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Muhammad Hanif

muhammadhanif.m@kkumail.com

Geoinformatics, College of Computing, Khon Kaen University, 40002, Thailand https://orcid.org/0000-0002-7106-3821

Sarun Apichontrakul

sarunap@kku.ac.th

Geoinformatics, College of Computing, Khon Kaen University, 40002, Thailand

Pichawut Manopkawee

Geological Science, Faculty of Science, Chiang Mai University, 50200, Thailand

Niti Mankhemthong

Geological Science, Faculty of Science, Chiang Mai University, 50200, Thailand

Triyatno

Geography, Faculty of Social Science, Universitas Negeri Padang, 25132, Indonesia

Sakpod Tongleamnak

Geoinformatics, College of Computing, Khon Kaen University, 40002, Thailand

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Integrated Spatial Statistical and Machine-Learning Analysis of Earthquake Clustering and Ground Motion Patterns in Myanmar

Muhammad Hanif[1], Sarun Apichontrakul[1]*, Pichawut Manopkawee[2], Niti Mankhemthong[2], Triyatno[3], Sakpod Tongleamnak[1],

[1]Geoinformatics, College of Computing, Khon Kaen University, 40002, Thailand

[2]Geological Science, Faculty of Science, Chiang Mai University, 50200, Thailand

[3]Geography, Faculty of Social Science, Universitas Negeri Padang, 25132, Indonesia

*Corresponding author:
Sarun Apichontrakul, Email: sarunap@kku.ac.th

Abstract

Myanmar constitutes a region of pronounced tectonic activity, predominantly governed by the Sagaing Fault, a major strike-slip structure responsible for generating large and highly destructive earthquakes that affect multiple socio-economic sectors. This study aims to characterize spatial patterns of seismicity, examine their association with the distribution of active faults, and assess seismic hazards in Myanmar through an integrated spatial analytical framework. The analysis utilizes seismicity data spanning from 1975–2025, obtained from the United States Geological Survey. To delineate and quantify spatial seismic patterns, the study applies Kernel Density Estimation, Getis–Ord Gi* hotspot analysis, Global Moran's I, and HDBSCAN clustering. Seismic ground motion hazards are estimated using Ground Motion Estimation techniques. The results demonstrate that the majority of earthquakes in Myanmar occur in close proximity to regional tectonic faults. The principal zone of seismic density is concentrated along the northwestern subduction margin. High-intensity hotspots, however, are primarily distributed along several tectonic sub-segments of the Sagaing Fault, particularly near its structural junction with the Gwecho subduction zone. A major seismic cluster extends along the western subduction interface, while four additional clusters are aligned with the Sagaing strike-slip system. Ground motion estimates indicate that spatial variability in shaking intensity is principally controlled by the combined effects of earthquake magnitude and focal depth. These parameters contribute to elevated seismic hazard levels along specific segments of the Sagaing Fault that are characterized by shallow, high-magnitude events. Overall, the integration of these analytical approaches establishes a comprehensive spatial framework for interpreting and assessing earthquake hazards in Myanmar.

Keywors: earthquake; seismicity; spatial data mining; clustering; geohazard.

Highlights

- The majority of earthquakes in Myanmar are spatially concentrated and structurally controlled by regional fault architecture. Seismic density is predominantly distributed along the western mountainous belt associated with the subduction system, whereas earthquake magnitude hotspots are principally located at the tectonic intersection between the Sagaing Fault and the Gwecho subduction zone.
- Myanmar's seismicity exhibits strong spatial autocorrelation, forming multiple statistically significant clusters governed by major tectonic structures, including the Sagaing Fault, the Kabaw subduction zone, the Indo-Burma Range, and the Mengxing Fault.
- Ground motion estimation reveals that regional peak ground acceleration patterns are not spatially synchronous with earthquake density. Although the western subduction belt generates high seismic density and extensive cluster coverage, relative ground motion levels remain moderate due to the occurrence of relatively deep-focus events. In contrast, segments of the Sagaing Fault exhibit comparatively elevated ground motion despite lower earthquake density, reflecting the predominance of shallow, high-magnitude strike-slip events.

1. Introduction

Earthquakes are natural phenomena generated by the sudden movement of active tectonic plates along faults, by subduction processes occurring within the Earth, or by volcanic activity (Zaw and Park, 2025). Myanmar is among the countries that frequently experience destructive earthquakes. Historical records document a series of major events during the first half of the twentieth century, including three significant earthquakes near Bago between 1929 and 1930 and two events north of Mandalay in 1946. The central segment of the Sagaing Fault, located between Mandalay and the transtensional zone near Nay Pyi Taw, has been identified as a seismic gap (Tsutsumi et al., 2009; Wang et al., 2014). This segment, approximately 180 to 250 km in length, is believed to have last undergone a major rupture during the 1839 Ava earthquake.

The 1956 Sagaing earthquake (Mw approximately 6.8) is interpreted to have ruptured only a limited portion of this segment south of 22°N. The 2012 Thabeikkyin earthquake (Mw 6.8) occurred near the northern boundary of the rupture zone and partially overlapped the rupture area of the 1946 event (Soe et al., 2017). Seismic activity in this region exhibits a quasi cyclical temporal pattern that persists to the present (Sloan et al., 2017).

The high level of seismic activity throughout Myanmar's history is closely associated with its regional tectonic configuration, which lies at the intersection of several major tectonic plates (Aung, 2009). The Sagaing strike slip fault, a principal structure linked to the Middle Andaman spreading center, is offset by northwest southeast oriented transform faults and is divided into five major segments (Wang et al., 2014). This fault system exhibits a sustained slip rate of approximately 18 to 24 mm per year (Sloan et al., 2017). Ongoing interactions among tectonic systems beyond the Sagaing Fault contribute to significant seismicity across Myanmar (Sloan et al., 2017).

Geomorphological evidence further documents the tectonic history of the Sagaing Fault. Meter scale lateral displacements, uplifted river terraces, and well developed pressure ridges indicate repeated surface rupturing earthquakes since the late Holocene (Sloan et al., 2017). Historical and instrumental records document at least nine earthquakes with magnitudes greater than 6.5 along the Sagaing Fault during the past century (Wang et al., 2014; Soe et al., 2017). Each segment is considered capable of generating earthquakes exceeding magnitude 7, with estimated recurrence intervals ranging from 100 to 300 years, either as individual segment ruptures or through multi segment rupture scenarios (Tsutsumi et al., 2009; Wang et al., 2011). The most recent major event, the Mw 7.7 Mandalay earthquake of March 28, 2025, has been reported in recent studies (Lindsey et al., 2025).

Earthquakes have profound impacts on both human populations and the environment in Myanmar. The major Mandalay earthquake of 2025, which was associated with the principal Sagaing Fault that governs the country's primary tectonic system, generated high peak ground acceleration and caused severe damage in areas surrounding the epicenter. Official reports indicate that 3,787 people were killed, 88 were reported missing, and 5,106 were injured. In total, 499,123 individuals were affected and 309,639 were displaced. The disaster resulted in the complete destruction of 11,981 buildings and damage to 639 infrastructure facilities, including railways and road networks (Asean Disaster Risk Reduction Center, 2025). The affected regions included Mandalay, Sagaing, Shan State (South), Nay Pyi Taw, Bago (East), Magway, and Shan State (North) (UN-HABITAT, 2025). These impacts demonstrate that major earthquakes can produce devastating consequences across regions closely associated with active tectonic systems and earthquake sources.

In seismogenic systems, multiple fault sequences are commonly associated with individual principal faults (Valoroso et al., 2014). Adjacent and clustered fault segments interact dynamically with earthquake sequences that occur along the main fault, thereby

influencing fault evolution and facilitating stress transfer that may trigger seismic activity on secondary branches (Bulut et al., 2012). The spatial complexity of fault dynamics exhibits a strong correlation with large earthquakes, energy release processes, and seismic hazard assessment, and therefore warrants careful consideration (Chu et al., 2021). During episodic energy release along locked fault planes, deformation may develop around the fault in the form of distributed strain or microcracking (Valoroso et al., 2014). Empirical evidence further indicates that increased spatial complexity in fault distribution is significantly associated with elevated seismic activity and reduced ground stability (Chatterjee et al., 2024). An integrated understanding of fault architecture, earthquake intensity, and surface stability at the regional scale is therefore essential for evaluating tectonic hazards and formulating comprehensive earthquake risk mitigation strategies.

Advances in computational technology have enabled the extensive application of spatial analysis and artificial intelligence in the study of long term seismic datasets. Various spatial analytical techniques have demonstrated effectiveness in extracting meaningful patterns from historical earthquake records (Barakbah et al., 2017). Machine learning based segmentation of seismic data can identify latent structures within complex numerical datasets and group them into clusters that correspond closely to tectonic processes (Muhajir et al., 2018; Rajagukguk et al., 2024). Several algorithms are capable of modeling non-linear relationships and multidimensional interactions among variables such as hypocentral depth, geographic location, and magnitude (Swari et al., 2022; Sinabela et al., 2024). The resulting cluster structures support seismological interpretation by clarifying relationships between seismicity and established geological features and, in some cases, by revealing previously unrecognized tectonic structures. These approaches also contribute to disaster risk assessment and probabilistic seismic hazard modeling (Hafid and Hidayat, 2025).

Several previous studies have evaluated seismic hazards in Myanmar through analyses of ground motion, surface deformation derived from field observations and Synthetic Aperture Radar data, photogrammetry, seismic intensity distribution, geodynamic processes, spatial correlation, and earthquake induced infrastructure damage (Cruz et al., 2025; Wang et al., 2025; Ghosh et al., 2025; Swe et al., 2025). In addition, Ground Motion Estimation models applied across different regions provide essential information for estimating the spatial distribution and intensity of earthquake induced ground shaking (Oo et al., 2025).

However, seismic behavior is inherently complex, spatially heterogeneous, and multiscale in nature, as it is governed by intricate interactions among tectonic segments (Bulut et al., 2012; Chu et al., 2021). A single geophysical analytical method is therefore insufficient to comprehensively capture the detailed characteristics of an entire fault system (Luo et al., 2026). A multi method approach offers a more robust and adaptable framework for understanding seismic characteristics, as no individual method consistently performs optimally across all spatial contexts (Stephenson et al., 2022). Despite their respective limitations, individual spatial analysis techniques provide complementary insights into seismicity, including event density patterns, statistical significance, internal cluster structure, and implications for ground shaking hazards.

Despite the well-recognized seismic activity of Myanmar, comprehensive spatial analyses that integrate statistical, machine learning, and ground-motion perspectives remain limited. Previous studies have typically focused on either tectonic interpretations or probabilistic hazard assessments, often without systematically examining how spatial clustering patterns correspond to regional ground-motion implications. This study addresses that gap by integrating multiple spatial analytical approaches including Kernel Density Estimation (KDE), Getis–Ord Gi* hotspot analysis, Moran's I spatial autocorrelation, and density-based machine learning clustering (HDBSCAN) to characterize the spatial structure of

earthquake occurrence across Myanmar from 1980 to 2025. By combining traditional spatial statistics with unsupervised clustering techniques, the analysis enables cross-validation of seismicity patterns and reveals internal spatial heterogeneity within major tectonic corridors, particularly along the Sagaing Fault and the Indo-Burman ranges. Furthermore, the study links these spatial patterns to deterministic peak ground acceleration (PGA) estimation to provide an integrated regional perspective connecting earthquake distribution with potential ground-motion intensity. Through this multi-method geospatial framework, the research contributes to improved understanding of earthquake clustering behavior and its implications for regional seismic hazard assessment in a tectonically complex and data-limited environment.

Accordingly, this study aims to characterize spatial seismicity patterns, examine their relationship with regional fault distribution, and assess seismic hazard in Myanmar using a peak ground acceleration based spatial analysis framework. The specific objectives of this research are as follows:

(1) To implement an integrated spatial analysis framework in order to characterize earthquake density patterns, identify statistically significant hotspots.

(2) To identify relationship and delineate seismicity clusters derived from long term seismicity datasets.

(3) To perform a regional scale analysis of the seismicity catalog using a generic Peak Ground Acceleration equation within a Ground Motion Estimation framework to evaluate spatial variations in ground shaking intensity.

Through the application of these analytical approaches, the study seeks to develop an integrated understanding of earthquake intensity, hotspot distribution, and spatial clustering in relation to regional fault architecture and surface stability. Such an understanding is essential for evaluating potential tectonic hazards and for strengthening comprehensive earthquake risk mitigation strategies.

2. Material and Method

2.1 Geology Setting of Myanmar

Myanmar shares land borders with China, Laos, Thailand, India, and Bangladesh. To the south, the country borders the Bay of Bengal and the Andaman Sea and maintains a maritime boundary with Malaysia. The geomorphology of Myanmar is defined by a series of horseshoe shaped mountain ranges that extend along the northern, western, and eastern margins of the country, enclosing fertile central river valleys and extensive delta plains (Oo et al., 2025). Major physiographic units include the Arakan Mountains, which form part of the regional orogenic system, the Shan Plateau, and the Ayeyarwady River Basin, as well as the Naga and Chin Hills (Geological Map of Myanmar, 1977; Aung, 2009). The country's highest peak, Mount Hkakabo Razi, which rises to 5,881 meters, is located in the northern mountainous region. Additional tectonic features, such as Lake Indawgyi, further reflect Myanmar's active geodynamic setting (Hasrah et al., 2024).

From a regional tectonic perspective, Myanmar exhibits a predominantly north to south structural orientation. Oo et al. (2025) emphasized that the country is characterized by a complex fault network dominated by the Sagaing Fault, an approximately 1,400 km long dextral strike slip fault with an estimated slip rate of about 20 mm per year (Sloan et al., 2017). This major structure defines the principal continental transform boundary within Myanmar. To the south, the Sagaing Fault connects with the Middle Andaman spreading center, which consists of a northeast to southwest trending ridge system offset by northwest to southeast oriented transform faults. Myanmar lies at the intersection of several major tectonic plates, and this configuration has generated sustained seismic activity throughout its geological history (Aung, 2009).

The western mountain belt represents an active subduction system, whereas the eastern mountainous region exhibits a more complex tectonic architecture composed of multiple fault

segments with orientations that differ from the Sagaing Fault and display varied kinematic characteristics (Sloan et al., 2017). The continued interaction and activity of these tectonic structures have produced significant seismicity across Myanmar, and most historical earthquakes have been associated with distinct segments of the Sagaing Fault system (Wang et al., 2014) (Figure 1).

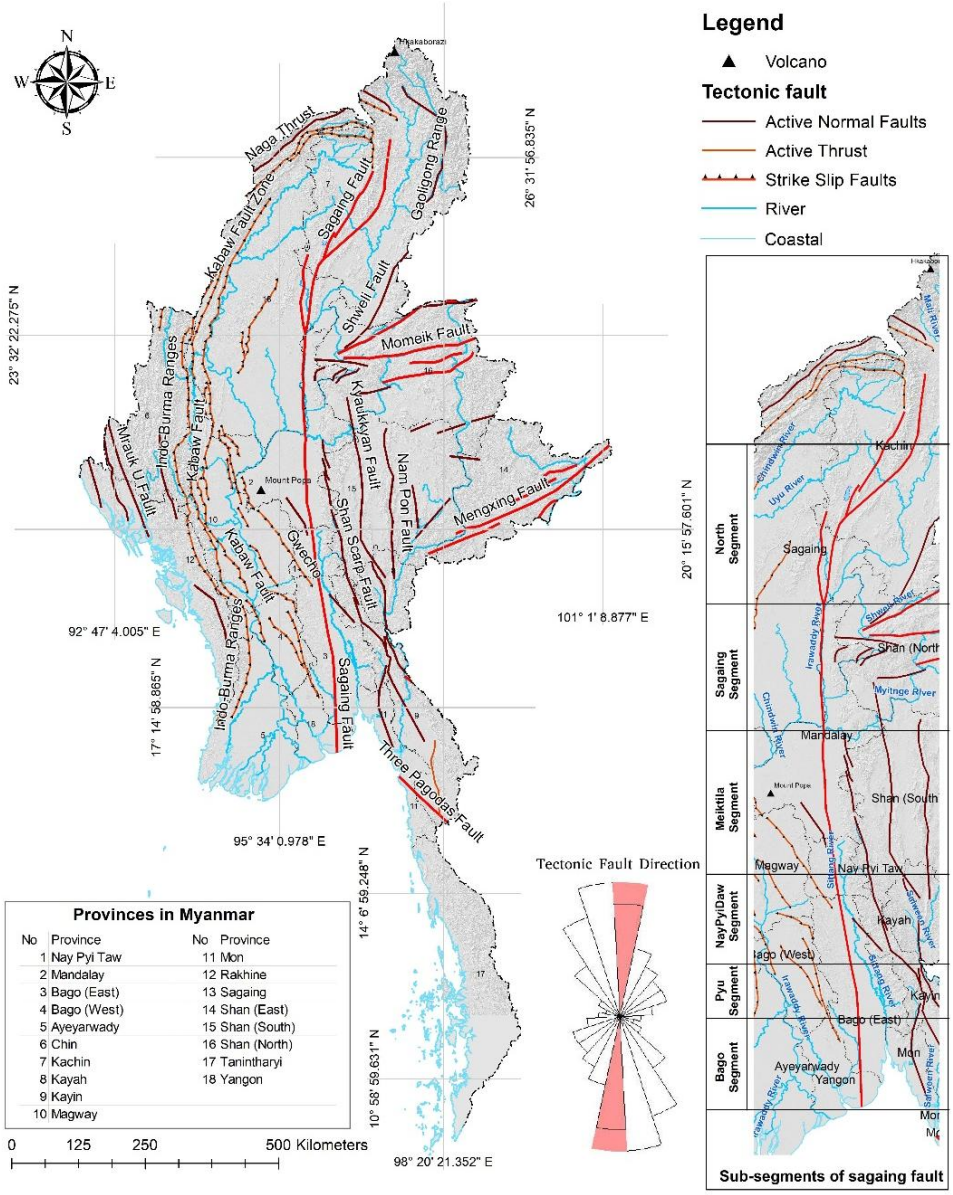


Fig 1. The geology structure of Myanmar region. Data sources: (Sloan at al., 2017, Geological Map of Myanmar 1977, and Gürboğa at al., 2025).

2.2 Data collection and pre-processing

The earthquake dataset used in this study covers a fifty years period from January 1, 1975 to December 31, 2025, and comprises 2,359 recorded events (Figure 2). The data were obtained from the United States Geological Survey earthquake catalog, which provides publicly accessible seismic records. The dataset includes spatial point information representing earthquake epicenters, together with associated attributes such as magnitude and focal depth.

Spatial data on the distribution of tectonic faults in Myanmar were derived from Sloan et al. (2017). The geological map of Myanmar was obtained from the Myanmar Geoscience Society (1977). The map delineating the segmentation of the Sagaing Fault was sourced from Gürboğa et al. (2025). Administrative boundary data for Myanmar, updated in 2024, were acquired from the open access dataset provided by the Humanitarian Data Exchange (HDX) (Figure 2).

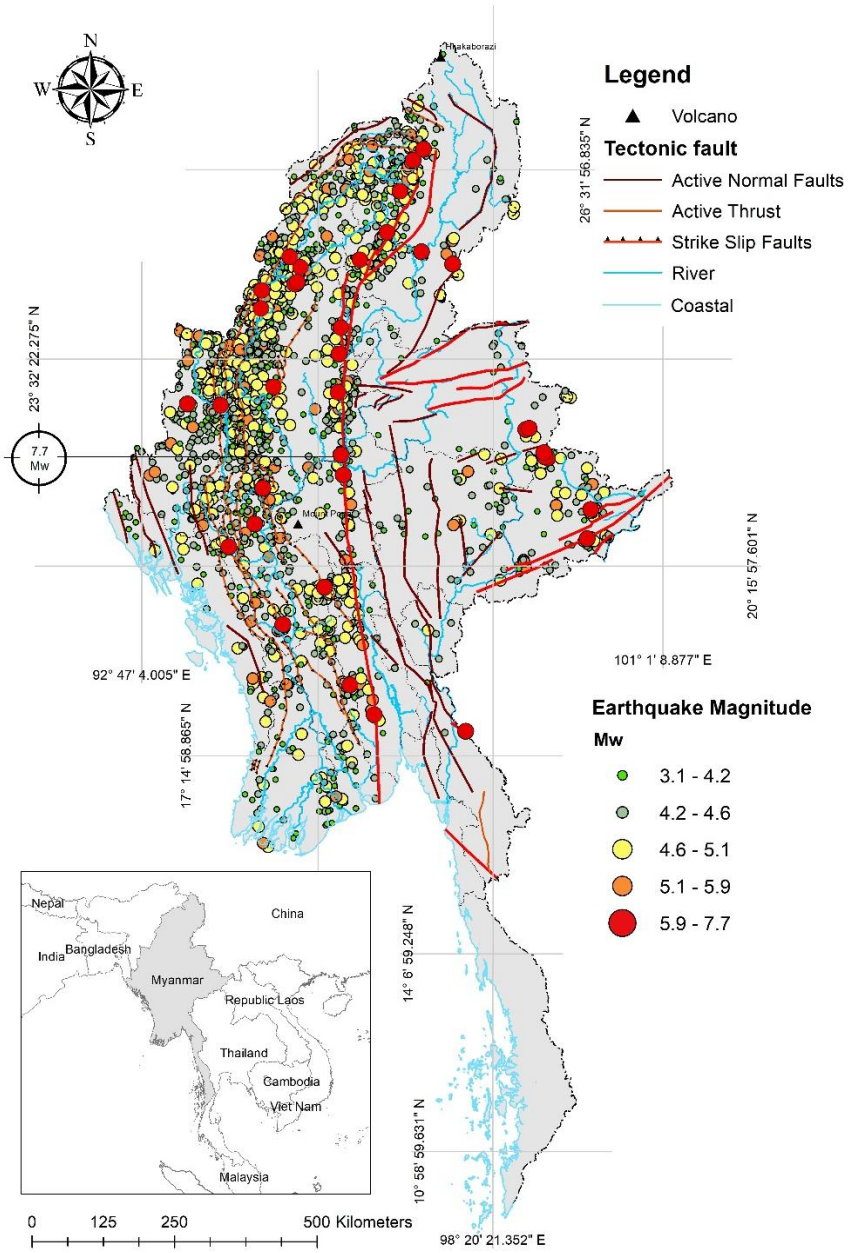


Fig 2. The distribution of earthquake magnitude (Mw) from 1975 to 2025. Data sources: (USGS, Sloan at al., 2017 and Geological Map of Myanmar 1977).

Earthquake magnitudes in the dataset range from a minimum of Mw 3.1 to a maximum of Mw 7.7, with a mean value of Mw 4.48 and a standard deviation of 0.45. These statistics indicate that most recorded events fall within the moderate magnitude range and display relatively low variability. In contrast, focal depths exhibit considerable variation, ranging from very shallow events at approximately 0.6 km to deep earthquakes reaching depths of up to 200

km. The mean focal depth is 60.89 km, with a standard deviation of 40.97 km. This substantial variability in depth reflects pronounced heterogeneity in earthquake source characteristics and highlights the complex tectonic framework of the Myanmar region. Further details are presented in Table 1.

Table 1. The statistical report of earthquake data in Myanmar 1975 to 2025.

Types	Max	Min	Mean	Stdv
Magnitude (Mw)	7.7	3.1	4.48	0.45
Depth (Km)	200	0.6	60.89	40.97

2.3 Analysis Data

2.3.1 Exploratory Earthquake Density Estimation and Hotspot

Initially, earthquake records were plotted and analyzed using descriptive statistical methods, including the calculation of minimum, maximum, and mean values, to characterize the seismic profile of Myanmar based on United States Geological Survey data. Earthquakes were also classified according to their distance from causative faults into three categories: near fault events located less than 20 km from a fault, intermediate fault events between 20 and 50 km, and far fault events located more than 50 km away (Todorov and Billah, 2021).

Subsequently, Kernel Density Estimation was applied as an initial exploratory technique to visualize the spatial distribution and concentration of earthquake events (Amandor et al., 2024). This method produces a continuous density surface that highlights areas of relatively high and low seismic activity, thereby facilitating the preliminary identification of active seismic zones without relying on predefined administrative boundaries or prior clustering assumptions (Tong et al., 2025). In this study, Kernel Density Estimation was first used to examine spatial concentration patterns descriptively. However, because high density patterns may result from random spatial processes, further spatial statistical analyses are

necessary to evaluate their statistical significance. The Kernel Density Estimation procedure employs a quartic kernel function based on a fourth degrees polynomial, as defined in the following equation (Silverman, 1986; Amandor et al., 2024).

$$K\,(x) = \frac{15}{16}(1 - x^2)^2 \tag{1}$$

In this formulation, *x* represents the normalized distance within the kernel's limited support, which is directly controlled by the bandwidth and constrained to values between −1 and 1. The kernel function is defined as zero for all *x* values outside this support.

Subsequently, hotspot analysis using the local Getis–Ord Gi* statistic was conducted to evaluate the presence of statistically significant spatial clustering of earthquake events (Songchitruksa & Zeng, 2010). This method identifies locations exhibiting significantly high (hotspots) or low (coldspots) concentrations of seismic activity relative to their surrounding neighborhoods (Jana & Sar, 2016). The Getis–Ord Gi* hotspot analysis, as implemented in ArcGIS, produces standardized statistical measures that quantify the intensity and significance of local spatial clustering (Manepalli et al., 2011; Pal et al., 2023), and is expressed as follows:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{[\,n\,\sum_{j=1}^{n} w_{i,j}^2 - (\sum_{j=1}^{n} w_{i,j})^2\,]}{n-1}}} \tag{2}$$

where, *xj* express the attribute value for feature *j*, *wi*. *j* represented the spatial weight between feature *i* and *j*, and n represent the total number of features, and:

$$X^- = \frac{\sum_{j=1}^{n} x_i}{n} \tag{3}$$

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n}} - (X^-)^2 \tag{4}$$

The results of this analysis provide spatially explicit evidence of areas that exhibit statistically significant seismic activity. However, hotspot analysis primarily highlights local intensity patterns and does not explicitly characterize the internal structure or heterogeneity of earthquake events within the identified hotspot regions (Pal et al., 2023). Although these

hotspots delineate zones of elevated seismicity, they do not clarify how individual events are spatially organized within those zones or how such patterns relate to the underlying seismotectonic processes.

2.3.2 Spatial Earthquake Clustering

In the first stage, spatial autocorrelation was assessed using Global Moran's I to examine the extent to which the values of a given variable are spatially associated among geographically proximate locations. This analysis is grounded in the fundamental assumption that geographic phenomena are not randomly distributed in space but instead exhibit systematic spatial patterns (Getis, 2009). Conceptually, spatial autocorrelation measures the degree of similarity or dissimilarity in attribute values among neighboring spatial units. Positive spatial autocorrelation occurs when similar values are spatially clustered, whereas negative spatial autocorrelation arises when dissimilar values are located near one another (Tian et al., 2023).

The analysis is typically conducted in three principal stages. The first stage involves defining spatial relationships among observational units through the construction of a spatial weight matrix, which may be based on distance thresholds, contiguity criteria such as rook or queen adjacency, or a k nearest neighbor approach (Chen, 2023). The second stage compares attribute values at each location with those of neighboring locations in order to detect potential spatial clustering patterns. The third stage consists of statistical significance testing to determine whether the observed spatial pattern deviates from a random spatial process (Du et al., 2024).

In this study, Global Moran's I was employed as the primary measure of spatial autocorrelation to evaluate the overall spatial dependence of seismicity across the study area. A Moran's I value greater than zero indicates positive spatial autocorrelation, a value less than zero indicates negative spatial autocorrelation, and a value close to zero suggests a spatially random distribution of earthquake events.

Subsequently, earthquake cluster analysis was performed using artificial intelligence which is namely as the Hierarchical Density Based Spatial Clustering of Applications with Noise algorithm. This is an unsupervised machine learning technique that has been widely adopted in seismological research (McInnes et al., 2017; Stewart and Al Khassaweneh, 2022). HDBSCAN is a density based clustering method that constructs hierarchical cluster structures from Minimum Spanning Trees, enabling it to capture complex and non uniform spatial patterns that commonly characterize seismic datasets (Tran et al., 2021). The algorithm incorporates internal validation metrics, including cluster stability, persistence scores, and condensed cluster trees, which support objective parameter selection and facilitate meaningful interpretation of clusters in relation to underlying geophysical processes (Wang et al., 2023). These features allow HDBSCAN to identify irregularly shaped clusters automatically and to distinguish noise without requiring a predefined distance threshold, making it particularly suitable for earthquake data characterized by heterogeneous event densities and an unknown number of clusters (Yang et al., 2025).

The analysis began with the compilation of an earthquake dataset for Myanmar that included geographic coordinates, magnitude, and focal depth. All variables were standardized using a StandardScaler to ensure comparability across feature scales and to prevent variables with larger numerical ranges from disproportionately influencing distance based computations. Parameter optimization was conducted through systematic testing of multiple combinations of the min_cluster_size parameter ranging from 5 to 30 and the min_samples parameter ranging from 5 to 20, using increments of five. Each parameter configuration was evaluated according to three criteria: cluster stability, the proportion of events classified as noise, and the number of valid clusters identified. These indicators were normalized and integrated into a composite evaluation score, with primary emphasis placed on cluster stability. The parameter set that

produced the highest composite score was selected as optimal and subsequently applied to derive a robust and representative earthquake cluster structure.

2.3.3 Ground Motion Estimation (GME)

The Ground Motion Estimation mathematical model is applied to estimate the intensity of ground shaking generated by an earthquake on the basis of parameters such as magnitude, source to site distance, focal depth, and local site conditions. One of the principal outputs of this model is Peak Ground Acceleration, which represents the maximum acceleration of ground motion that occurs or is expected to occur at a specific location during an earthquake.

In this study, a simplified formulation within the Ground Motion Estimation framework was adopted in accordance with modifications proposed in previous research. The model incorporates four primary controlling variables: earthquake magnitude, focal depth, hypocentral distance, and fault type. It also includes regression coefficients, correction factors, and associated statistical error terms.

The first stage in the implementation of the Ground Motion Estimation model involves calculating the hypocentral distance, denoted as Xeq. This parameter is essential because a single earthquake can generate substantially different Peak Ground Acceleration values at different sites depending on the distance between the source and the observation point (Fukushima and Tanaka, 1990). The hypocentral distance is expressed by the following equation:

$$X_{eq} = \sqrt{d^2 + h^2} \tag{5}$$

Where d represents the horizontal (epicentral) distance in kilometers, and h denotes the earthquake focal depth. The subsequent calculation of Peak Ground Acceleration (PGA) is described by the following equation, based on established GME formulations (Bindi, 2011; Boore & Atkinson, 2008; Triyatno et al., 2024).

$$Log\ A = 0.5\ Mw\ +\ 0.0036\ D\ + \sum d_i s_i -\ log\ X_{eq} -\ 0.003\ X_{eq} +\ e\ +\ \varepsilon \qquad (6)$$

where A denotes the maximum ground acceleration (PGA) expressed in gal, Mw is the moment magnitude, D represents the hypocentral depth (km), Xeq is the hypocenter-to-site distance (km), d is the epicentral distance to the observation location, s is a dummy variable representing fault type (s = 1 when the specified fault condition is satisfied), e is the regression coefficient (0.6), and ε denotes the model standard deviation (0.24).

The equation proposed by Triyatno et al. (2024) can be interpreted as a simplified Ground Motion Prediction Equation (GME), in which the −log R and −0.003 R terms represent geometric spreading and anelastic attenuation, respectively, while the magnitude-dependent components follow the general structure of conventional GMPE formulations. This approach was adopted in consideration of data availability and the objectives of the present study, which are regional in scale and emphasize spatial characterization rather than detailed probabilistic assessment or site-specific microzonation.

The calculated Peak Ground Acceleration values derived from the seismic dataset at each earthquake event location were subsequently interpolated using the Inverse Distance Weighting method (Alavi et al., 2025). The principal advantages of the Inverse Distance Weighting approach include its conceptual simplicity, computational efficiency (Cheng et al., 2025), and flexibility in controlling interpolation behavior through the selection of sample points and weighting parameters. The method performs effectively when parameters exhibit anomaly distributions and ensures that interpolated values remain within the range of the observed sample data (Barudžija et al., 2024; Benmoshe, 2025).

The subsequent stage involves conducting a sensitivity analysis based on Equation 7 to evaluate the influence of controlling variables on the estimated Peak Ground Acceleration values.

$$S_m = \frac{\Delta \ln(PGA)}{\Delta Mw} \qquad (7)$$

Due to limitations in the performance evaluation of this estimated PGA model, direct validation using field observation data over very large regional scales is not feasible. Therefore, a sensitivity analysis is conducted using the PGA values (Sandi, at al., 2025). This analysis evaluates the response of PGA to variations in earthquake magnitude, source-to-site distance, and source depth through defined sensitivity parameters (Jia, at al., 2023). As the PGA values are derived from a deterministic ground-motion formulation, the analysis emphasizes parameter sensitivity rather than predictive accuracy.

3. Result

3.1 Earthquake Density and Hotspot

A review of earthquake characteristics in Myanmar provides important insight into seismic activity over the past fifty years. Overall, the analysis indicates that earthquake magnitude is not strongly controlled by focal depth but is more closely associated with source mechanisms and regional tectonic conditions. The depth distribution shows that most events occur at shallow to intermediate levels, predominantly within the 0 to 70 km range (See Table 2).

Table 2. The statistical report depth of earthquake events from the surface

Depth from tectonic fault				Magnitude (Mw)		
Classification	Depth (Km)	Earthquakes	(%)	Max	Min	Mean
Shallow focus	0-70	1352	57.3	7.7	3.1	4.5
Intermediate focus	70-300	1007	42.6	7.3	3.2	4.4
Deep focus	300-700	0	0	0	0	0

Table 3 further presents the relationship between moment magnitude (Mw) and distance from mapped tectonic faults. Considerable magnitude variability is observed at short fault

distances, including several higher magnitude events. The distribution demonstrates that the majority of earthquakes are concentrated relatively close to tectonic fault structures.

Table 3. The statistical report distance of earthquake events from tectonic fault

Distance from tectonic fault				Magnitude (Mw)		
Classification	Distance (Km)	Earthquakes	(%)	Max	Min	Mean
Near-fault	< 20	1623	68.8	7.7	3.2	4.45
Intermediate-fault	20 – 50	666	28.2	6.8	3.1	4.45
Far-fault	> 50	70	3.0	5.5	3.8	4.45

More than half of the recorded earthquake events are spatially distributed along and oriented around mapped tectonic faults. This pattern is followed by events occurring at intermediate distances, whereas only a limited number of earthquakes are observed at locations far from the fault system (See Table 3).

The frequency of earthquake occurrences decreases as the distance from the fault system increases, and magnitudes at greater distances tend to cluster within the low to moderate range. These findings indicate that most earthquake events are strongly associated with active tectonic mechanisms. However, the results do not demonstrate a strong linear relationship between earthquake magnitude and distance from the nearest fault.

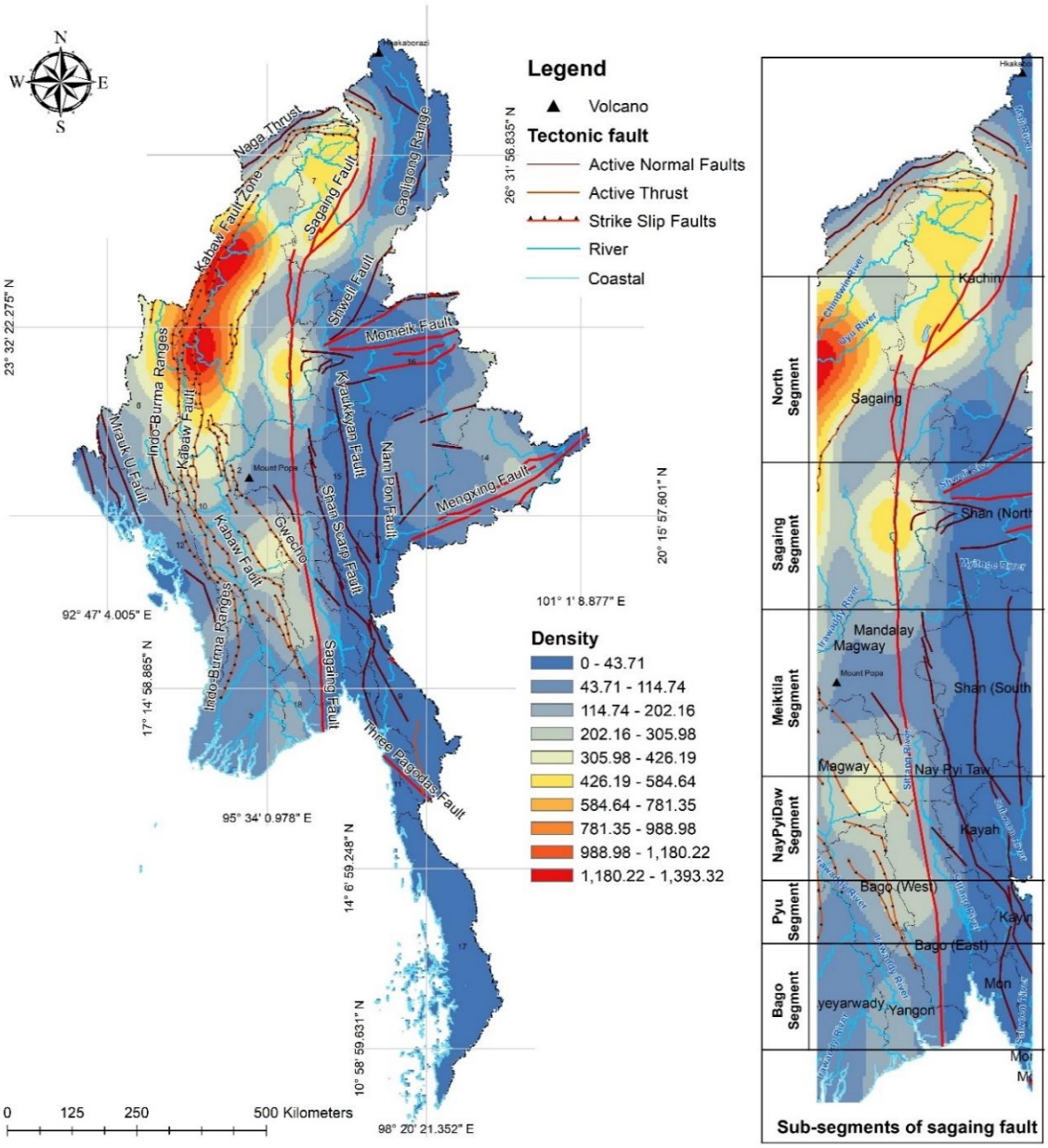


Fig 3. The highlights high-density seismic zones concentrated along the Kabaw Fault and central Sagaing Fault, indicating strong tectonic control on earthquake distribution

Seismic concentration patterns across Myanmar were delineated using the Kernel Density Estimation approach. The analysis indicates that the highest frequencies of seismic energy release, ranging from 781.35 to 1,393.32, are concentrated in northwestern Myanmar, particularly in the vicinity of the Kabaw Fault subduction zone and the Indo–Burma Range.

Moderate earthquake densities, ranging from 305.98 to 781.35, are distributed across the principal fault activity zones and remain closely associated with the Sagaing and North Sagaing fault segment systems (see Figure 3). In contrast, coastal areas in southern Myanmar exhibit relatively low seismic energy release frequencies, ranging from 0 to 43.71, suggesting limited seismic activity in these regions.

The dataset further indicates that several big-magnitude earthquakes have occurred within this high-density zone since 1990, including events of Mw 5.9 to 6.9 (2022) (See Fig 2 and Fig 3). In addition, the Sagaing segment north of Mandalay demonstrates elevated seismic energy release, reflected in the high frequency of recorded events, with the largest event reaching Mw 6.8 in 2012. Another zone of increased seismic density is identified near the intersection of the Gwecho Thrust Fault and the Sagaing Fault, where the largest recorded event reached Mw 6.6 in 2003.

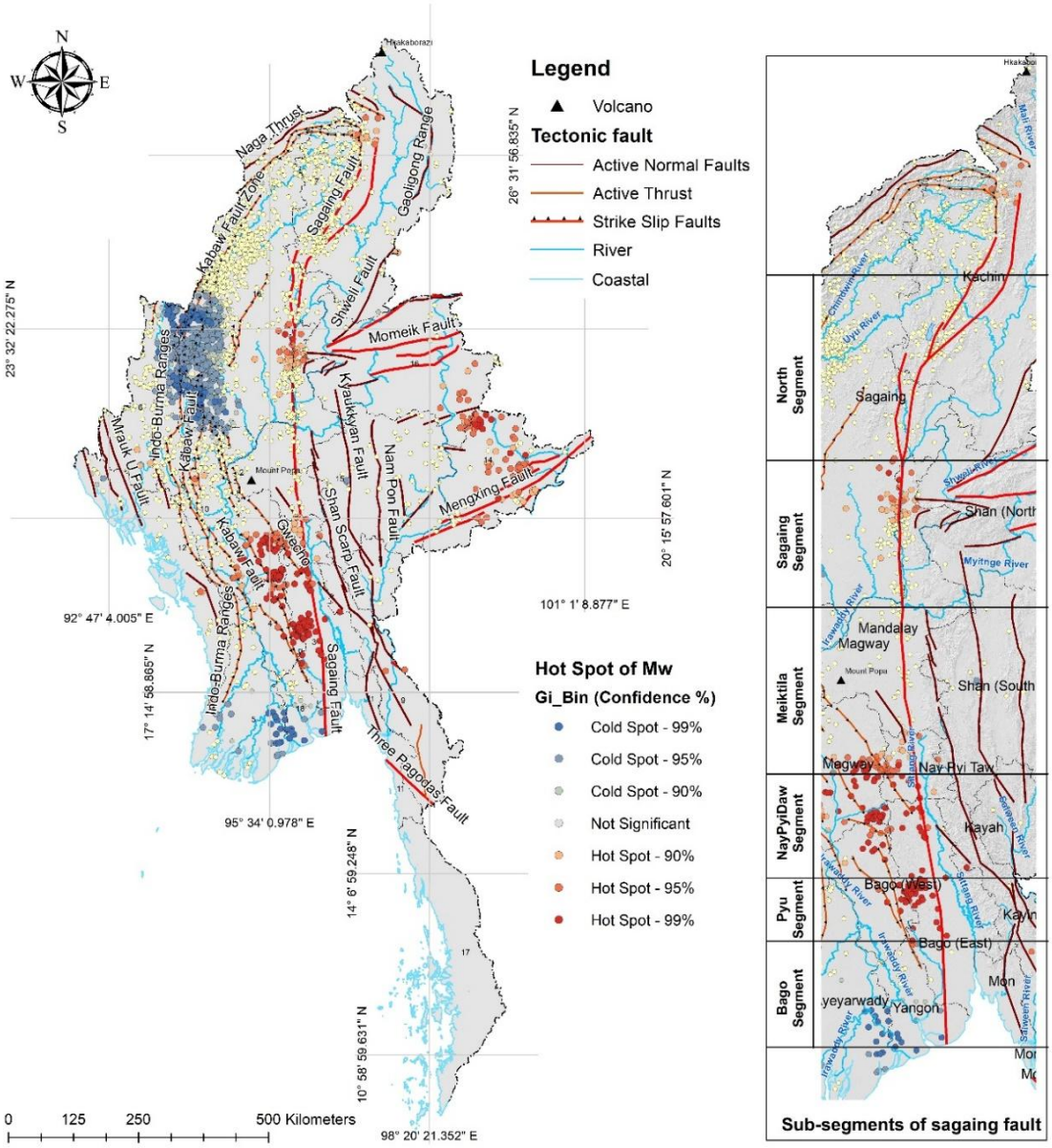


Fig 4. The hot spots and cold spots from the magnitude of earthquake events

The characterization of seismic history is reflected in the spatial distribution of statistically significant hotspots and cold spots of earthquake magnitude. The area surrounding the intersection of the Gwecho subduction fault and the Sagaing Fault emerges as a magnitude hotspot at the 99 percent confidence level. The region north of Mandalay also forms a hotspot at the 95 percent confidence level, which is consistent with its position along the active Sagaing Fault system (Figure 4).

Along the Myanmar–China border, particularly within the Eastern Shan and Northern Shan administrative regions, several distinct tectonic segments are delineated by statistically significant hotspots. These include the Mengxing Fault segment, which forms an independent hotspot cluster, as well as the active fault tip zone located along the administrative boundary between Eastern Shan and Northern Shan. Both areas are identified at the 95 percent confidence level. In contrast, the western subduction zone, specifically within the Indo Burma Range and along the Kabaw Fault, is characterized as a cold spot in terms of earthquake magnitude. However, despite this lower magnitude clustering, the overall density of earthquake occurrences in this region remains high.

3.2 Spatial Earthquake Relationship and Clustering

A deeper understanding of the relationship between earthquake distribution and magnitude is provided by the statistical evaluation of spatial dependence across Myanmar. The Global Moran's I analysis indicates a significant spatial association among earthquake events. The calculated Moran's I value of 0.016916 is positive, which signifies positive spatial autocorrelation and a tendency for similar seismic values to occur in geographically adjacent areas. Although the magnitude of the index is relatively small, its positive value reflects a nonrandom clustering pattern. This interpretation is reinforced by a z score of 3.862341, which lies in the upper tail of the standard normal distribution, and a corresponding p value of 0.000112, which is well below the 1 percent significance threshold. These statistics confirm that the observed clustering of earthquake events is highly unlikely to have occurred by chance. Consequently, seismicity in Myanmar exhibits significant spatial dependence and is closely associated with surrounding geological structures, particularly the distribution of active fault systems.

The spatial organization of these seismotectonic events is further clarified through cluster analysis. The results identify five distinct clusters, each represented by a separate

classification, which collectively demonstrate a structured spatial pattern rather than a random distribution (Fig 5). High density clusters are predominantly concentrated within active deformation zones and at intersections of major fault systems. In contrast, events classified as noise are more sparsely distributed and tend to occur outside the principal zones of seismic activity and away from mapped tectonic structures.

Cluster 1 is associated with the Mengxing strike slip fault and adjacent active fault structures. Cluster 2 exhibits a north to south orientation and corresponds closely with the deformation zone of the Indo Burma Range subduction system, including the Kabaw Fault within the western mountain belt. Clusters 3 through 6 are concentrated along different subsegments of the Sagaing strike slip fault system. Cluster 3 is located at the northern termination of the Sagaing Fault. Cluster 4 is situated at the southern end of the fault within the Pyu subsegment, which marks the interaction between subduction related deformation and strike slip movement. Cluster 5 is concentrated near the junction between the Gwecho subduction system and the Meiktila subsegment of the Sagaing Fault. Cluster 6 is centered within the Mandalay segment.

These findings demonstrate a strong correspondence between earthquake cluster patterns and the configuration of active fault structures, thereby confirming the dominant role of tectonic architecture in controlling the spatial distribution of seismicity throughout Myanmar.

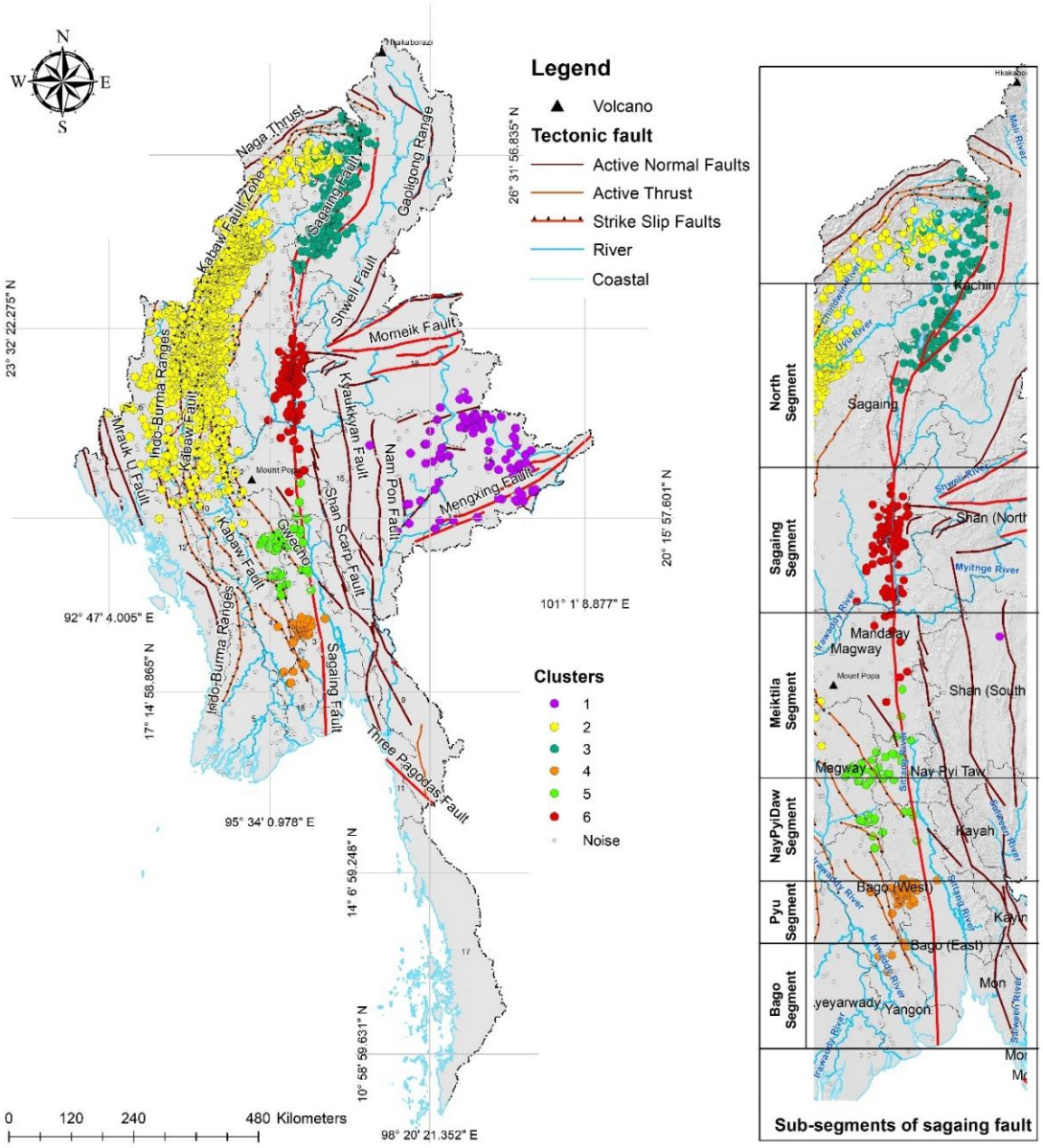


Fig 5. The spatial distribution of earthquake clusters forms several concentrated zones that are closely associated with the configuration and alignment of regional tectonic faults.

Across the identified clusters, maximum earthquake magnitudes range from Mw 4.90 to Mw 5.90, whereas minimum magnitudes vary between Mw 3.70 and Mw 4.20. The mean magnitude values across the clusters fall within a relatively narrow interval of Mw 4.33 to Mw 4.66, which indicates a broadly consistent level of seismic energy release among the different groups. In contrast, focal depths display considerable variability. Maximum depths across the

clusters range from 33.40 km to 166 km, and mean depths vary between 12.09 km and 88.39 km (Table 4). This pronounced variation in depth reflects significant differences in the underlying seismotectonic characteristics of each cluster. Among all identified clusters, only Cluster 2 is characterized by a relatively deep earthquake source, with a mean focal depth of 88.39 km. In contrast, Cluster 1 has an average depth of approximately 19 km below the surface. The remaining clusters, particularly those distributed along the Sagaing Fault system, exhibit shallower focal depths ranging from 10.14 km to 28.77 km.

Table 4. The statistical report of HDBSCAN clustering of each clusters

Cluster	Magnitude (Mw)				Depth (Km)			
	Max	Min	Ave	Stdv	Max	Min	Ave	Stdv
1	5.00	3.80	4.43	0.27	47.90	6.24	19.80	11.62
2	5.40	3.70	4.43	0.29	166.34	10.00	88.39	27.56
3	5.20	3.80	4.45	0.26	61.11	3.80	28.77	13.55
4	5.20	4.20	4.66	0.27	33.00	10.00	12.38	5.27
5	4.90	4.60	4.40	0.14	16.30	4.47	10.14	1.58
6	5.20	4.00	4.48	0.27	33.00	3.80	12.09	5.35
Noise	7.70	3.10	4.59	0.64	200.00	0.60	49.78	40.40

Several seismic events recorded between 1975 and 2025 displayed sporadic spatial patterns and did not form coherent clusters; consequently, they were classified as noise by the HDBSCAN algorithm. This classification reflects the fundamental mechanism of the algorithm, which identifies regions with stable high point densities across multiple density scales. Events that occur in areas of low density, lie far from cluster cores, or fail to satisfy the minimum sampling threshold are labeled as outliers.

These noise points are therefore considered inconsistent with the local distribution structure that defines each cluster. They were excluded from cluster membership because they did not meet the minimum density and proximity criteria required for cluster formation. Within this noise category, earthquake magnitudes reached a maximum of Mw 7.70, corresponding to the 2025 Mandalay earthquake, while the minimum magnitude was Mw 5.20. Focal depths for these events ranged from approximately 4 km to 150 km, with an average depth of 51.18 km across all events classified as noise.

3.3 Regional Ground Motion Zone

The seismic hazard map derived from the GME approach demonstrates pronounced spatial variability in ground shaking intensity as represented by Peak Ground Acceleration (PGA) (Figure 6). The overall spatial pattern indicates that maximum ground shaking is strongly controlled by proximity to the Sagaing strike slip fault and by the broader regional tectonic framework. The integrated map, which combines calculated ground motion values with the regional active fault network, shows PGA values ranging from 0.63 to 131.06 Gal. The highest PGA values are concentrated along the Sagaing strike slip fault and are spatially associated with major active structures, including the Kabaw Fault, the Kyaukkyan Fault, and related tectonic features.

At a finer spatial resolution, elevated PGA values are predominantly distributed along the Sagaing strike slip system and its subsegments. Particularly high ground motion values are observed near the Irrawaddy River, which separates the Sagaing and Meiktila segments within the Mandalay Region. This area represents one of the most significant zones of ground shaking intensity. The transition between the central Sagaing segment and the northern segment, which remains structurally associated with the Irrawaddy corridor, also exhibits high PGA values. The southern Sagaing segment, specifically the Pyu subsegment, shows similarly elevated ground motion estimates.

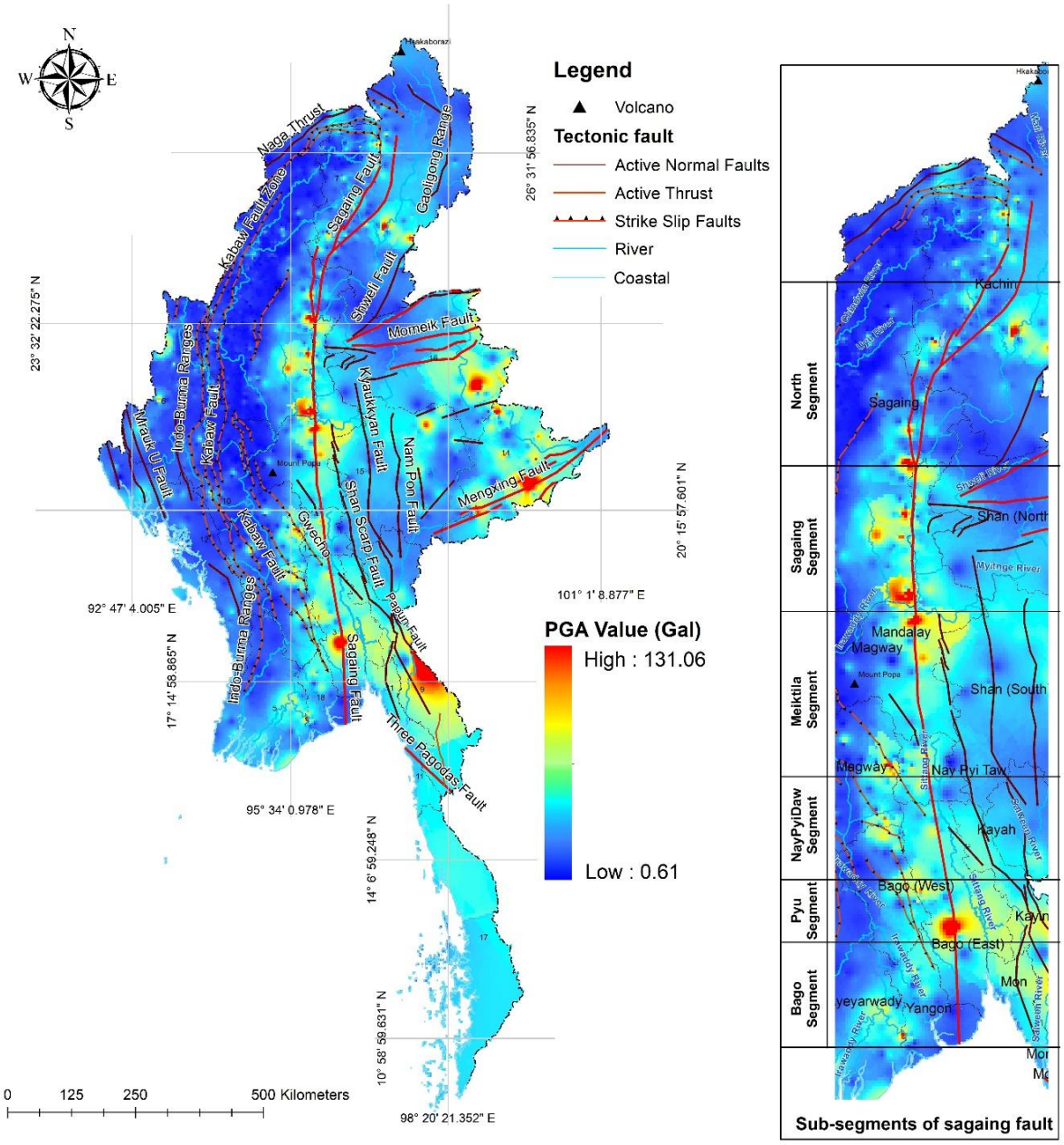


Fig 6. The ground motion estimation from earthquake dataset

Additional concentrations of peak ground motion correspond to the Gwecho Thrust, especially near its junction with the Sagaing Fault. In eastern Myanmar, within the Mengxing Fault zone, high PGA values coincide with areas intersected by several active subsidiary faults. In contrast, lower PGA values are generally observed in regions located farther from the principal fault systems, particularly within the mountainous terrain of western Myanmar. Elevated PGA values are also identified in areas surrounding the Papun Fault and the Three

Pagodas Fault, further emphasizing the strong tectonic control on spatial patterns of seismic hazard.

A more comprehensive interpretation of tectonic earthquake cluster patterns, their relationship to distance from regional fault structures, and the results of the GME analysis, including the sensitivity of the model to magnitude and focal depth, is presented in Figure 7.

The highest frequency of earthquake occurrences is observed at distances of less than 20 km from mapped faults, which highlights the dominant role of tectonic structures in controlling seismic energy release and earthquake intensity. The number of events decreases progressively as the distance from the fault system increases, and magnitudes at greater distances tend to cluster within low to moderate ranges. This pattern suggests that seismic energy release is more concentrated in proximity to active fault zones.

However, the results do not indicate a strong linear relationship between earthquake magnitude and distance from faults. Most large magnitude events occur close to mapped fault structures, and several shallow earthquakes significantly influence the estimated ground motion intensity, as reflected in elevated Peak Ground Acceleration values.

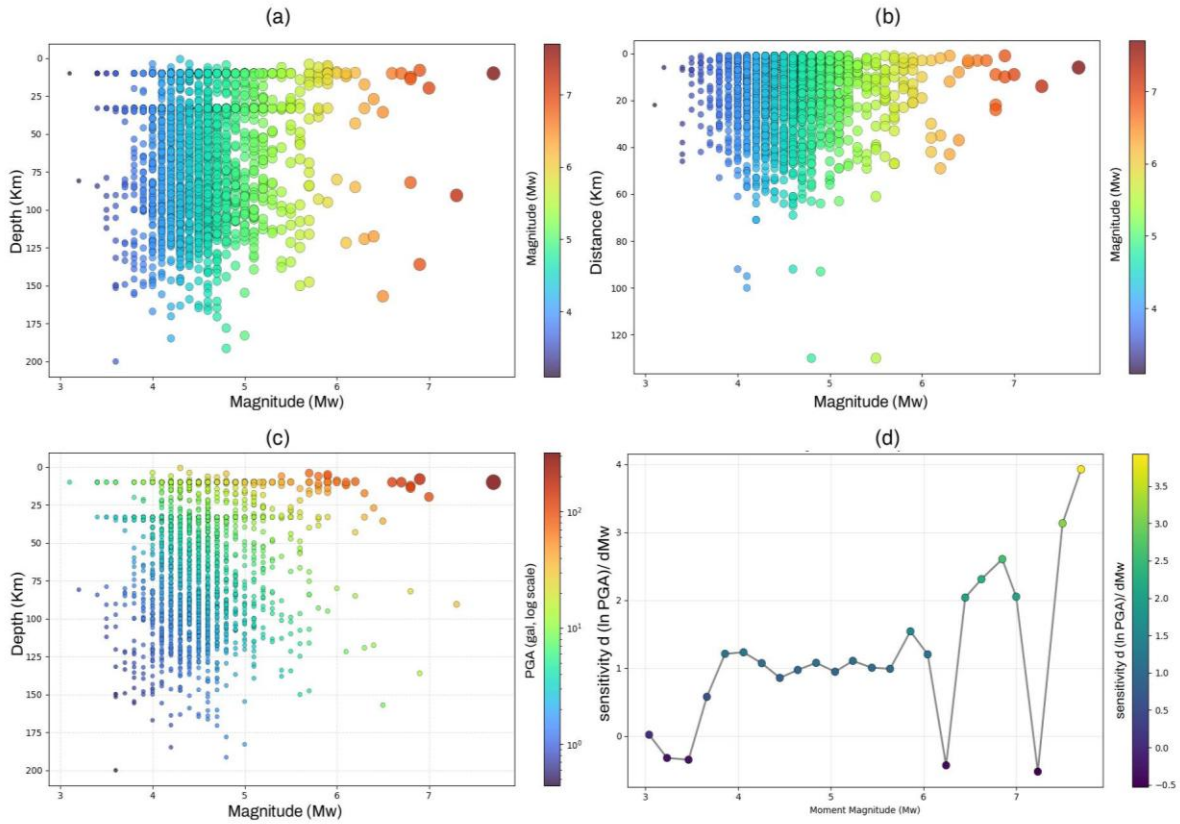


Fig 7. The scatter plot illustrates the earthquake intensity profile in Myanmar for the period 1975 to 2025: (a) The relationship between earthquake magnitude and focal depth. (b) The relationship between earthquake magnitude and distance from mapped tectonic faults. (c) The seismicity profile expressed in terms of ground motion values derived from the Ground Motion Prediction framework, represented by Peak Ground Acceleration in Gal units. (d) The sensitivity analysis showing the relationship between moment magnitude (Mw) and estimated ground motion intensity in Peak Ground Acceleration units (Gal).

The graph demonstrates that GME derived Peak Ground Acceleration values are sensitive to variations in earthquake magnitude (Mw). This sensitivity, however, is not uniform across all observations and exhibits considerable variability. The pattern reflects the nonlinear and heterogeneous response of PGA to changes in magnitude and underscores the complexity of earthquake processes. Source characteristics, source to site distance, and focal depth all exert significant influence on estimated PGA values across Myanmar. As illustrated in Figure 7,

increases in magnitude do not consistently produce proportional increases in PGA because additional parameters, particularly focal depth, strongly affect the calculation. This interaction produces intervals of apparent instability in the PGA–magnitude relationship.

Several significant earthquakes have strongly influenced the spatial distribution of high ground shaking shown in Figure 6. These include a Mw 5.9 event at a depth of 6 km in 1975 south of the Papun Fault, a Mw 6.1 earthquake at a depth of 10 km in northern Myanmar in 1994, and a Mw 6.8 event at a depth of 12 km in eastern Myanmar in 1995 that was associated with a normal fault system. A Mw 6.9 earthquake at a depth of 8 km occurred in 2011 and was linked to the Mengxing Fault system, followed by a Mw 6.8 event at a depth of 14 km in 2012. More recently, the 2025 Mandalay earthquakes, with magnitudes of Mw 7.7 and Mw 6.7 at depths of approximately 10 km, were associated with the Sagaing Fault system. Collectively, these shallow to moderately shallow, high magnitude earthquakes have played a dominant role in generating localized zones of very high ground shaking across the study area.

The results indicate that earthquakes occurring at depths greater than 50 km generally contribute less to high ground motion values, whereas events shallower than 25 km with magnitudes exceeding Mw 5 exert a substantially stronger influence on surface shaking. In particular, very shallow earthquakes with focal depths less than 20 km and magnitudes greater than Mw 5 are associated with significant ground motion and pose considerable risk to surface stability. These findings provide a clear spatial delineation of zones with elevated seismic hazard potential across Myanmar and offer an important basis for earthquake risk interpretation and disaster mitigation planning.

More specifically, under large magnitude earthquake scenarios, even modest increases in Mw can produce substantial increases in PGA. This pattern indicates that magnitude becomes the dominant controlling factor of ground shaking intensity in high magnitude events.

These findings have important implications for regional seismic hazard assessment, especially in areas susceptible to major earthquakes.

4. Discussion

Spatial analysis of seismic records from the past fifty years reveals patterns in seismic profiles, event density, and hotspot distribution. The results indicate that seismic energy release is predominantly concentrated near regional tectonic fault systems, including normal, subduction, and strike-slip faults. Earthquake frequency and magnitude decrease with increasing distance from these fault systems.

Kernel density estimation further demonstrates that earthquake density forms spatial patterns closely aligned with regional tectonic fault structures. A prominent high-density zone occurs in the Horseshoe Mountains in the northwest, which is closely associated with the Kabaw Fault and the Naga Thrust Fault. The movement of surrounding Miocene geological formations, particularly anticlines that compress multiple sides of the Kabaw Fault, renders this area more active in thrust faulting (Sloan et al., 2017). Farther south along the Chindwin River, an extensive area of Upper Miocene–Pliocene formations characterized by subsidence-related tectonic movement, known as the Chindwin Syncline, is present (Khin et al., 2023). These observations suggest that earthquake frequency is largely controlled by regional tectonic mechanisms, although no strong linear relationship exists between earthquake magnitude and distance from the fault.

The moderate density concentration within the Northern Sagaing Segment supports the interpretation that fault terminations and branching zones are prone to strain accumulation (Hasrah et al., 2024; Melgar et al., 2025). The Sagaing Segment, which runs parallel to the Irrawaddy River, also exhibits moderate seismic intensity, reflecting the role of this major strike-slip fault in accommodating regional tectonic deformation and dividing two tectonic domains in Myanmar (Vera et al., 2025). Elevated seismic density at the intersection of the

Gwecho Thrust Fault and the Sagaing Fault confirms strong interaction between these two tectonic systems, thereby increasing the complexity and intensity of accumulated energy release (Min et al., 2022; Limon and Mahmud, 2025).

Hotspot analysis provides statistical confirmation of persistently active seismic zones. One prominent hotspot is located at the intersection of the Gwecho subduction fault and the Nay Pyi Taw segment of the Sagaing Fault near the Sittang River. This concentration indicates that the interaction between reverse faulting along the Gwecho subduction system and the surrounding anticline structures generates additional stress within the subduction zone. Interaction with the strike-slip motion of the Sagaing Fault further contributes to the concentration of seismic activity (Khin et al., 2023).

Additional hotspots appear at the northern termination of the Sagaing Segment and within the North Segment, both of which remain part of the highly active Sagaing Fault system. Ongoing tectonic deformation in these areas produces crustal extension and recurrent seismic energy release along the fault (Hussain et al., 2025). In the Myanmar–China border region, particularly between the Momeik Fault and the Mengxing Fault, several hotspots occur within discrete normal fault segments (Melgar et al., 2025). This pattern indicates that tectonic deformation in this region is not confined to a single strike-slip structure but also involves active normal faults that contribute significantly to seismic energy release.

Correlation analysis of all recorded earthquake events confirms that the spatial distribution of seismicity is not random but exhibits statistically significant clustering, which indicates the presence of an underlying spatial structure governing seismic activity. The identified clustering pattern provides a structural perspective on the spatial and seismological characteristics of earthquakes across Myanmar, including the delineation of six major clusters and several extreme events that do not belong to any cluster. The spatial distribution of these six principal clusters demonstrates a strong association with active regional fault systems. This

clustering framework establishes a robust basis for subsequent analyses that link earthquake characteristics to fault geometry and tectonic controls.

One cluster is concentrated in the eastern region and is associated with strike-slip and normal faults. A second cluster is located in the western mountainous subduction zone. The remaining four clusters correspond to distinct subsegments of the Sagaing strike-slip fault system. Historically, this tectonic configuration has generated numerous large and destructive earthquakes throughout Myanmar (Oo et al., 2025). From a seismological perspective, these findings indicate that earthquake events are spatially concentrated within defined zones and exhibit spatial interdependence with neighboring events (Lindsey et al., 2023). Such clusters commonly reflect geological controls, particularly active fault systems and subduction interfaces, where tectonic stress accumulates and is periodically released as seismic energy (Chen, 2023; Ghosh et al., 2025). This interpretation aligns with the documented regional earthquake history reported in earlier studies.

The spatial distribution of historical seismicity also reveals substantial variation in ground motion estimates, typically expressed as peak ground acceleration. Earthquakes of larger magnitude and shallow focal depth located near active faults generally generate stronger surface shaking in adjacent areas. The observed ground motion pattern is non-random and closely corresponds to the regional physiographic and structural framework. These results are consistent with prior hotspot and clustering analyses, which collectively demonstrate that seismic activity in Myanmar forms interconnected spatial patterns controlled by regional tectonic structures (Zaw and Park, 2025).

In principle, the distance between the seismic source and a given site exerts a significant influence on peak ground acceleration, such that PGA increases as source-to-site distance decreases. Conversely, PGA typically attenuates with increasing distance from the source. At the microscale, however, seismic response is further governed by site-specific geotechnical

parameters. Soil density and the angle of internal friction are critical factors, particularly in areas prone to liquefaction. The bending moment of instrumented piles is strongly influenced by the angle of internal friction, whereas the shear modulus of loose sandy soils plays a dominant role in zones that are less susceptible to liquefaction (Jia et al., 2023).

Historical and instrumental records document at least nine major earthquakes with magnitudes exceeding 6.5 along the Sagaing Fault during the past century, with estimated tectonic slip rates of 18–24 mm per year (Sloan et al., 2017). Analyses of historical intensity data and geomorphological indicators have subdivided the central and southern sections of the fault into several major segments separated by distinct morphological features and river channels (Wang et al., 2014; Soe et al., 2017). Each segment is considered capable of generating earthquakes larger than magnitude 7, with recurrence intervals estimated between 100 and 300 years. These events may occur as single-segment ruptures or as multi-segment scenarios, as inferred for the 2025 earthquake (Tsutsumi et al., 2009; Wang et al., 2011).

The Sagaing Fault governs an extensive alluvial system characterized by major river channels that run parallel to active fault traces and by thick sedimentary deposits derived from the Ayeyarwady and Sittang river systems. Ground motion amplification is particularly significant in this setting because unconsolidated sediments are highly susceptible to seismic shaking (Islam et al., 2025). Earthquake clusters in this region generally originate at shallow focal depths ranging from approximately 10 to 12 km.

In contrast, the western mountainous region of Myanmar, associated with the Kabaw Fault, the Indo-Burma Mountains, and the Mrauk-U Fault, typically exhibits lower ground motion values (Lindsey et al., 2023). Although this region contains a dense cluster of earthquake events, the majority of these earthquakes are deep-focus events with an average focal depth of approximately 88 km. This contrast demonstrates that national-scale variations

in ground motion are strongly controlled by earthquake magnitude, focal depth, and structural connectivity to the Sagaing Fault.

Localized zones of elevated ground motion occur near structural complexities, including the separation of fault segments by the Irrawaddy River, junctions within the northern segment, intersections between the Sagaing Fault and the Kabaw and Gwecho subduction systems, and areas influenced by the Mengxing Fault (Sethanant et al., 2025; Cruz et al., 2025). These structural junctions represent critical sites of stress concentration and recurrent seismic energy release. The interaction between the Sagaing Fault and adjacent thrust faults reflects the tectonic transition from westward subduction to eastward microplate collision (Islam et al., 2025).

Earthquake patterns near major active faults exhibit higher event density and greater variability in magnitude, which underscores the dominance of primary tectonic energy release along Myanmar's principal fault systems (Oo et al., 2025). By contrast, earthquakes located farther from the main fault trace occur less frequently and are generally of intermediate magnitude, which likely represents a secondary response to regional stress redistribution rather than direct rupture along the principal fault.

The derived ground motion estimates carry significant implications for earthquake hazard and risk assessment in Myanmar. Areas characterized by elevated ground motion, particularly those associated with the Sagaing Fault system, including the administrative regions of Sagaing Region, Mandalay Region, Bago Region, Shan State, and Kachin State, constitute zones with substantial potential for severe seismic impact (Wang et al., 2014; Zelenin et al., 2025). These findings can be integrated with spatial data on population distribution, critical infrastructure, and site conditions that are susceptible to seismic amplification and liquefaction.

The occurrence of localized high ground motion patterns indicates that seismic hazard in Myanmar is not solely regional in scale but is also strongly site-specific. Effective mitigation strategies therefore require consideration of local variability, including detailed seismic microzonation where necessary. From a geodynamic perspective, these results advance the understanding of Myanmar's tectonic framework by clarifying the spatial relationships among seismicity distribution, active fault systems, and ground motion intensity.

Although this study does not present a probabilistic seismic hazard assessment or a formal microzonation map, it emphasizes the spatial analysis of interactions among earthquake occurrence, fault-controlled tectonic structures, and regional landslide characteristics. The findings provide a rigorous scientific basis for spatial planning, earthquake-resistant structural design, and the development of spatially informed disaster risk reduction policies.

5. Conclusion

The implementation of an integrated spatial analysis framework to characterize earthquake density, hotspots, and seismic clusters using seismic records from the past fifty years demonstrates that earthquake distribution in Myanmar is not random but systematically related to the regional tectonic fault network. Concentrations of seismic energy release occur predominantly near normal faults, subduction interfaces, and major strike-slip structures, where earthquake frequency and magnitude generally decrease with increasing distance from fault traces. Kernel density estimation and hotspot analysis identify statistically significant active zones associated with the Sagaing Fault, the Kabaw Fault subduction zone, and their interaction with the Gwecho Subduction Zone. The observed clustering pattern indicates that fault terminations, branch zones, and structural intersections act as loci of strain accumulation and therefore represent areas with elevated potential for tectonic energy release. The six principal clusters exhibit strong spatial correspondence with active fault systems in the eastern region, the western mountainous subduction belt, and the subsegments of the Sagaing system.

These results confirm that structural controls govern the spatial organization of seismicity at the national scale.

Spatial variations in historical seismicity also have direct implications for ground motion estimates, expressed in terms of peak ground acceleration. Large, shallow earthquakes occurring near active faults tend to generate higher PGA values, whereas deeper or more distant events produce lower levels of surface shaking. At the regional scale, source-to-site distance exerts a dominant influence on PGA. Several major earthquakes accompanied by significant tectonic slip rates have been recorded along the Sagaing Fault, and each segment retains the capacity to generate high-magnitude earthquakes within characteristic recurrence intervals. In general, national-scale differences in ground motion reflect the combined effects of earthquake magnitude and focal depth.

A principal limitation of this study lies in the restricted applicability of the ground motion estimation analysis at the microzonation scale, as the results were not validated against field-based strong motion measurements. Nevertheless, the findings remain relevant for regional spatial planning, preliminary seismic zoning assessments, and the development of spatially informed earthquake risk mitigation strategies. Future research should incorporate more advanced analytical approaches, including artificial intelligence techniques and the integration of environmental spatial datasets, to refine risk identification in areas suspected to be highly earthquake-prone. This study relies primarily on data from the United States Geological Survey, and no event relocation or magnitude correction was performed because of limitations in station coverage.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit authorship contribution statement

MH: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. SA: Writing – review & editing, Supervision, Methodology, Investigation, Conceptualization. PM: Review, Supervision, Methodology, Data curation. NM: Review, Supervision, Data curation. T: Methodology. ST: review & editing.

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Data Sources

Earthquake data from USGS https://earthquake.usgs.gov/earthquakes/search/.

Administrative boundary Map of Myanmar https://data.humdata.org/dataset/.

Geological Map of Myanmar https://www.lyellcollection.org/doi/full/10.1144/M48.33

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