PROBABILISTIC SEISMIC HAZARD ASSESSMENT FOR YANGON REGION, MYANMAR

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Abstract

According to the seismicity and the records of the previous considerably high magnitude earthquakes, Yangon Region can be regarded as the low to medium seismicity region. Moreover, tectonically the region is surrounded by the subduction zone between the Indian Plate and Burma Plate to the west and the right lateral Sagaing fault to the east. The most significant earthquake happened around this region is the Bago earthquake of 5th May, 1930 with the magnitude of 7.3. This earthquake caused 500 casualties and great destruction in Bago. However, considerable damage and 50 deaths were recorded in Yangon. It was originated from the Sagaing fault. The seismic hazard analysis is performed for Yangon Region by applying the probabilistic way. In conducting seismic hazard analysis, firstly the most possible seismic sources are identified and the seismic source parameters are then determined for each sources. Based on the seismicity, focal mechanism study of the previous events, and the geological data, the main seismic sources to cause the earthquake potentials for this region are subduction zone of Indian Plate beneath Burma Plate, Sagaing fault, and Kyaukkyan fault. Including those sources, thirteen areal seismic sources and two fault sources are identified. After that the seismic source parameters such as the seismicity parameters of a- and b-values, maximum magnitude of earthquake potentials and earthquake recurrence parameters for certain magnitude of each seismic source are estimated. The seismic hazard analysis is carried out for 10% and 2% probabilities of exceedance in 50 years and the seismic hazard maps are represented in terms of peak ground acceleration and spectral acceleration at the periods of 0.2s and 1.0s for those recurrence intervals.

Keywords: Bago earthquake, Peak ground acceleration, Sagaing fault, Seismic hazard analysis, Spectral acceleratoin, Subduction zone

Introduction

Yangon Region is one of the major regions of Myanmar and the former capital, Yangon, is located in this region. Based on the seismicity and the records of the previous considerably high magnitude earthquakes, this region can be assumed as low to medium seismicity region (Figure 1). Some of the large earthquakes that caused the considerable damages to some buildings and some casualties in and around Yangon Region can be recognized in the past records, e.g. the magnitude 7.3, earthquake that struck on May 5, 1930 and December 3, 1930 earthquake with the same magnitude (Figure 2). The former earthquake, well-known Bago earthquake, caused 50 deaths and great damages in Yangon while 500 casualties were resulted in Bago. The other significant earthquakes are Yangon earthquakes of September 10, 1927 and December 17, 1927. These events also resulted in a certain amount of damage in Yangon. All of these events and their consequences, and the rapid growth of population and various sorts of structures alarm to conduct the seismic hazard analysis for this region and the seismic hazard assessment was therefore performed applying the probabilistic way.

Seismotectonics

The major tectonics of Myanmar comprises of the subduction zone of Indian Plate beneath Burma Plate in the west, and the collision zone of Indian Plate with Eurasia Plate in the north. The rate of subduction is 35 – 50 mm/yr and the direction of subduction is NE to NNE [1]. The other major structures present within Myanmar are the major fault systems of well-known Sagaing fault, Kyaukkyan fault, Gwegyo thrust, and West Bago Yoma fault. Most of the earthquakes, which occurred in the central region of Myanmar, are related with Sagaing fault, and in the eastern part, the focal depth is not greater than 40 km while the earthquakes in the western portion include from shallow, through intermediate to deep focus earthquakes. The shallow focus earthquakes along the western margin belong to the subduction zone earthquakes and the focal depth of the earthquakes, which are generated from the subduction zone gradually increase to the eastward. In the eastern margin of the Western Ranges or Indoburma Ranges, the shallow focus events indicate their correspondence with the crustal faults.
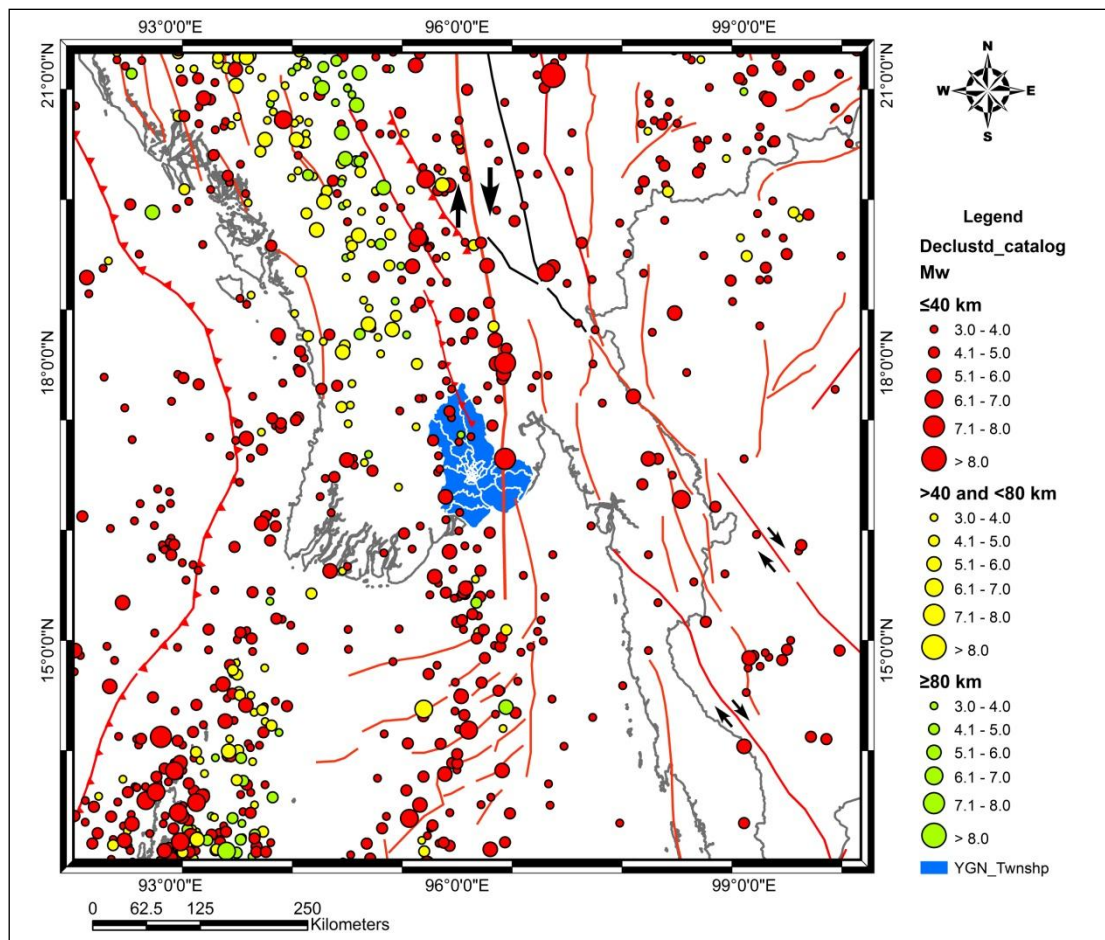

Figure 1. The seismicity of Yangon region (Data Source – ANSS earthquake catalog, 1963 – 2009)

The right lateral, strike-slip Sagaing fault which caused the 5th July, 1917 event, the magnitude 7.3, May 5, 1930 Bago earthquake and December 3, 1930 (M7.3) earthquake, extends through the central part of the country for a length of more than 1,000 km. It runs from the Gulf of Mataban in the south through Bago, Pyinmana, Yamethin, Tharzi, and

Sagaing till Putao in the north. The records of the previous significant earthquakes showed that some destructive earthquakes with the magnitudes ≥ 7 originated from this fault. The focal mechanisms of the previous earthquakes happened along the Sagaing fault represents the strike-slip mechanisms, confirming the compressional force in NE-SW direction and extensional force in NW-SE direction. However, the events that are located in the northernmost part of Sagaing fault, i.e. northern segments, show strike-slip mechanism with the dominant trust mechanism. The slip rate of Sagaing fault is about 20mm/yr [2]. This character corresponds to the gradual changes or influence of the collision of Eurasia and Burma Plates on the Sagaing fault system. The second-most significant fault system is the Kyakkyan fault that strikes nearly N-S in direction and it extends southward from Pyin Oo Lwin – Naungcho area through Taunggyi – Innle Lake with a length of > 450 km. It is also right lateral strike-slip fault and the slip rate is about 1 mm/yr. The largest earthquake on this fault is the Richter magnitude 8.1 on 23 May, 1912 [3, 4, 5]. However, very few (about 5 small events) have been recorded around this fault subsequently.
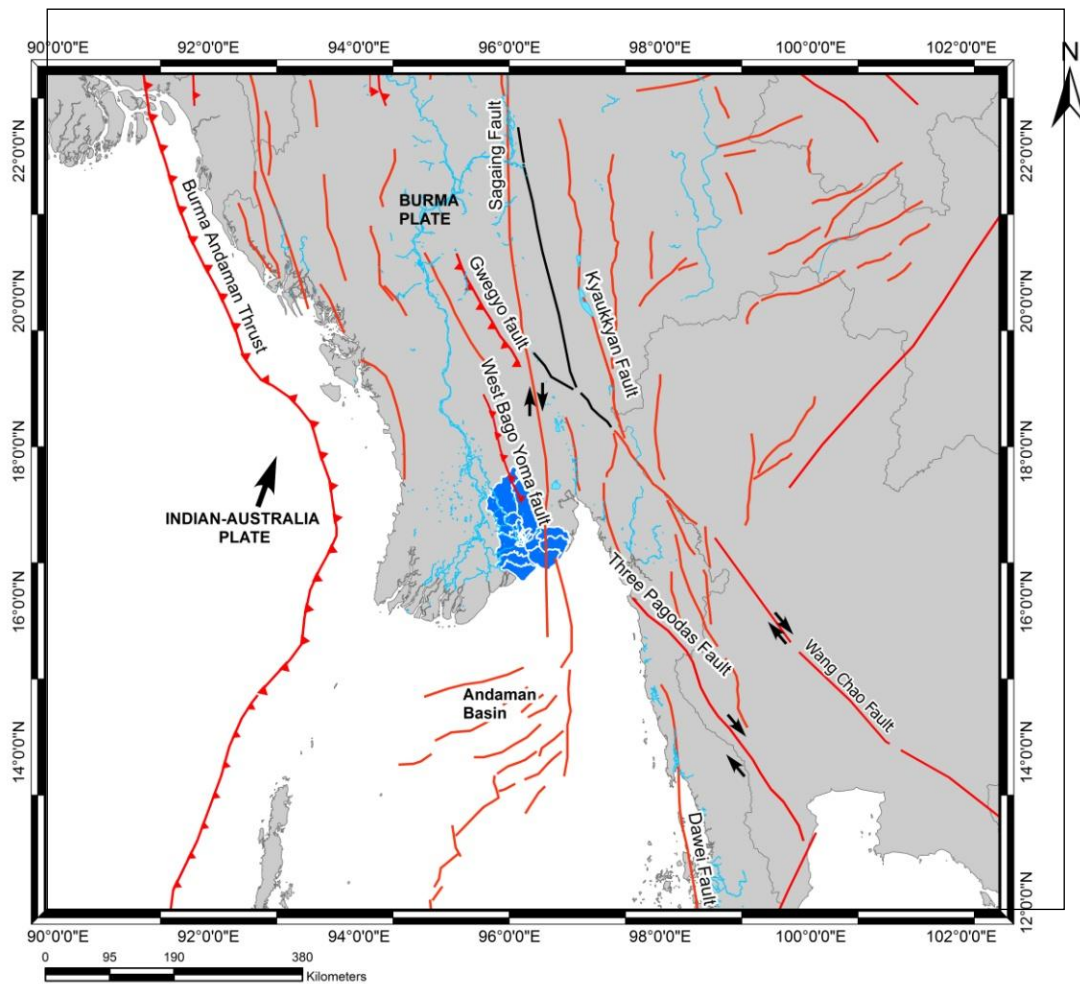

Figure 2. The tectonic map of Yangon region

Yangon Region is tectonically bounded by the Indian-Burma plates subduction in the west, Sagaing fault in the east, West Bago Yoma fault in the north, Kyaykkyan fault in the north-east, and the Andaman rift zone in the south. The earthquakes observed in the Andaman sea region are shallow focus earthquakes that show not only the normal fault mechanisms but also the strike-slip fault mechanisms.

In and around Yangon Region, most of the earthquakes happened are shallow focus earthquakes, especially within about 250km in radius. Most are related with Sagaing fault, some corresponds to the blind faults located under Yangon Region and subduction zone of Indian and Burma Plate (Part of Eurasian Plate), and the Andaman Rift Zone. Moreover, some other faults whose geometry and other parameters are not well-known in and around this region also generated some earthquakes. Small numbers of intermediate and deep focus earthquakes can be seen in this region and those are caused by the subduction zone of Indian-Burma Plates.
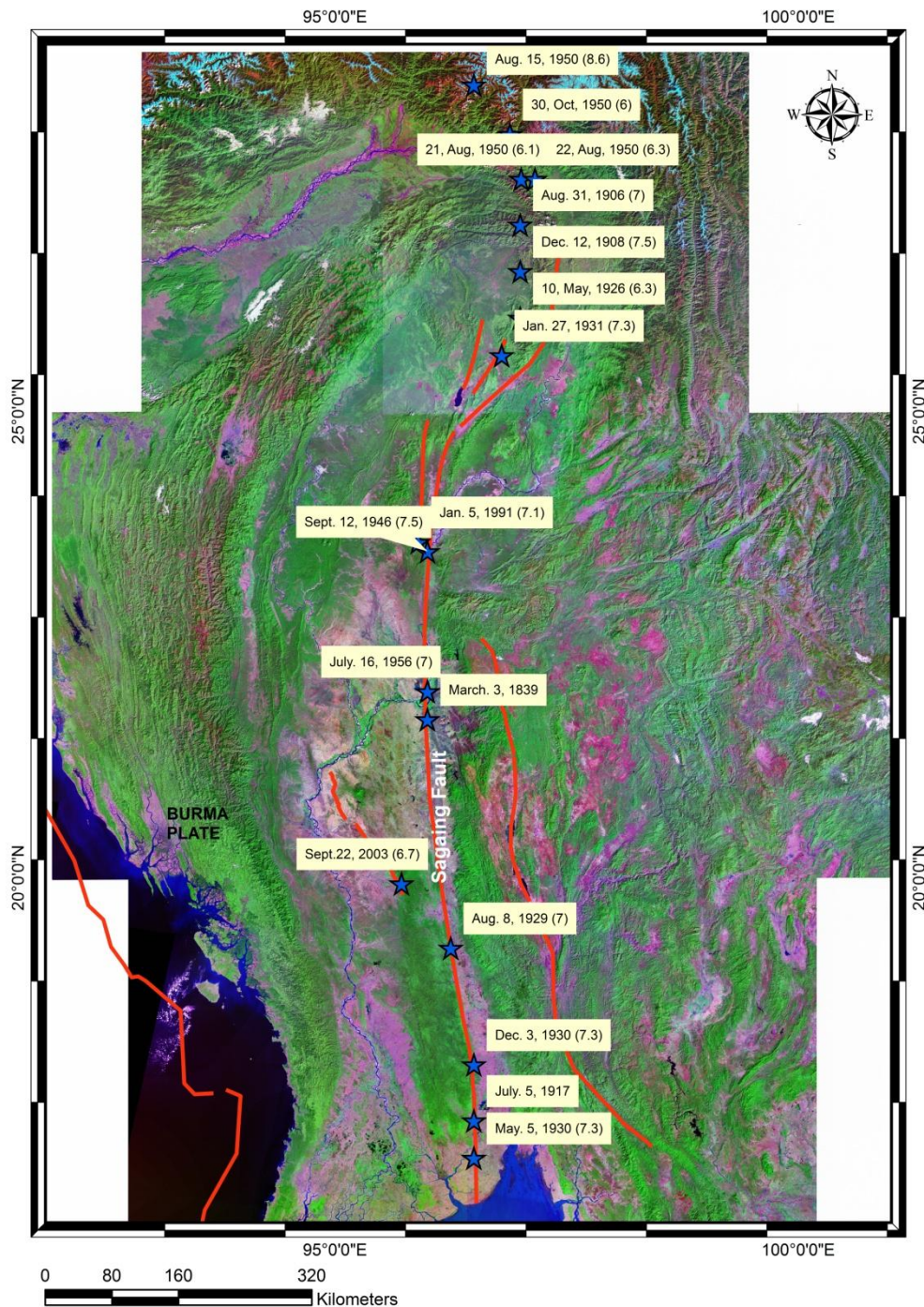

Figure 3. The epicenters of significant events occurred along the Sagaing fault

Analyzed Data

The earthquake catalog of ANSS (1963-2009) is utilized with the complement of USGS (1973-2009) and declustering of the dependent earthquakes was also carried out for the present research by removing the foreshocks and aftershocks. For focal mechanisms study, the CMT catalog of Havard University (1963-2009) is used in this research.

Methodology

The seismic hazard analysis for Yangon Region was carried out by probabilistic way, i.e. Probabilistic Seismic Hazard Analysis (PSHA) [6]. It includes four steps: (1) Identification and characterization of the possible seismic sources, (2) Characterization of the spatial and temporal distribution of the earthquake recurrence, (3) Determination of the ground motion using the ground motion predictive relationship, and (4) Estimation of the probability that the ground motion parameter will be exceeded during the particular time period [7, 8]. The EQRISK program [9] was used to calculate the seismic hazard, the ground motion parameter, peak ground acceleration (PGA) and spectral acceleration (SA) for the periods of 0.2s and 1.0s.

Earthquake Sources Identification

Seismic sources are identified as areal seismic sources and fault sources according to the geology (tectonics), seismicity and focal mechanisms study of the previous earthquakes. Thirteen areal seismic sources are identified as eight sources (MAS_01, MAS_02, MAS_03, MAS_04, MAS_05, MAS_06, MAS_07 and MAS_23) in the west of Yangon Region, representing the subduction zone earthquakes, two (MAS_15 and MAS_16) in the south, Andaman Rift Zone, one (MAS_24) representing Gwegyo thrust and West Bago Yoma fault in the north, and two (MAS_17 and MAS_18) in the east, including some strike-slip faults of eastern highland (Figure 4 and Table 1). In this case, some faults are identified as the areal seismic sources due to the lack of adequate information.

In the surroundings of this region, two significant fault systems are observed and those are well-known Sagaing fault and Kyaukkyan fault. Two fault sources are therefore identified and the fault segmentation of those faults was done based on the seismicity, geological structures and studies on the focal mechanisms of the obtainable previous earthquakes, and three major segments for Sagaing fault as SGSMN in the northern portion of that fault, SGSMM in the middle portion and SGSMS in the southern portion. The Kyaukkyan fault was also segmented as three segments from north to south as KK01, KK02 and KK03. For this region, the most influence segments from those two fault sources are SGSMM02_02, SGSMS01, SGSMS02, SGSMS03 and SGSMS04 which are of Sagaing fault and KK03, the southernmost segment of Kyaukkyan fault (Figure 5 and Table 1). The seismicity that does not belong to certain faults is assumed as the background source in seismic hazard estimation.

Earthquake Sources Characterization

The characterization of the seismic sources includes the determination of the seismic source parameters of each seismic source such as seismicity parameters; a- and b- values, the maximum magnitude of the earthquake potentials (M_{max}), and the recurrence rate of certain earthquakes $\geq$ M, especially for lower bound events. In determination of seismic source parameters, the seismicity corresponds to each seismic source is used for all. However, for earthquake recurrence estimation in fault source model the slip rates of each fault are applied with the characteristic model.

Estimation of Seismicity Parameters (a- and b- Values)

The seismicity parameters of *a*- and *b*- values are estimated by applying the classical Gutenberg-Richter recurrence law (*Log N_m = a – bm*, in which N_m is the cumulative number of earthquakes having magnitude *m*, *a* is the measure of seismic activity and *b* is a parameter of the ratio of larger to smaller earthquakes) [10]. Moreover, the maximum likelihood method [11] was also applied as a complementary.
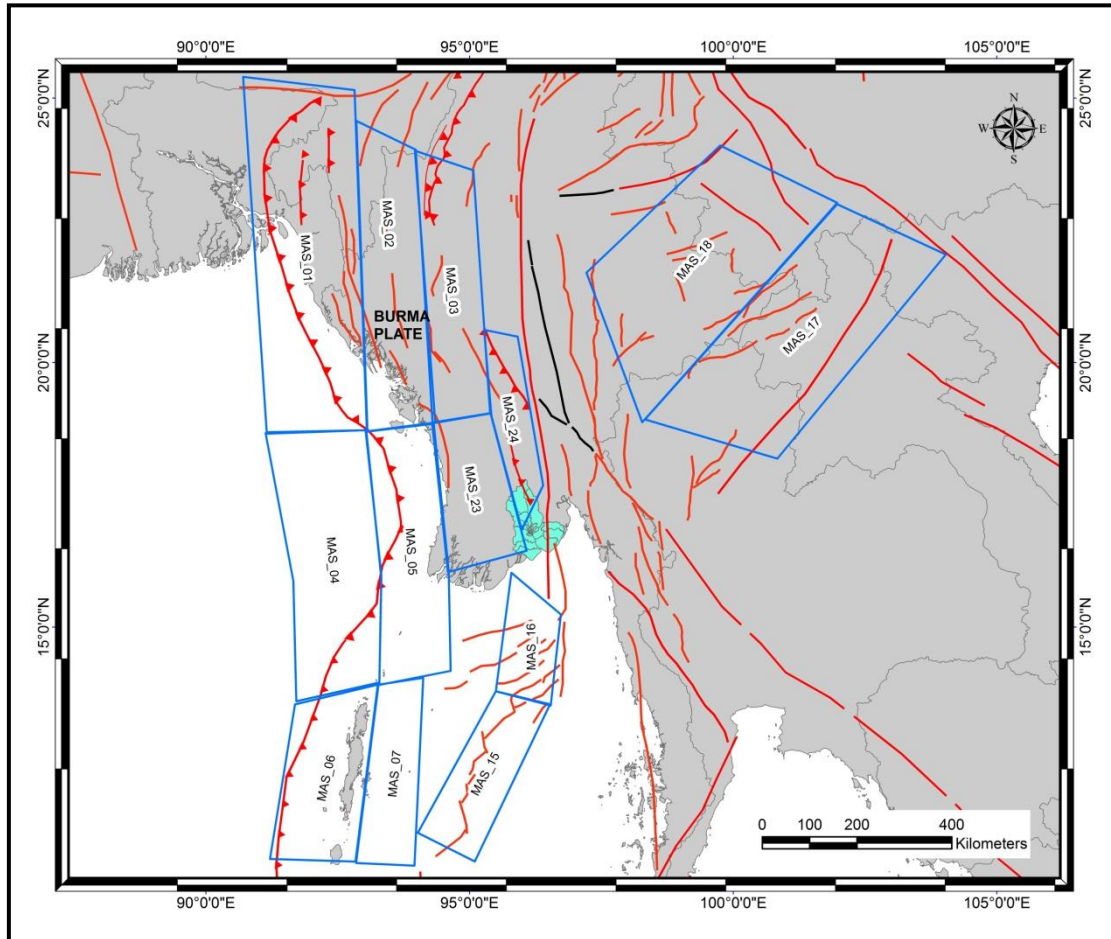

Figure 4. Map of areal seismic sources (areal seismic sources within the radius of 300km are considered in calculation of the seismic hazards for Yangon region)

Estimation of Maximum Earthquake Potentials

The magnitude of the earthquake potential is another important seismic source parameter in seismic hazard analysis. This parameter was estimated for areal seismic sources and fault sources separately. For areal seismic sources, maximum likelihood method [12] was used and the relationship is as follow:

$$m_{max} = m_{max}^{obs} + [\{E_1(n_1) - E_2(n_2)\}/\{\beta \exp(-n_2)\}] + m_{min} \exp(-n) \tag{1}$$

$$\text{where, } E_1(z) = \{(z^2 + a_1 z + a_2)/[z(z^2 + b_1 z + b_2)]\} \, exp\,(-z) \tag{2}$$

$$n_1 = n / \{1 - exp\,[-\beta\,(m_{max} - m_{min})]\} \tag{3}$$

$$n_2 = n_1 \, exp \, [-\beta \, (m_{max} - m_{min})] \tag{4}$$

in which n is the number of earthquakes $\geq m_{min}$, $\beta = b \ln(10)$, $a_1 = 2.334733$, $a_2 = 0.250621$, $b_1 = 3.330657$, and $b_2 = 1.681534$.
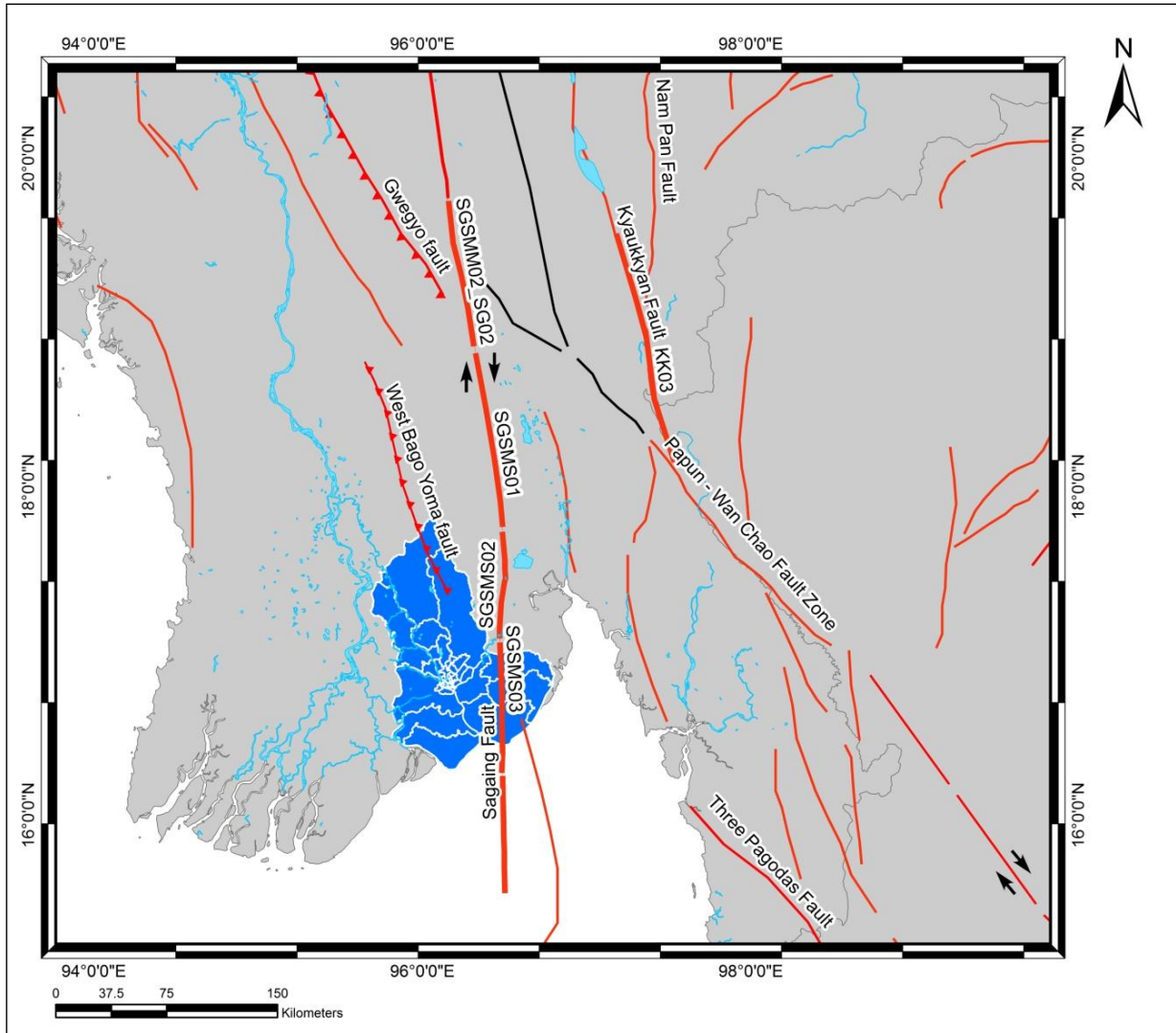

Figure 5. The map of the fault seismic sources used in this seismic hazard analysis and some other faults around Yangon region

It must be noted that Equation 2 does not constitute a direct estimator for m_{max} since expressions n_1 and n_2, which appear on the right-hand side of the equation, also contain m_{max} and the maximum earthquake potential, m_{max} is obtained by the iterative solution of Eq. 2. However, m_{max} can be obtained without interaction 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 $m_{max}(obs)$ [12]. The resulted maximum earthquake potentials for each areal seismic source are represented in Table 1. In estimating the maximum earthquake magnitudes for fault sources, the empirical relationships of the fault (rupture) length and the magnitude [13] is used complement with the other relations [14, 15, 16, 17, 18].

Estimation of Earthquake Recurrence rate

The recurrence rate of the lower bound magnitude earthquake (λ) for each seismic source, which is used in calculating the seismic hazard is determined by the Gutenberg-Richter recurrence relation (Table 1). The focal depth of the earthquake potential is also estimated based on the depth of the previous earthquakes.

Table 1. Seismic Source Parameters of each Seismic Sources; Fault Specific Sources and Areal Seismic Sources ($M_0 = 5$ for All Seismic Sources)

No	Region	Code	M_{max}	b	β	λ
1	Subduction zone of Indo-Australia plate beneath Burma microplate	MAS_01	8.1	0.6478	1.4916	0.2315
2		MAS_02	7.7	0.7238	1.6666	0.4420
3		MAS_03	7.8	0.7158	1.6482	0.5092
4		MAS_04	9.3	0.7629	1.7566	0.0822
5		MAS_05	9.3	0.7629	1.7566	0.0930
6		MAS_06	9.1	0.5681	1.3081	0.3333
7		MAS_07	8.2	0.7515	1.7304	0.3194
8	Andaman Basin	MAS_15	7	0.7515	1.7304	0.3914
9		MAS_16	7	0.7515	1.7304	0.3914
10	Eastern Highland	MAS_17	7.9	0.7297	1.6802	0.3151
11		MAS_18	8.1	0.6406	1.4750	0.2504
12	Some crustal faults	MAS_23	7	0.6119	1.4090	0.0742
13		MAS_24	7.4	0.5917	1.3624	0.0709
14	Sagaing Fault	SGSMM02_SG02	7.7	0.6812	1.5685	0.2535
15		SGSMS_01	7.8	0.6335	1.4587	0.1112
16		SGSMS_02	7.6	0.6335	1.4587	0.1112
17		SGSMS_03	7.6	0.6335	1.4587	0.1112
18		SGSMS_04	7.6	0.6335	1.4587	0.1112
19	Kyaukkyan fault	KK03	8.2	0.7879	1.8142	0.0885

Ground Motion Model

Seven ground motion prediction equations for PGA and SA are utilized in validating the ground motion model such as the relationships of Fukushima and Tanaka (1992), Abrahanson and Silva (1997), Boore et al. (1997), Campbell (2003), Idriss (2004) and Atkinson and Boore (2006). The correlation of the PGA results obtained by applying the different relations are represented in Figure 6, accordingly the PGA results of Atkinson and Boore (2006) and Campbell (2003) seems to be overrated and that of Fukushima and Tanaka (1992) to be underrated, the rest of four are consistent for Myanmar. Among them Boore et al. (1997), Abrahanson and Silva (1997) and Idriss (1999) are in equal weight. Boore et al. (1997) is plump for the seismic hazard analysis for Yangon Region for PGA and SA determination.

The attenuation relation of Boore et al. (1997) is as follow:
$$\ln Y = b_1 + b_2(M_w - 6) + b_3(M_w - 6)^2 + b_5 \ln r + b_v \ln(V_s / V_A) \tag{5}$$

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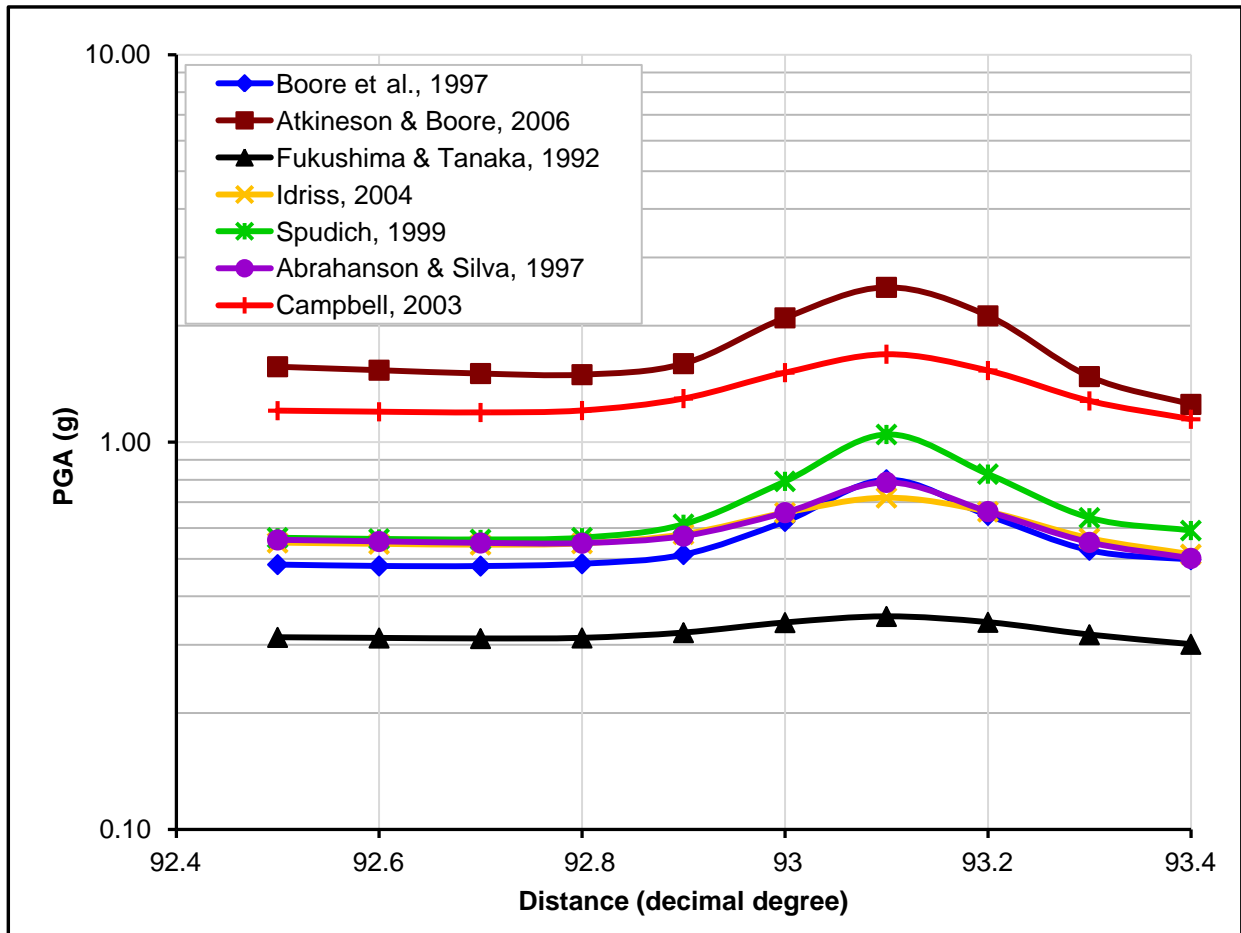

Figure 6. The correlated plots of peak ground acceleration (PGA) with distance for seven attenuation relations (at loc. 93.1˚ where the Myauk-U fault exit), in which the sites are taken along the latitude of 20.6˚)

Calculation of the Seismic Hazard

The seismic hazards are calculated for Yangon Region in grid interval of 0.1˚ x 0.1˚ for 10% and 2% probability of exceedance in 50 years and the results are represented in term of peak ground acceleration, by considering the site condition is rock.
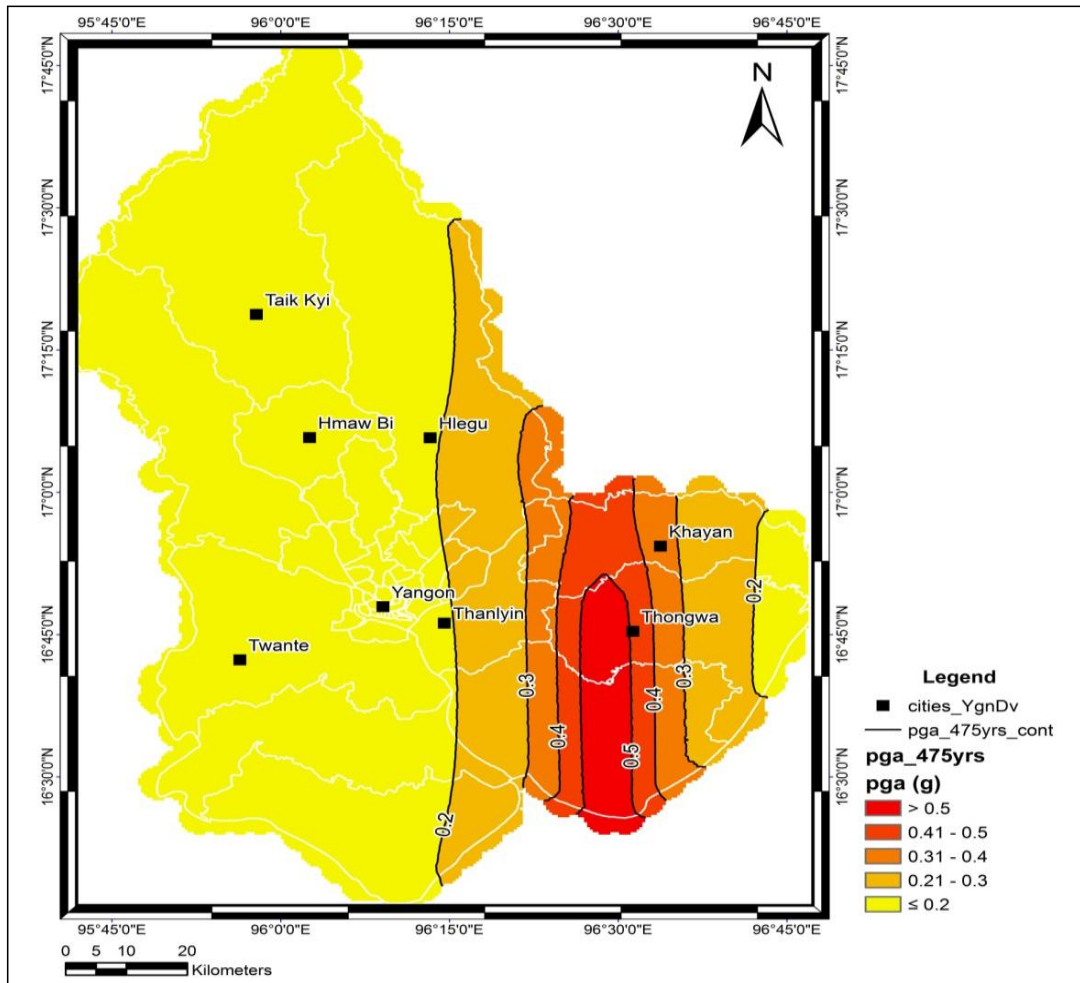
Figure 7. Probabilistic seismic hazard (PGA) map of Yangon region with 10% probability of exceedance in 50 years

The seismic hazard maps (peak ground acceleration and spectral acceleration at the periods of 0.2s and 1.0s in rock condition) for Yangon Region are depicted in Figure 7 to Figure 12. The PGA map predictable in 10% probability of exceedance in 50 years is illustrated in Figure 7. In this recurrence interval, the maximum seismic hazard zone comprise the eastern portion of Yangon Region with value of > 0.5g, while the minimum hazard areas are in western portion and the eastern margin with the value of < 0.2g. The SA map anticipated for 10% probability of exceedance in 50 years can be observed in Figure 8 and 9.

The seismic hazards are also calculated for Yangon for 2% probability of exceedance in 50 years. The respective hazard maps are displayed in Figures 10 to 12. Figure 10 exposes the PGA map of 2% probability of exceedance in 50 years, in which the maximum PGA consequence is > 0.9 g and the minimum one is ≤ 0.3g, while Figure 11 and 12 depict the SA maps at the periods 0.2 s and 1.0 s for 2% probability of exceedance in 50 years. When the seismic hazards are observed, the distribution pattern is nearly the same in each result. However, the SA results at the period of 0.2 s in both 10% and 2% probability of exceedance in 50 years (in Figure 8 and 11) are observed, the northern most part of Yangon region is influenced by the areal seismic source MAS_24, especially in 2% probability of exceedance in 50 years.
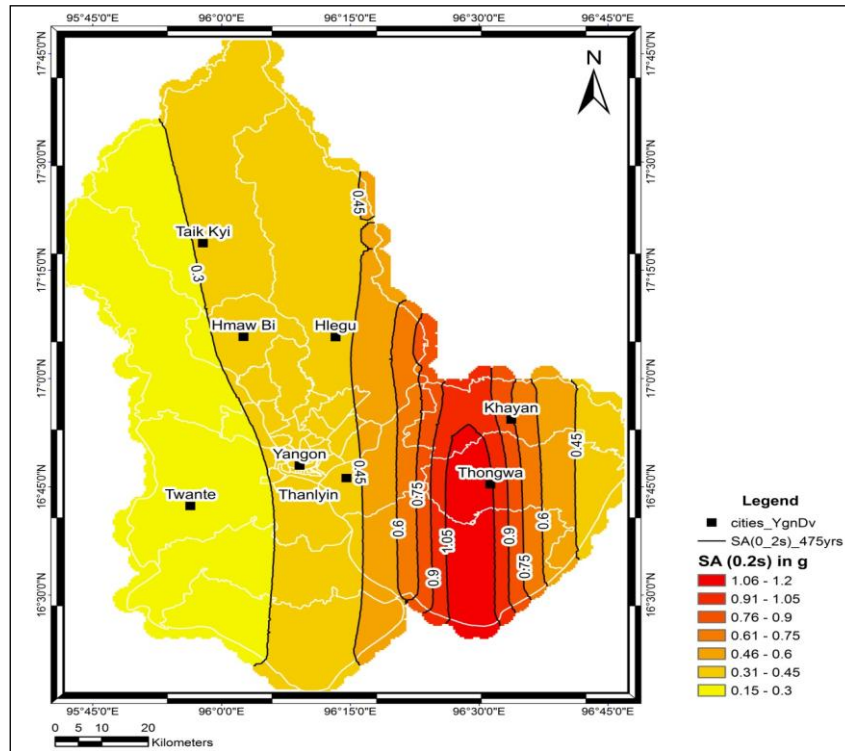
Figure 8. Probabilistic seismic hazard (SA at the period of 0.2s) map of Yangon region with 10% probability of exceedance in 50 years
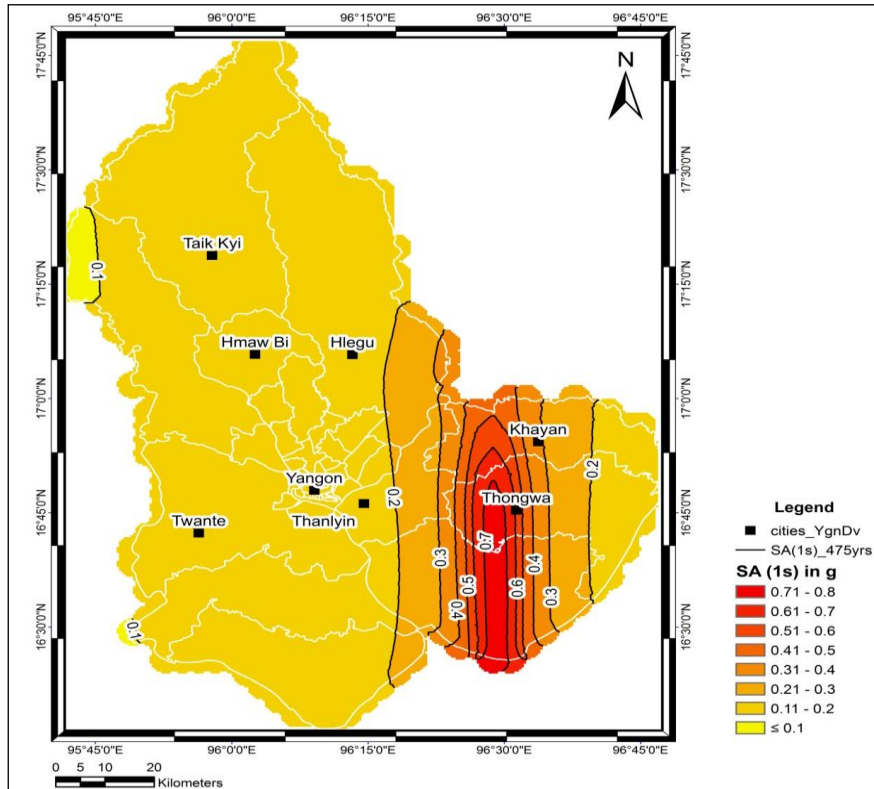

Figure 9. Probabilistic seismic hazard (SA at the period of 1.0s) map of Yangon region with 10% probability of exceedance in 50 years
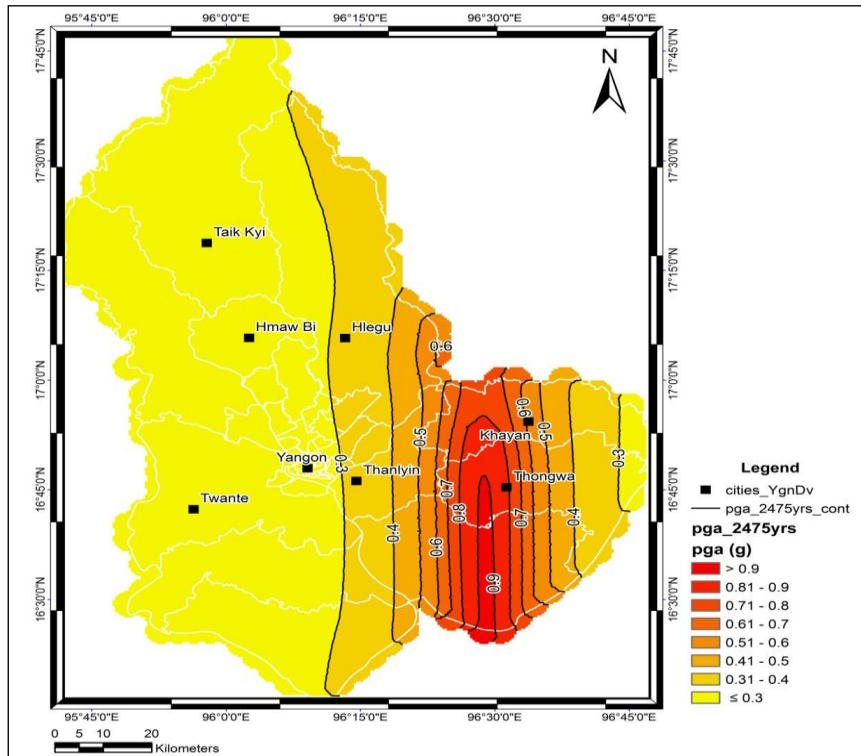
Figure 10. Probabilistic seismic hazard (PGA) map of Yangon region with 2% probability of exceedance in 50 years
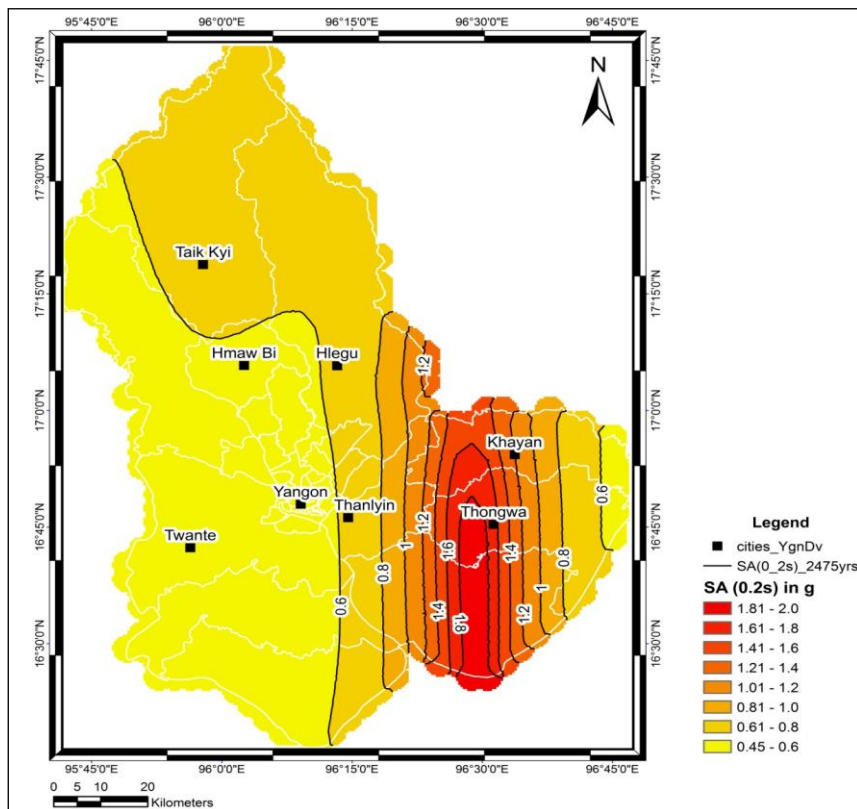

Figure 11. Probabilistic seismic hazard (SA at the period of 0.2s) map of Yangon region with 2% probability of exceedance in 50 years
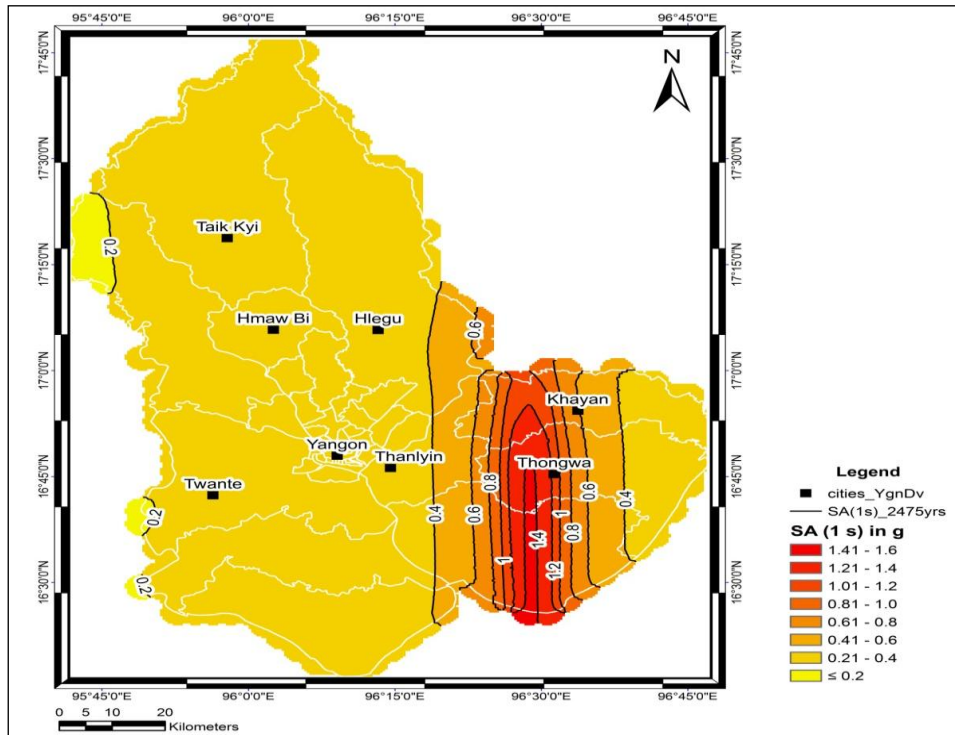
Figure 12. Probabilistic seismic hazard (SA at the period of 1.0s) map of Yangon region with 2% probability of exceedance in 50 years

Discussion and Conclusions

The seismic hazard maps for Yangon Region in which the largest city of Myanmar is located, are insistently required because of development of various categories of buildings and the speedy growth of population. This is the first attempt in seismic hazard assessment of a region in Myanmar. For Yangon Region the most significant seismic sources are the Sagaing fault and the subduction zone of Indo-Australia Plate beneath Burma Plate. Hazard is the highest in the area along the Sagaing fault. The maximum contribution of the seismic hazard to Yangon Region is resulted from the Sagaing fault since the source-to-site distance is closer than those from other source and the recurrence rate is also high for the large earthquakes. The second highest influence seismic sources are the areal seismic sources of MAS_23 from where the intraplate earthquakes can be originated and MAS_24 which occupies the West Bago Yoma fault, and Gwegyo Thrust because the source-to-site distances from these sources are also close although the recurrence rate is low for the high magnitude earthquakes. Although the Kyaukkyan fault caused the largest earthquake in Myanmar, the 8.1 Magnitude, May 23, 1912 event, because of its low recurrence rate of large earthquake and distant source-to-site distance from that fault, the small influence of this source cause Yangon Region negligible seismic hazard. Even though tectonically the second − most significant seismic source rather than Sagaing fault for this region is the subduction zone of the Indo − Australia Plate beneath Burma Plate, the seismic sources (MAS_04, MAS_05, MAS_06 and MAS_07) from this result the low seismic hazard because they occur far from the site. However, the recurrence rate of large earthquakes from the sources MAS_06 and MAS_07 are high and those from sources MAS_04 and MAS_05 are low. The other one is the Andaman Rift zone (seismic sources: MAS_15 and 16) also contribute the low seismic hazard to this region due to the distal source from the site.

For the present region, there are some issues that are still needed to carry out, concerned with fault parameters such as slip rate and recurrence rate of certain large earthquake by performing the paleoseismic analysis. For the site characterization in this seismic hazard analysis, the bore-hole data used are very diminutive in amount (around 30 bore-holes), some are in shallow depth. Therefore it is still required to conduct the site characterization process.

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