# Frequency magnitude distribution of large earthquakes with special reference to Kopili fault and surrounding regions of NER, India

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**Vickey Sharma**
**Registration No. TZ203954 of 2023**

**Department of Physics**
**School of Sciences**
**Tezpur University**
**Tezpur 784028, Assam, India**
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# Chapter 7

# Conclusion and Future scope

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In the present chapter, we have meticulously condensed and presented a comprehensive summary of the pivotal discoveries and insights garnered throughout the entirety of this thesis. Additionally, we have diligently elucidated the potential avenues for further exploration and advancement that lie ahead, thereby outlining the future scope of the present thesis work.

### 7.1. Conclusions

In this section, we endeavor to encapsulate and distill the salient discoveries and insights gleaned from every individual chapter within the thesis. Below, we delineate the primary points and findings from each chapter for comprehensive understanding and reference:

**Chapter 1** of the thesis provides an overview of earthquake occurrences, delving into the various precursors associated with these natural events. This chapter begins with a comprehensive literature survey, offering a detailed context for understanding the existing body of research on earthquakes. Following this, the motivations driving the research are discussed, highlighting the gaps in current knowledge and the need for further investigation. The chapter concludes by outlining the main objectives of the thesis, setting the stage for the detailed analysis and findings presented in the subsequent chapters.

**Chapter 2** of the thesis delves into the significance of the GR power law in seismology [1]. Additionally, it explores the seismological importance of the spatio-temporal variation in the b-value as an indicator of impending earthquakes. Furthermore, it examines the application of the b-value in the GEV theory [2], [3], offering insights into its utility for estimating seismic parameters.

In **Chapter 3**, the focus shifts towards identifying potential seismic zones within a 300 km radius centered at Tezpur in the Kopili fault region, renowned for its heightened seismic activity owing to intricate tectonic features. The study area is divided into four distinct seismic zones: the NEHSZ, the SASZ, the BSSZ, and the IBSTZ. Through a meticulous examination of a comprehensive earthquake catalog, the research evaluates various seismic risk attributes for each zone, encompassing parameters like maximum earthquake magnitude (Mmax), T(m), mean annual activity rate, and likelihood of occurrence.

The major findings and implications of the **chapter 3** are summarized as follows:

1) The NEHSZ, SASZ, BSSZ, and IBSTZ seismic zones has b-values of 0.83 ± 0.04, 0.91 ± 0.04, 0.81 ± 0.07, and 0.94 ± 0.03, respectively. The highest b-value was found in IBSTZ, while the lowest b-value was associated with BSSZ. The high b-value in IBSTZ indicates a larger proportion of smaller magnitude earthquakes compared to larger magnitude earthquakes, suggesting that the seismic occurrences in this area is primarily influenced by frequent, lower magnitude events. Conversely, the smallest b-value linked to BSSZ, indicating that the zone is characterized by infrequent but more significant earthquakes.

2) The four distinct seismic zones, NEHSZ, SASZ, BSSZ, and IBSTZ, yielded maximum magnitude (Mmax) values of 8.11 ± 0.51, 8.60 ± 0.52, 8.10 ± 0.91, and 7.70 ± 0.50, respectively.

3) The seismic occurrence rate (λ) values for NEHSZ, SASZ, BSSZ, and IBSTZ were determined as 5.34 ± 0.74, 6.92 ± 1.36, 3.05 ± 0.66, and 11.45 ± 1.71, respectively. IBSTZ showed the highest lambda value, indicating a higher seismic occurrence rate, and suggesting that earthquakes are more frequent in this region. This implies a higher level of seismic activity and a higher probability of earthquakes occurring within a given time period. On the other hand, BSSZ exhibited the smallest lambda value, implying a lower seismic occurrence rate, indicating that earthquakes are less frequent in this specific seismic zone. This suggests a relatively lower level of seismic activity and a lower probability of earthquakes occurring within a given time period.

4) The values of H for NEHSZ, SASZ, BSSZ, and IBSTZ were found to be 5.3, 5.4, 4.7, and 5.5, respectively.

5) The seismic zones of NEHSZ, SASZ, and IBSTZ show the highest chance of earthquake occurrence with $M_W \leq 6.0$ within the next half-century.

Conversely, the probability of earthquakes with higher magnitudes ($M_W \geq 6.5$) occurring in the same time frame exponentially decreases for all seismic zones. Additionally, when considering the likelihood of an earthquake with $M_W$ 8.5 occurring within the next hundred years, the order of probabilities among the four seismic zones follows the trend: NEHSZ > SASZ > IBSTZ > BSSZ.

**Chapter 4** of the thesis conducts a spatial, temporal, and depth-wise analysis of the b-value as a potential earthquake precursor preceding four significant recent earthquakes: the Assam earthquake on April 28, 2021 ($M_W$ 6.4), the Mizoram earthquake on November 26, 2021 ($M_W$ 6.1), the Nepal earthquake on November 9, 2022 ($M_W$ 6.3), and the Gaziantep, Türkiye Earthquake on February 6, 2023 ($M_W$ 7.8). Through spatial analysis, it was observed that the epicenters of these events were located in regions characterized by low b-values. Similarly, temporal decreases in the b-values were noted well before the occurrence of these earthquakes. Additionally, the depth-wise analysis of the b-value indicates an stress accumulation in the upper crustal region, suggesting its significance as a precursor to seismic activity.

The major findings of the **chapter 4** are as follows:

1) In this subsection of Chapter 4, a sub-sectional approach was used to formulate the b-value as an earthquake precursor before the 28th April 2021, Mw 6.4 Assam earthquake. The study region exhibited a b-value of 0.98 ± 0.02 with a $M_C$ of 3.9, determined using the MAXC approach [4]. To ensure accuracy, careful estimation of the $M_C$ was undertaken. The b-values were then correlated with the focal depth of events in the Kopili fault and surrounding areas in northeastern India. The study divided the region into subsections and analyzed 750 well-located events, finding b-values vacillating from 0.66 to 1.25. A significant low b-value (0.76 ± 0.03) near the epicenter of the 28th April 2021 earthquake indicated higher stress accumulation. Low b-values (0.66-0.76) in the shallow crust suggested Homogeneous conditions and high pressure accumulation, with high seismic moment release in the uppermost crust also contributing to low b-values.

2) In this subsection of Chapter 4, the spatio-temporal variation in b-value, along with depth-wise b-value analysis, was conducted before the 26th November 2021 Mizoram earthquake (Mw 6.1). Using a database of 767 well-located events from ISC-EHB and GCMT between 1964 and 2021, the study established the temporal disparity of b-value as an earthquake precursor for the Mizoram earthquake. The b-values varied from 0.84 to 1.51, indicating crustal homogeneity and high seismic

activity in low b-value regions, while high b-value areas were under tensional stress. Key observations include: a mean b-value of 0.98 ± 0.03 for the study area, with low b-values in highly seismic regions and high b-values in tectonic stress areas; a significant dip in the b-value curve ($b<1$) before the Mizoram earthquake; and low b-values in the upper crust indicating high-stress accumulation, while deeper regions had high b-values.

**3)** This subsection of Chapter 4 examines the spatiotemporal and depth-wise variance in b-value prior to the 6th February 2023 Gaziantep, Türkiye Earthquake ($M_W$ 7.8) using earthquake data from 1905 to 2018 and recent data from KOERI, ISC, and USGS. The study found the $M_C$ to be 2.5 and, after declustering, compiled a catalog of 25,341 events. The average b-value across the study area was 0.98±0.01, with spatial b-values ranging from 0.6 to 1.12. The earthquake's epicenter was in a low b-value (<1.0) square grid, indicating high stress accumulation and crustal deformation. A significant 32% drop in b-value from February 2020 to December 2022 was observed, confirmed by the K-S test. High seismicity rates were noted in the upper crust (5-20 km depth), with the epicenter at 10 km depth, suggesting higher stress and seismic activity in the region.

**4)** In this subsection of Chapter 4, the study investigates the spatio-temporal and depth-wise variation in b-value preceding the November 9, 2022 earthquake. Using a unified earthquake catalog from ISC and USGS, the analysis identifies the epicenter of this event in a low b-value square grid, indicative of high stress accumulation and potential crustal deformation. Similar patterns were observed for the epicentral locations of the 2011 Nepal-Sikkim earthquake ($M_W$ 6.8) and the 2015 Gorkha earthquake ($M_W$ 7.8), with the former also in a low b-value square grid and the latter in an intermediate b-value grid. Temporal analysis reveals a decrease in b-value before each of these major earthquakes, suggesting a predictive potential for seismic activity. Additionally, the study finds higher seismic moment release in regions with low b-values, particularly in the upper crust, highlighting elevated seismicity rates and stress accumulation compared to deeper regions.

**Chapter 5** of the thesis explores the practical application of the b-value in the GEV theory for estimating various seismic parameters. Specifically, it focuses on estimating the maximum annual earthquake, return period, and probability of occurrence of earthquakes over different time periods for several regions, including the Kopili fault zone, Indo-Burma zone (IBZ), and the EAFZ. By applying the b-value within the framework of the GEV theory, this chapter provides valuable insights into the seismic characteristics and potential hazards of these distinct geographical areas.

The major findings of the **Chapter 5** are as follow:

1) In this subsection of Chapter 5, the GEV theory have been Adopted for estimating the b-value for the Kopili fault and its environs. The probability of occurrence and return period for design and observed earthquakes have been estimated using the α and β values. The 'H' is found to be 4.99 for the Kopili fault and its surrounding region. The probability of occurrence for design-based earthquakes with magnitude 4, 4.5, 5, 5.5, 6, 6.5,7, 7.5 in the next 100 years is found to be 100%,100%, 100%, 100%, 99%, 96%,66%, 25%. The probable annual number of earthquakes with different magnitudes is also estimated. The exponential fall in the annual number of earthquakes having a large magnitude is observed. The estimated return period of the significantly damaging earthquake seems to be more realistic than the earlier observations.

2) In this subsection of Chapter 5, the b-value for the Indo-Burma area was estimated using the GEV theory. The α and β values have been used to estimate the return period and chance of occurrence for designed and observed earthquakes. A magnitude of 5.352 is shown to be the most likely yearly earthquake for the Indo-Burma area. It is determined that the likelihood of earthquakes of magnitude 4, 4.5, 5, 5.5, 6, 6.5, 7, 7.5, 8 in the next 100 years is 100%, 100%, 100%, 100%, 96%, 70%, and 39%. The return periods for the earthquakes stated above are as follows: 23 days, 62 days, 176 days, 1.36 years, 3.85 years, 10.88 years, 30.78 years, 87.09 years, and 246.41 years. Also being assessed is the yearly likelihood of earthquakes of various magnitudes. It is noted that the yearly number of earthquakes with a large magnitude is falling exponentially. The anticipated return time for the earthquake with major damage seems to be more plausible than the prior findings. The research makes use of a homogeneous and homogenous earthquake catalog to get a trustworthy conclusion. As a result, the conclusions drawn from this research may serve as a key input for the probabilistic evaluation of seismic risk in the studied area.

3) In this subsection of Chapter 5, the GEV theory is applied to analyze seismic characteristics of the EAFZ. Key findings include estimating maximum annual earthquake magnitudes for specific fault sections: 5.7 ($M_W$) for Amanos, 5.1 ($M_W$) for Pazarcık, 4.3 ($M_W$) for Erkenek, and 4.1 ($M_W$) for Çardak. The study also determines shorter return periods for major earthquakes ($M_W \geq 6.5$) in the Amanos section compared to Pazarcık, Erkenek, and Çardak sections, indicating higher frequency of major seismic events in Amanos. This suggests a heightened likelihood for Amanos to experience major earthquakes over the next century compared to the other fault sections, emphasizing its higher seismic risk potential.

**Chapter 6** of the thesis establishes plausible correlations between temporal variations in the b-value and fluctuations in radon gas concentration, highlighting their potential as earthquake precursors across different mediums. The observed seismic pattern, characterized by temporal decreases in the b-value, corresponds with an increase in soil radon concentration and a simultaneous decrease in atmospheric and groundwater radon gas concentrations prior to major earthquake events. This analysis underscores the significance of monitoring both seismic and environmental parameters for improved earthquake prediction and preparedness strategies.

### 7.2. Future Scope

Building on the conclusions drawn from this thesis, several promising avenues for future research have been identified. Firstly, extending the analysis of b-value variations across other significant fault zones globally could provide a more comprehensive understanding of seismic precursors and their predictive capabilities. Integrating additional geophysical and geochemical data, such as ground deformation and gas emissions, with b-value studies may enhance the accuracy and reliability of earthquake forecasting models. Further exploration of the temporal and spatial patterns of seismicity, particularly using advanced machine learning techniques, could yield new insights into the complex dynamics of earthquake generation. Additionally, longitudinal studies examining the long-term effectiveness of the GEV theory in different tectonic settings would be valuable. Investigating the interplay between radon gas concentrations and b-value anomalies in diverse geological contexts could refine our understanding of the mechanisms driving these precursors. Expanding this research to include other volatile gases and environmental parameters might also uncover new indicators of seismic activity. Finally, practical applications of this research should be pursued, such as developing real-time monitoring systems for regions with high seismic risk. Collaborative efforts with policymakers and disaster management agencies could facilitate the implementation of these systems, ultimately enhancing earthquake preparedness and mitigating the impact of future seismic events. These research directions not only aim to build on the groundwork laid by this thesis but also to push the boundaries of knowledge in seismology and earthquake risk mitigation.

### 7.3. References

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