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ESTIMATION OF MAXIMUM EARTHQUAKE MAGNITUDE OF EARTHQUAKE POTENTIALS FOR YOGYAKARTA DEPRESSION AREA, INDONESIA

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Abstract

Maximum magnitudes of earthquake potentials are estimated for Yogyakarta depression area by using the fault-length and earthquake magnitude relations for fault specific seismic sources. For estimation of maximum earthquake magnitude, the fault specific seismic sources are modeled as 18 normal faults and 6 strike-slip faults sources referring the geological map of McDonald, 1984 and Rihardjo et al., 1995. For the present area the subduction zone earthquakes are expected to happen in the offshore region regarding the study on the seismicity of the region and the focal mechanisms of the past earthquakes. So three area sources are also assumed for this region and the possible maximum earthquake magnitudes for these sources are determined by probabilistic approaches.

1 Introduction

Estimation of maximum earthquake magnitude for any site of interest plays a crucial role in seismic hazard analysis. It comprises of both Deterministic and Probabilistic Seismic Hazard Analysis. Since it constitutes as one of seismic source parameters, it relates with the seismic source characterization for the interested area. For Yogyakarta Depression Area, there is no adequate data for identifying seismic sources e.g., the information of geological structures as faults for determination of fault parameters; fault rupture length, fault width, etc., therefore some assumptions are accomplished to determine the most possible maximum earthquake magnitude. In this work, the earthquake magnitude and fault (rupture) length relations of Otsuka (1964), Iida (1965) Ambraseys and Zatopek (1968), Yonekura (1972), Natsuda (1977), Inoue et al., AIJ (1993), Papazacchos et al. (2004) and Mohammadioun and Serva (2001) are utilized for fault sources and those of Tate (1959), Gibowicz and Kijko (1994) and Kijko (2004) are applied for area seismic sources and the results are compared to achieve the most reliable magnitude for the present area. Alexander and et al. (2003) investigated the seismic hazards for the northern part of Central Java, especially for the region around the Muria volcano, Pati for nuclear power plant site and he used the equation of Mohammadioun and Serva (2001) by assuming the fault parameters for the fault seismic source occurred around that area.

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2 Characterization of possible seismic sources for Yogyakarta area

Seismic sources can generally be distinguished as two types; fault specific sources and areal sources. Since most of the faults presented in the Yogyakarta Depression area are blind faults, the sufficient data cannot be available for fault parameters determination. Most of the earthquakes occur along the active faults and there are some definitions about the active fault. Fraser (2001) defined as active seismic source as the fault has ruptured within the last 35,000 years. The fault can be classified as the active fault that caused at least one time of movement in the last 1.8 million years. In the present area, most of the faults can generally be assumed as the active faults by correlating the age of the lithologic units cropped out in the Yogyakarta depression area. For current work, the geological structural maps developed by McDonald (1984) and Rahardjo et al. (1995) were used to develop the fault specific seismic sources model. The fault structures located around and in the Yogyakarta depression area are presented in Figure 3. As described above since the structural data of the faults are lack, the fault parameters as the fault rupture lengths will be assumed for determination of the maximum earthquake magnitude of each fault. For offshore region, the three areal seismic sources are established accordingly the seismicity of region, geological structure and focal mechanisms of the past earthquakes. The earthquake catalogs of ANSS (1970-2007/07) and the NEIC, USGS (1973-2007/07) were used to evaluate the seismicity of the Yogyakarta depression area within the radius of about 150km, with the supplement of BMG, Yogyakarta record (2000-2004). The historical earthquakes record (1840-1969) around Yogyakarta compiled from Newcomb and McCann, 2001, Utsu, 2002, Elnashai et al., 2006, and USGS, 2007 is also used in this work.

3 Seismicity of the region

The present study area can be regarded as the low seismicity region when compared with the other regions of Indonesia since it is located in the Central Java although the Eastern and Western Java region are in considerable high seismicity. The seismicity around Yogyakarta area is represented in Figure 1a-b with distribution of the epicenters of the previous earthquakes of the magnitude greater than 3.3 (Mb) and the depth less than 70 km. According to the instrumental records most of the earthquake happened 1970-2007/07 are not more than 6.5 in magnitude. However, the historical records show that some considerable high magnitude earthquakes also happened around the Yogyakarta Depression area for example 7.2 Magnitude, September 27, 1937 earthquake occurred at the coordinate of 8.88°S and 110.65°E that caused one people dead and 2,526 houses damages in Yogyakarta province (Elnashai et al., 2006) and the magnitude 8.1, July 23, 1943 earthquake with the epicenter of 8.6°S and 109.9°E resulted about 213 people deaths, over 3,900 people injured and 166 houses damaged and the largest damaged area was Bantul where 31 people were dead, 564 injured and 26,82 houses were collapsed (Newcomb & McCann, 2001, and Utsu, 2002). Moreover the Yogyakarta Depression area is located along the tectonically active region of Java trench with the length of 1,100km, resulted from the subduction of Indo-Australia plate under the Eurasia plate with the velocity of about 63mm/yr. Therefore this area can be regarded as the earthquake prone area like other areas.

4 Methodology

The evaluation of the maximum magnitude of earthquake potentials which are expected to be developed by fault specific sources is conducted by using the equation of (Ambraseys, 1988)

$$M_{sc} = 1.43 \log L + 4.63 \tag{1}$$

in which M_{sc} = the expected surface wave magnitude and
L = the fault length
The equation of Mohammadioun and Serva (2001) is also used and his relation is as follows:

$$M_s = 2 \log L + 1.33 \log \Delta\sigma + 1.66 \tag{2}$$

where, M_s is the surface wave magnitude, L is the fault rupture length (km) and $\Delta\sigma$ is the stress drop released by the earthquake (in bars) that depends on the width of the faults and type (kinematics) of the faults; normal, reverse or strike-slip. Stress drop parameters for each fault are calculated by applying the following relationship (Mohammadioun and Serva, 2001); $\Delta\sigma N$ = 10.6 $\times$ $W0.5$ and $\Delta\sigma SS$ = 10.6 $\times$ $W0.8$ in which $\Delta\sigma N$ and $\Delta\sigma SS$ are stress drop (in bars) for normal and strike-slip faults and W is the fault width (km) which is also determined by utilizing the relation of fault length and fault width; $L = 2W$ (Cheng and Cheng, 1989, Bormann & Baumbach, 2000). The following equations used to correlate the results of maximum earthquake magnitude for earthquake potential are $M = (\log L + 6.4)/1.13$ (Ambraseys and Zatopek, 1968), $M = 2.0 \log L_{max} + 3.6$ (Otsuka, 1964), $M = 2.0 \log L_{max} + 3.5$ (Iida, 1965), $M = 2.0 \log L_{max} + 3.7$ (Yonekura, 1972) in which L_{max} is the maximum earthquake fault length, $M = (\log L + 1.9)/0.5$, Inoue et al., AIJ (1993), $M = (\log L + 1.86)/0.5$ (for Oblique faults with $\sigma = 0.13$, $6.0 \leq M \leq 7.5$) and $M = (\log L + 2.3)/0.59$ (for Strike slip faults with $\sigma = 0.14$, $6.0 \leq M \leq 8.0$) (Papazacchos et al., 2004) and $M = 1.7 \log L + 4.8$ (Matsuda, 1977). The maximum magnitude of the earthquake potentials which can be originated from the offshore region as the subduction zone earthquakes are also determined by using the relationship of Kijko (2004);

$$\begin{aligned} m_{max} &= m_{max(obs)} + \frac{E_1(n_2) - E_1(n_1)}{\beta \exp(-n_2)} \\ &\quad + m_{min} \exp(-n) \end{aligned} \tag{3}$$

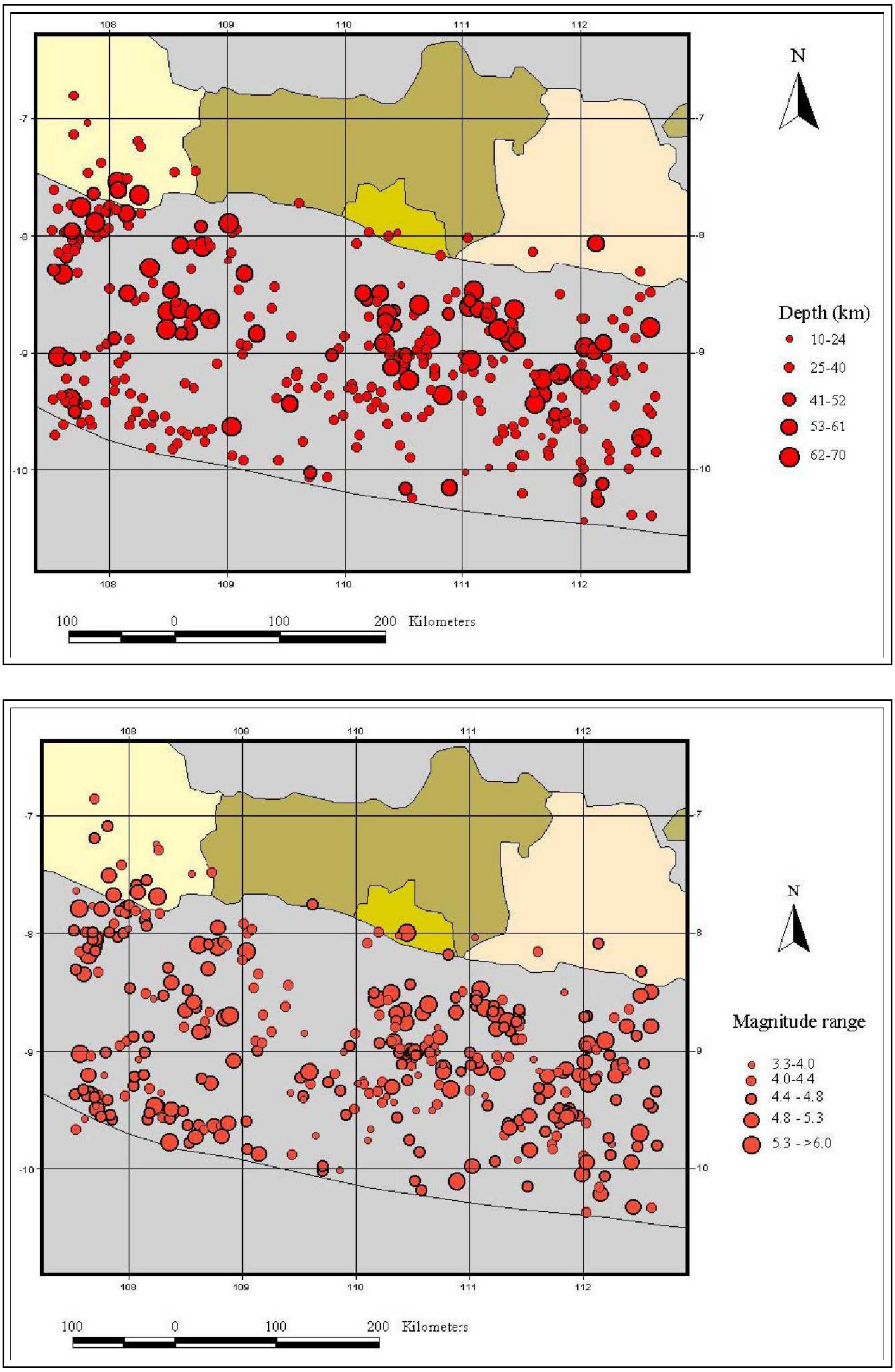

Figure 1: Distribution of the epicenters of the earthquakes (magnitude greater than 3 Mb in (a) and less than 70 Km in focal depth in (b)) that happened during 1970-2007/07 (Source: ANSS, NEIC, USGS and BMG records).

Where, m_{max} is the maximum earthquake magnitude, $m_{max(obs)}$ is the observed maximum earthquake magnitude, m_{min} is threshold of the completeness of the earthquake catalog, n is the number of earthquakes greater than or equal m_{min}, $\beta = b\ln(10)$, and $n_1 = n/(1-\exp[-\beta(m_{max}-m_{min})])$, $n_2 = n_1\exp[-\beta(m_{max}-m_{min})]$, $E_1(z) = [(z_2 + a_1 z + a_2)/z(z_2 + b_1 z + b_2)]\exp(-z)$, in which $a_1 = 2.334733$, $a_2 0.250621$, $b_1 = 3.330657$, and $b_2 = 1.681534$. It must be noted that equation (3) does not constitute an estimator for mmax since expressions n_1 and n_2, which appear on the right-hand side of the equation, also contain m_{max}. Generally the assessment of m_{max} is obtained by the interactive solution of equation (3).

However, when $m_{max} - m_{min} \leq 2$, and $n \geq 100$, the parameter m_{max} in n_1 and n_2 can be replaced by $m_{max(obs)}$, thus providing an m_{max} estimator which can be obtained without iteractions (Kijko, 2004). Tate's (1959) equation can also be utilized to estimate the maximum magnitude of the earthquake potentials mmax for the site of interest and his equation is as follows:

$$\begin{aligned} m_{max} &= m_{max(obs)} \\ &\quad + 1/n\frac{(1-\exp[-\beta(m_{max}-m_{min})])}{\beta\exp[m_{max(obs)}-m_{min}]} \end{aligned} \tag{4}$$

The equation first used by Gibowicz and Kijko (1994) for the assessment of the magnitude of the maximum possible seismic events is also applied in this work. Their equation is

$$\begin{aligned} n_{max} &= -1/\beta\ \ln\exp(-\beta m_{min}) - [\exp(-\beta m_{min}) \\ &\quad - \exp m_{max}(\text{obs})][(n+1)/n] \end{aligned} \tag{5}$$

For the present work, these above mentioned three equations are used to estimate the maximum magnitude of the most possible earthquake potentials from three area seismic sources for the Yogyakarta depression area.

5 Results and discussion

The historical records show that some inland earthquakes happened around the Yogyakarta region as June 10, 1867 (MMI⇒VIII) happened at 7.8°S and 109.5°E that caused 5 people deaths and 372 buildings collapsed around Yogyakarta region. There are no evidences of the relationships between the previous inland earthquakes and the fault structures. The data related with the inland fault parameters are very rare since most of them are the buried faults. Some of the geophysical surveys as CSAMT, Gravity and Magnetic Methods were conducted around the present region but the resulted data cannot sufficiently support to obtain the representative fault parameters. Therefore some assumptions are made for the fault parameters as the fault length, fault width and stress-drop.

To estimate the maximum magnitude of the future earthquake potentials for Yogyakarta region the fault specific sources and three areal sources in offshore regions are assumed as the most possible seismic sources for this area. The geological maps of McDonald (1984) and Rahardjo *et al.* (1995) are assigned to deduce the parameters of the faults around this region Figure 3. Most relations used to evaluate the maximum magnitude are rupture length and magnitude relations although some are fault length and magnitude relations. The observed fault length on the geological map of McDonald (1984) and Rahardjo *et al.* (1995) are assumed as the basis parameters and the two gradual 5 km increments are made for each individual fault to adjust the results of maximum earthquake magnitude since the seismic hazards are tended to calculate for the present area by using Probabilistic method. Fault length and Magnitude relations of Otsuka (1964), Iida (1965) Ambraseys and Zatopek (1968), Yonekura (1972), Matsuda (1977), Inoue *et al.* (1993), Papazacchos *et al.* (2004) and Mohammadioun and Serva (2001) are applied and the results are presented in Table (1) for normal faults and in Table (2) for strike-slip faults.

The results obtained by utilizing the Equations of Mohammadioun & Serva (2001), Otsuka (1964), Yonekura (1972) and Iida (1965) are smaller in magnitude compared with the results attained from the calculation by employing the formula of Ambraseys (1988), Ambreasseys & Tatopek (1968) and Matsuda (1977), e.g., for normal fault YN1 whose observed fault length is about 6.1 km and the estimated magnitude calculated by using the equations of Mohammadioun and Serva (2001), Otsuka (1964), Yonekura (1972), Papazacchos *et al.* (2004), Inoue *et al.* (1993) and Iida (1965) are 4.9, 5.2, 5.1, 5.3, 5.4 and 5.3. However the value obtained by utilizing the relations of Ambraseys (1988), Ambraseys & Tatopek (1968) and Matsuda (1977) are 5.6, 6.2 and 5.9. When compared the results and the fault length to the previous earthquake around the world the later values are high in magnitude. Therefore for the determination of maximum magnitude for the present area, the parameters resulted from Mohammadioun & Serva (2001), Otsuka (1964), Yonekura (1972), Papazacchos et al. (2004), Inoue *et al.*, AIJ (1993) and Iida (1965) are tended to be applied in calculating the seismic hazards for Yogyakarta area.

For offshore region of the Yogyakarta area, three areal sources are designated since the subduction zone earthquakes; interplate and intraplate earth-

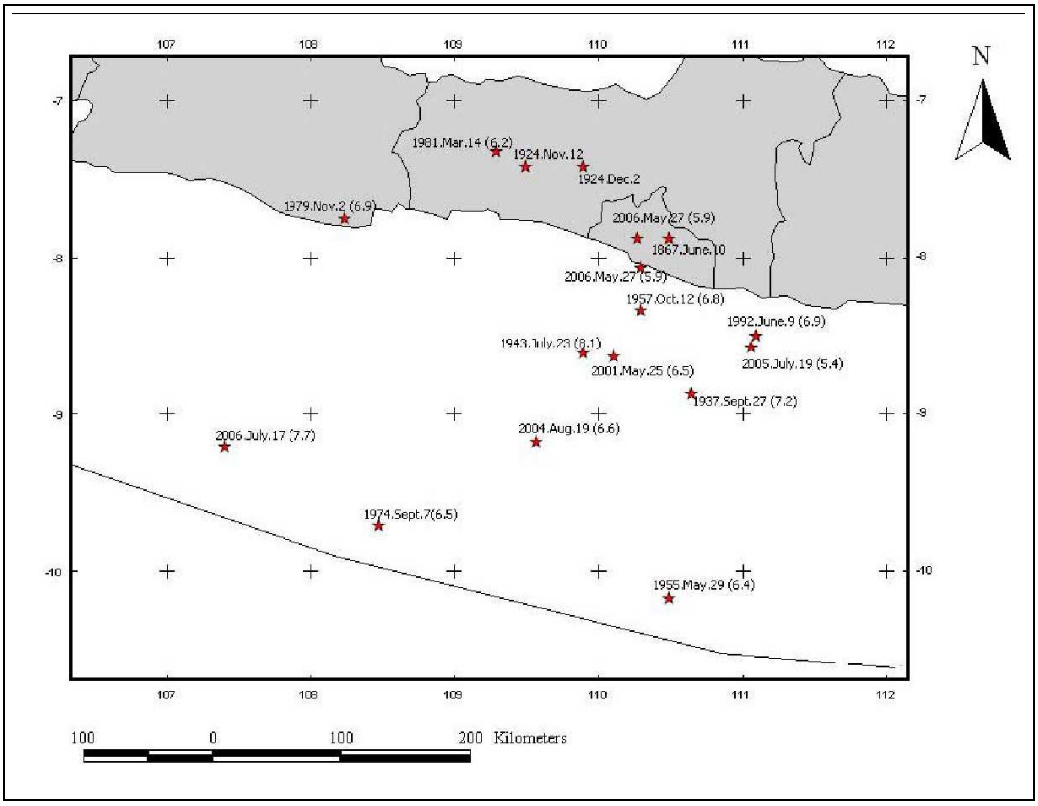

Figure 2: Epicenters distribution of the historical earthquakes happened around the Yogyakarta area (Newcomb and McCann, 2001; Utsu, 2002; Elnashai *et al.*, 2006; and USGS, 2007).

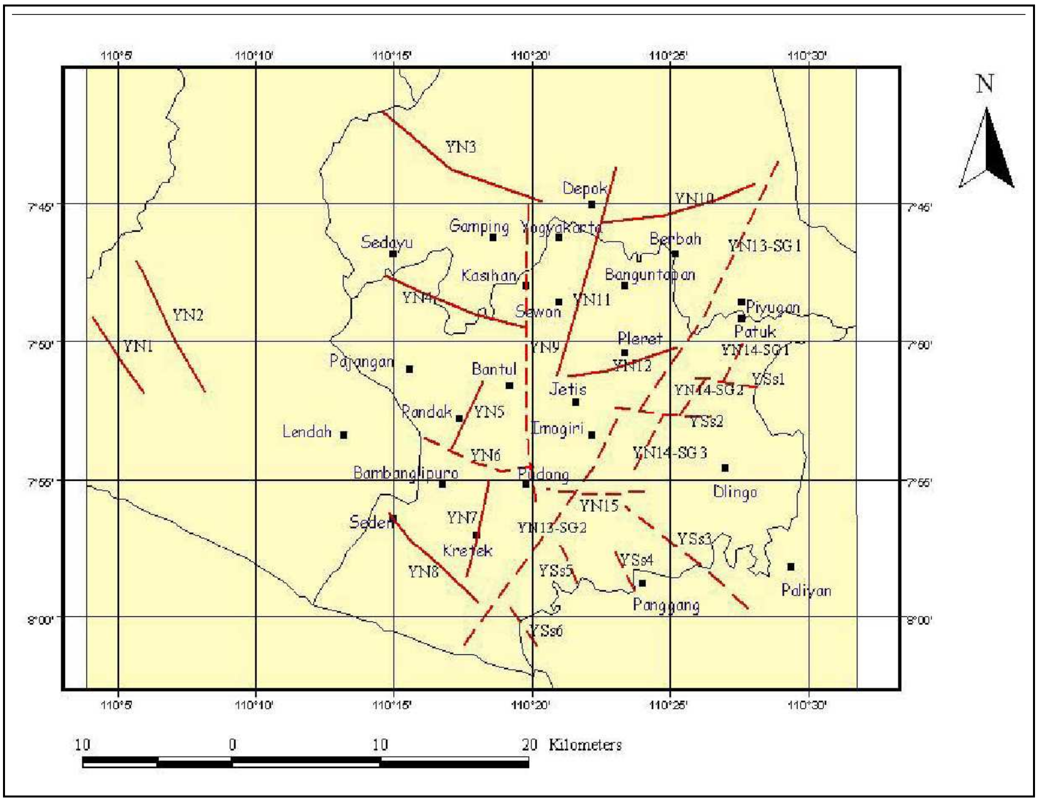

Figure 3: The fault specific sources model for Yogyakarta depression area (McDonald, 1984 and Rahardjo *et al.*, 1995).

quakes are expected to occur in this region Figure 4. When the b-values are determined for each areal source, the instrumental record period is too short so the data of the seismicity are considered as not enough for individual source and the b-value is estimated for the whole region. The estimated b-value for this region is 1.045. One of the most important parameter for the determination of maximum earthquake potential magnitude for areal source for probabilistic approach is the observed maximum earthquake magnitude, mobs max . The historical records show the observed maximum magnitude is 8.1 for areal source, S-2 but 6.6 for S-1 and 6.9 for S-3. But the historical record started from 1840 and the period of recording is also short and the observed maximum earthquake magnitude of S-1 and S-2 is too small. Therefore the observed maximum magnitude is assumed as 8.1 for all of the area seismic sources.

Kijko's (2004) equation is used for determining the maximum magnitude of earthquake potential for three areal sources and the results are shown in Table (3). Moreover the relations of Tate (1959) and Gibowicz & Kijko (1994) which was first used for the assessment of the magnitude of the maximum possible seismic events in the Klerksdorp gold mining district in S-Africa are also applied in this work and all of the results are consistent with each other. Although the resulted value of maximum earthquake magnitude for all individual sources obtained by applying the equation of Tate (1959) is 8.1, those attained from the formulae of Gibowicz & Kijko (1994) and Kijko (2004) are 8.2. Moreover, Kanamori's (2006) equation of relationship of earthquake magnitude and tectonic parameters is also utilized and the value of earthquake potential magnitude is about 7.9. According this equation, the magnitude (7.9+) earthquake can be expected for this region. Therefore the expected maximum magnitude of earthquake potential for the Yogyakarta Depression area can be regarded as around 8.2.

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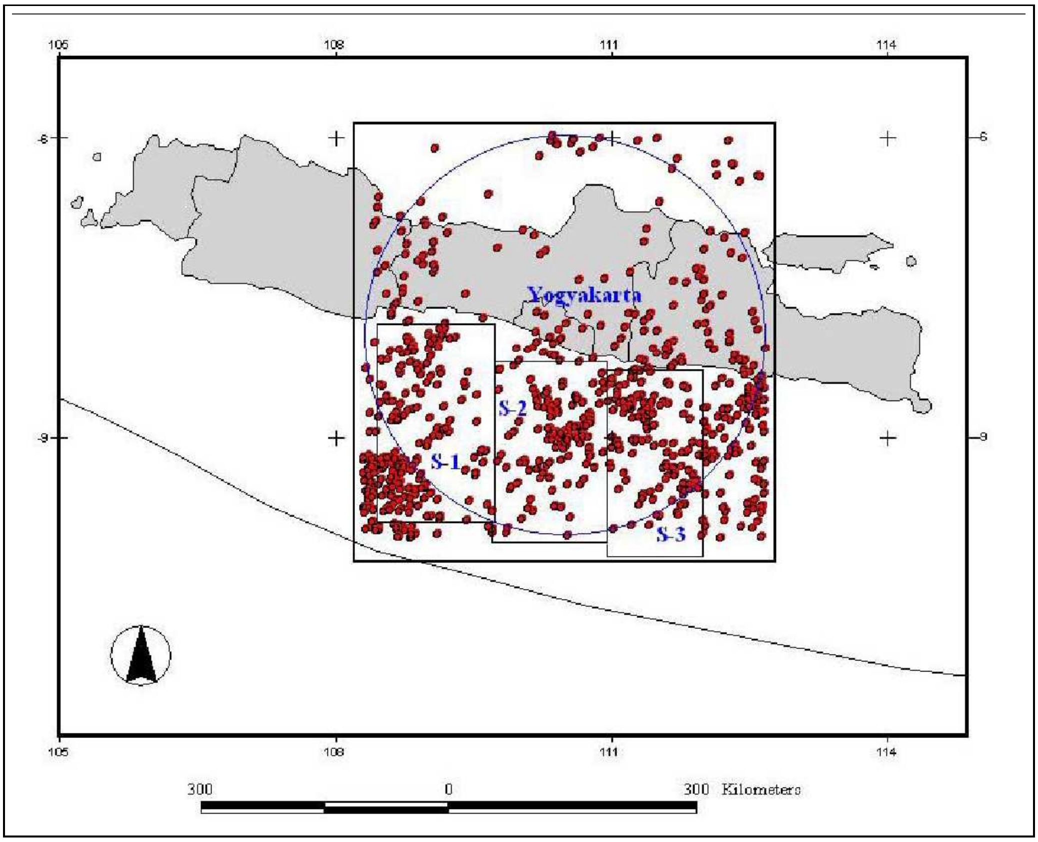

Figure 4: Three possible area seismic sources for Yogyakarta depression area and the seismicity of each source.

