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Seismic Hazard Assessment of Kavre Valley Municipalities

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Abstract

Probabilistic seismic hazard assessment in terms of peak ground acceleration at bed rock of Kavre Valley municipalities (Banepa, Panauti and Dhulikhel) has been carried out. A detailed catalogue of historical and recent seismicity within 350 km radius around the Banepa, Panauti and Dhulikhel has been compiled and new seismotectonic map and seismic distribution map has been generated for the region. Twenty five numbers of areal sources has been proposed for the study. Characterization and identification of these sources were done by plotting the refined catalogue in the map of Nepal. The completeness of the data has been checked. Finally earthquake data were analyzed statistically for all areal sources and the seismicity of the region around the city sites and magnitude frequency relationship have been evaluated by defining 'a' and 'b' parameters of Gutenberg-Richter recurrence relationship for corresponding areal sources. Finally, probabilistic hazard maps corresponding to 10% and 2% probability of exceedance in 50 years have been developed for the study area.

Keywords

PSHA – seismo-tectonic – earthquake – faults – attenuation laws

1. Introduction

Nepal lies under one of the highly seismically very active part of the world. Among the various natural disasters, earthquake is the most dangerous which can cause plenty of damages in terms of human casualties and damage of the physical property. On an average, about 10,000 people die each year due to structural and non-structural damage caused by earthquake, while economic losses are billions of dollars and often large percentage of the gross national product of the country is highly affected. With high annual population growth and one the highest urban densities in the world, Kathmandu Valley and its surrounding municipalities and other parts of Nepal are under the earthquake risk. Newly constructed buildings and other services must be earthquake resistance. For this purpose it is necessary to analyze and quantify the hazard mainly ground shaking.

Nepal lies under highly seismic zone which has been proved by historical earthquakes. During the century thousands of people have lost their lives in major earthquake in Nepal. The most destructive was Bihar/Nepal earthquake in 1934 AD[1]. The similar size of earthquake has occurred in 19th century; 1810, 1833, and 1866. From the seismic record extended back to 1680, 1407, 1259 and 1255 suggest that the earthquake of similar size likely occur approximately every 75 years. It is obvious that the next large earthquake to strike near Kathmandu Valley and its surrounding municipality and VDCs would cause significantly greater loss of life, structural and non-structural damage and economic losses than the past earthquakes. To reduce or mitigate such type of loss from upcoming earthquakes, the main task of earthquake engineering professional is to work for earthquake resistance design of structures. Hence, it is necessary to quantify site specific design ground motion parameters. So an attempt of seismic hazard assessment of Municipalities of Kavre Valley (Banepa, Dhulikhel and Panauti) has been carried out. Finally seismic hazard map and uniform hazard curve for the study area (Banepa, Dhulikhel and Panauti) which is located at the 25 Km east of Kathmandu Valley, is area situated between the latitudes of N 27°33'30" and N 27°39'00" and the longitudes of E 85°29'00" and E 85°34'30" and consists of combined boundaries of the municipalities corresponding to 10% and 2% probability of exceedances in 50 years have been developed for the region.

2. Regional Seismicity

Historical data is very scanty in the case of Nepal. Instrumental data are also very limited because instrumental monitoring of earthquakes in Nepal started only 25 years ago. The other data comes from the United States Coast and Geodetic Survey(USCGS) U.S.A. and International Seismological Centre (ISC), seismic catalogue have been developed. Historical destructive earthquakes, their impacts as well as the threats of future earthquakes have been studied by well-known researcher and scientists such as Roger Bilham [2] and Khattri, K. N. (1987, 1992). They have collected and compiled historical earthquake data in the Himalayan region. Epicenters of earthquakes which occurred before 1900 were estimated after the interpretation of macroseismic data (e.g., destruction data) by the corresponding authors. In the last century, the Himalayan Range has hosted four destructive great earthquakes, killing many people and destroying economy of the region. The region between the 1905 Kangra Earthquake (M7.8) and 1934 Bihar-Nepal Earthquake (M8.1) has not produced any great earthquake $(M > 8)$ possibly at least since the last five hundred years. This stretch of the Himalaya has been identified as 'seismic gap' [2] and stands as a potential site for future great earthquake(s). Instrumentally recorded seismicity data for earthquakes having magnitude greater than or equal to 4.0 after 1964 AD are available from International Seismological Centre, UK. Department of Mines and Geology, Government of Nepal has been running a network of seismic stations since 1995. The detection threshold of the network is local magnitude (ML) for any earthquake that occurs in Nepal [2]. Recent M7.8 (USGS) April 24, 2015, Barpak earthquake 2015 has ruptured eastern part of Nepal Himalaya whereas still some seismic gap is remaining in the western part of Nepal Himalaya. The monitoring of local seismicity by DMG has revealed an exceptional picture of seismic activity in the Nepal Himalaya. Distribution of significant earthquakes along Himalayan region has been presented in Figure 1.

A continuous belt of seismic activity has been observed at the front of the Nepal Himalaya [3].The microseismic activity in the Nepal Himalaya is characterized by shallow focus $(10km < depth < 25km)$ earthquakes [4]. Comparatively, shallow focus earthquake are more destructive than deeper ones. The epicentral region of the 1988 earthquake is an exception all along the Himalaya, where the focal depth of earthquakes ranges up to upper mantle 58 km,[5]. The seismicity belt is narrow (50 km) in the east of 820 E and is divided into two sub-parallel belts in the west of 820 E.The study area (Banepa, Dhulikhel and Panauti) falls in the western extremity of the source region that produced the 1934 great earthquake. It is believed that this region has to wait for some 5 hundreds of years before it gets matured to produce great earthquake $(M > 8.0)$ again, but we should not ignore the possibility that this region has collected some energy in the last about 80 years (after the 1934 Bihar-Nepal Earthquake) and this energy might be equivalent to one M7.0 earthquake at the present (Figure 2).

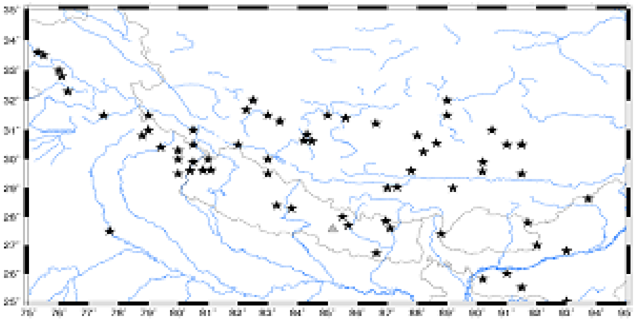

Figure 1: Distribution of earthquakes (M.6) after ISC 2012

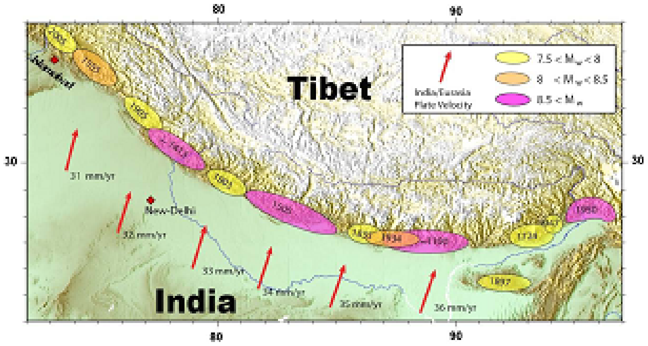

Figure 2: Ruptures in the Himalayan Earthquakes

The main (M7.8) that occur following a large earthquake, in the same general area as the earthquake and during the following days-to-years. Both the magnitude 7.8 Gorkha mainshock and the subsequent May 12 magnitude 7.3 aftershock have triggered aftershocks (USGS). Aftershocks have the potential to create damage, just like other earthquakes. There is huge seismic gap in the western part also which might occur any time in the future and massive damage than the Barpak M7.8, 2015 earthquake.

The belt of intense microseismic activity in central Nepal coincides with the front of the Higher Himalaya and close to the MCT. This belt correlates well with the zone of maximum vertical uplift revealed by spirit leveling data [6] and maximum gradient of horizontal GPS velocities[7]. The microseismic activity is interpreted to reflect the strain accumulation[4]in the Himalaya, in the inter-seismic period. The belt further correlates with the location of geometrical ramp, inferred to join the locked portion and creeping part of the MHT. The historical earthquakes and micro faults have been presented in Figure 3.

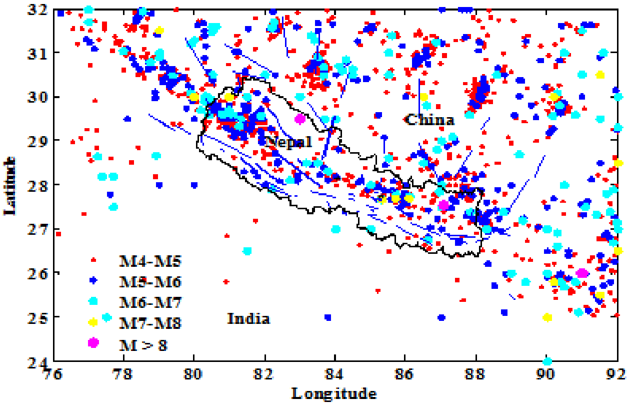

Figure 3: Seismicity of the region

Seismotectonic map is shown in Figure 4. It was generated using interpreted faults within the radial distances of 350km from study area and formerly developed 6 nos. of areal sources [8] has been used for identification of seismic sources. Total of 25 areal sources have been identified in an area of 350km radius around the study area. Earthquake data collected from various websites, agencies and available literature have been superimposed on the base map along with all tectonic sources. Figure 4 shows the seismotectonic model for Banepa, Dhulikhel and Panauti region. The earthquake catalogue for this area was prepared by combining and consolidating the available information from different sources and covers the time period 1255-2014. The earthquake data were collected from different sources, i.e., United States Geological Survey (USGS). Department of Mines and Geology (DMG), International Seismological Centre (ISC).In addition to that, a few more data were collected from the catalogues published by different researchers such as[9]. Uniformity of data base was prepared using [10],[11]and [12].

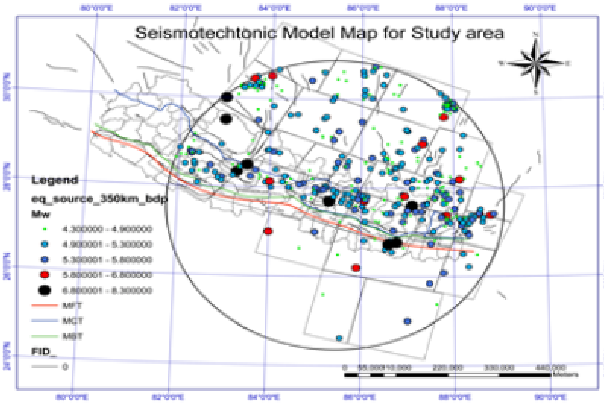

Figure 4: Earthquake sources

3. PSHA

The Probabilistic Seismic Hazard Assessment (PSHA) analysis refers to the estimation of some measure of the strong earthquake ground motion expected to occur at a selected site. This is necessary for the purpose of evolving earthquake resistant design of a new structure of importance. One important application of hazard analysis is the preparation of seismic zoning maps for generalized applications. Present study deals with the estimation of peak ground acceleration based on one of the two state of art methods of seismic hazard analysis probabilistic seismic hazard analysis. Probabilistic hazard analysis (PSHA) uses probabilistic concepts to predict the probability of occurrence of a certain level of ground shaking at a site by considering uncertainties in the size, location, rate of occurrence of earthquake, and the predictive relationship. The PSHA is carried out using the following steps [10], [13]and [14].The first step is to identify and characterize the earthquake sources probabilistically. This involves assigning a probability of occurrence of an earthquake at a point within the source zone. Generally, a uniform probability distribution is assumed for each source zone, that is, it is assumed that the earthquake originating from each point within the source zone is equally likely. Secondly, the probability distribution of the source to site distance, considering all points in the source zone to be potential sources of an earthquake, is determined from the source geometry.The second step is to characterize the seismicity of each source zone.The seismicity is specified by a recurrence relationship indicating the average rate at which an earthquake of a particular size will be exceeded.The standard Gutenberg–Richter recurrence law is used for this purpose, that is,

$$\lambda_m = (10)^{a-bM} = exp(\alpha - \beta M) \tag{1}$$

Here,λ_m denotes the average return period of the earthquake of magnitude m.

If earthquakes lower than a threshold value m_0 are eliminated,then the expression for λ_m is modified as:

$$\lambda_m = Vexp[-\beta(m - m_0)] \tag{2}$$

where,
$V = exp(\alpha - \beta(m_0), m > m_0,\ \alpha = 2.303a, \beta = 2.303b$
Similarly,if both the upper and lower limits are incorporated, then $\lambda_m$is given by:

$$\lambda_m = \frac{Vexp[-\beta(m - m_0)] - exp[-\beta(m_{max} - m_0)]}{1 - exp[-\beta(m_{max} - m_0)]} \tag{3}$$

The CDF (cumulative distribution function) and PDF (probability density function) of the magnitude of earthquake for each source zone can be determined from this recurrence relationship as:

$$f_M(m) = \frac{\beta exp[-\beta(m - m_{min})]}{1 - exp[-\beta(m_{max} - m_{min})]} \tag{4}$$

In the third step, a predictive relationship is used to obtain a seismic parameter (such as the PGA) at the site for a given magnitude of earthquake and source to site distance for each source zone. The uncertainty inherent in the predictive relationship (attenuation law) is included in the PSHA analysis. Generally, the uncertainty is expressed by a log normal distribution by specifying a standard deviation for the seismic parameter and the predictive relationship is expressed for the mean value of the parameter.Finally, the uncertainties in earthquake location, earthquake size, and ground motion parameter prediction are combined to obtain the probability that the ground motion parameter will be exceeded during a particular time period.This combination is accomplished through the following standard equation[13]and [15].

$$V_{y^*} = \sum_{i=1}^{N_s} V_{i_{M\,\min}} \int\int P[Y > y^*|m,r] f_{Mi}(m) f_{Ri}(r)\ \text{dm dr} \tag{5}$$

$$V_{y^*} = \sum_{i=1}^{N_s}\sum_{j=1}^{N_r}\sum_{k=1}^{N_m} V_{i_{M\,\min}} \rho_i P[Y > y^*|m,r] P[M = m] P[R = r] \Delta m \Delta r \tag{6}$$

Where, N_s is number of sources in the region, $V_{iMmin} = exp(\alpha_i - \beta_i m_{min})$is total rate of exceedences of threshold magnitude (M=5.0) is taken in this study.

$P[Y > y^*|m,r]$ is conditional probability that chosen acceleration exceeded for a given magnitude (M) and distance (R), and $f_{Mi}(m)$ ans f_{Ri}(r) are probability density functions for magnitude and distance respectively.Here,M and m are used as random variable and specific value for magnitude respectively.The first term within the integral considers the prediction uncertainty,the second term considers the uncertainty in earthquake size,and the third term considers the uncertainty in location of the earthquake.The above uncertainties for all source zones are considered by way of the double integration summation. A seismic hazard curve is then constructed by plotting the rate of exceedence of the seismic parameter for different levels of the seismic parameter and calculated by using CRISIS 2007.

4. Ground Motion Attenuation

Ground motion attenuation relations so far developed, can be categorized into four groups, shallow crustal earthquakes in active regions, shallow crustal earthquakes in stable regions and subduction zones focusing America and Japan where big earthquake database available. No earthquake attenuation relations have been developed for the Himalayan region specially. Because of unavailability of sufficient data, here, instead of developing new equation for the region, attenuation equations among already developed equations for subduction zone Crouse[16], Fukushima and Tanaka[17], Molas and Yamazaki[18], Young [19], Gregor[20]Atkinson and Boore [21],Kanno[22], Zhao[23] 2006 which supports the tectonics, geology and faulting system are studied.[21]. Youngs[19] has been developed from worldwide seismic environment including Crouse [16]. Zhao[23] relation uses Fukushima and Tanaka[17], and Molas and Yamazaki[18] and is derived from Japanese earthquake database. Kanno [22] relationship has also been developed based on Japanese catalogue adding shallow crustal earthquakes from outside Japan. Atkinson and Boore[21] compiled the database of both Youngs citeYoungs1997and Crouse[16], added many recent earthquakes data from Japan through 2001, formed four times big database for subduction zone events and developed new ground motion relation. Gregor [20] relation has been also developed for Cascadia subduction zone. Both attenuation equations have focused on Cascadia fault geometry and ground motion parameter is estimated based on fault distances. Considering these five equations represent typical seismic environment - Youngs[19], Gregor [20], and Atkinson and Boore [21], Kanno [22]. 2008 and Zhao [23] attenuation laws are selected for this study. Among them, Atkinson and Boore [21] predicts lowest and Zhao [23] highest values. There is no certainty that future earthquake obey any particular attenuation law. Thus, seismic hazard is estimated considering all attenuation giving equal weight. In subduction zones, there is possibility of occurring both interface and intra-plate earthquakes. None of the past earthquakes in the Himalayan regions have been categorized as interface or intra-plate earthquake. Regarding the information available in the region, there is shallow angle thrust faults which is very similar situation of subduction interface earthquakes as in other part of the world. For intra-plate, earthquakes are basically categorized by deep focus and volcanic activities. There are no reported evidences of volcanic activities in the central Himalayas. So, subduction interface ground motion relations are considered in this study. Most of the earthquakes occurring in Nepal are considered to be interface events due to subduction of Indian plate beneath the Eurasian plate. Hence, in this research work attenuation relationship suitable for subduction zone proposed by Youngs [19] is used. For the rock site it is expressed by the following relation:

$$\begin{aligned}\ln(y) =& 0.2418 + 1.414M + C_1 + C_2(10-M)^3 \\ &+ C_3\ln(r_{rup} + 1.7818e^{0.554M}) \\ &+ 0.00607H + 0.3846Z_T \end{aligned} \tag{7}$$

Standard Deviation = $C_4 + C_5M$

Where, y is spectral acceleration in g, M is moment magnitude,r_{rup} is closest distance to rupture (km), H is depth (km) and Z_T coefficient for source type which is 0 for interface event and 1 for intra-slab event. The Coefficients C_1, C_2, C_3, C_4 and C_5 are taken from Young et. al [19] relation. Similarly, for soil site the attenuation relationship is given by the following equation:

$$\begin{aligned}\ln(y) =& -0.6687 + 1.438M + C_1 + C_2(10-M)^3 \\ &+ C_3\ln(R + 1.0978e^{0.617M}) \\ &+ 0.00648H + 0.3846Z_T \end{aligned} \tag{8}$$

Standard Deviation = $C_4 + C_5M$

Where, y, M, H and Z_T are the same as defined above and the coefficients C_1, C_2, C_3, C_4 and C_5 are taken in Young's et al[19]. The standard deviation of the predicted parameter like peak ground acceleration and spectral acceleration are calculated in order to account for uncertainty related with scatter of seismic data and randomness in rupture of seismic sources. From the probability distribution of particular ground motion parameter, the probability that this parameter Y exceeds a certain value,$y*$, for an earthquake of a given magnitude, m, occurring at a distance, r, is given by

$$P[Y > y*|m,r] = 1 - F_y(y*) \tag{9}$$

Where, F_Y(y) is the value of the cumulative distribution function of Y at m and r. The value of F_Y(y) depends on the probability distribution used to represent Y. In general, ground motion parameters are usually assumed to be log normally distributed (the logarithm of the parameter is normally distributed); however, the unbounded characteristics of that distribution can attribute to a nonzero probability to unrealistic values of the ground motion parameters.

5. Results and discussions

Following the above mentioned theory and procedure and CRISIS 2007[24] software, obtained results are presented in the following figures.

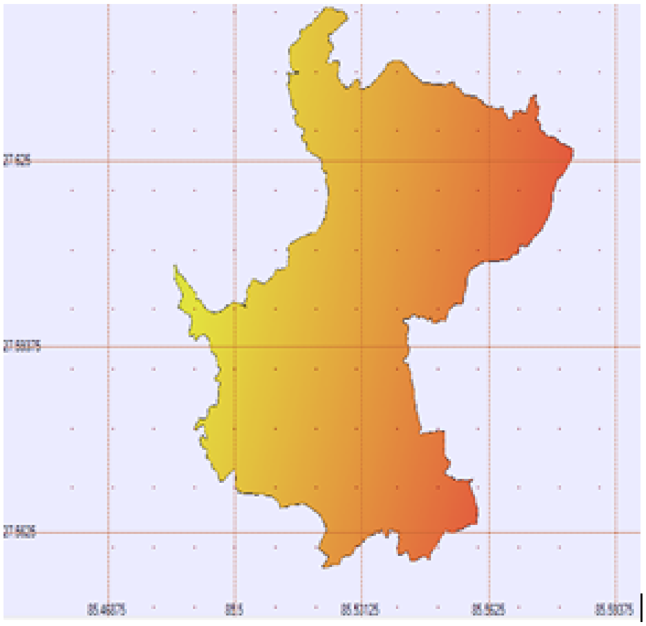

Figure 5: PGA for 10% exceedance in 50 years rock site

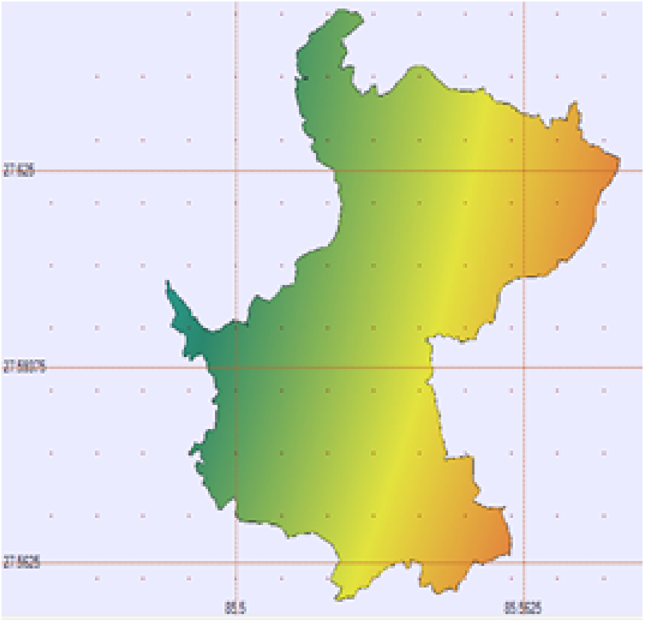

Figure 6: PGA for 2% exceedance in 50 years rock site

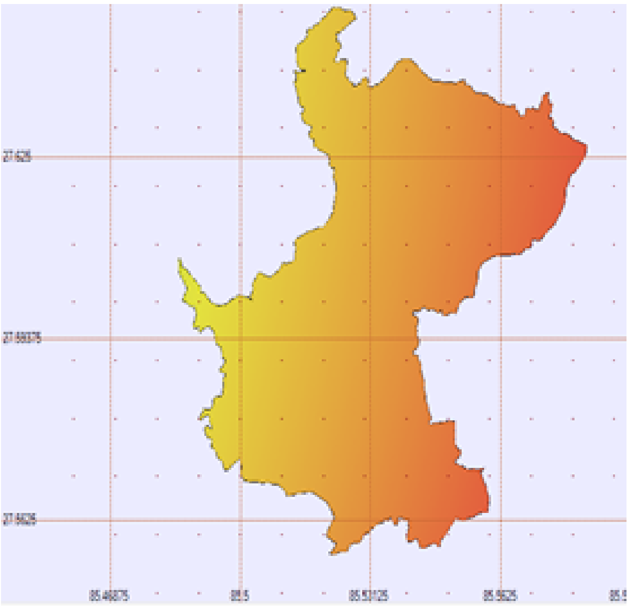

Figure 7: PGA for 10% exceedance in 50 years soil site

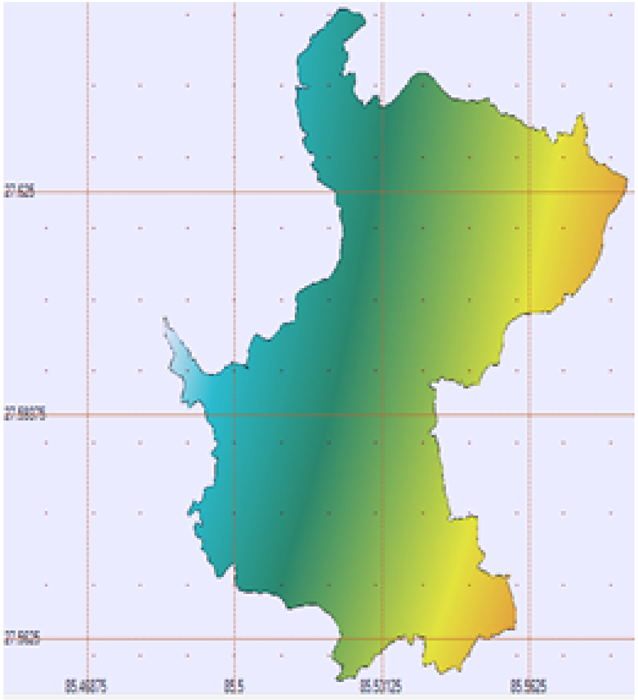

Figure 8: PGA for 2% exceedance in 50 years soil site

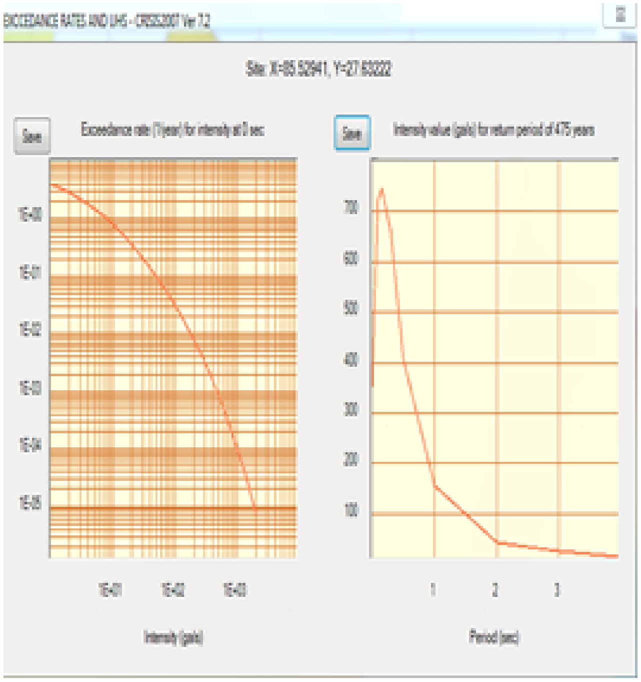

Figure 9: UHC - RT 475 yrs PGA 0.31g at rock Banepa

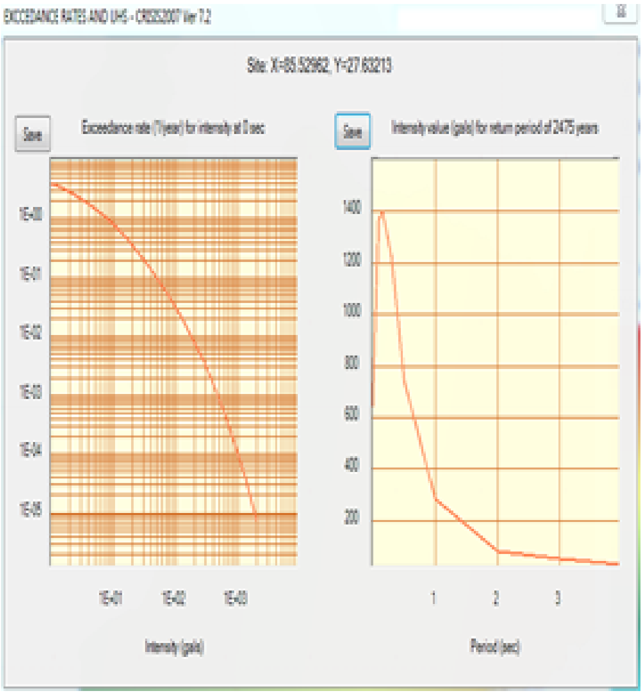

Figure 10: UHC for RT 2475 yrs PGA 0.6g at rock Banepa

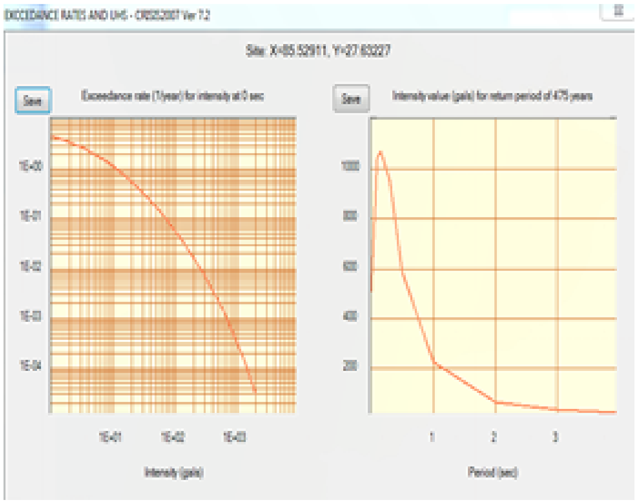

Figure 11: UHC for RT 475 yrs PGA 0.4g at soil Banepa

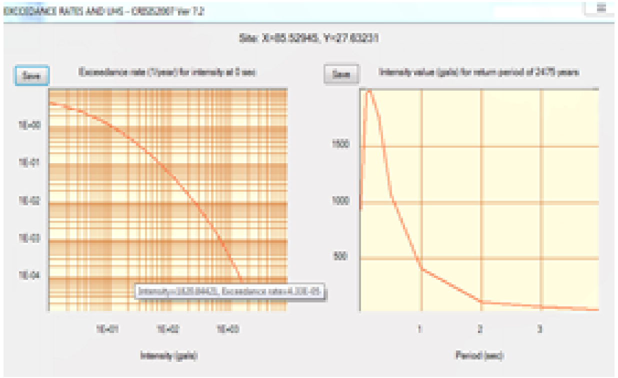

Figure 12: UHC for RT 2475 yrs PGA 0.83g at soil Banepa

6. Conclusion

The precision and accuracy of a PSHA depends on the accuracy with which uncertainty in earthquake size, location, recurrence and effects can be characterized and errors incorporated in attenuation model. Need of proper method of seismic risk evaluation in order to make decisions, planning and seismic risk reduction process to address the issue by development of site specific elastic response spectra for advocating infrastructure development is the need of today. Further research is recommended for determining the Gutenberg–Richter parameters (a, b) as it is highly governing factor for the precise result in seismic hazard analysis. Other limitation can be the selection of suitable attenuation relationship and proper use of other attenuation model to define standard error limit. Strong recommendation to develop our own attenuation relationship for the particular region is utmost important. Seismic PGA Intensity is increasing from North-Western and South-Western side to North-Eastern and South-Eastern side ranging from 285gal(0.29g) to 385 gal(0.35g) for Bed Rock at 10% PE in 50 years due to presence of active areal source zone closest to North-Eastern and South-Eastern side of research area (Banepa, Dhulikhel and Panauti).Surface Level Peak Ground acceleration is increasing from North-Western and South-Western side to North-Eastern and South-Eastern side ranging from 485gal(0.46g) to 537gal(0.55g) for free field at 10% PE in 50 years due to presence of active areal source zone closest to North-Eastern and South-Eastern side of research area (Banepa, Dhulikhel and Panauti) 25 numbers of seismic aerial sources has been made considering fault/thrust orientation, magnitude potential, number and density of earthquake and epicentral depth including significant earthquake, modified and revised as suggested By BECA[25]. It also needs further refinement to develop reliable b value to define site specific seismicity.

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