 14, 15].

The attenuation relation can be expressed as follow:

$$LnY = b_1 + b_2(M - 6) + b_3(M - 6)^2 + b_5 \ln r + b_v \ln \frac{V_S}{V_A} \qquad [12]\ (5)$$

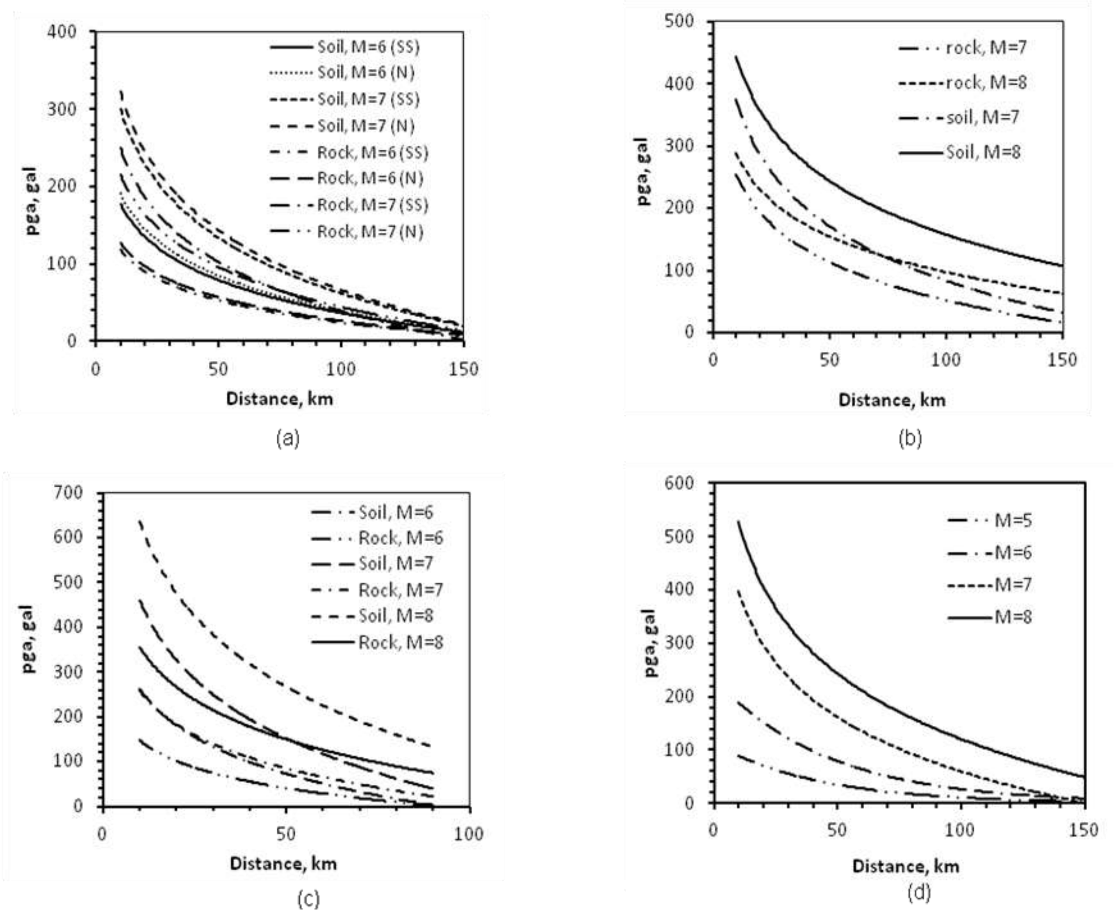
where, $r = \sqrt{r_{jb}^2 + h^2}$, ***Y*** is peak ground acceleration, ***M*** is the moment magnitude, $\boldsymbol{r_{jb}}$ is the closest horizontal distance to the surface projection of the rupture plane in km, $\boldsymbol{V_S}$ is the average shear – wave velocity to 30m (m/s) and $\boldsymbol{b_1}$, $\boldsymbol{b_2}$, $\boldsymbol{b_3}$, $\boldsymbol{b_5}$, and $\boldsymbol{b_V}$ are the constants.

$$Log_{10} A = 0.42 M_w - \log_{10}(R + 0.025 \cdot 10^{0.42 M_w}) - 0.0033 R + 1.22 \qquad [14]\ (6)$$

where ***A***= peak ground acceleration (PGA) in cms^{-2} , *Mw* is the moment magnitude, and ***R*** = the shortest distance between site and fault rupture in km.

$$\log_{10}(Y) = aM - bX - \log_{10}(X + c \cdot 10^{dM}) + e(h - 20)\delta_h + S_k \qquad [15]\ (7)$$

in which ***Y*** = peak ground acceleration in cms^{-2}, ***M*** = moment magnitude, ***X*** = source distance (km), ***h*** = focal depth (km), $\boldsymbol{\delta_h}$ = 0 (***h***<20) or 1 (***h***≥20), $\boldsymbol{S_k}$ = site term, and ***a***, ***b***, ***c***, ***d*** and ***e*** are the constants.



(a) (b) (c) (d)

Figure 3. Variation of peak ground acceleration (PGA) with source distance for attenuation relation (a) [12], (b) [13], (c) [14] and (d) [15]

Characterization of the Attenuation Relation

The fault length and width are estimated by applying the empirical relation of the fault length and earthquake magnitude [8] and the relationship of fault length and width of $\boldsymbol{L} = 2\boldsymbol{W}$. Since the magnitude of that event is assumed as 6.3 Mw, the length of the earthquake source fault can be estimated as about 17.5 km and the width is about 8.75 km. Although the focal depths of the aftershocks are as shallow as 1.0 km and the deepest one is 22.5 km, the upper boundary of the fault plane is assumed as started at around 3.5km for this study. By applying these parameters of fault geometry, the PGA values of 27, May 2006 Yogyakarta earthquake were estimated. The peak ground acceleration values are determined for the Yogyakarta depression area by spacing 0.01° x 0.01° grid interval. When the distribution pattern of the damage areas and the areas of high PGA values are compared, the PGA values of the high damage areas are as nearly high as in those areas which are in the closest distance from the source in the PGA maps of 27 May 2006 Yogyakarta earthquake developed by utilizing the attenuation relationships [12, 14].

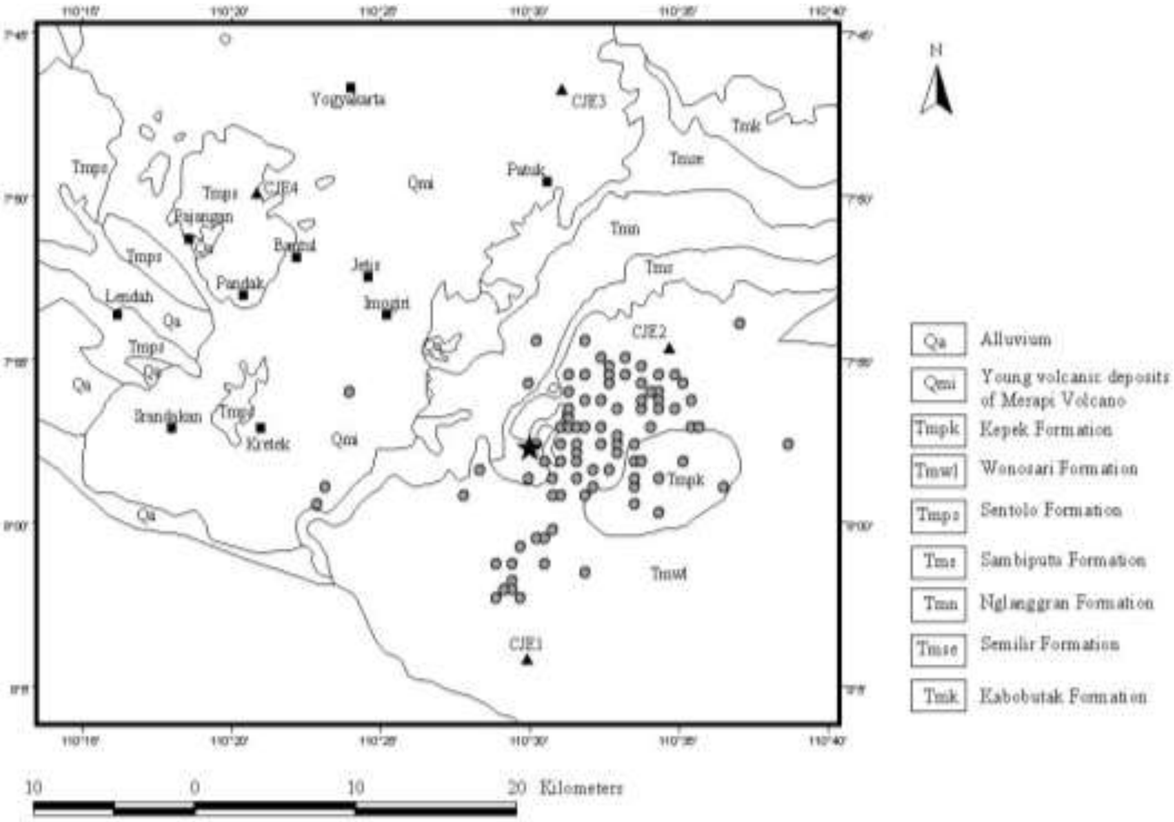
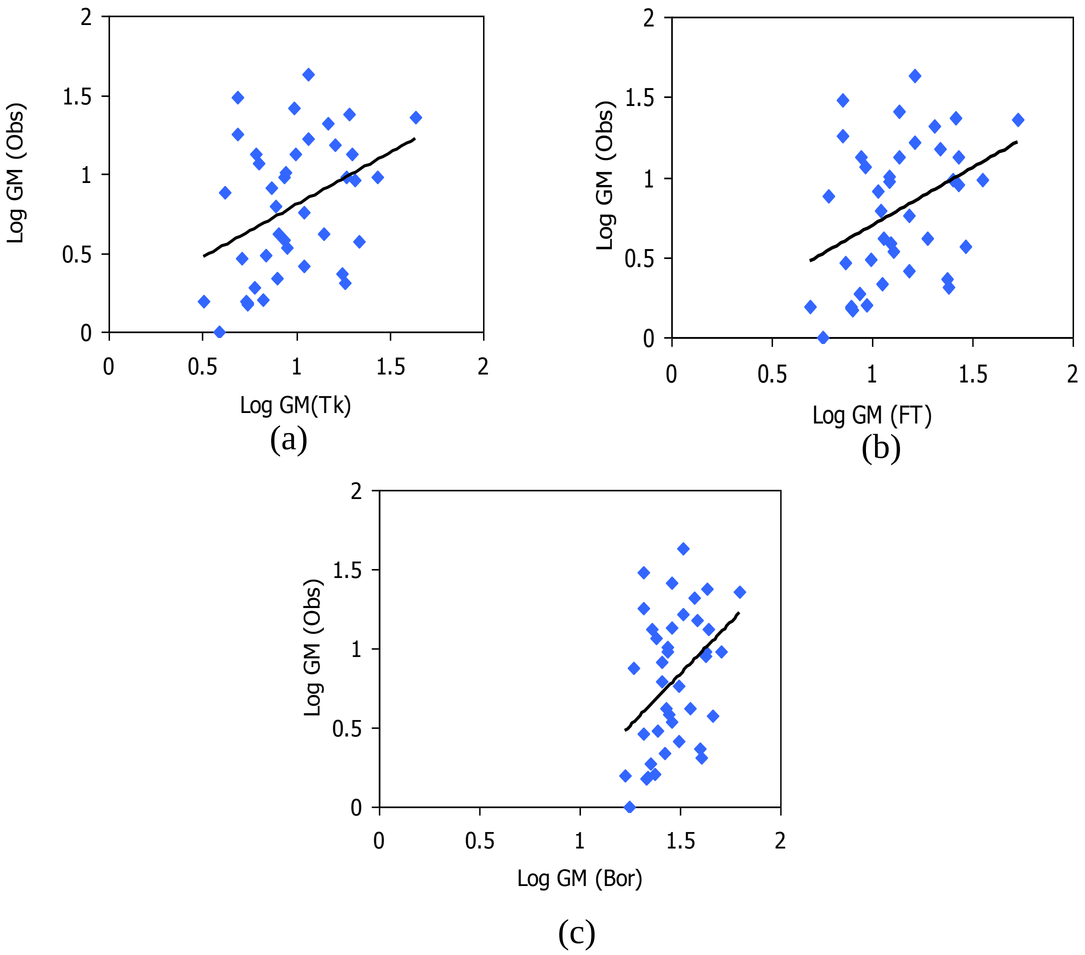


Figure 4. Map representing the epicentral distribution of the aftershocks (grey circles) and the 27 May 2006 Yogyakarta earthquake (Black star) in which the black rectangles are the recorded stations of aftershocks [6]



(a)

(b)

(c)

Figure 5. The plots of observed ground motion parameters; GM(Obs) against the resulted ground motion parameters using (a) [15] (GM (Tk)), (b) [14] (GM (FT)) and (c) [12] (GM (Bor))

Probabilistic Peak Ground Acceleration Maps

We utilized the computer program, EQRISK [2] for Probabilistic Seismic Hazard Analysis. The input parameters for this program is the coordinates of the seismic sources, the seismic parameters for each seismic source as lower bound and upper bound earthquake magnitude, ***b***-value, earthquake annual earthquake recurrence rate, and focal depth, the attenuation parameters and the coordinates of the site at which the seismic hazard want to be determined. Annual probability of earthquake occurrence and the seismic hazards are the output. We modified the EQRISK program for performing the probabilistic seismic hazard analysis for the Yogyakarta depression area.

Five probabilistic seismic hazard maps expressed in term of peak ground acceleration (PGA, gal) are represented in Figure 6 to 10 for recurrence interval of 10, 50, 100, 200 and 500 years.

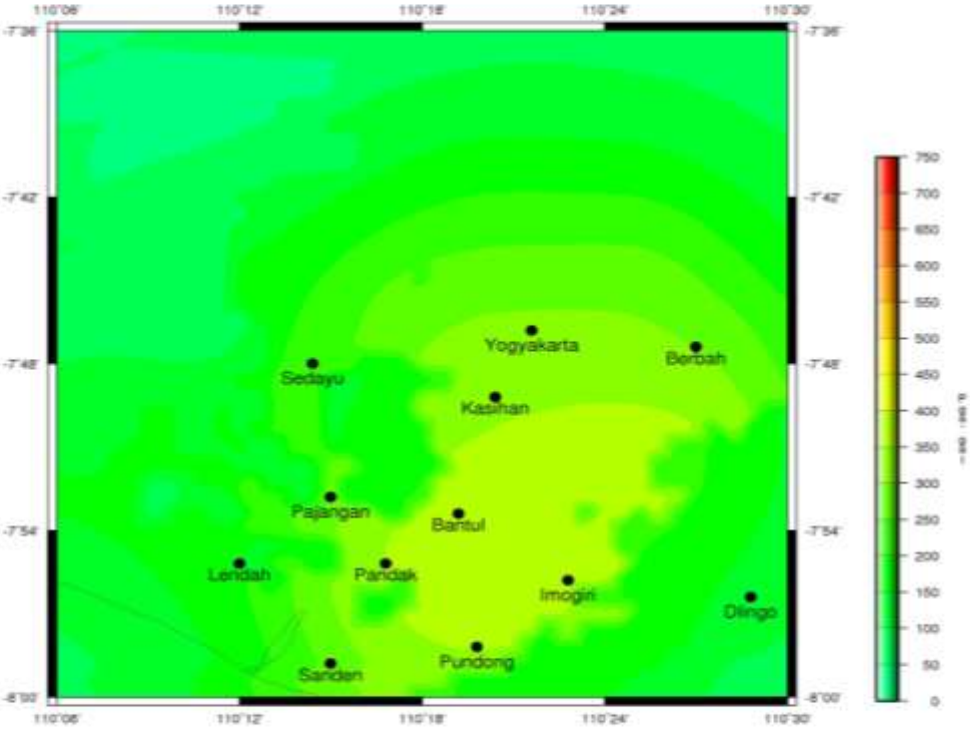


Figure 6. Seismic hazard maps expressed in PGA (gal) for 10 years return interval

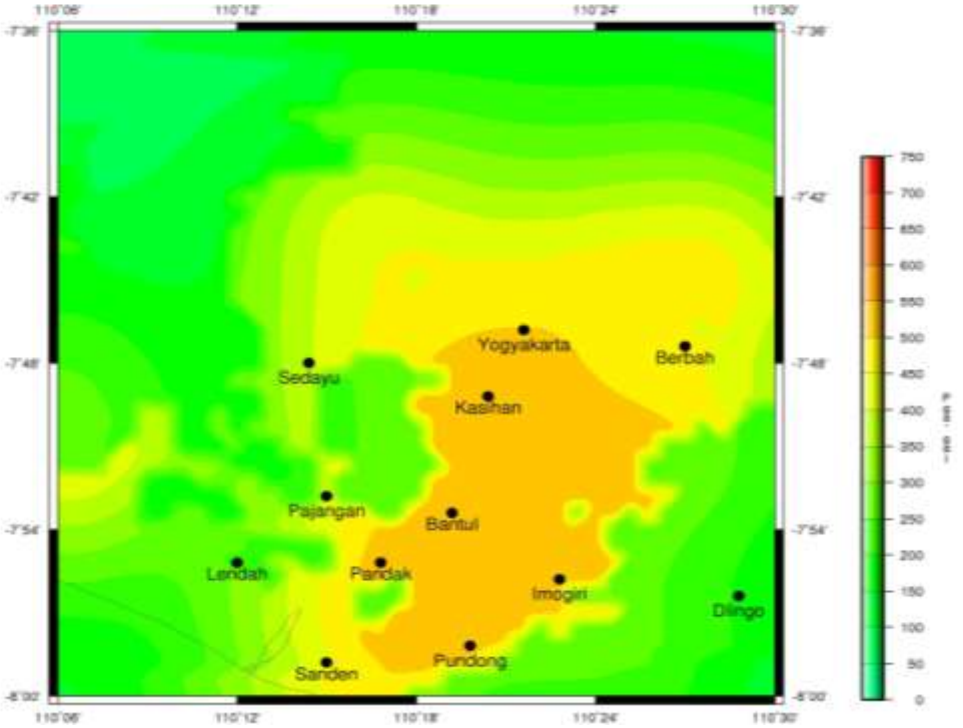


Figure 7. Seismic hazard maps expressed in PGA (gal) for 50 years return interval

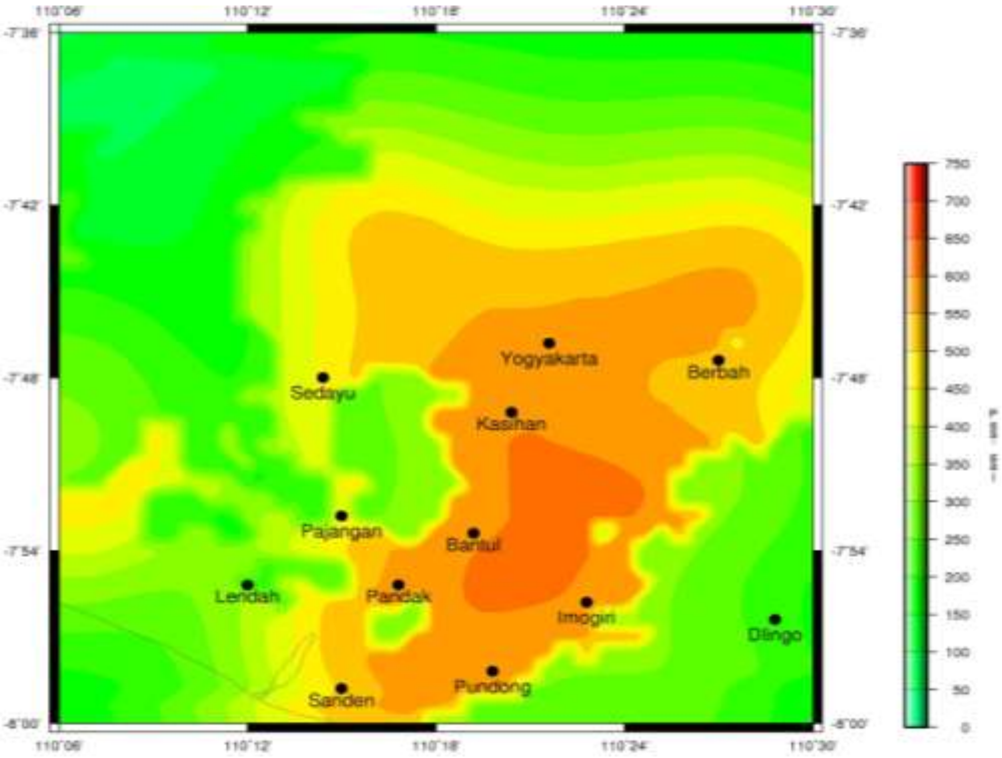


Figure 8. Seismic hazard maps expressed in PGA (gal) for 100 years return interval

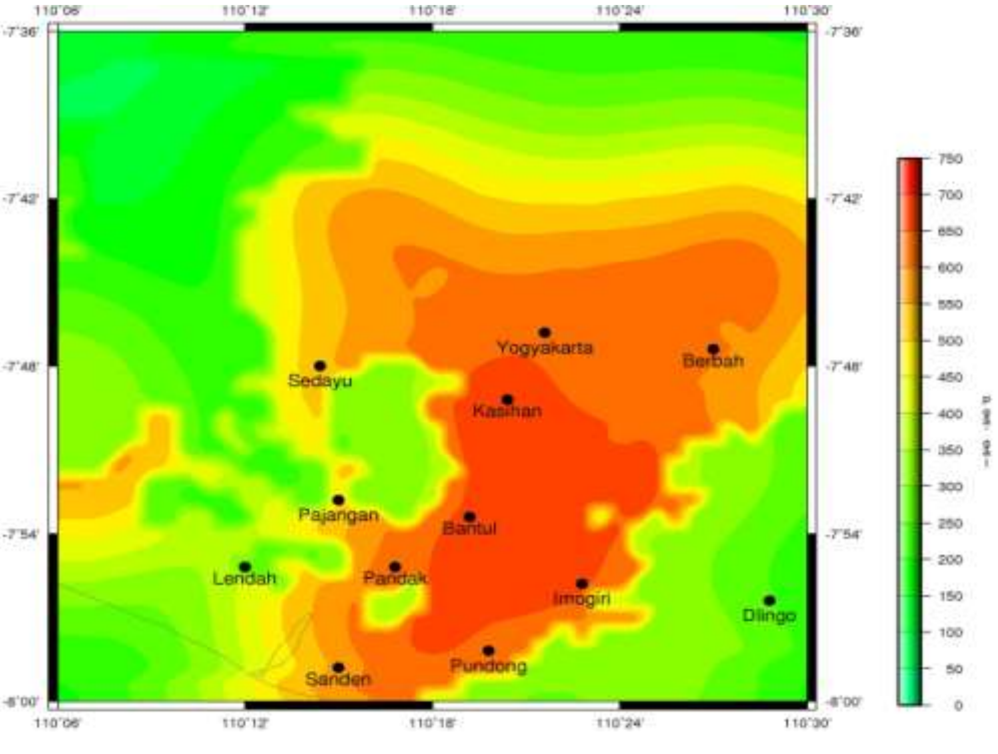


Figure 9. Seismic hazard maps expressed in PGA (gal) for 200 years return interval

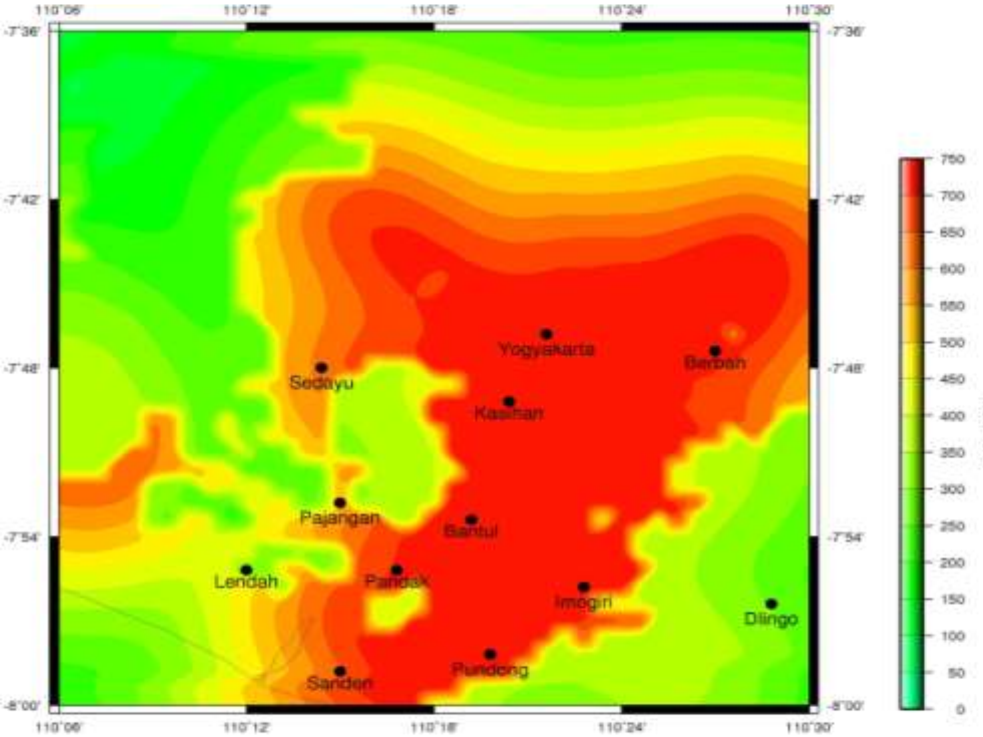


Figure 10. Seismic hazard maps expressed in PGA (gal) for 500 years return interval

Conclusions

The probabilistic seismic hazard maps expressed in terms of peak ground acceleration (PGA) for return intervals of 10, 50, 100, 200 and 500 years were built for Yogyakarta depression area. High seismic hazard areas are occupied in most part of the Yogyakarta depression area for 500 years recurrence interval with the maximum PGA value of 750 gal as in Yogyakarta, Kasihan, Bantul, Imogiri, Pandak, Pundong and Berbah. However, the high seismic hazard characteristics are commonly distributed in the central portion of the area with the maximum PGA value of 700 gal for 200 years recurrence interval especially in Kasihan, Bantul and Imogiri area that consist of the young volcanic deposits of Merapi volcano. However the resulted PGA values seem to overestimate since the sufficient data are not available for this area. There would be some input parameters which are still needed to perform in detailed analysis. Therefore the seismic hazards from the fault specific sources likely results more effects for the present area, compared with the seismic hazards resulted from the areal sources. By acquiring these required information further more fulfill seismic hazard map would be expected for the Yogyakarta depression area.

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