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DETERMINISTIC SEISMIC HAZARD ASSESSMENT FOR NEPAL

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Abstract

A deterministic seismic hazard analysis (DSHA) study was carried out for Nepal. The catalogue of earthquakes was updated for Nepal and the adjoining region (26°-31.7°N, 79°-90°E) from 1255 to August 2015. DSHA for Nepal was carried out by calculating peak ground accelerations (PGAs) at bedrock level over the grid of 0.2° × 0.2° (longitude and latitude) covering the entire territory of the country considering every seismic event in the updated catalogue as a point source, determining shortest source-site distances, and selecting a suitable ground motion prediction relationship. The resulting deterministic seismic hazard map indicates distinct characteristics of spatial distribution of PGA in Nepal: high hazard (0.88 g) in the north-eastern section of the country, and low hazard (0.07 g) in southern Nepal. The calculated PGA values in the present analysis are compared with the values of PGA estimated recently for the 10% probability of exceedance in 50 years and found a general agreement in the north-eastern segment of Nepal.

Keywords: Deterministic Seismic Hazard; Peak Ground Acceleration; Nepal

1. Introduction

Nepal is one of the well identified seismically active nations located in the central most segment of the Himalayan seismic belt with a population exceeding 26 million people [1]. The earthquake-prone country has a prolonged history of occurrence of damaging earthquakes and was shaken time to time by several strong and six large-great damaging earthquakes (1255, 1408, 1505, 1833, 1934, and 2015) with magnitudes 7.6 and above since 1255 and have inflicted serious disasters with huge human casualties and countless economic-losses. Among them, the 1934 (M_w= 8.4) and 2015 (M_w= 7.8) are the two most destructive earthquakes and both of them caused numerous casualties (more than 8500 deaths) with substantial material damage and economic-losses in the country.

Due to the occurrence of such damaging strong to great earthquakes both in historical and recent times in Nepal and its vicinity, the region captured the great interest of Nepalese and foreign scientists and much research works have been done in the last 50 years devoting on several aspects of earthquake science such as seismic monitoring [2], geodetic observations [3, 4, 5, 6], geomorphological analysis [7, 8] and fault investigations [e.g., 9, 10, 11, 12, 13, 14] and published their intensive research findings in the scientific literature. Broadly speaking, the combination of these seismological, geodetic, geomorphological and faults investigations have yielded a much improved understanding of seismicity, tectonic deformation and geological structures that led us to point out earthquake potential of this region, but the earthquake hazard of the region has not yet completely understood. The active tectonic deformation, existence of main longer surface faults (Fig.1) and a relatively high level of seismicity and seismic potential of this study region pose a major threat to people, cities, towns, villages, infrastructures and environment in Nepal and its nearby region. Clearly, the potential risk principally associated with future earthquakes in this region is anticipated to increase considerably during the coming decades owing to the continued population growth, rapid rate of urbanization, construction of civil infrastructures, and reconstruction of destroyed structures. The anticipated increasing risk primarily from future local and remote earthquakes can be reduced effectively to a large degree only through the proper evaluation of seismic hazard and subsequent improvement in building materials and methods with aseismic construction of modern structures, reconstruction of destroyed structures and effective fortification planning and mitigation activities in Nepal.

Although the country has a prolonged history of earthquakes, the seismic hazard study in Nepal is still a new area of research. In recent years, there have been increased efforts toward the assessment of seismic hazard for Nepal at the national scale using the probabilistic approach [15, 16]. However, so far to our best knowledge, there is not a single scientific study that had quantified the seismic hazard of Nepal using the deterministic approach. Here, the present study focuses on performing the Deterministic Seismic Hazard Analysis (DSHA) for Nepal.

This study aims to produce a seismic hazard map of Nepal by using the deterministic approach. For this purpose, we calculated PGAs at bedrock level for Nepal from each available seismic event and the shortest distance using the selected ground motion attenuation relationship. The resulting seismic hazard map address ground motion hazard in terms of mean peak ground accelerations (PGAs) at bedrock level. Furthermore, the deterministic seismic hazard map prepared in this study is compared with the recently produced probabilistic hazard map of Nepal.

2. Earthquake Data and recent PSHA study of Nepal

Recently, a homogeneous seismic catalogue of earthquakes with surface wave magnitudes 4.0 and above that occurred in Nepal and the surrounding region (26°N-31.7°N latitudes, 79°E-90°E longitudes) for the period 1255-2011 was compiled by Thapa and Wang [16] in the course of quantifying the seismic hazard in Nepal. In this study, we extended the earthquake catalogue for the same region through 2012 to August 2015 after compiling data from the International Seismological Centre (ISC) [17], the United States National Earthquake Information Centre (NEIC) [18], and the National Seismological Center (NSC) [19]. These compiled seismicity data are analysed carefully by removing duplicated events and aftershocks and converted into surface wave magnitude scale (Ms) as in previously the catalogue analysis [16, 20]. The newly analyzed earthquake catalogue were then merged with the earthquake catalogue data of Thapa and Wang [16] to create a uniform and homogeneous earthquake catalogue for Nepal and the surrounding region (Fig.1). This new earthquake data set consists of 963 earthquakes occurred from 1255 to 2015 and epicenter locations of these earthquakes are shown in Fig.1.

As previously mentioned, the seismic hazard assessment for Nepal has been carried out most recently by Thapa and Wang [16]. Fig.2 displays the probabilistic seismic hazard map of Nepal for the 10% probability of exceedance in 50 years. This map shows the values of PGA are varied from 0.21 to 0.62 g in Nepal. The map further indicates the highest seismic ground motion hazard (PGA exceeded 0.60 g) in the far-western and eastern segments of Nepal and the lowest seismic ground motion hazard (PGA below 0.22 g) in southwestern Nepal.

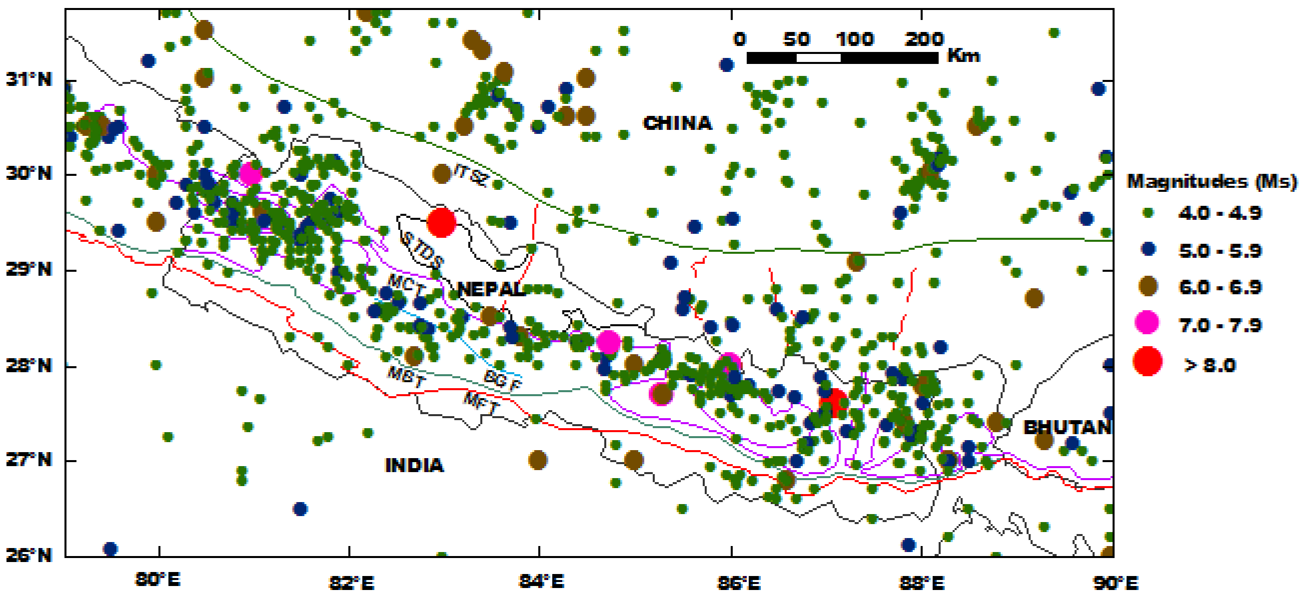

Fig. 1 – Major faults and earthquakes in Nepal and the surrounding region (ITSZ-Indus Tsangpo Suture Zone; STDS-South Tibetan Detachment System; MCT- Main Central Thrust; BGF- Bari Gad Fault; MBT- Main Boundary Thrust; and MFT- Main Frontal Thrust). STDS; MCT; BGF; MBT and MFT in Nepal modified from Amatya and Gnawali [21], active normal faults (red discontinuous lines) and ITSZ in southern Tibet modified from Taylor and Yin [22]. Dots (coloured circles) indicate epicenters of seismic events (Ms ≥ 4.0) in Nepal and the adjoining region (1255-2015)

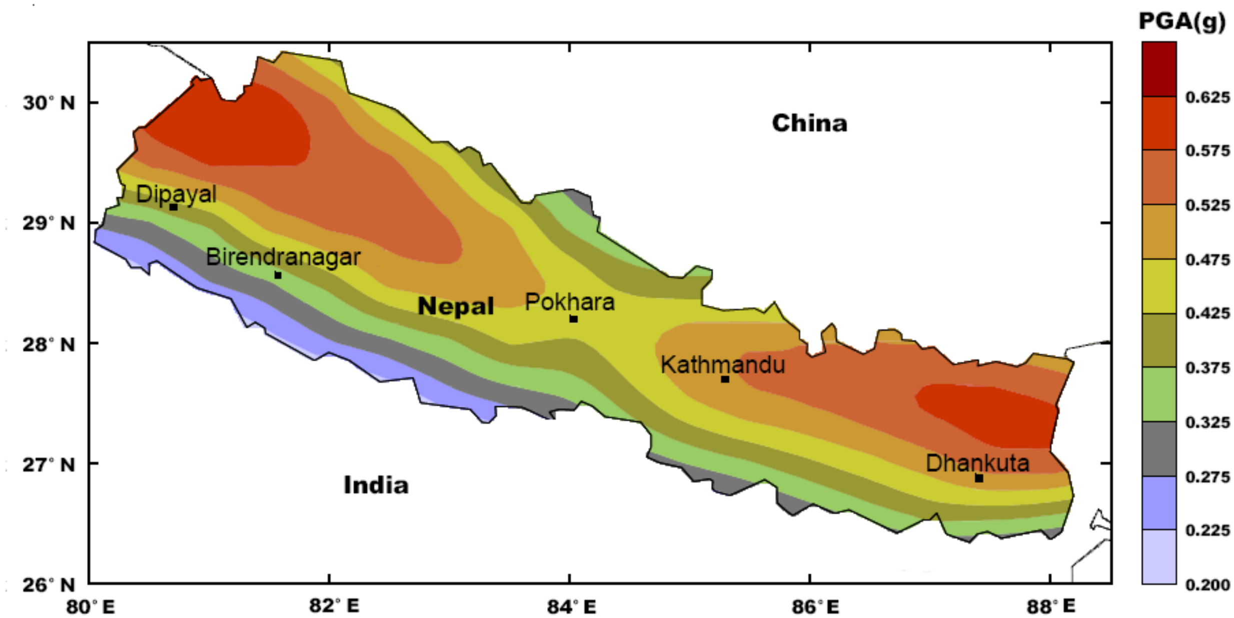

Fig. 2 – Probabilistic seismic hazard map for Nepal in terms of PGA with 10% probability of exceedance in 50 years [16]

3. Ground motion prediction equation (GMPE)

Although the seismic history of Nepal extends over eight centuries, there is no enough datasets of strong ground motion recordings of earthquakes. Due to the lack of enough recorded strong motion datasets from earthquakes in Nepal, it is not possible to derive an empirical attenuation relationship appropriate for Nepal and the surrounding region in this analysis. Thus, it is necessary to choose a ground motion prediction relationship developed for other regions in order to prepare the seismic hazard map for Nepal in our analysis. In the present study, the attenuation relationship developed for western China by the China Earthquake Administration [23] has been used to estimate the seismic ground motion for Nepal. The elliptical attenuation model of PGA [23] for the major axis and minor axis are specified here below in Eqs. (1) and (2) as follows:

$$\ln a_{Ra} = 5.912025 + 1.836588\,M - 2.84658\,\ln(R_{Ra} + 3.400\,\mathrm{Exp}(0.451M)) \quad (1)$$

And

$$\ln a_{Rb} = 2.509012 + 1.360759\,M - 1.79151\,\ln(R_{Rb} + 1.046\,\mathrm{Exp}(0.451M)) \quad (2)$$

in which M denotes the surface-wave magnitude, a_{Ra} denotes the peak ground acceleration along the major axis, R_{Ra} denotes the hypocenter distance for the major axis, a_{Rb} denotes the peak ground acceleration along the minor axis, and R_{Rb} denotes the hypocenter distance for the minor axis.

4. Deterministic Seismic Hazard Analysis

The Deterministic Seismic Hazard Analysis (DSHA) approach commonly practice today worldwide requires to define earthquake magnitudes and the shortest distances from sources to sites [24, 25], which is relatively easy to perform than the Probabislistic Seismic Hazard Analysis (PSHA) [e.g., 25, 26, 27, 28, 29, 30, 31]. An assessment of seismic hazard of any region, province or country using the deterministic approach essentially quantifies largest motion resulted from individual source [24, 25], which requires to define earthquake magnitudes and the shortest distances from sources to sites and the appropriate ground motion attenuation relationship for the area of interest, province or country.

To evaluate the seismic ground motion hazard for Nepal in this study, 963 earthquakes (Ms ≥ 4.0) listed in a homogeneous catalogue of Nepal were selected and the shortest distance from epicenters of these earthquakes to each grid (0.2° × 0.2°) covering the whole territory of Nepal were determined. A hypocenter depth of 10 km was set for all earthquakes in this study as in the most recent PSHA study for Nepal [16]. After considering the earthquake catalogue as the sources of earthquakes with a hypocenter depth of 10 km, determining the shortest source-site distance, the seismic ground motion hazard at all gridded points (0.2° longitude × 0.2° latitude) covering the entire territory of Nepal were calculated utilizing a PGA ground motion prediction relationship developed by CEA [23]. The quantified maximum seismic ground motion hazard for each gridded point was expressed here in terms of PGA and plotted in the DSHA map in Fig.3.

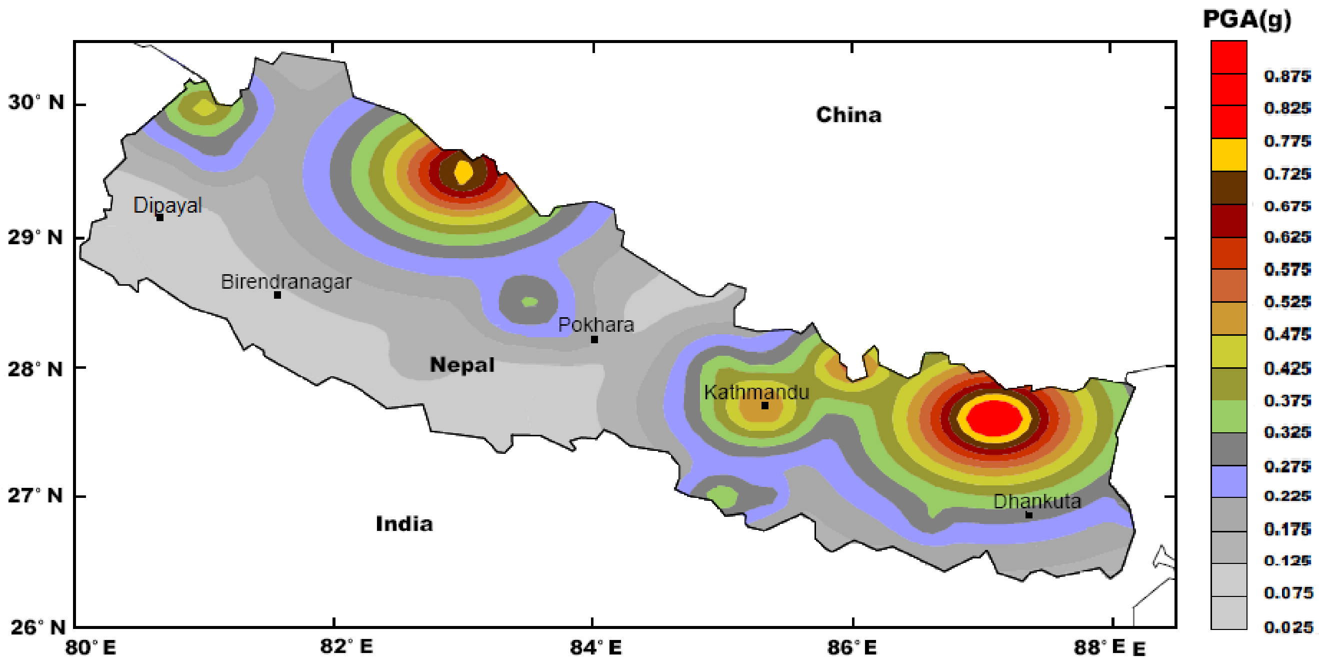

Fig. 3 – Deterministic seismic hazard map for Nepal in terms of mean PGA.

It is emphasized that the present analysis consider each seismic event in the updated seismic catalogue herein for Nepal and the surrounding region from 1255 to 2015 as individual source and utilizes the same attenuation relationship used by Thapa and Wang [16] to prepare the probabilistic seismic hazard maps for Nepal. In addition, PGA at bedrock level over a regular grid with spacing 0.2° × 0.2° covering the entire territory of Nepal has been calculated in this study as in the recent PSHA study. Hence, it is reasonable to compare the results of this DSHA study with the results of a recent PSHA study for Nepal.

5. Results and Discussions

An assessment of seismic hazard for Nepal at bedrock level was carried out herein using a DSHA method. The evaluated deterministic earthquake hazard for Nepal was expressed here in terms of PGA at bedrock level. Fig. 3 shows the deterministic seismic hazard map of Nepal in terms of PGA. The values of PGA calculated here at bedrock level for Nepal ranges from 0.07 to 0.88 g. The pronounced earthquake ground motion hazard is found in the northeastern part of Nepal where the PGA value is greater than 0.82 g, while the lowest seismic ground motion hazard is found in the southwestern part of Nepal where the value of PGA is less than 0.12 g. The highest seismic ground motion hazard is predominantly concentrated in the northeastern part of the country between 86.94°E and 87.26°E. The second highest seismic ground motion hazard is found in the northwestern part in the location from 82.8°E to 83.19°E where the calculated value of PGA exceeded 0.72 g. The seismic ground motion hazard is very low in the southwestern part of the country, particularly along the southern border of Nepal with India in the west of 84.02°E where the values of PGA is less than 0.12 g. The PGA distribution in the deterministic seismic hazard map of Nepal (Fig.3) clearly indicates that the highest seismic hazard is controlled by great earthquakes. The highest seismic ground motion hazard is found, particularly in locations where great earthquakes have occurred in the past (Mw = 8.1; 1505, and Mw = 8.4; 1934) in Nepal (Fig.1).

The PGA distribution in the deterministic seismic hazard map presented here (Fig.3) is compared with the recently prepared probabilistic seismic hazard map of Nepal (Fig.2) for the 10% probability of exceedance in 50 years. The comparison between the deterministic seismic hazard map for Nepal (Fig.3) and the probabilistic seismic hazard map of Nepal for the 10% probability of exceedance in 50 years (Fig.2) generally reveal the pronounced seismic ground motion hazard in the eastern portion of the country and the lowest seismic ground motion hazard in the southwestern part of Nepal. Both of these seismic hazard maps exhibit the highest level of seismic hazard in the eastern segment of Nepal near the epicenter zone of the great Bihar-Nepal earthquake and low hazard in southwestern Nepal where there are very few accounts of small earthquakes (Fig.1).

However, there are some discrepancies exist in the values of PGA quantified for Nepal by using two different methods. The calculated PGA values in Nepal using the DSHA approach yielded a relatively higher seismic hazard than the PSHA method in northwestern Nepal, particularly in the epicenter area of the great 1505 earthquake (Fig.2). In contrast, the PGA values calculated in the southwestern portion of Nepal by using DSHA are lower than the PGA values calculated in the same region by using PSHA.

To sum up, the DSHA study yielded the high hazard in the epicenter zones of great earthquakes, whereas the PSHA estimate produced the high hazard in the area of high seismic activity in Nepal. Such obtained difference in the spatial PGA distribution for Nepal is largely due to fact that the seismic ground motion hazard is greatly sensible to the size of the earthquake in DSHA rather than the seismic activity of the study region as in PSHA.

6. Conclusions

In this study, the seismic hazard map for Nepal has been prepared using the deterministic approach. The deterministic seismic hazard map of Nepal prepared here represents the ground motion hazard in terms of PGA at bedrock level. The values of PGA calculated here for Nepal at bedrock level over a grid of 0.2° × 0.2° are of the order of 0.07-0.88 g. The highest seismic ground motion hazard is found in the northeastern segment of Nepal where the value of PGA is exceeded 0.82 g, while the lowest earthquake ground motion hazard is found in the southwestern part Nepal where the PGA value is less than 0.12 g.

In addition, the seismic ground motion hazard calculated in this study is compared with the recently estimated values of PGA for Nepal at 10% probability of exceedance in 50 years. Both maps generally show the pronounced earthquake ground motion hazard in the eastern section of the country where the values of PGA exceeded 0.60 g and the lowest earthquake ground motion hazard in the southwestern portion Nepal. It is found that the general trend of the seismic ground motion hazard in the deterministic seismic hazard map of Nepal is in good agreement with the recently produced probabilistic hazard map of Nepal at the 10% probability of exceedance in 50 years.

The seismic hazard has been estimated in Nepal for the first time using the deterministic approach. It provides valuable seismic ground motion information relevant for the city planners to set up city development and disaster mitigation planning, and for the engineers to choose appropriate locations and design of civil structures such as dams, hospitals, long-span bridges, powerhouses, schools, and tunnels on bedrock foundations. The earthquake hazard analysis performed here is based on each earthquake event in the updated seismic catalogue as a seismic source. Further studies, especially recognize the potential sources by pattern recognition to define seismic source in the sites where there are no records of earthquakes in the past and incorporate the results of pattern recognition with the updated catalogue as inputs and utilize the more advanced attenuation relation are necessary to revise the deterministic seismic hazard map of Nepal in the future.

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