Chapter 1

Introduction

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1.1. Earthquake:

An earthquake is triggered by the periodic release of seismic energy from the crust of the Earth, which travels as seismic waves and results in the shaking of the surface of the Earth. The earthquake events primarily occur along tectonic plate boundaries where plates collide, pull apart, or slide past each other. The majority of earthquakes are concentrated in the Pacific Ring of Fire, a zone characterized by frequent seismic activity due to numerous subduction zones. However, earthquakes can also occur within tectonic plates, known as intraplate earthquakes, often caused by stress accumulation from distant plate interactions. Advances in seismology and technology have improved the detection and understanding of earthquakes, but predicting the exact time and location of an occurrence remains a challenge. Earthquakes can have severe consequences, causing fatalities, damaging infrastructure, and initiating secondary hazards such as tsunamis, landslides, and fires. Mitigating the risks associated with earthquakes involves a combination of scientific research, engineering practices, and public preparedness. Retrofitting older buildings and infrastructure is also a critical step in enhancing resilience. Public education campaigns emphasize the importance of emergency preparedness, such as having an earthquake kit, knowing safe spots within buildings, and conducting regular drills. In addition to local efforts, international collaboration plays a vital role in improving earthquake resilience. Organizations like the Global Seismographic Network (GSN) contribute to global monitoring and information sharing. Research continues to explore the underlying mechanisms of earthquakes, with the aim of better understanding the complexities of fault lines and stress accumulation. While predicting the exact timing of earthquakes remains beyond current capabilities, probabilistic seismic hazard assessments help estimate the likelihood of future events in different regions. This knowledge is essential for guiding land-use planning, insurance, and emergency response strategies. Overall, while earthquakes are an inevitable natural hazard, proactive measures and continuous advancements in science and technology are vital in reducing their impact on human societies. The economic and social impacts of earthquakes can be profound, especially in densely populated areas. In the aftermath of a significant earthquake, communities often face challenges such as displacement of residents, disruption of services, and long-term recovery and rebuilding efforts. The cost of reconstruction can be immense, and the psychological effects on survivors, including post-traumatic stress disorder (PTSD), require comprehensive mental health support. International aid and relief efforts are critical in the immediate response to major earthquakes, providing necessary resources such as food, water, medical supplies, and temporary shelter. Effective coordination between government agencies, non-governmental organizations, and international bodies is crucial to address the urgent needs and facilitate efficient recovery operations. The role of technology in disaster response has been increasingly significant, with innovations such as drones for damage assessment, satellite imagery for mapping affected areas, and mobile applications for locating survivors and disseminating information. Long-term strategies for earthquake risk reduction emphasize the importance of resilient infrastructure, robust urban planning, and community engagement. Incorporating traditional knowledge and practices of local communities can enhance the effectiveness of modern scientific approaches. Education and training programs aimed at building local capacities and fostering a culture of safety are essential components of sustainable earthquake preparedness. Furthermore, addressing the socioeconomic disparities that exacerbate the vulnerability of certain populations is critical. Ensuring equitable access to resources for preparedness, response, and recovery can significantly mitigate the adverse effects of earthquakes on marginalized groups. In conclusion, while earthquakes are an unavoidable natural phenomenon, their impact can be substantially mitigated through a combination of scientific research, technological innovation, community preparedness, and international cooperation. Continued efforts in these areas are essential to protect lives, reduce economic losses, and enhance the resilience of societies to seismic hazards.

1.2. Earthquake precursor:

Researchers have extensively studied various earthquake precursors in an effort to develop reliable prediction methods, although accurately forecasting earthquakes remains elusive. Some of the key precursors that have been investigated include seismic activity patterns, ground deformation, gas emissions, and changes in groundwater levels. Seismic activity, such as foreshocks—smaller tremors occurring before a major quake—has been observed in some instances, though not consistently enough to serve as a reliable predictor. Ground deformation, detected through techniques like GPS and

InSAR (Interferometric Synthetic Aperture Radar), can indicate the buildup of tectonic stress in earthquake-prone areas. Variations in the emission of radon gas, a radioactive gas released from the Earth's crust, have also been monitored, as sudden increases in radon levels have been noted before some earthquakes. Additionally, fluctuations in groundwater levels and temperature have been studied, as stress changes in the Earth's crust can affect subsurface water. Despite these efforts, the complexity and variability of geological processes make it challenging to identify definitive precursors, and thus, predicting the exact time and location of earthquakes remains beyond current scientific capabilities. Nonetheless, ongoing research continues to enhance our understanding of these phenomena, contributing to improved seismic risk assessments and early warning systems. Further exploration into earthquake precursors has also included the study of electromagnetic anomalies, and atmospheric changes. Electromagnetic anomalies, such as changes in the Earth's magnetic field and low-frequency electromagnetic emissions, have been reported prior to some seismic events. These anomalies are thought to result from stress-induced changes in the Earth's crust, which generate electric currents. Atmospheric changes, such as variations in the ionosphere have also been linked to impending earthquakes. Satellite data have shown that ionospheric disturbances sometimes precede seismic events, potentially due to the release of gases or other effects of stress changes in the crust. Despite these diverse lines of investigation, a universally reliable method for predicting earthquakes has not yet been achieved. The challenge lies in the fact that not all earthquakes are preceded by noticeable precursors, and when they do occur, these signals can be subtle and easily confused with other natural or human-induced phenomena. Continuous advancements in technology and data analysis, such as the use of machine learning algorithms, hold promise for improving the detection of potential precursors and enhancing early warning systems. By analyzing vast amounts of seismic, geodetic, and atmospheric data, researchers aim to identify patterns and correlations that might not be apparent through traditional methods. The integration of interdisciplinary research efforts, combining geology, physics, chemistry, biology, and engineering, is essential for advancing our understanding of earthquake precursors. Moreover, ongoing efforts focus on developing more sophisticated monitoring systems that can detect subtle changes in the Earth's crust and atmosphere with higher precision and sensitivity. For example, advancements in seismology, including the deployment of dense seismic networks and the development of advanced seismological techniques, enable researchers to better track seismic activity and identify potential precursors. Similarly, advances in satellite technology and remote sensing allow for the continuous monitoring of ground deformation, gas emissions, and other relevant parameters over large geographic areas. In addition to technological innovations, researchers are increasingly exploring the integration of different data sources and methodologies to improve earthquake prediction capabilities. Although precise earthquake prediction may still be on the horizon, ongoing advancements in monitoring, data analysis, and interdisciplinary collaboration offer hope for improving our ability to anticipate and mitigate the impacts of the seismic events in the future.

1.3. Gutenberg-Richter power law

The Gutenberg-Richter (GR) power law **[1]** in seismology gives the equation that describes the distribution of earthquakes with respect to their magnitudes within a specific region over a given period. This law states that the frequency of earthquakes decreases exponentially with the increasing magnitude, following a logarithmic relationship. In other words, there are far more small earthquakes than large ones, and the frequency of earthquakes decreases rapidly as magnitude increases. Mathematically, the GR law is expressed as $\log_{10}(N) = a - bM$, where N represents the number of earthquakes of a certain magnitude or greater, M is the magnitude of the earthquake, and 'a' and 'b' are constants determined empirically for a specific region. This law has profound implications for seismic hazard assessment, as it allows scientists to estimate the likelihood of earthquakes of different magnitudes occurring within a given area and time frame. The b-value, a key parameter in the GR equation, is widely studied in seismology as a potential earthquake precursor. It represents the slope of the logarithmic relationship between earthquake frequency and magnitude. A higher b-value indicates a greater proportion of smaller earthquakes relative to larger ones, while a lower b-value suggests a higher likelihood of larger earthquakes. Changes in the b-value over time or across different regions can provide valuable insights into the seismic activity and stress distribution within the Earth's crust. Anomalous deviations from the typical b-value for a specific region may indicate changes in tectonic conditions, such as increased stress accumulation or the potential for a significant seismic event. Therefore, monitoring and analyzing variations in the b-value can serve as a potential precursor for identifying areas of heightened earthquake risk and informing earthquake preparedness and mitigation efforts. However, while the b-value is an essential parameter in seismic analysis, its interpretation as a reliable earthquake precursor remains a subject of ongoing research and debate within the scientific community. Studies investigating the b-value as an earthquake precursor often focus on detecting changes in seismicity patterns that could precede major earthquakes. Researchers analyze long-term seismic catalogs to determine if there are any significant deviations from the expected b-value for a given region. For example, an increase in the b-value may indicate a period of heightened seismic activity characterized by a larger number of smaller earthquakes, which could potentially lead to a larger event. Conversely, a decrease in the b-value may suggest a period of stress accumulation or release, potentially increasing the likelihood of larger earthquakes. While changes in the b-value have been observed before some seismic events, it is essential to interpret these variations cautiously. The b-value can be influenced by various factors, including data quality, completeness, and temporal and spatial scale. Additionally, changes in the b-value may not always lead to significant seismic events, as they can also result from natural fluctuations in seismic activity or local geological conditions. Despite these challenges, researchers continue to explore the potential of the b-value as an earthquake precursor, leveraging advanced statistical methods and improved data analysis techniques. Integrating the b-value with other seismic parameters and geodetic observations may enhance its predictive capabilities and contribute to more reliable earthquake forecasting and early warning systems. In summary, while the b-value holds promise as a potential earthquake precursor, its interpretation requires careful consideration of various factors and uncertainties. Continued research and collaboration among seismologists and geophysicists are essential for advancing our understanding of the b-value and its insinuations for seismic hazard analysis and earthquake risk extenuation.

1.4. Literature survey

The b-value, which indicates the ratio of small to large earthquakes, has demonstrated unusual behavior before major seismic events. Researchers worldwide have documented this phenomenon, providing insights into earthquake forecasting. A notable study by [2] reported a temporal decrease in the b-value leading up to the catastrophic 26th December 2004 Sumatra earthquake (M_W 9.0). Similarly, [3] observed a 36% reduction in the b-value before the same event. This pattern of b-value decline is not isolated to the Sumatra earthquake. In Japan, [4] documented a decrease in the b-value preceding the 26th July 2003 Miyagi earthquake (M 6.2). In Taiwan, [5] analyzed seismic data from 1999 to 2009 and observed a concordance in b-value anomalies and the epicentral locations of significant earthquakes. The factors influencing these anomalies are multifaceted. [6] suggested that local seismicity, stress accumulation, and fault mechanics contribute to the observed decreases in b-value. Supporting this, [7] found a drop in the b-value prior to the 23rd October 2011 Van–Erciş earthquake in Turkey (Mw 7.2). Moreover, [8] noted anomalous b-value behavior before the 2008 Wenchuan earthquake in China (Mw 7.9). These studies collectively indicate that a decrease in the b-value may serve as a precursor to significant seismic events, driven by underlying changes in stress and fault dynamics.

Likewise, several research efforts have been undertaken in the northeast India for the analysis of the b-value before the occurrence of some major events. In a recent study [9] observed the decline in the b-value before the occurrence of the 2016 Manipur earthquake (Mw 6.7). Northeast India, a region of significant seismic activity, has been the focus of various studies which analyzed the b-value—a key parameter in earthquake forecasting—prior to major seismic events. These studies reveal a consistent pattern of b-value decline before significant earthquakes, underscoring the potential of b-value analysis in earthquake prediction. In a notable study, [9] documented a decrease in the b-value leading up to the 2016 Manipur earthquake (Mw 6.7). This decline indicated a buildup of stress in the region, which culminated in the earthquake. [10] also observed significant fall in b-value before the occurrence of the 28th April 2021 Sonitpur earthquake (M_W 6.5). These consistent observations across different events in Northeast India highlight the importance of b-value monitoring as a tool for anticipating seismic activity. The decline in b-value observed in these studies is consistent with global patterns, where a reduction in b-value often precedes significant seismic events. This phenomenon is typically attributed to increased stress and changes in fault mechanics, which are critical indicators of an impending earthquake. These findings emphasize the value of continuous b-value monitoring in Northeast India, enhancing our ability to predict and prepare for future seismic events.

1.5. Motivation behind the work

Seismic analysis has been a crucial field of study globally, including in Northeast India. Historically, studies on b-value analysis have often covered extensive regions. This broad approach, while insightful, tends to overlook the microscopic heterogeneity within specific fault zones. Additionally, these studies typically employed conventional methods, which may not fully capture the complexity of seismic activities. Recognizing these gaps, our recent research has taken a more refined approach. We performed a detailed b-value analysis, incorporating the Kolmogorov-Smirnov statistical method, focusing on the Kopili Fault region, the Indo-Burma region, Nepal and the East Anatolian Fault Zone. This methodology allows for a more precise understanding of the seismic behavior in these highly active areas. Furthermore, we integrated the GEV theory to enhance the seismic parametrization of these regions. This theory helps in assessing the probability of extreme seismic events, providing a more comprehensive risk evaluation. Researchers have previously noted a plausible correlation between b-value and various factors such as seismic moment, depth, and fault mechanisms. Importantly, anomalies in b-value and radon gas levels have been observed prior to major earthquake events, suggesting their potential as two distinct earthquake precursors. We also intended to find a connection between b-value anomalies and radon gas anomalies in our study. The findings could enhance our understanding of earthquake precursors and improve predictive models, potentially leading to better preparedness and mitigation strategies in seismically active regions. This approach not only advances the methodology of seismic analysis but also contributes to the broader field of earthquake prediction and hazard assessment.

1.6. Objectives of the thesis

The main objectives of the present work are as follow:

a) Seismic source zonation around kopili fault region.
b) Spatio-temporal analysis of b-value before the occurrence of major earthquake events.
c) Application of the GEV Approach for Seismic Hazard Analysis.
d) Plausible correlation between b-value and radon gas anomaly.

1.7. Thesis Outline:

Chapter 1 provides an overview of the thesis, introducing the key topics and objectives addressed throughout the study. It outlines the significance of investigating seismic phenomena and the role of b-values in earthquake prediction.

In *Chapter 2*, the focus shifts to a detailed exploration of b-values. This chapter delves into the theoretical underpinnings of b-values, discussing their significance in seismic analysis and their relationship to earthquake occurrence.

Chapter 3 presents the seismic source zonation in the vicinity of the kopili fault zone of northeast India, established through b-value analysis. It examines how variations in b-values can inform the delineation of seismic zones within the region, offering insights into potential earthquake hazards.

In *Chapter 4*, spatio-temporal anomalies preceding recent significant earthquakes are investigated. The analysis focuses on events such as the 2021 Assam earthquake, 2022 Mizoram earthquake, 2022 Nepal earthquake, and the 2023 Turkey earthquake, exploring patterns and precursors observed in b-values.

Chapter 5 introduces the Gumbel extreme value theory, a statistical approach used to model extreme events such as earthquakes. This chapter explores how this theory can enhance our understanding of seismic risk assessment and prediction.

Chapter 6 explores the plausible correlation between radon levels and b-value anomalies. It investigates whether variations in radon gas concentrations could serve as precursors to seismic events, potentially enhancing early warning systems.

In *Chapter 7*, the thesis concludes with a summary of findings and conclusions drawn from the study. Additionally, this chapter outlines future research directions in b-value analysis, highlighting areas for further exploration and refinement of earthquake prediction methodologies.

1.8. References

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