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Probabilistic Seismic Hazard Analysis Of Dehradun City , Uttrakhand

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ABSTRACT

Dehradun is very old city and also rapidly growing urban area located in valley at foothills of Garhwal Himalayas. Dehradun city and adjoining region in western Himalayas is a is a very active seismic region of Himalayan belt , stretching from Pamir - Hindukush to Arkans in Burma.According to seismic zoning map of India , Dehradun city lies in Zone 4 and expected MSK intensity 8 .Dehradun city is located in the vicinity of twenty four independent seismic source zones which in reality are active faults. This creates uncertainties in size , location and the rate of recurrence of earthquakes. Probabilistic seismic hazard analysis provides a framework in which these uncertainties can be identified , quantified and combined in a rational manner to provide a more complete picture of the seismic hazard . This study presents a PSHA of the Dehradun city using the attenuation relationship given by Cornell et al (1979) in order to determinate various levels of earthquake-caused ground motion that will be exceeded in a given future time period.

Keywords: *seismic source zones , active faults , attenuation relationship , recurrence of earthquakes , seismic hazard , fault length , uncertainties*

I. Introduction

Dehradun city has been subjected to frequent earthquakes of moderate intensities and about once i a century to disastrous earthquake of higher magnitude . Greatest earthquake recorded in Dehradun region on September 1 , 1803. The magnitude of this earthquake was about 9.0.

Magnitude-Frequency data on earthquakes in Dehradun and its surrounding region is given below.

EARTHQUAKES OF MAGNITUDES IN RICHTER SCALE	5 TO 6	6 TO 7	7 TO 7.5	7.5 TO 8	>8
NO. OF EVENTS	36	11	2	1	2
RECURRENCE INTERVAL IN YEARS	2	5	10	31	190

TABLE 1 : Earthquakes in Dehradun and its surrounding region

Recent earthquake near Dehradun city are shown in figure 1 :

FIG 1 : Recent earthquakes near Dehradun

Dehradun city is encompassed betwee two major active fault systems , the Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT) , has experienced many disastrous earthquakes in the past . This city of approximately 500,000 inhabitants in the foothills of Himalayas is characterized by a considerable seismic hazard (Lang et al. , 2012) .Existence of densely populated , very old traditional stone buildings to new masonry and RC buildings , generally without the implementation of seismic code demonstrate the need for and challenges in the seismic hazard assessment of the city .

The seismic vulnerability of Dehradun is clearly justified, however study of the seismic hazard potential of the valley has not been performed systematically. The seismic hazard potential of a site is identified by conducting probabilistic seismic hazard analysis and constructing hazard curves. Hazard curve is a graphical representation of seismic intensity parameter such as peak ground acceleration and its annual probability of exceedence. It requires the identification of seismic source zones affecting the site, rate of recurrence of earthquake at each source, distance from each source to the site, probability density function of magnitude and systematic synthesizing of these to obtain the probability of exceedence of certain peak ground acceleration at the site due to all sources in its vicinity.

II. Numerical Study

The seismic hazard curve does not vary significantly across the length and breadth of the city due to its small size thus making it cogent to consider only the centre of the city. The twenty four independent seismic source zones, near the centre of Dehradun, which in reality are active faults are characterized in table 2 :

SOURCE ZONE	EQ SOURCES(Faults)	FAULT TYPE	FAULT LENGTH(KM)	MAGNITUDE (M_{max})	a	b	DISTANCE (KM)
1	MCT	RF	489.6534	7.7	4.79	.84	163.2178
2	AF	RF	50.0452	6.5	4.79	.84	16.68173
3	MBT	RF	605.287	7.8	4.79	.84	201.7623
4	ISZ	RF	102.6068	6.9	4.79	.84	34.20226
5	MCT 1	RF	574.5193	7.8	4.79	1	191.5064
6	MF	RF	27.42032	6.1	4.79	1	9.140160
7	MFT	RF	113.9163	6.9	4.79	1	37.97209
8	NAT	RF	245.923	7.3	4.79	1	81.97434
9	RT	RF	184.2846	7.2	4.79	1	61.4282
10	SAT	RF	98.63989	6.8	4.79	1	32.87996
11	TZ-2	RF	98.67167	6.8	4.79	1	32.89056
12	TZ-1	RF	172.4367	7.1	4.79	1	57.4789
13	TZ-3	RF	248.1017	7.3	4.79	1	82.70057
14	TZ-4	RF	76.76542	6.7	4.79	1	25.58847
15	TZ-5	RF	154.684	7.1	4.79	1	51.54932
16	G-4	RF	45.92785	6.4	4.79	1	15.30928
17	DT	RF	133.9915	7	4.79	1	44.66382
18	G-1	SS	17.02207	6	4.79	1	5.674022
19	G-2	SS	32.6743	6.3	4.79	1	10.89143
20	G-3	SS	21.02778	6.1	4.79	1	7.00926
21	MBF	SS	149.095	7	4.79	1	49.69834
22	R-1	SS	16.09106	6	4.79	1	5.363685
23	MORADABAD	NF	36.30643	6.3	4.79	1	12.10214
24	KFS	NF	43.29493	6.4	4.79	1	14.43164

TABLE 2 : Characteristics of seismic sources and magnitudes

Mean Annual Occurrence Rate :

The threshold magnitude is taken as 4.5 since smaller magnitude earthquakes are not believed to be capable of damaging structures and are thus unnecessary to consider for seismic hazard analysis. The mean annual occurrence rate of earthquake (ν) of magnitude larger than the threshold magnitude (m_o=4.5) calculated for each source using Guttenberg-Richter recurrence law is divided by 16.

$$v_i = \frac{10^{a-bm_0}}{16} \quad \text{(i = 1,2,3.....for all 24 sources)}$$

Where , a = overall occurrence rate of earthquake for each source
b = relative ratio of small and large magnitudes for each source

The mean annual occurrence rate of earthquake greater than magnitude 4.5 at each source is tabulated in Table3.

SOURCE	MEAN ANNUAL OCCURRENCE RATE(ν)
1	0.6395
2	0.6395
3	0.6395
4	0.6395
5	0.1218
6	0.1218
7	0.1218
8	0.1218
9	0.1218
10	0.1218
11	0.1218
12	0.1218
13	0.1218
14	0.1218
15	0.1218
16	0.1218
17	0.1218
18	0.1218
19	0.1218
20	0.1218
21	0.1218
22	0.1218
23	0.1218
24	0.1218

TABLE 3 : Mean annual occurrence rate of 10 sources

Probability Density Function Of Magnitude :

Each source is capable of producing earthquakes with a variety of magnitudes with an upper bound of maximum moment magnitude ($M_{w,max}$) and a common lower bound of the threshold magnitude ($m_o = 4.5$). The total range of earthquake magnitudes is divided into 7 equal intervals for all sources.

m_l - m_u	4.5-5.0	5.0- 5.5	5.5-6.0	6.0-6.5	6.5-7.0	7.0-7.5	7.5-8.0
Mean (m)	4.75	5.25	5.75	6.25	6.75	7.25	7.75

TABLE 4: Discretization of earthquake magnitudes

Each interval is discretely represented by its mean value. If the value of maximum moment magnitude of any source lies within any particular interval, the interval will have an upper bound value equal to the same maximum moment magnitude. The distribution of the earthquakes of various magnitude is assumed to follow Bounded Guttenberg-Ritcher model.

There are three cases now :

Case I :M_u , max> m_u

P (M=m) = P ($m_1 < m < m_u$) = $\frac{2.303*b*e^{-2.303\,b(m-m_0)}}{1-e^{-2.303\,b(M_{w,max}-m_0)}} * (m_u - m_1)$

Case II :$M_{w,max} < m_u$ and $M_{w,max} > m_1$

P (M = $\frac{m_1+M_{w,max}}{2}$) = P ($m_1 < m < M_{w,max}$) = $\frac{2.303*b*e^{-2.303\,b\left(\frac{m_1+M_{w,max}}{2}-m_0\right)}}{1-e^{-2.303\,b(M_{w,max}-m_0)}} * \left(M_{w,max} - m_1\right)$

Case III :$M_{w,max} < m_1$

P (M) = 0

The probability density function of magnitude for all the 24 sources are tabulated in table5 and plotted in figure3

SOURCE	MAGNITUDE = 4.75	MAGNITUDE = 5.25	MAGNITUDE = 5.75	MAGNITUDE = 6.25	MAGNITUDE = 6.75	MAGNITUDE = 7.25	MAGNITUDE = 7.75
1	0.59758	0.22715	0.08635	0.03282	0.01248	0.00474	0.0018
2	0.60907	0.23152	0.08801	0.03345	0.01272	0.00483	0.00184
3	0.59736	0.22707	0.08632	0.03281	0.01247	0.00474	0.0018
4	0.60215	0.22889	0.08701	0.03307	0.01257	0.00478	0.00182
5	0.59736	0.22707	0.08632	0.03281	0.01247	0.00474	0.0018
6	0.62463	0.23744	0.09025	0.03431	0.01304	0.00496	0.00188
7	0.60215	0.22889	0.08701	0.03307	0.01257	0.00478	0.00182
8	0.59902	0.2277	0.08655	0.0329	0.01251	0.00475	0.00181
9	0.59959	0.22792	0.08664	0.03293	0.01252	0.00476	0.00181
10	0.60341	0.22937	0.08719	0.03314	0.0126	0.00479	0.00182
11	0.60341	0.22937	0.08719	0.03314	0.0126	0.00479	0.00182
12	0.60028	0.22818	0.08674	0.03297	0.01253	0.00476	0.00181
13	0.59902	0.2277	0.08655	0.0329	0.01251	0.00475	0.00181
14	0.65158	0.206	0.06513	0.02059	0.00651	0.00206	0.00065
15	0.6491	0.20522	0.06488	0.02051	0.00649	0.00205	0.00065
16	0.65572	0.20731	0.06554	0.02072	0.00655	0.00207	0.00065
17	0.64952	0.20535	0.06493	0.02053	0.00649	0.00205	0.00065
18	0.6686	0.21139	0.06683	0.02113	0.00668	0.00211	0.00067
19	0.65789	0.208	0.06576	0.02079	0.00657	0.00208	0.00066
20	0.66414	0.20998	0.06639	0.02099	0.00664	0.0021	0.00066
21	0.64952	0.20535	0.06493	0.02053	0.00649	0.00205	0.00065
22	0.6686	0.21139	0.06683	0.02113	0.00668	0.00211	0.00067
23	0.65789	0.208	0.06576	0.02079	0.00657	0.00208	0.00066
24	0.65572	0.20731	0.06554	0.02072	0.00655	0.00207	0.00065

TABLE 5: Probability Density Function of magnitude P(M)

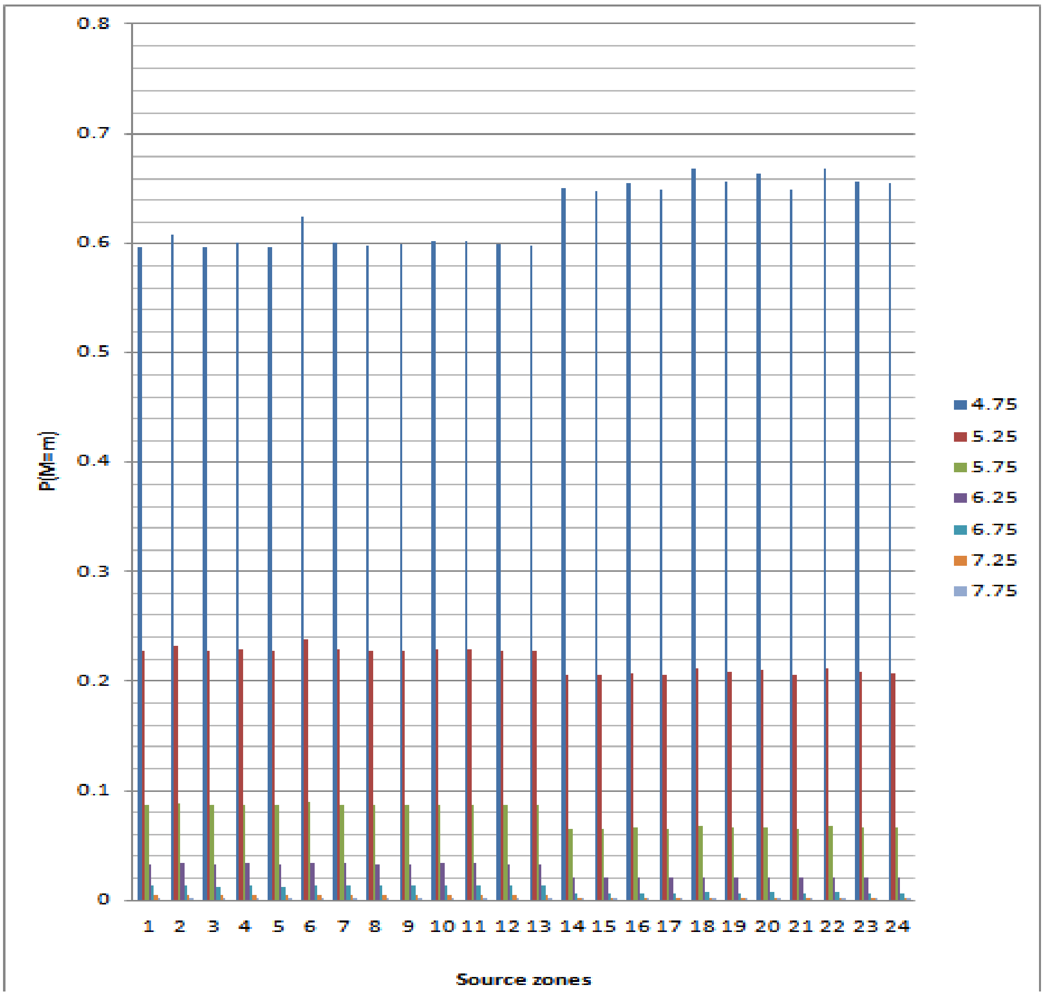

FIGURE 2 : Probability density function of magnitude

Probability Of Exceeding Certain Peak Ground Acceleration Level Provided A Fixed Magnitude Of Earthquake :

The attenuation relationship used for the Probabilistic Seismic Hazard Analysis is the one proposed by Cornell et al. (1979) for the mean of natural logarithm of Peak ground acceleration .

$$\ln PGA = 6.74 + 0.859\, M - 1.80 \ln (R+25)$$

where, PGA is in gal and $\sigma = \sigma_{\ln PGA} = 0.57$

The natural log of PGA is normally distributed, so the conditional probability of exceeding any PGA level (PGA*) is,

$$P\,(PGA>PGA^{*} \mid M=m, R=r) = 1 - \Phi \left(\frac{ln\ PGA^{*} - \ln PGA}{6}\right)$$

where, Φ( ) is the standard normal cumulative distribution function.

A total of 60 PGA levels starting from 0.01g m/s^2(9.81 gals) to 0.6g m/s^2(588.6 gals), i.e., ln(PGA*) have been considered in this hazard analysis.

All the source zones are point sources, so each source to site distance R is known to be r, consequently the probability of R = r is 1 and the probability of R ≠ r is 0.

$$P(R = r) = 1 \text{ and } P(R \neq r) = 0$$

Probability Of Exceeding Certain Peak Ground Acceleration Level :

Since all continuous distributions for M and R have been discretized, so the total probability of exceeding certain PGA level is given by,

$$\lambda \text{ (PGA > PGA*)} = \sum_{i=1}^{n_s} \nu \left(M_i > M_0\right) \sum_{j=1}^{n_m} \sum_{k=1}^{n_r} P \left(PGA > PGA^* \mid m_j , r_k\right) \text{ P } \left(M_i = m_j\right) \text{ P (} [R_i = r_k]$$

where, the range of possible M_i and R_i has been discretized to n_M and n_R intervals respectively. In this analysis, n_s = 24 sources, n_m = 7 and n_r = 1

$$\lambda \text{ (PGA > PGA*)} = \sum_{i=1}^{10} \nu \left(M_i > M_0\right) \sum_{j=1}^{6} P \left(PGA > PGA^* \mid m_j , r\right) P \left(M_i = m_j\right)$$

The total probability of exceeding certain PGA level is tabulated in table6.

PGA^*(Times g)	$\lambda(PGA>PGA^*)$
0.01	0.16689
0.02	0.11221
0.03	0.0666
0.04	0.04626
0.05	0.03326
0.06	0.02451
0.07	0.0183
0.08	0.01401
0.09	0.01187
0.1	0.00849
0.11	0.00748
0.12	0.00516
0.13	0.00407
0.14	0.00321
0.15	0.00345
0.16	0.00289
0.17	0.00245
0.18	0.00217
0.19	0.00176
0.2	0.00153
0.21	0.00132
0.22	0.00124
0.23	0.00106
0.24	0.00093
0.25	0.00084
0.26	0.00072
0.27	0.00062
0.28	0.00058
0.29	0.00051
0.3	0.00049
0.31	0.00047
0.32	0.00041

0.33	0.00036
0.34	0.00033
0.35	0.0003
0.36	0.00029
0.37	0.00025
0.38	0.00023
0.39	0.00022
0.4	0.00018
0.41	0.00017
0.42	0.00016
0.43	0.00015
0.44	0.00014
0.45	0.00013
0.46	0.00011
0.47	0.0001
0.48	0.0001
0.49	0.00009
0.5	0.00009
0.51	0.00008
0.52	0.00008
0.53	0.00007
0.54	0.00007
0.55	0.00006
0.56	0.00006
0.57	0.00005
0.58	0.00004
0.59	0.00003
0.6	0.00003

TABLE6: $\lambda(PGA > PGA*)\ \ for\ cumulative\ effect\ of\ all\ 24\ sources$

Poisson's Model :

The temporal occurrence of earthquake is described by using Poisson's model since the events of earthquake occurrence are assumed to be independent of each other in time and space. The rate of exceeding a certain PGA level atleast once in a period of "t" years is given by,

$$P\ (N\geq 1) = 1 - e^{-\lambda t}$$

The rate or probability of exceeding a range of PGA levels atleast once in 1 year, 50 years and 100 years is tabulated in table7.

PGA* (times g)	1-exp(-λt) All sources and t=1 yrs	1-exp(-λt) All sources and t=50 yrs	1-exp(-λt) All sources and t=100 yrs
0.01	0.153707	0.999762	1
0.02	0.106143	0.996341	0.999987
0.03	0.064431	0.964207	0.998719
0.04	0.045206	0.901036	0.990206
0.05	0.032713	0.810431	0.964063
0.06	0.024212	0.706389	0.913793
0.07	0.018134	0.599483	0.839586
0.08	0.013912	0.503663	0.75365
0.09	0.0118	0.447609	0.694865

0.1	0.008454	0.345903	0.572157
0.11	0.007452	0.312023	0.526688
0.12	0.005147	0.227405	0.403097
0.13	0.004062	0.18413	0.334356
0.14	0.003205	0.148282	0.274577
0.15	0.003444	0.158442	0.29178
0.16	0.002886	0.134545	0.250988
0.17	0.002447	0.115294	0.217295
0.18	0.002168	0.102821	0.19507
0.19	0.001758	0.084239	0.161382
0.2	0.001529	0.073647	0.14187
0.21	0.001319	0.063869	0.123659
0.22	0.001239	0.060117	0.11662
0.23	0.001059	0.05162	0.100575
0.24	0.00093	0.045435	0.088806
0.25	0.00084	0.04113	0.080569
0.26	0.00072	0.03536	0.069469
0.27	0.00062	0.030524	0.060117
0.28	0.00058	0.028584	0.05635
0.29	0.00051	0.025178	0.049721
0.3	0.00049	0.024202	0.047819
0.31	0.00047	0.023226	0.045913
0.32	0.00041	0.020291	0.040171
0.33	0.00036	0.017839	0.03536
0.34	0.00033	0.016365	0.032461
0.35	0.0003	0.014888	0.029554
0.36	0.00029	0.014395	0.028584
0.37	0.00025	0.012422	0.02469
0.38	0.00023	0.011434	0.022738
0.39	0.00022	0.01094	0.02176
0.4	0.00018	0.00896	0.017839
0.41	0.00017	0.008464	0.016856
0.42	0.00016	0.007968	0.015873
0.43	0.00015	0.007472	0.014888
0.44	0.00014	0.006976	0.013902
0.45	0.00013	0.006479	0.012916
0.46	0.00011	0.005485	0.01094
0.47	1E-04	0.004988	0.00995
0.48	1E-04	0.004988	0.00995
0.49	9E-05	0.00449	0.00896
0.5	9E-05	0.00449	0.00896
0.51	8E-05	0.003992	0.007968
0.52	8E-05	0.003992	0.007968
0.53	7E-05	0.003494	0.006976
0.54	7E-05	0.003494	0.006976
0.55	6E-05	0.002996	0.005982
0.56	6E-05	0.002996	0.005982
0.57	5E-05	0.002497	0.004988
0.58	4E-05	0.001998	0.003992
0.59	3E-05	0.001499	0.002996
0.6	3E-05	0.001499	0.002996

TABLE 7: Rate of exceeding given PGA level atleast once in ’t’ years

Seismic Hazard Curve :

Seismic hazard curve gives a strong basis for analyzing the seismic hazard potential at a site. The seismic hazard curve presented in figure4 gives the probability of exceedence of certain PGA level (from 0.01g to 0.6g where g = 9.81m/s^2) at the Dehradun city in 1 year, 50 years and 100 years.

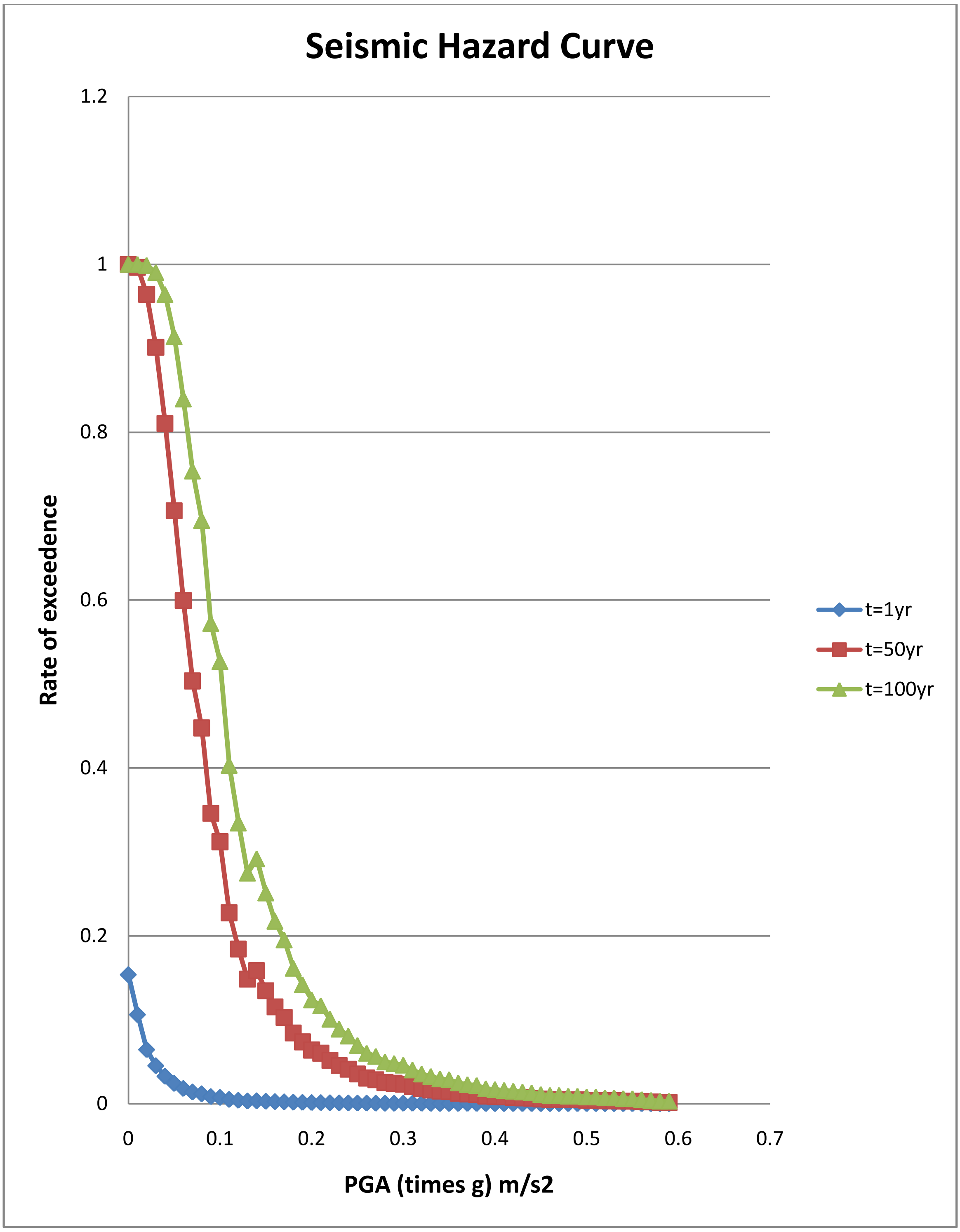

FIGURE 3: Seismic Hazard Curve

Conclusion

The probability density function for magnitude lends credible support to the frequent occurrence of moderate earthquakes and occasional occurrence of disastrous earthquakes. Earthquake source zone 3 (MBT) and 7 (MFT) are more dangerous than the other sources as these two could induce higher magnitude which is disruptive. If a magnitude of around 7 occurs at Dehradun, it can be inferred that source zones 3 and/or 7 have become dominant. Out of the two, source 3 is particularly threatening because it has greater mean annual occurrence rate of earthquake exceeding the threshold than source 7. Similarly, the probabilistic seismic hazard analysis yields unsurprisingly high value of peak ground acceleration that is likely to occur any time in future at Dehradun city. It is evident from the seismic hazard curve that there is a 2% rate of exceeding PGA of 0.31g in 50 years which is comparable to MMI scale of VIII and a 10% rate of exceeding PGA of 0.18g in 50 years comparable to MMI scale of VII. The PGA level of 0.5g to 0.55g is often compared with MMI scale IX (Violent earthquake). The probability of such an earthquake in Dehradun once in a century is around 0.007 or 0.7%; so the apprehension for a “Big One” in Dehradun is pertinent.

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