PROBABILISTIC SEISMIC HAZARD ANALYSIS OF KATHMANDU VALLEY

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1. INTRODUCTION

Any physical phenomenon associated with an earthquake (e.g. ground motion, ground failure, liquefaction, and tsunami) and its effects on land, man-made structures, and socioeconomic systems that have the potential to produce a loss is termed as seismic hazard. And the process of quantifying the ground motion expected at a particular site is called the Seismic Hazard Analysis (SHA).

The SHA can be performed in two ways:

a) Deterministic Seismic Hazard Analysis (DSHA)
b) Probabilistic Seismic Hazard Analysis (PSHA)

DSHA is generally useful for the quantification of a single or relatively small number of individual earthquake scenarios, whereas PSHA can be used for quantification of the rate (or probability) that a specified level of ground motion will be exceeded at least once at a site or in a region given all possible earthquakes during the specified exposure time.

This study focuses on the SHA of Kathmandu Valley using probabilistic approach. For that purpose the ((Cornell, 1968) (McGuire, 1976)) procedures, known often as the Cornell-McGuire procedure for the PSHA is used for the computation of seismic hazard. The procedure of PSHA as shown in include following four steps;

a) Identification and characterization if earthquake sources
b) Characterization of temporal (seismicity) distribution
c) Use of Ground Motion Prediction Equation (GMPE) to determine the Ground Motion (GM) produced at site by earthquake of any possible size occurring at any possible point within the source zone
d) Final step is to combine the uncertainties in earthquake location, size and ground motion parameter

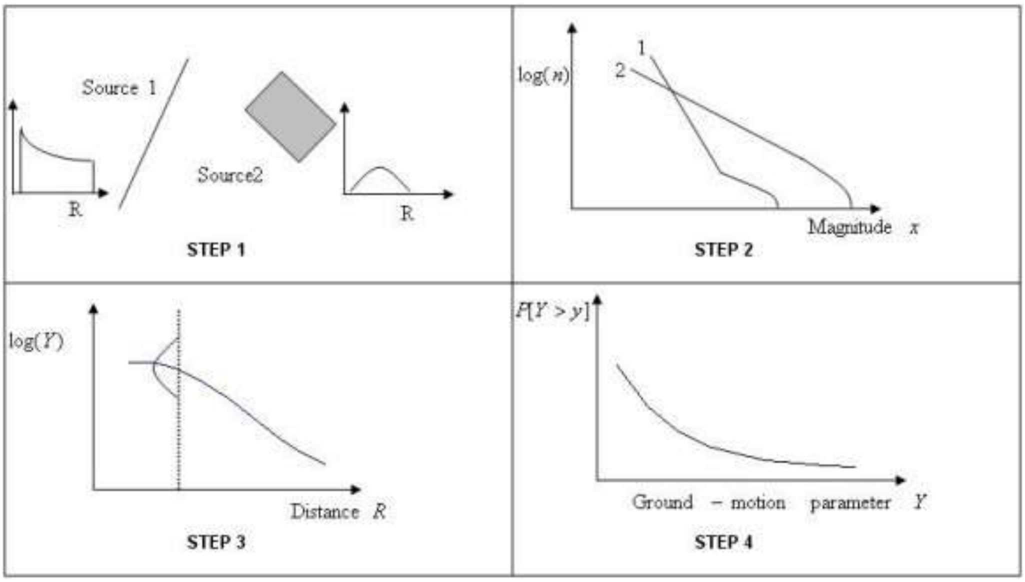

Figure 1: Four steps of PSHA

2. METHODOLOGIES

The general methodology of this study is represented in the following figure:

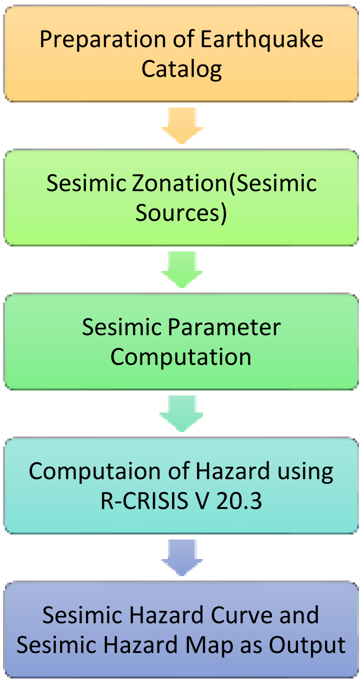

Figure 2: Methodologies for the PSHA study

2.1. Preparation of Earthquake Catalog

Earthquake catalog provides the basic data for delineating seismogenic sources and computing the seismicity parameter, especially the mean seismic activity rate λ, the Gutenberg-Richter b value, and the maximum expected earthquake magnitude M_{max}. The historical and instrumental earthquake catalog are collected from Nepal Seismological Centre (NSC) and U.S Geological Survey (USGS). The catalog obtained from these sources contained earthquake data from 1255 AD to 2021 AD. All magnitudes of the earthquake data are converted into the moment magnitude scale using relation shown in Table 1.

$M_W = 0.67\ M_S + 2.07$ for $3.0 \le M_S \le 6.1$		$M_W = M_D + 0.5$ ($M_D < 3.0$)
$M_W = 0.99\ M_S + 0.08$ for $6.2 \le M_S \le 8.2$	$M_W = 0.67(\pm 0.11) + 0.56(\pm 0.08)\ M_L + 0.046(\pm 0.013)\ M_L^2$	$M_W = M_D + 0.6$ ($M_D \ge 3.0$)
$M_W = 0.85\ M_b + 1.03$ for $3.5 \le M_b \le 6.2$		

Notes: M_W: Moment magnitude; M_S: Surface wave magnitude; M_L: Local magnitude; M_b: Body wave magnitude; M_D: Duration magnitude.

Table 1: Magnitude Scaling Relations

After conversion of all magnitudes in moment magnitude scale the aftershock and foreshock data are removed using the declustering window algorithm given by (Gardner, 1974). The earthquake data only within the 300 KM radius range from the Kathmandu was selected for the purpose of this study. Thus obtained final earthquake catalog contained 443 no. of earthquake events spanned between 1255 AD and 2021 AD.

For the assessment of completeness of the entire catalog Visual Cumulative Method (VCM) was used. The figure 3 shows the cumulative no. of earthquake events plotted against the time period.

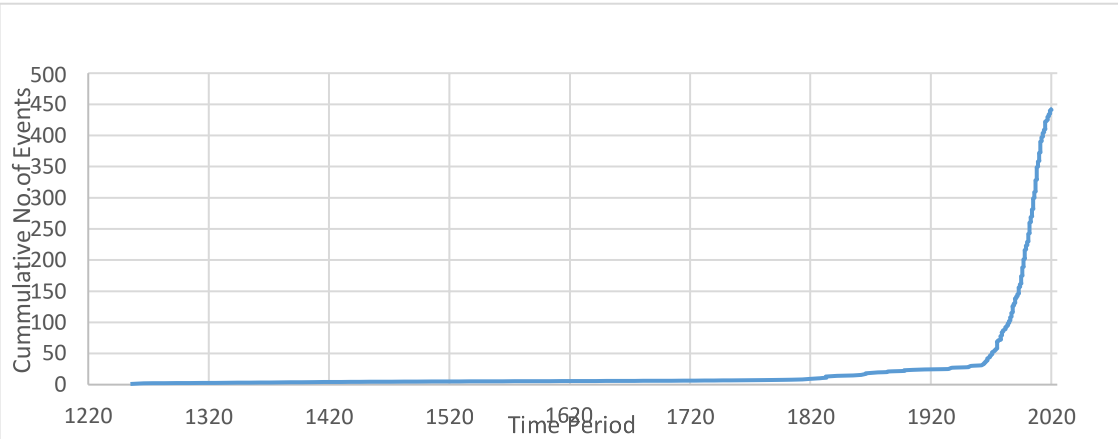

Figure 3: Completeness Verification using Visual Cumulative Method

Figure 3 shows the steep rise in slope of the curve beyond 1964 AD, depicting that the catalog beyond 1964 AD is relatively complete than the catalog prior to 1964 AD. Hence the entire catalog is divided into two sub catalog:

a) One containing data from 1255 AD to 2021 AD
b) One containing data from 1964 AD to 2021 AD

The earthquake data in each of this two sub-divided catalog are considered to be complete in this study.

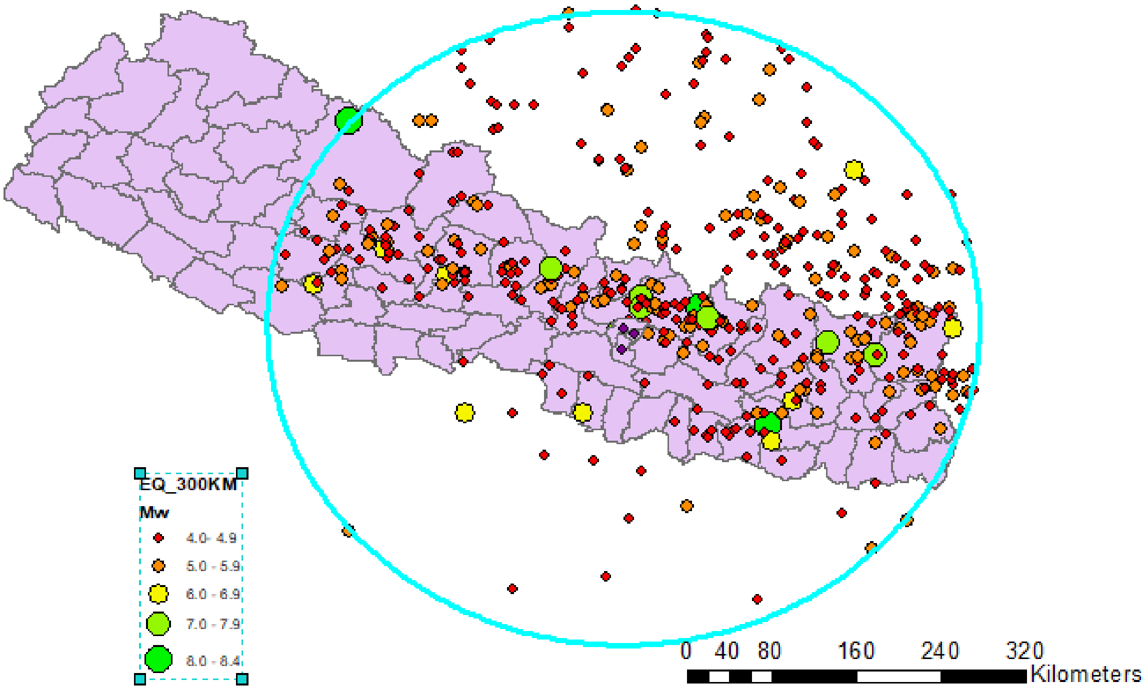

Figure 4: Spatial Distribution of earthquake events of final earthquake catalog

2.2. Seismic Sources

Two types of earthquake source model (Linear and Areal) is incorporated in this study.

2.2.1. Areal Sources

The PSHA study performed by (Ram & Wang, 2013) has delineated 23 seismic zone based on the quantitative analysis of earthquake distribution, fault information, and tectonic settings. In this study the area zone within in the vicinity of 300 KM radius range from Kathmandu was adopted.

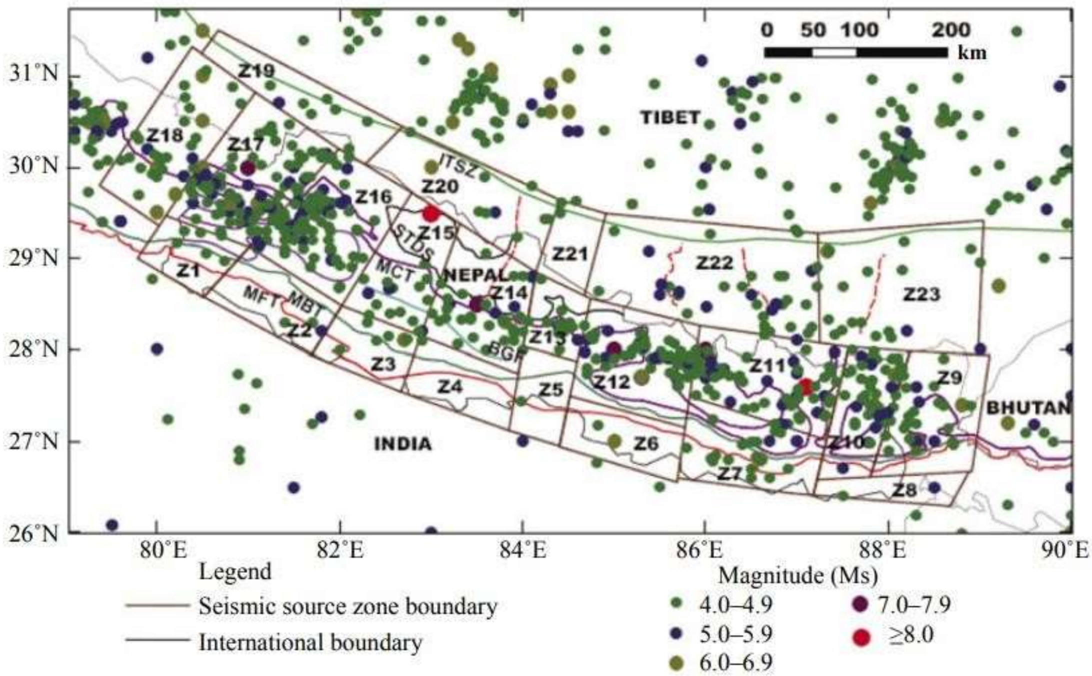

Figure 5: Sesimic Zones delineated by Thapa and Wang,2013

Beside these areal sources the 300 KM circular radial zone is also considered as an areal source. Hence two areal source model is prepared in this study. One containing the circular source zone and another contained the seismic zones delineated by (Ram & Wang, 2013). Weightage of 0.5 was provided to both model at the end for seismic hazard map preparation.

2.2.2. Linear Source

Major earthquakes are associated with active faults, and in seismic hazard assessment these active faults are considered as linear seismic sources. Total of 11 faults were considered as active linear sources for this study.

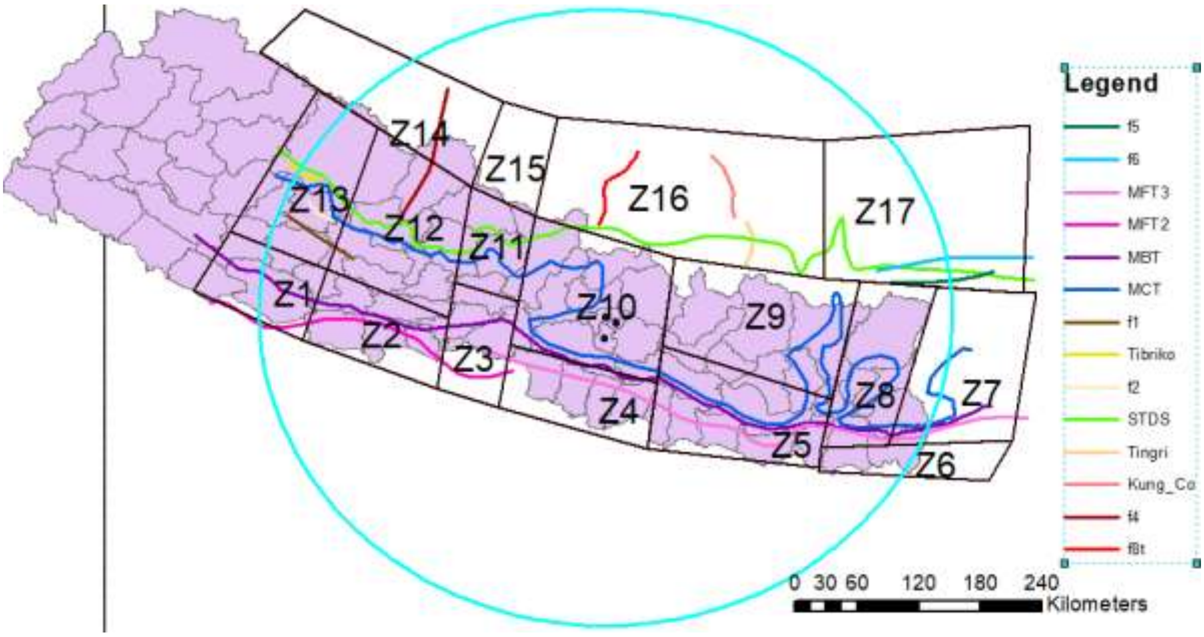

Figure 6: All Seismic Sources for the PSHA study

2.3. Seismic Parameters

The seismic parameters like M_{max}, M_{min}, annual rate of exceedance (λ), a and b - value are computed for the each of the areal seismic sources, whereas for linear sources the seismic parameters were taken from the values given by (Moklesur Rahman & Bai, 2018). For the computation b-value and λ of the circular source zone the method by (Aki, 1965) is used.

$$\beta = \frac{1}{\overline{m} - m_{\min}},$$

$$r_1 = \frac{n_1}{n_1 + n_2}, \quad \text{and} \quad r_2 = \frac{n_2}{n_1 + n_2},$$

$$\frac{1}{\hat{\beta}} = \frac{r_1}{\hat{\beta}_1} + \frac{r_2}{\hat{\beta}_2},$$

$$\hat{\lambda}(m_{\min}) = \frac{n}{\sum_{i=1}^{s} t_i \exp[-\hat{\beta}(m_{\min}^i - m_{\min})]}.$$

Table 2: Seismic Parameters computed for areal sources

S.N	Zones	Mmax	a	b	λ
1	Z1	6.2	2.787	1.036	0.044
2	Z2	7	2.903	1.036	0.057
3	Z3	5.5	2.406	1.036	0.018
4	Z4	7	2.373	1.036	0.017
5	Z5	8.4	3.179	1.036	0.108
6	Z6	5.4	2.380	1.036	0.017
7	Z7	7	3.254	1.036	0.129
8	Z8	7.8	14.788	1.036	0.061
9	Z9	8.1	3.176	1.036	0.108
10	Z10	7.8	3.390	1.036	0.176
11	Z11	5.5	2.406	1.036	0.018
12	Z12	7	2.903	1.036	0.057
13	Z13	5.5	3.036	1.036	0.078
14	Z14	7.3	2.929	1.036	0.061
15	Z15	5.5	2.406	1.036	0.018
16	Z16	6	3.252	1.036	0.128
17	Z17	6.2	2.958	1.036	0.065
18	Circular	8.4	4.764	1.036	4.173

Table 3: Seismic Parameters for Linear Sources

S.N	Fault names	b	σ	λ	Mu
1	f1	0.54	0.12	0.154	7.197
2	f2	0.55	0.22	0.048	7.058
3	f4	0.69	0.16	0.425	7.597
4	f5	0.71	0.1	0.223	7.356
5	f6	0.63	0.1	0.148	7.745
6	f8	0.54	0.21	0.102	7.289
7	MFT2	0.61	0.04	2.703	8.105
8	MFT3	0.73	0.09	1.371	8.630
9	Tingri	0.51	0.1	0.233	6.928
10	Kungco	0.44	0.09	0.090	7.181
11	Tibriko	0.69	0.14	0.055	7.127

2.4. Seismic Hazard Computation

The hazard computation was done using the CRISIS V 20.3 software. The enite study area was divided into 0.1^o x 0.1^o grid zones.

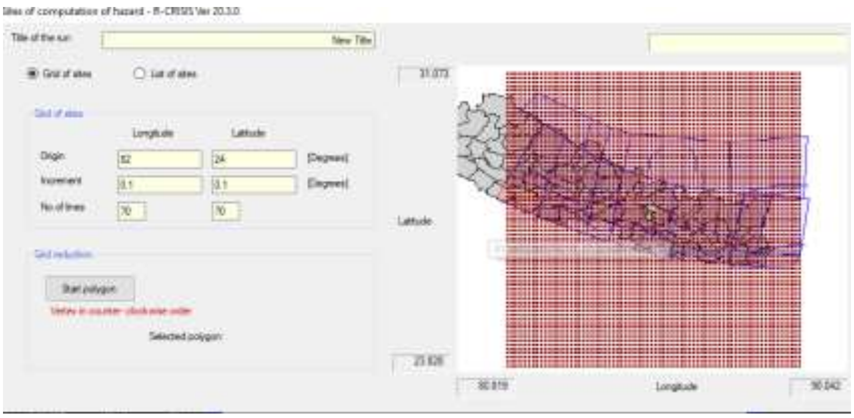

Figure 7: Defining Grid of Site and source geometry in CRISIS

After defining the site grid and source geometry the seismic parameters are entered into the corresponding seismic sources in the software. The attenuation relation given by Youngs was used for hazard computations.

3. RESULTS AND DISCUSSIONS

Seismic Hazard curve and Seismic Hazard map was obtained as the result of the SHA. The seismic hazard map was prepared for the 10 % probability of exceedance in 50 years.

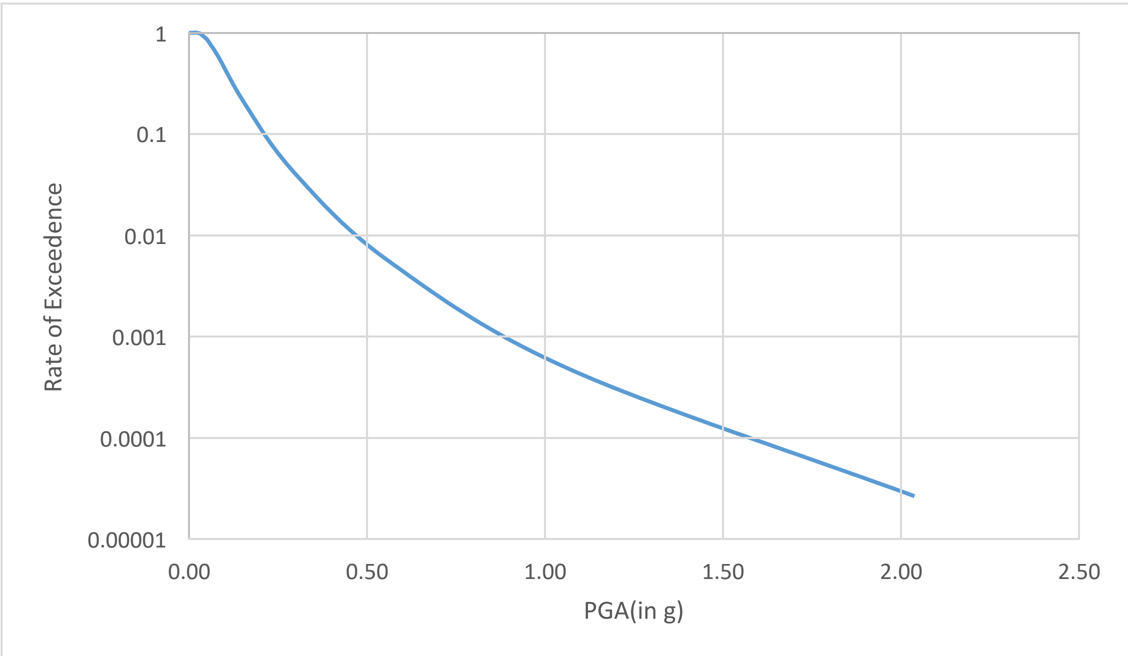

Figure 8: Seismic Hazard Curve for Circular Source Zone for Katthmandu

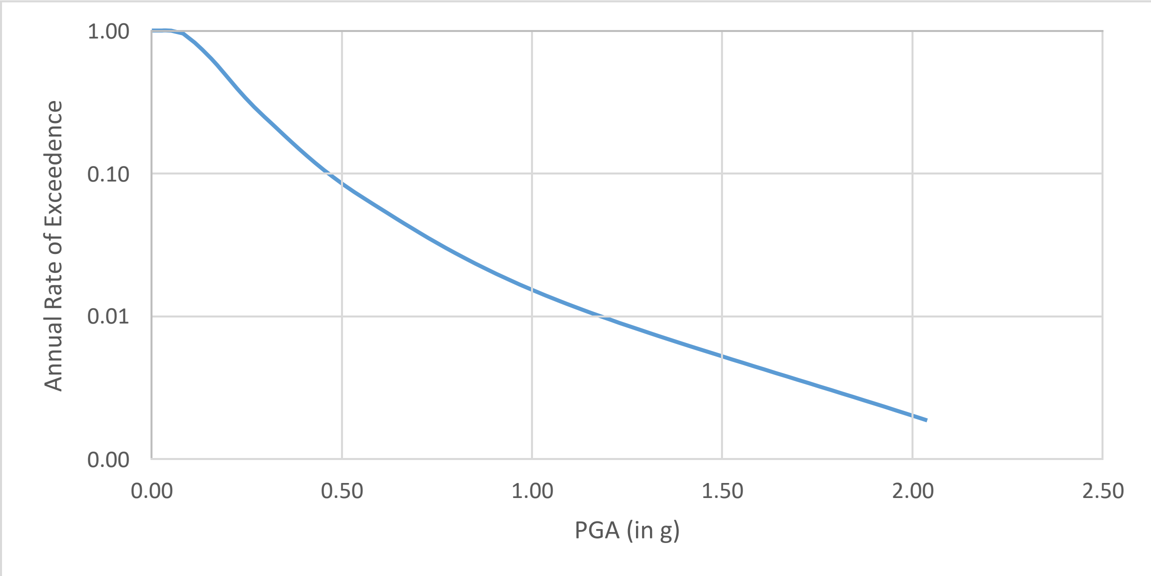

Figure 9: Seismic Hazard Curve for Linear and Areal sources for Kathmandu

From figure 8 and 9 we can see that PGA at Kathmandu for 10 % probability of exceedance in 50 years is 0.45g.

Similarly PGA is obtained for all gridded sites from both source model, and the PGA is summed with their respective weightage of the source model and then seismic hazard map is prepared.

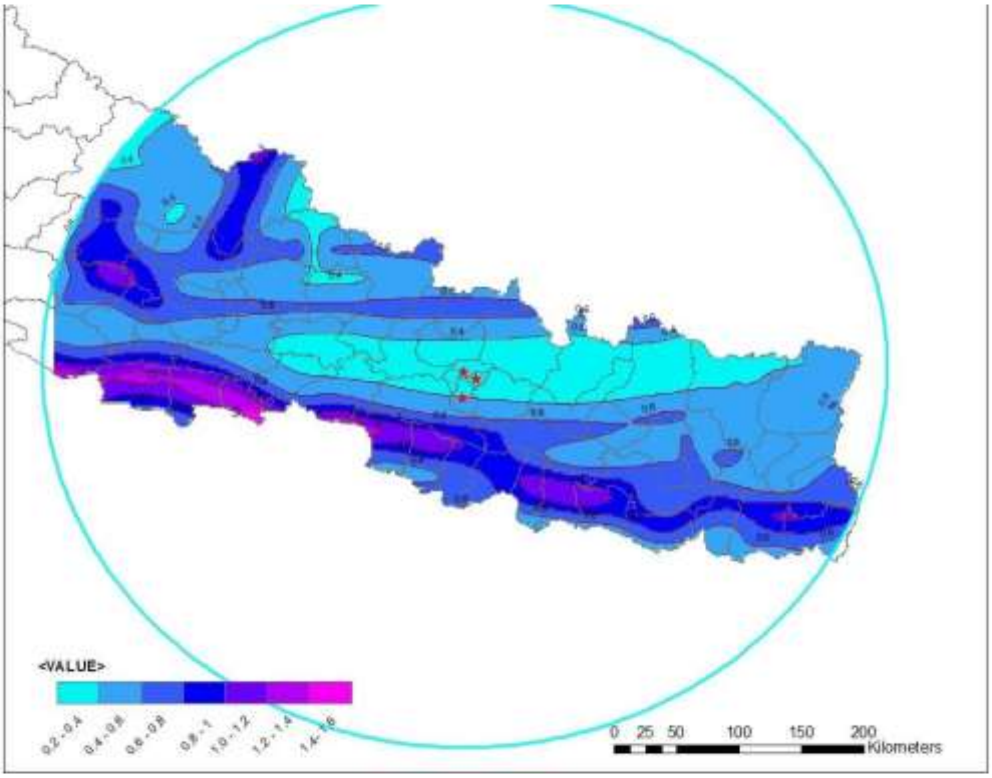

Figure 10: Seismic Hazard Map

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