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# Earthquake intensity for Lalitpur, Nepal

Hari Ram Parajuli[a,*], Milan Thapa[b]

[a] *Institute of Engineering, Tribhuvan University, Kathmandu, Nepal*
[b] *Khowpa Engineering Collage, Purwanchal University, Nepal*

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Abstract

Using probabilistic seismic hazard analysis (PSHA), an effort has been made to evaluate the seismic hazard at rock level in terms of peak horizontal acceleration (PHA) at two locations in the Lalitpur district. The site's earthquake database was created by combining the several databases. To depict the region's earthquake recurrences, a magnitude frequency relationship was created. The probabilistic spectra for the two sites were then generated by estimating the peak ground acceleration using Young's et al. 1997 attenuation relation. The findings indicate that there is a greater degree of seismic risk in the locations that support the current design guidelines for earthquake resistance.



## 1. Introduction

Lalitpur is one of the three districts within the Kathmandu valley. The Kathmandu valley has a history of experiencing numerous earthquakes over the years. Historical records indicate that destructive earthquakes have been documented as far back as 1255 AD [1][2][3][4][5]. Table 1 illustrates the significant earthquakes that have occurred in Nepal [6]. The earthquakes of 1255, 1833, and 1934 caused extensive damage to the Kathmandu valley [7][8][9]. In 1988, a powerful earthquake struck, inflicting damage on the eastern side of Nepal [10]. The recent M7.8 earthquake in Barpak, Gorkha, followed by an M7.3 aftershock in Dolakha in 2015, caused severe destruction along an 80-kilometer stretch of the Himalayas, located just north of the Kathmandu valley. The study area is situated at the western edge of the source region responsible for the 1934 great earthquake. It is believed that this area may require approximately 500 years to accumulate the necessary conditions to generate another significant earthquake (M>8.0). However, it is essential to consider the possibility that this region has been accumulating energy over the past 80 years (since the 1934 Bihar-Nepal Earthquake), which could be equivalent to a magnitude M7.0 earthquake at present.

The recent and powerful Barpak M7.8 earthquake generated an acceleration of 240gal in Kathmandu. Another crucial aspect is its exceptionally long duration of 56 seconds, with a period of 4 to 5 seconds. Thousands of buildings sustained damage, soil liquefaction occurred in numerous locations, ground failure was reported, resulting in 8,922 fatalities [6] and 23,000 injuries [11]. Reviewing the historical recurrence of significant earthquakes (those with a magnitude exceeding 7.5), it has been noted that such events have transpired within an interval of 80 to 100 years. This interval is considerable and indicates a significant seismic risk in the area. Similar studies conducted in other regions have been highlighted by various researchers [12][13][14], underscoring the urgent necessity to reassess seismic risk and make decisions based on the updated risk scenario.

## 2. Earthquake catalogue

The earthquake catalogue for this region was compiled by integrating and consolidating the available data from various sources, covering the timeframe from 1255 to 2014 AD. The earthquake information was gathered from multiple sources, including the United States Geological Survey (USGS), the Department of Mines and Geology (DMG), and the International Seismological

*Corresponding author:
hariparajuli@ioe.edu.np (H.R. Parajuli)

Table 1: Significant Nepal Earthquakes

Source: https://en.wikipedia.org/wiki/List_of_earthquakes_in_Nepal}cite_note-DPNET-Nepal-2

| Date | Location | Latitude | Longitude | Deaths | Magnitude |
|---|---|---|---|---|---|
| 1255 | Kathmandu, Nepal | 27.70 | 85.30 | 2200 | 7.8 |
| 1260 | Sagarmatha, Nepal | 27.10 | 86.80 | 100 | 7.1 |
| 1344 | North Mechi, Nepal | 27.50 | 87.50 | 100 | 7.9 |
| 1408 | Tibet, China | 27.90 | 86.00 | 2500 | 8.2 |
| 1505 | Mustang, Nepal | 29.50 | 83.00 | 6000 | 8.9 |
| 1681 | North Koshi, Nepal | 27.60 | 87.10 | 4500 | 8.0 |
| 1767 | North Bagmati, Nepal | 28.00 | 85.50 | 4000 | 7.9 |
| 1833 | Rasuwa, Nepal | 27.90 | 85.50 | 6500 | 8.0 |
| 1934 | Nepal–Bihar | 26.77 | 86.76 | 8519 | 8.4 |
| 1869 | Kathmandu, Nepal | 27.70 | 85.30 | 750 | 6.5 |
| 1905 | Tibet, China | 30.00 | 81.00 | 3500 | 7.7 |
| 1905 | Doti, Nepal | 29.55 | 80.85 | 80 | 6.3 |
| 1905 | Pithoragarh, India | 29.60 | 81.09 | 200 | 6.5 |
| 1905 | Kathmandu, Nepal | 26.78 | 86.62 | 1091 | 6.9 |
| 2011 | Sikkim, India | 27.33 | 88.62 | 111 | 6.9 |
| 2015 | Gorkha, Nepal | 28.15 | 84.71 | 8857 | 7.8 |
| 2015 | Dolakha, Nepal | 27.97 | 85.96 | 213 | 7.3 |
| 2022 | Doti, Nepal | 29.30 | 81.16 | 6 | 5.7 |
| 2023 | Jajarkot, Nepal | 28.84 | 82.18 | 157 | 5.7 |

Centre (ISC). Additionally, further data were obtained from catalogues published by various researchers. A uniform database was established using the works of Scordilis [15] and Pant [7]. The catalogue was finalized by taking into account both the Historical Catalogue and Seismicity (1255–1910 A.D.) as well as the Instrumental Catalogue and Seismicity (1911-2014 A.D.)

### 2.1. Declustering

To prevent the redundancy of dependent events, such as foreshocks and aftershocks, a process known as declustering was employed. Declustering serves as a technique for filtering overlapping events. Given that the available earthquake data encompasses foreshocks, main shocks, and aftershocks, distinguishing the main shock from background or dependent events proves to be challenging. Therefore, after converting the reported magnitudes (Ms or Mb) and intensities into moment magnitudes (Mw), all dependent events (foreshocks and aftershocks) were eliminated through a windowing procedure based on the algorithm proposed by Gardner and Knopoff [16].

### 2.2. Catalogue completeness

The gathered earthquake data encompasses various magnitude scales and intensities, which are ultimately transformed into moment magnitude to ensure uniformity in completeness, utilizing the empirical relationships established by Johnston [17] and Scordilis [15]. A residual catalogue is generated following the declustering of dependent events, resulting in a compilation of independent earthquakes. The earthquake catalogue is compiled excluding magnitudes below M5, as earthquakes with magnitudes less than 5 contribute minimally to seismic hazard assessment. In this study, a total of 1900 unclustered main shocks were collected spanning the period from 1255 to 2014 A.D. Upon achieving completeness of the earthquake data, a magnitude frequency relationship was formulated for all sources.

### 2.3. Seismic source zone

The initial phase of seismic analysis involves identifying the earthquake sources that are most likely to impact the site of interest where the seismic hazard assessment will be conducted. Indeed, the characterization of seismic source zones relies on the interpretation of geological, geophysical, and seismological data gathered through various methods, including tectonic theory, seismic activity, surface geological studies, and subsurface geophysical techniques. The discontinuity in the tectonic boundary of the study area has been categorized into 25 distinct quadratic and polygon-shaped areal sources.

### 2.4. Gutenberg – Richter Coefficients (a, b)

Following the characterization of the earthquake sources, the logarithmic values of the exceedance rates of earthquakes associated with specific sources are plotted against the magnitudes of the earthquakes to determine the Gutenberg-Richter parameters. The slope of the resulting curve indicates the "b" value, while the rate at which earthquakes exceed certain magnitudes signifies the "a" value [18].

### 2.5. PSHA formulation

The Probabilistic Seismic Hazard Assessment (PSHA) pertains to the evaluation of a specific measure of the anticipated strong ground motion from earthquakes at a designated location. The formulation of the PSHA adheres to the procedures outlined in the Cornell references [19], [20], and [13]. Seismicity is characterized by a recurrence relationship that denotes the average frequency at which an earthquake of a certain magnitude is likely to be surpassed. For this purpose, the conventional Gutenberg–Richter recurrence law is employed, which states that,

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

Here, $\lambda_m$ denotes the average return period of the earthquake of magnitude m. If earthquakes lower than a threshold value $m_o$ are eliminated, then the expression for $\lambda_m$ is modified as:

$$\lambda_m = \nu \exp\left[-\beta(m - m_0)\right] \tag{2}$$

where, $\exp\left(\alpha - \beta m_o\right)$, $m > m_0$, $\alpha = 2.303a$ ,and $\beta = 2.303b$

Similarly, if both the upper and lower limits are incorporated, then $\lambda_m$ is given by:

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

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:

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

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 [20].

$$V_{y^\star} = \sum_{i=1}^{N_s} V_{\text{iMmin}} \iint P[Y > y^\star \mid m, r]\, f_{M_i}(m)\, f_{R_i}(r)\, dm\, dr \tag{5}$$

$$V_{y'} = \sum_{i=1}^{N_s} \sum_{j=1}^{N_r} \sum_{k=1}^{N_m} V_{iM\,min} \rho_i \left[P[Y > y^\star \mid m, r]\right] P[M = m] P[R = r]\, \Delta m\, \Delta r \tag{6}$$

Where, $N_s$ is number of sources in the region, $V_{\text{iMmin}} = \exp\left(\alpha - \beta_i m_{\min}\right)$ is total rate of exceedences of threshold magnitude (M=5.0 is taken in this study). $P[Y > y^\star \mid m, r$ is conditional probability that chosen acceleration exceeded for a given magnitude (M) and distance (R), and $f_{\text{Mi}}(m)$ and $f_{\text{Ri}}(r)$ are probability density functions for magnitude and distance respectively.

In this context, M and m represent a random variable and a specific magnitude value, respectively. The initial term in the integral addresses the uncertainty in predictions, the subsequent term accounts for the uncertainty regarding the size of the earthquake, and the final term pertains to the uncertainty related to the earthquake's location. The aforementioned uncertainties across all source zones are incorporated through a double integration summation. Consequently, a seismic hazard curve is generated by graphing the exceedance rate of the seismic parameter for various levels of the seismic parameter that were computed.

## 3. Attenuation equation

Despite the existence of numerous attenuation laws formulated for different regions around the globe, there are no specific earthquake attenuation relationships established for the Himalayan region. Due to the lack of adequate data, this study does not aim to create a new equation for the area; instead, it examines the attenuation equations from previously developed models for subduction zones, as referenced in Crouse [21][22][23][24][25][26][27][28], which align with the tectonic, geological, and faulting systems. The majority of earthquakes in Nepal are classified as interface events resulting from the subduction of the Indian plate beneath the Eurasian plate. Therefore, this research utilizes the attenuation relationship appropriate for subduction zones as proposed by Youngs et al. [24].

The probability distribution of a specific ground motion parameter indicates that the likelihood of this parameter Y surpassing a certain threshold, y*, for an earthquake of a specified magnitude, m, occurring at a distance, r, is expressed as follows:

$$P[Y > y^{\star} \mid m, r = 1 - F_Y(y^{\star}) \quad (7)$$

In this context, $F_Y(y)$ denotes the value of the cumulative distribution function of Y at points m and r. The value of $F_Y(y)$ is contingent upon the probability distribution employed to characterize Y. Typically, ground motion parameters are presumed to follow a log-normal distribution, meaning that the logarithm of the parameter itself is normally distributed.

## 4. Results and discussion

In accordance with the procedure detailed in the preceding sections, the uniform hazard spectrum (UHS) and the probabilistic seismic hazard assessment (PSHA) for the Balkumari area and Godawari in the Lalitpur region have been calculated, with the findings illustrated in Figures 1 and 2. The probabilistic spectra indicate a 10% probability of exceedance over a 50-year period corresponds to a return period (RP) of 475 years, and higher return period also, as determined using CRISIS software. The results obtained are depicted in the respective figures. The figures clearly demonstrate a higher level of seismicity at both sites, which is beneficial for planners and designers to ensure a greater level of safety. Considering the proximity of the two locations, despite the distance being only slightly greater, Godawari indicates a higher peak ground acceleration value, which suggests the presence of soft strata. The values obtained in both instances imply a need to revise the values provided in the Nepal Building Code NBC-105 2020.

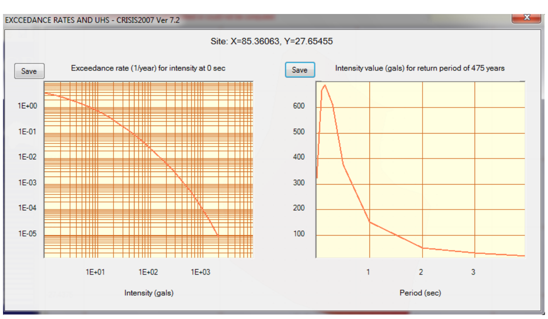


Figure 1: Balkumari PGA 0.30g showing Hazard Map for RP=475 yrs

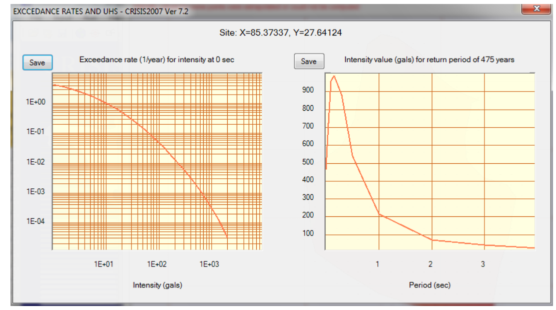


Figure 2: Godawari PGA 0.40g showing Hazard Map for RP=475 years.

## 5. Conclusions

For RP 475 years, PGA is recorded at 0.31g in the Balkumari area and 0.59g in the Godawari area. The PGA value in the Balkumari area appears to be consistent with the data presented in BECA 1993 [29], whereas the value in the Godawari area is significantly higher. The examination of these two closely spaced locations indicates that the underground soil conditions differ between them. Although the Kathmandu valley is not particularly large, it exhibits a wide variety of underground soil types, leading to frequent variations in soil amplification. This necessitates site-specific hazard assessments at each location for the construction of high-rise buildings.

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