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Analyzing Strong Earthquakes in the Central Himalayan Region in Nepal

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Abstract

This is a descriptive-analytical research design study that analyzes strong earthquakes (magnitude ≥5) that occurred in the Central Himalayan region over the past 210 years (1800–2010). Data from multiple international catalogs, including the National Earthquake Information Center (NEIC), United States Geological Survey (USGS), International Seismological Centre (ISC), and Global Centroid Moment Tensor (GCMT), were compiled and homogenized for analysis. A total of 225 significant earthquakes were examined for spatial, temporal, and depth distribution, b-value estimation, and seismotectonic interpretation. The results reveal that the majority of seismic events were shallow, concentrated mainly along the Main Central Thrust (MCT) and Main Boundary Thrust (MBT). The estimated b-value (0.89) indicated high stress accumulation and suggests the potential for future major earthquakes. Spatial and temporal analyses highlight distinct zones of seismic clustering and variable activity over time, with increasing seismicity in the last five decades due to improved detection networks. The findings underscore the dominance of thrust and strike-slip faulting mechanisms within the Himalayan compression zone, driven by the ongoing convergence of the Indian and Eurasian plates. This work contributes to understanding regional seismotectonics and seismic hazard potential across Nepal and adjoining regions.

Keywords: central himalaya, earthquake distribution, Nepal, seismic energy

1. Introduction

The Himalayan region is one of the most seismically active zones in the world due to the convergence of the Indian and Eurasian tectonic plates(Raquel, n.d.).The continuous northward movement of the Indian plate and its collision with the Tibetan landmass generate immense stress accumulation, leading to frequent earthquakes of varying magnitudes. Nepal, situated along the central part of the Himalayan arc, experiences repeated seismic events that have historically resulted in significant damage to life and infrastructure (Bilham, 2004).

Understanding the seismic characteristics of this region is, therefore, essential for disaster preparedness and risk mitigation.

This study compiles and analyzes earthquake data from 1800 to 2010 A.D., focusing on strong events ($M \geq 5$). The main objectives are to examine spatial and temporal patterns, focal depth distribution, and seismic energy release trends. The study also interprets faulting mechanisms to provide insights into the tectonic behavior governing the region's seismicity.

1.1 Significance of the Study

The Himalaya is one of the most seismically active regions globally, and Nepal, located in its central portion, is characterized by intense seismic activity. Understanding earthquake occurrence patterns is critical because the continuous northward movement and collision of the Indian plate with the Tibetan landmass generate significant stress released as strong earthquakes. This systematic study helps identify seismotectonic behavior, which is essential for future hazard assessment, disaster mitigation planning, and upgrading the current understanding of seismic activity in a small-scale window.

1.2 Delimitations of the study

The study is bound by the following constraints:

- **Study Area:** Limited to the Central Himalayan region (Nepal and neighboring parts of India and Tibet), bounded by 79°–90° E longitude and 26°–31° N latitude.
- **Magnitude:** Only "strong" earthquakes with a magnitude ≥5.0($M \geq 5$) are included
- **Time Period:** Covers a 210-year interval from 1800 to 2010 A.D.
- **Data Completeness:** The data file is noted as incomplete before 1960 due to the limited number of reported events before the establishment of global seismic networks, such as the WWSSN.

1.3 Literature Review

1.3.1 Himalayan Region

The Himalaya formed due to the Cenozoic collision between the Indian and Eurasian plates. It is divided into longitudinal zones: the Sub-Himalaya (Siwaliks), Lesser Himalaya, Higher Himalaya, and the Tibetan Plateau, separated by major northward-dipping thrusts, including the Main Frontal Thrust (MFT), Main Boundary Thrust (MBT), and Main Central Thrust (MCT). (Cooley, 1959)

An earthquake is a natural calamity caused by the trembling movement of the Earth's crust, generating seismic waves that pass through the Earth. In the Himalaya, the primary cause is the continuous northward movement of the Indian plate, and its collision/under-thrusting beneath the Tibetan landmass.

Earthquakes are measured using seismographs or accelerometers. Size is expressed via magnitude scales:

- **Local Magnitude (M_L):** Based on trace amplitude from a Wood-Anderson seismograph.
- **Body Wave Magnitude (M_b):** Based on the amplitude of body waves with a period of ~1 second.
- **Surface Wave Magnitude (M_S):** Based on the amplitude of surface waves with a period of ~20 seconds.
- **Moment Magnitude (M_W):** Based on the scalar seismic moment; it is preferred for all ranges as it does not "saturate" for large events.

1.3.2 Earthquake Distribution

Seismicity in the Central Himalaya is non-uniform and primarily shallow. High activity is clustered in Western and Eastern Nepal, while Central Nepal (west of Kathmandu) has shown lower activity in recent historical records.(Upreti, 1999)

1.3.3 Seismic Energy

Seismic energy is the energy released during an earthquake, transformed from potential to kinetic energy. The study uses the Gutenberg-Richter relationship ($\log N = a - bM$) to estimate the b-value, which indicates the general stress state. A b-value of 0.89 was estimated for this region, suggesting high compressive stress.

1.3.4 Comparison with International Strong Earthquakes

The study cites recent strong earthquakes globally to illustrate their impact:

- **Haiti (2010):** A strong earthquake (**M 7.0**) killed 222,570 people and destroyed nearly 100,000 houses. (Pinto, 2010)
- **Chile (2010):** A great earthquake (**M 8.8**) killed 507 people and produced a tsunami. (Cowan et al., 2011)
- **Turkey (2010):** A strong earthquake (M 6.1) killed 51 people and destroyed 1,000 buildings. (Akkar et al., 2011)

  While these events occur in different tectonic settings (e.g., subduction in Chile vs. collision in the Himalaya), they all represent the high-energy release characteristic of "strong" seismic events.

2. Materials and Methods

This is a quantitative, descriptive, and analytical study. It uses historical and instrumental seismic data to perform statistical analysis (frequency-magnitude distributions) and spatial mapping of events to conclude the tectonic behavior of the region.

Earthquake data were compiled from eight major international and national catalogs, including Oldham (1882), National Earthquake Information Center (NEIC), United States Geological Survey (USGS), International Seismological Centre (ISC), and Global Centroid Moment Tensor (GCMT), Gutenberg and Richter (G-R). Events with a magnitude of 5.0 or higher were selected, resulting in a dataset of 225 earthquakes within the region bounded by 79°–90°E longitude and 26°–31°N latitude, covering Nepal and adjacent areas of India and Tibet. Duplicates were manually removed, and magnitude scales were standardized using Gutenberg and Richter (1944) relationships. The intensity values from pre-instrumental records were converted to magnitudes using the empirical relationship $M = 1 + (2/3)\, I_0$.

Seismicity was analyzed in terms of frequency–magnitude distribution, focal depth, and spatiotemporal trends. The Gutenberg–Richter relation ($\log N = a - bM$) was applied to determine the b-value, a key indicator of the regional stress regime. Seismic segmentation was performed by dividing the study area into five zones based on the spatial clustering of epicenters. Fault plane solutions for 20 major earthquakes were examined to interpret dominant faulting mechanisms.

3. Results and Discussion

The compiled earthquake catalog indicates that most seismic activity occurs north of the Main Boundary Thrust, with dense clustering along the Main Central Thrust. The frequency–magnitude relationship yielded a b-value of 0.89, suggesting high stress accumulation. This value is slightly below the global average ($b=1.0$), consistent with regions under tectonic compression.

Spatial analysis revealed five seismic subregions with varying activity levels. The central and eastern blocks show higher seismicity rates, particularly near Kathmandu and the Arun-Kanchanjunga fault systems. The western region displayed a relative seismic gap, possibly indicating stress buildup. Depth distribution analysis showed that about 97% of events were shallow (≤35 km), typical of continental collision zones. Only a few intermediate-depth events (>70 km) were recorded, primarily in Tibet.

Temporal analysis showed two major active phases: 1816–1869 and 1916–1936, separated by quiescent periods. The 1934 Nepal–Bihar earthquake (M8.4) remains the most destructive in recorded history. Seismic activity increased after 1963 due to expanded seismographic coverage, highlighting frequent moderate earthquakes but no great events (M≥8) since 1950.(Ni & Barazangi, 1984)

Fault plane solution studies indicate that thrust faulting dominates the Himalayan compression zone, with strike-slip components in some transverse faults. In the adjoining Tibetan Plateau, normal faulting prevails, indicating extensional deformation (Molnar & Tapponnier, 1975). These findings align with previous research, confirming that ongoing plate convergence continues to drive complex seismotectonic interactions. (Bollinger et al., 2004; Kayal, 2001)

4. Conclusion

The analysis of 225 earthquakes over the past two centuries demonstrates that the Central Himalayan region remains highly seismically active, dominated by shallow thrust-type events. The computed b-value (0.89) and spatiotemporal patterns indicate high stress accumulation, especially along the Main Central and Main Boundary Thrusts. The clustering of events and historical seismic gaps suggests that large earthquakes are possible in the near future, particularly in segments that have remained quiescent since the early 20th century.

Understanding the regional seismic behavior is essential for future hazard assessment and mitigation planning. Further geodetic and seismological monitoring should be emphasized in the central and western Nepal segments to refine seismic risk models and prepare for potential high-magnitude events.

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