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Probabilistic Seismic Hazard Analysis for Nepal Using Areal and Longitudinal Faults Source

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Abstract

Probabilistic seismic hazard analysis is carried out for region enclosed with longitude and latitude 81 31, 80.5 30, 80 29.5, 80 28.5, 81 28, 86 26.2, 88.5 26, 88.5 28, grid spacing of five kilometers each (9842 sites) by using python based global earthquake model Open quake engine. Since the no specific sources are defined for the region, logical tree approach is used by considering the different area source and Longitudinal fault sources. Earthquake catalogue are collected from different sources start from 1255 to 2018 November having magnitude greater than 4 Mw. All the data are converted into moment magnitude by appropriate relationship, repeated events are removed manually. Minimum magnitude considers as 4.5 Mw and maximum magnitude calculated from empirical relation developed by researcher. Declustering using Gardner and Knoff (1974) windowing algorithm and assume that the earthquake catalogue followed possion's distribution. Completeness for each source has been performed using stepp 1972, catalogue consideration after 1918. The seismicity of the Nepal is very complex and no also no any specific ground attenuation relationship is derived so, in the current research mix type of GMPEs derived for active shallow crustal and subduction interference have been used by giving the weightage by considering the uniform velocity 760 m/sec. The peak ground acceleration (PGA), for 1%, 2%, 5%, 15% and 40% probability of exceedance in 50 years are Obtained the contour and intensity of PGA plots by Using ArcGIS.

Keywords

Seismic Hazard Analysis, Areal source, Faults, Earthquakes, Open-Quake, Logical Tree, PGA

1. Introduction

Earthquake is one of the most devastating natural disasters which can cause lots of damages within few minutes in terms of human life and properties. Nepal lies in seismically very active zone with records of occurrence of about 17 percent of largest earthquakes in the world [1]. It is located on the subduction region formed by the convergence of Indian and Eurasian plates at the depth of 4-18 km with low dip angle of about 10 degree [2], where the Indian plate is moving towards the Eurasian plate at the rate of 30-40 mm/year [3] resulting in the accumulation of large amount of strain energy which can generate Mw 8+ earthquakes [4]. A total of 92 active faults have been mapped throughout the country by the study of BECA World International.Among them MFT MBT and MCT are most active thrust. Since 1826, Nepal has experienced 206 earthquakes of magnitude greater than or equal to 5 magnitude. Among them major earthquakes greater than Magnitude of 7 occurred in 1255, 1344, 1408, 1505, 1681, 1767, 1833, 1866, 1916 Aug 28, 1934 Jan 15 and 2015 April. Two strong shocks – M7.8 and M7.3 of Recent Gorkha Earthquake 2015 followed by series of aftershocks prompted devastating impact claiming lives and damages of properties on Nepal. More than 8,702 people were killed, more than 23,000 were injured, and thousands of people became homeless [5]. Nepal is in the 11th position in the list of most vulnerable country of earthquake in the world, and from the perspective of probability of human casualties in the city, Kathmandu holds the 1st position.Statistics of past earthquake occurrence shows that we can expect two earthquakes 7.5 - 8 local magnitude in every forty years and of magnitude greater than 8 Mw in every eighty years [6]. Earthquakes claim an average loss of 290 million (NRs) annually in Nepal [1]. Global records show 154 out of 245 nations have experienced more than 7000 damaging earthquakes with damage of 2.9 trillion US dollars between 1900 and 2012 [7]. The main objective of earthquake engineering is to design the structure capable of withstanding the given level of shaking produced by the seismic source. Seismic hazard refers to the severity of ground motion at a site of the structures by considering all available databases on seismicity, tectonics, geology and attenuation characteristics of the seismic waves in the area of interest to provide an estimate of the site-specific design ground motion. Seismic hazard analysis began in nineteenth century by Cornel et al.,1968 for the hazard related effect minimization and to reduce seismic risk. In the contest of Nepal, the seismic hazard analysis was started by a team of BECA World International (New Zealand) in association with SILT Consultants (P.) Ltd. (Nepal), TAEC Consult (P.) Ltd. (Nepal), Golder Associates (Canada) and Urban Regional Research (USA). (1993). Seismic Hazard Mapping and Risk Assessment for Nepal has been also performed by many researchers Pandey et. al., Maskey P.N., Parajuli et. al., Thapa and Guoxin, Chaulagain et. al., Bhattrai et. al. etc.

2. Tectonic of Nepal

The Nepalese Himalayas is the youngest mountain range of the world formed by the subduction of the Indian tectonic plate under the Eurasian Plate. The region is seismically very active even now. Out of 2400 km, 800 km of the Himalaya range lies within the boundary of Nepal. The narrow width of Nepal, which is only about 193 km itself, can be subdivided into Indo-Gangetic Plain, Sub-Himalayan, Lesser Himalayan, Higher Himalayan and Tibetan Tethys zone separated by four fault systems-Main Central Thrust (MCT), Main Boundary Thrust (MBT) and Himalayan Frontal Thrust (HFT) and South Tibetan Tethys system (STDS) running east to west throughout the length of Nepal. MFT, separating Sub-Himalayan and the Indo-Gangetic Plain, is a very active thrust which subsume several active faults like SanguKhola fault, Jumla Fault, 140 km Long Barigadh faults, 17 km Long Dorpatan Fault, 15 km long JimrukKhola Fault, 10 km Long Kulekhani Fault, 7 km Long Sunkoshi-Roshi Fault and historically, the maximum recorded magnitude in this zone is 6.5. MBT, which is the boundary between Sub-Himalayan and the Lesser Himalayan,includes 80 km long Rangunkhola Fault,120km long SurkhetGhorahi Fault, 60 km long Arun Khola Fault, 40 km long Hetauda faults, 85 km long Udayapur faults and SaptakoshiMechi fault running from Dharan to Mechi. Historically, the maximum recorded magnitude in this zone is 8.0. MCT is another active thrust, lies between the Lesser Himalayan and Higher Himalayan, and major faults identified are Dharma Fault, 10 km long Talphi fault, 20 km long tibrikot fault, 20 km long Dhaulagiri faults, Thakkhola fault, Bari-gad faults [8]. Historically, the maximum recorded magnitude in this zone is 7.5.

[h]

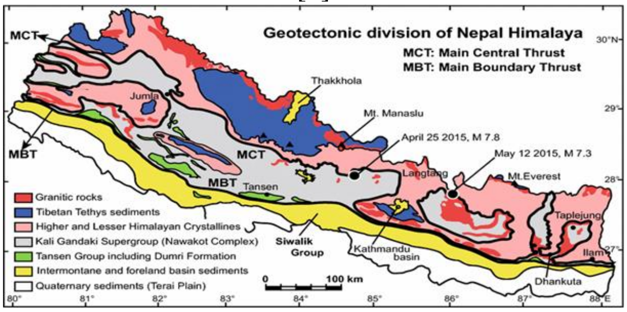

Figure 1: Tectonic of Nepal (https://media.springernature.com/original/springer-static/image/art%3A10.1186%2Fs40623-016-0413-5/MediaObjects/40623_2016_413_Fig1_HTML.gif)

3. Data and Methods

3.1 Earthquake Catalogue

Nepal lies within 26.5-30.5N latitude and 80-89E longitude and thus, all the historical earthquake data within the area till 2018-11-24 was collected. The earthquake catalogue was formed merging the data from U.S. Geological Survey, National seismological center Nepal (1994 to 2018-11-24), International seismological center (ISC), and various Literatures including Parajuli 2015, Thapa and Guoxin. The repeated catalogue was removed manually and total of 1614 earthquake collected with magnitude greater than 4 from 1255 to 2018. Due to unavailability and lack of instrumental data before 1918 the completeness analysis from 1918 were used. The collected data,are measured in various magnitude such as Richter scale, Moment Magnitude, Surface Magnitude and Body Wave Magnitude, were converted into Moment Magnitude for declustering and completeness work. The Richter Magnitude (rm) and surface waves (sm) are converted by Ambraseys and Douglas 2004 relationships and the body waves (bm) are converted by Scordilis 2006 relationships which is appropriate for the region[5].

[9]For bm less than or equal to 6.2,

Wm = 0.69 x rm + 1.7738Wm = 0.69 x bm + 1.03

[9]For bm greater than 6.2,

Wm = 0.69 x sm - 1.0825Wm = 0.69 x bm + 0.08

Since the earthquake data fits the Poisson's distribution and hence follows the Gutenberg Richter (GR) law[10]. GR relationship cannot provide the lower and upper limit, so modified GR relationship was developed and the mean rate of exceedance with lower and upper bound magnitude is given by equation of (McGuire and Arabasz,1990) [11].

$$\lambda_M = \gamma * \left(\frac{\exp\exp[-\beta(m - m_m in)] - \exp\exp[-\beta(m_m ax - m_m in)]}{1 - \exp\exp[-\beta(m_m ax - m_m in)]} \right.$$

where, a and b are GR parameters

$$\gamma = \exp(\alpha - \beta m_m in), \alpha = 2.303a, \beta = 2.303b \quad (1)$$

In the present study,minimum magnitude is taken as 4.5 since quakes lesser in magnitude are less significant from engineering point of view. Maximum magnitude depends on fault dimensions and stress drop, and most of the empirical scaling relations are developed based on this assumption,developing the relations as the function of rupture area and slip length. (PSHA theory). For the catalogue coversdata of long period, some literature used maximum magnitude observed plus 0.5 for maximum magnitude of the site. Ellsworth (2001), Wells and Coppersmith (1994), Somerville et al (1999) have provided different equations based on statistical analyses of worldwide historical earthquake data for different types of source.Wells and Coppersmith (1994) empirical equations method is used in this study. For the linear source. For area source.

$$M_w = 5.08 + 1.16logLMw = 4.07 + 0.98logA \quad (2)$$

Where L is the rupture length in km Where A is the rupture area in km^2

3.2 Declustering Earthquake Catalogue and Completeness

Catalogue of main shocks can be used in estimating seismic risk by virtue of statistical model when aftershocks are removed from total event listing and assumed that the earthquake occurrence the Poisson's distribution. There are several declustering algorithms that have been proposed over the years. Up to now, most users have applied either the algorithm of Gardner and Knoff (1974) or Reasenberg (1985), mainly because of the availability of the source codes and the simplicity of the algorithms [12]. In the current research windowing technique proposed by Gardener and Knop off 1974 was applied to identify aftershocks [13]. It is very difficult to perform completeness analysis for each source due to the insufficient earthquake catalogue. So, first of all, the whole region of Nepal and its surroundings is divided into different areas for different area sources suggested by different previous literatures. The region is divided into five area for linear fault and Thapa and Guoxin [14] area source, four area for pandey et al 2002 [15] area source, four area also for Parajuli 2015 area source [5]. Completeness analysis is separately for each area using spreadsheet based on stepp 1972 paper [16], assuming that earthquake catalogue followed the Poisson's distribution. To obtain the value of parameters 'a' and 'b' of FMD for each source, it is assumed that the seismicity (i.e.b) remains same for the parent source and the divided source while the value of the number of earthquake occurrence (i.e.a) should be different which is obtained by using the following relation.

$$\text{Earthquake per year for a divided source} = \frac{\text{Area of divided source}}{\text{Area of parent source}} \times \text{earthquake per year for parent source} \quad (3)$$

3.3 Earthquake Source Models

Identification and delineation of regional seismic source capable to produce significant ground motion is important for seismic hazard analysis. For proper identification of seismic source some detective works are done which includes Geologic evidence and Fault Activity, Tectonic Evidence, Historical seismicity, Instrumental Seismicity and the above tasks to be performed include Identification of Geologic evidence, Field reconnaissance, Trench logging, Test pits borings, Air-photo interpretation, Remote sensing, Geophysics Historical seismicity, Instrumental Seismicity, etc [17]. In the contest of Nepal, by considering different sources in hazard analysis, different Literatures have provided different value of PGA for same locations. The major reason behind this discrepancy is the lack of enough information about the sources of earthquakes. So, in this research, mixed types of sources are considered which consists of Linear and areal sources. All the areal sources considered by various literatures such as pandey et al 2002, parajuli 2016, Thapa and Guoxin) have been used in the current research by giving equal weightage while forming the Logical tree. For the Linear source, major faults are collected from Pandey et al 2002, parajuli 2015, Stevaes et al., Rahaman et al [18] and Bothara et al 2002 [19] without repetition. MFT is taken as major active faults in the current research. The areal and linear sources considered in the research are depicted in figure 2, 3, 4 and 5.

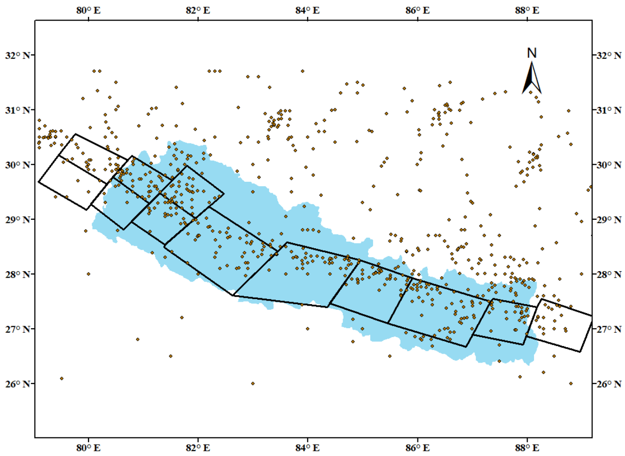

Figure 2: Area source suggests by pandey et al 2002

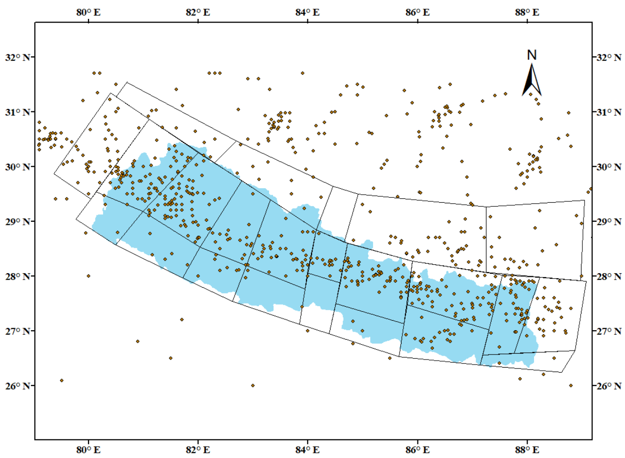

Figure 3: Area source suggests by Thapa and Guoxin

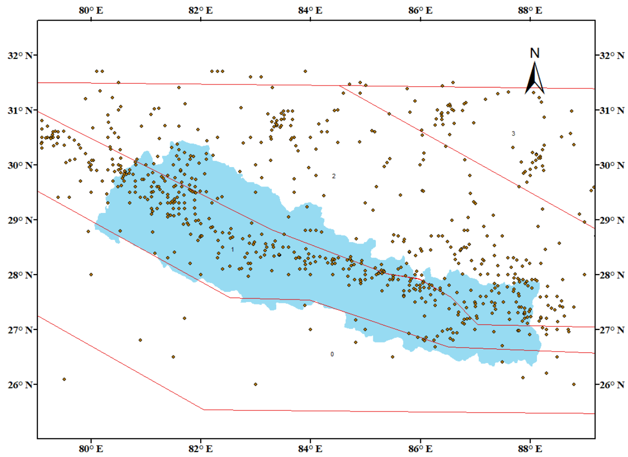

Figure 4: Area source suggests by parajuli 2015

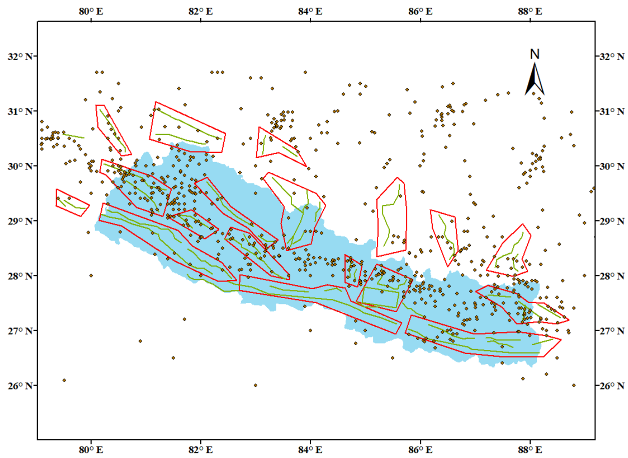

Figure 5: Linear source including various active faults

3.4 Attenuation of Ground Motion

Ground motion prediction equations (GMPEs) are developed by considered the statistical regression of observations from large libraries of observed ground motion intensities.Since the no definite GMPEs is developed in the contest of Nepal, analysts are obligated to use different GMPEs developed for subduction zone, active shallow crustal regions in other parts of the world.The complex seismotectonic setting of the Himalayan orogenic belt further makes the selection process of GMPEs a very difficult task for analysist.Jonathan et al developed the selection of ground motion prediction equations for the global earthquake model and they suggested to review the GMPEs derived data (local or global), saturation with magnitude, magnitude dependent distance scaling and mimic effects anelastic attenuation etc.before selection of GMPEs. For proper estimation of hazard, the latest ground motion attenuation relationship must be used which characterized the seismic sources by the details of the fault – rupture model.

Various researchers have used different GMPEs for hazard analysis of Nepal. [20] (BECA, 1993) used attenuation law Kawashima et al. (1984), Pandey et al. (2002) and Maskey (2005)have used Youngs et al. (1997) GMPE. Pandey et al. (2002), in their studies, made the GMPE to fit with approximately horizontal acceleration recorded in Uttarkashi earthquake of Mw =6.8 and Chamauli earthquake of magnitude Mw=6.6 [15]. Similarly, Thapa and Guoxin (2014) used attenuation relationship developed by CEA (2005)[14]. Chaulagai et al. (2015) have used Boore and Atkinson (2008), Chiou and Youngs (2008), Cambell and Bozorgnia (2008), Boore and Atkinson (2003) and Youngs et al. (1997) are used in logical tree for seismic hazard [21]. Parajuli (2015) used Youngs et al, Gregor et al (2002), Boore and Atkinson (2008), Kanno et al (2008) and zhao et al (2006) attenuation model for his research [5]. V.L stevens et al. (2018) used 4 GMPEs with equal probability; Abrahamson et al (2016), zhao et al (2006), Boore and Atkinson (2003), Boore et al (2014) for subduction interface events and Asimki (2017), Chiou and Youngs (2014), Boore et al (2014), Chiou and Youngs (2008), Boore and Atkinson (2008) considered for active shallow crustal region of Nepal [3]. Rahaman and Bel (2018) have used GMPEs considering for both active shallow crustal and subduction interface [18]. In their study they have used Abrahamson et al (2014), Ambraseys et al (2005), Chiou and Youngs (2014) and Zhao et al. (2006) for active shallow crustal and Abrahamson etal. (2016), Boore and Atkinson (2003), Youngs et al. (1997), Zhao et al (2006) for subduction interface by giving weightage.

Eleven different GMPEs,which are used by previous researchers for the hazard analysis of Nepal, are incorporated in the present study by the use of logical tree structure which is shown in figure 6.

3.5 Logic Tree Structure

Probabilistic seismic hazard analysis possesses various epistemic uncertainties and these affect the hazard analysis significantly. Since the earthquake sources and GMPE are not clearly defined, combination of different sources and GMPEs from different literatures is used to minimize the probable error in the seismic hazard analysis.

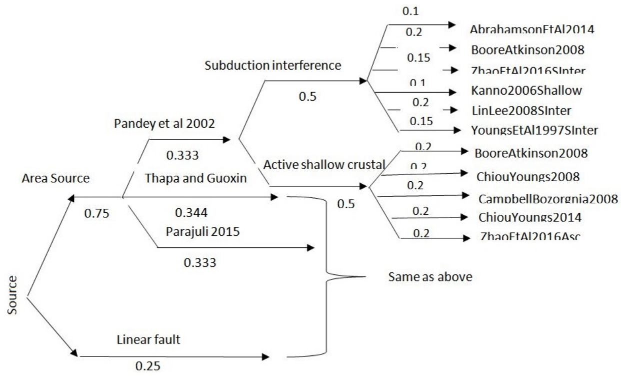

Figure 6: Systematic Logical Tree for Hazard calculation

Generally, epistemic uncertainties are related to source model and attenuation relation (GMPEs) which are handled by forming the standard procedure known as logical trees as per suggested by Power et al 1981, Kulkarni et al 1984 and Coppersmith and Youngs 1986 [17]. The logical tree approach (a method for effectively organizing) allows the use of alternative model by assigning the weighting factor for each alternative. The weights represent the relative credibility of each alternative model and must sum to unity at each branch [22]. Logical trees can be used not only for sources and GMPEs, but can be used for maximum magnitude, recurrence law, magnitude distribution and other seismic parameters also. In the current study, two types of seismological source (areal source and linear source) and two sets of GMPEs, Subduction Interference and active shallow region, with eleven ground motion prediction equations, are combined by using logical tree with weightage modeled in Global Earthquake Model open-quake engine. The systematic logical tree constructed is depicted in figure 6.

4. Result, Analysis and Discussions

The open quake model, considering different source model (having definite value of seismicity parameters- i.e. Gutenberg parameter ‘a’ and ‘b’, minimum and maximum magnitude, fault strike, dip and rake value given by different previous literatures) and GMPEs by use of logical tree, was generated in Microsoft XML Notepad 2007. The open quake model includes Source model, Source Model Logical tree, and GMPEs Logical Tree. The model was simulated in Python based Open quake engine using uniform shear wave velocity (Vs-30) 760 m/sec for evaluation of hazard map of earthquakes of different return periods

(80, 100,200,300,1000, 2500 and 5000-year return period) and different ground motion acceleration at different natural time period (0 sec commonly known Peak Ground Acceleration, 0.5 sec, 1 sec and 2 sec) considering 5% damping. For the analysis region define by having longitude and latitude 81 31, 80.5 30, 80 29.5, 80 28.5, 81 28, 86 26.2, 88.5 26, 88.5 28 with region grid spacing of five kilometers are consider. The hazard maps were plotted in GIS using color ramp and contour to represent earthquake hazard intensity, which are shown in figure7, 8, 9, 10, 11 and 12. Obtained hazard maps show that maximum earthquake hazard occur in hilly areas of Far-Western Region, Central Region (around Kathmandu) and Far-Eastern region.

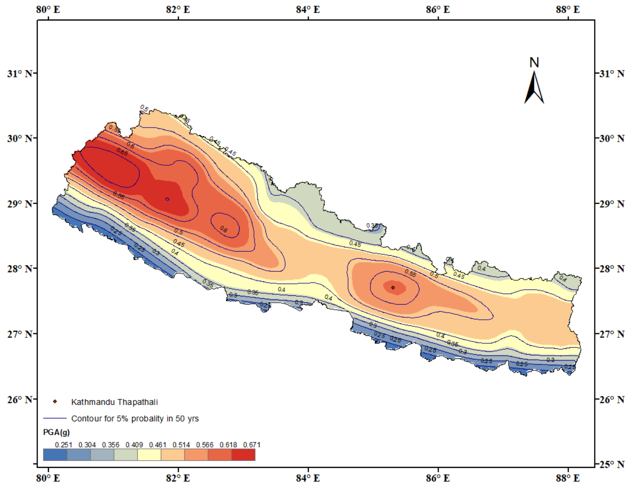

Figure 9: contour for 5% probability in 50 yrs

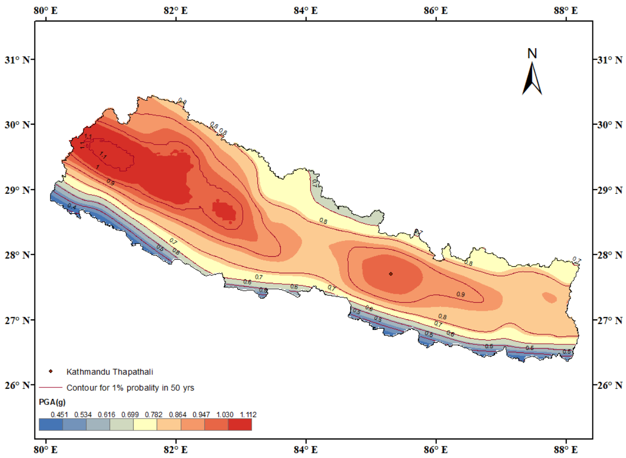

Figure 7: contour for 1% probability in 50 yrs

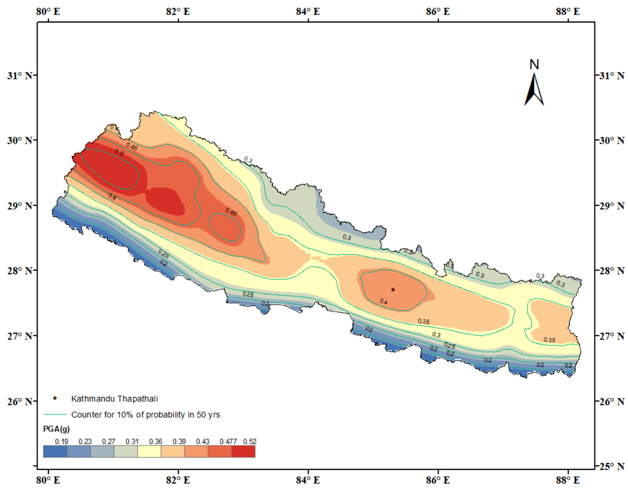

Figure 10: contour for 10% probability in 50 yrs

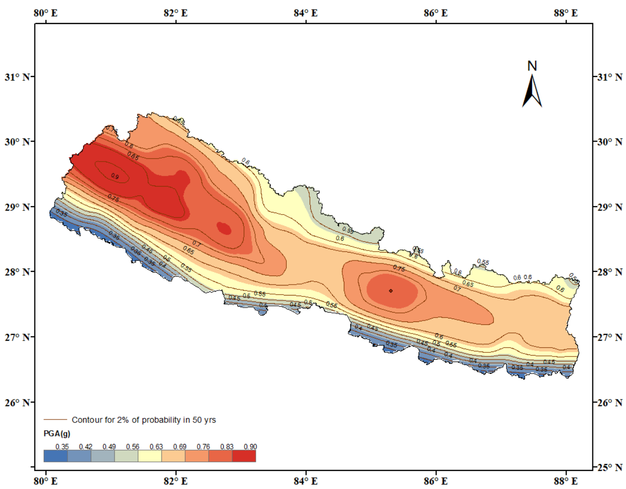

Figure 8: contour for 2% probability in 50 yrs

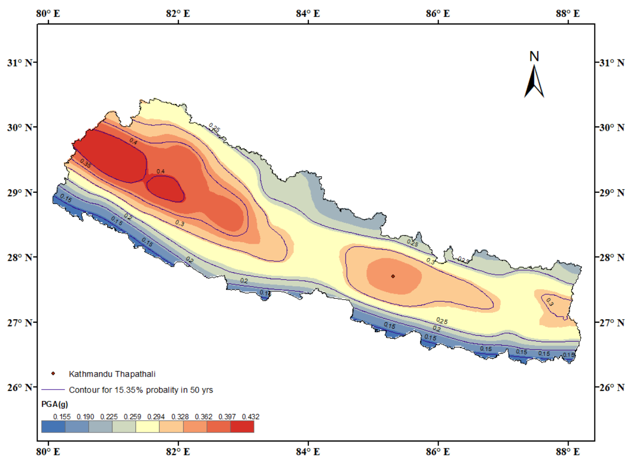

Figure 11: contour for 15.35% probability in 50 yrs

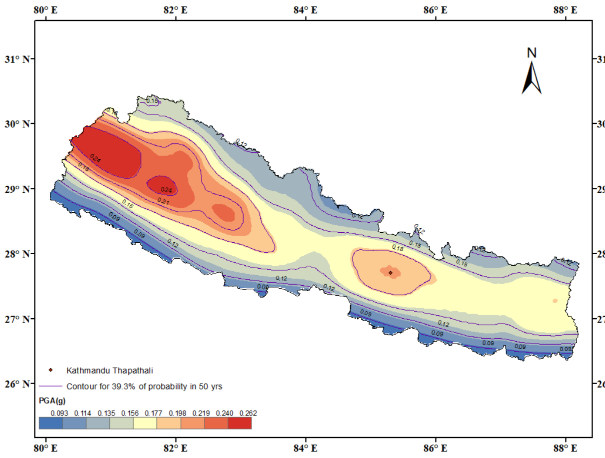

Figure 12: contour for 39.3% probability in 50 yrs

5. Conclusion

Probabilistic seismic hazard analysis of Nepal has been carried out for different probability of exceedance in 50 years using the recent earthquake information with the help of Global Earthquake Model Open Quake engine by making the logical tree to reduce the source and GMPEs uncertainty. The PGA value increase with increasing the return period and found maximum value at far western and central region, where the historical earthquake concretion is higher. ArcGIS is used to draw the contour and color ramp for earthquake hazard level. Among the various return period, Design Basis earthquake (DBE) defines the peak horizontal accelerations with 10% probability of exceedance in 50 years. The 475-year return period (or 10 percent probability of exceedance in 50 years) event is the most common standard used in the industry for assessing seismic risk, and it is also the basis for most building codes for seismic design.

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