https://doi.org/10.5194/egusphere-2025-3774
Preprint. Discussion started: 12 September 2025

Geospatial Analysis of Fault–Epicenter Dynamics in Bangladesh and Adjacent Regions Using Remote Sensing and Statistical Modeling

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Abstract

Bangladesh and its adjacent regions are situated at the junction of several tectonic plates and are hence highly susceptible to earthquakes. This study investigates the spatial dynamics between fault lines, their classifications, and earthquake epicenters in Bangladesh and its neighboring countries. With a high-density population, absence of urban planning, and inter-border seismic hazards, identifying the way fault types interact with seismic activity is crucial for an effective estimation of the hazard in this area.

Landsat 8 Thermal Infrared Sensor (Band 10) satellite imagery was used for the detection of faults, followed by the extraction of lineaments using PCI Geomatica and spatial analysis in ArcMap 10.8. Fault lines were identified as four principal types: normal, reverse, left-lateral, and right-lateral, based on geometric and spatial features. Earthquake epicenter data between 1924 and 2024 were derived from the USGS Earthquake Catalog. Spatial autocorrelation analysis (Moran's I), Kruskal-Wallis test, Dunn's test, and multinomial logistic regression were used to examine fault-epicenter relationships.

Approximately 40,000 fault lineaments were identified. Moran's I index (0.298, $p<0.000001$) confirmed significant spatial clustering of epicenters and fault lines. Dunn's test demonstrated that reverse faults significantly differ from the others in terms of proximity to epicenters. Multinomial logistic regression revealed that earthquakes tend to be closer to normal ($p = 0.042$) and left-lateral faults ($p = 0.016$), whereas reverse faults ($p = 0.676$) did not exhibit significant differentiation based on proximity.

This work highlights the crucial need to incorporate fault types and epicenter spatial relationships into seismic hazard models. The results offer practical insight into regional earthquake risk

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mitigation, infrastructure design, and transboundary disaster preparedness in Bangladesh and adjacent regions.

Keywords: Earthquake, Fault line, Fault line types, Epicenter, Satellite image, Statistical modeling, Bangladesh

1 Introduction

Earthquakes are sudden ruptures in the Earth's crust or mantle caused by tectonic stress, resulting in the release of seismic waves, and occur when rocks are abruptly disturbed, often along fault lines where tectonic plates meet (Kanamori, 1994). They are the most disastrous of all natural calamities, which damage life and property in the shortest possible time (Al-Dogom et al., 2021). Earthquakes are a natural disaster that have long dynamically affected the Earth's landscape and caused serious injury to living creatures, drastic changes to the living environment, and catastrophic damage to the economy and infrastructure (Hossain et al., 2020). In the 20th century, earthquake disasters caused casualties of close to 2 million people worldwide and claimed an average of over 25,000 lives annually (Yariyan et al., 2020; Mohammadi et al., 2025). Earthquakes also have the potential to cause secondary consequences such as landslides, fires, and tsunamis, which pose significant risks to human life, infrastructure, and the environment (Alavi et al., 2024).

Bangladesh is also at risk of catastrophic earthquakes due to its position on the northeastern Indian plate, which is located at the junction of three tectonic platforms: the Indian plate, the Eurasian plate, and the Burmese microplate, where severe earthquakes have occurred in the past. (Morino et al. 2011, 2014; Steckler et al. 2016; Biswas et al., 2018; Salman et al., 2023). In 2015, an earthquake resulted in 6 deaths and over 200 injuries in the country (Biswas et al., 2016). This shows the damage and also the potential for damage from earthquakes in Bangladesh. This region is also seismically vulnerable due to high population density, unplanned urbanization, and non-engineered construction practices (Rahman et al., 2020). Moreover, the cities of Bangladesh are facing unplanned urban growth, rapid rural to urban migration, and environmental degradation, which expose the urban populations to earthquake hazards. (Alam & Haque, 2022). The country is affected by earthquakes originating in India and Myanmar. In order to construct a complete geography of the hazard, it is necessary to consider active seismic sources from the adjacent countries, particularly adjoining Bangladesh (Alam & Dominey-Howes, 2014). That is why in this study, the adjacent regions of Bangladesh are included.

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Earthquakes are processes associated with objects known as fault zones. Therefore, earthquake physics is dictated to a considerable extent by fault zone properties. (Ben-Zion & Sammis, 2003). Fault lines are critical features in tectonic studies, representing zones of localized motion within the Earth's crust and lithosphere (Handy et al., 2007). Furthermore, fault lines significantly influence earthquake behavior and attenuation. Thus, the distribution of seismic intensity and damage is affected by fault mechanisms and rupture extent (Bureau, 1978).

Fault damage zones play a crucial role in long-term earthquake behavior, which influences earthquake size variability, hypocenter locations, and seismic wave reflections. Understanding fault damage zone properties could improve earthquake hazard assessments by providing insights into future earthquake depths (Thakur et al., 2020). There are some methods popular for detecting fault lines. Recent research revealed advanced fault detection techniques in geosciences, combining geophysical, remote sensing, and computational methods (Adwan et al., 2024). Remote sensing methods, including satellite imagery analysis, have proven effective in detecting both active and inactive faults (Tanner et al., 2019)

There are mainly four fault types, e.g., reverse, normal, left-lateral, and right-lateral. (USGS, 2025). A significant relationship is seen between fault types and earthquake characteristics, and different fault types exhibit varying TEC anomaly patterns before large earthquakes (Ulukavak et al., 2022).

The primary objectives of the study were to identify geotectonic fault lines and fault line types in Bangladesh and its adjacent regions, and to examine the spatial dynamics among fault lines, fault line types, and earthquake epicenters. In this study, appropriate and up-to-date methods were used to accomplish the objectives. From the study, we will determine whether there is a relationship between earthquake epicenters and fault lines, and which fault type is most likely to generate an earthquake in and around Bangladesh.

2 Materials and methods

2.1 Study area

The study area for this study is Bangladesh and its adjacent regions, including India, Myanmar, Nepal, and Bhutan, as shown in Fig. 1. This region is geologically active and forms part of the

https://doi.org/10.5194/egusphere-2025-3774
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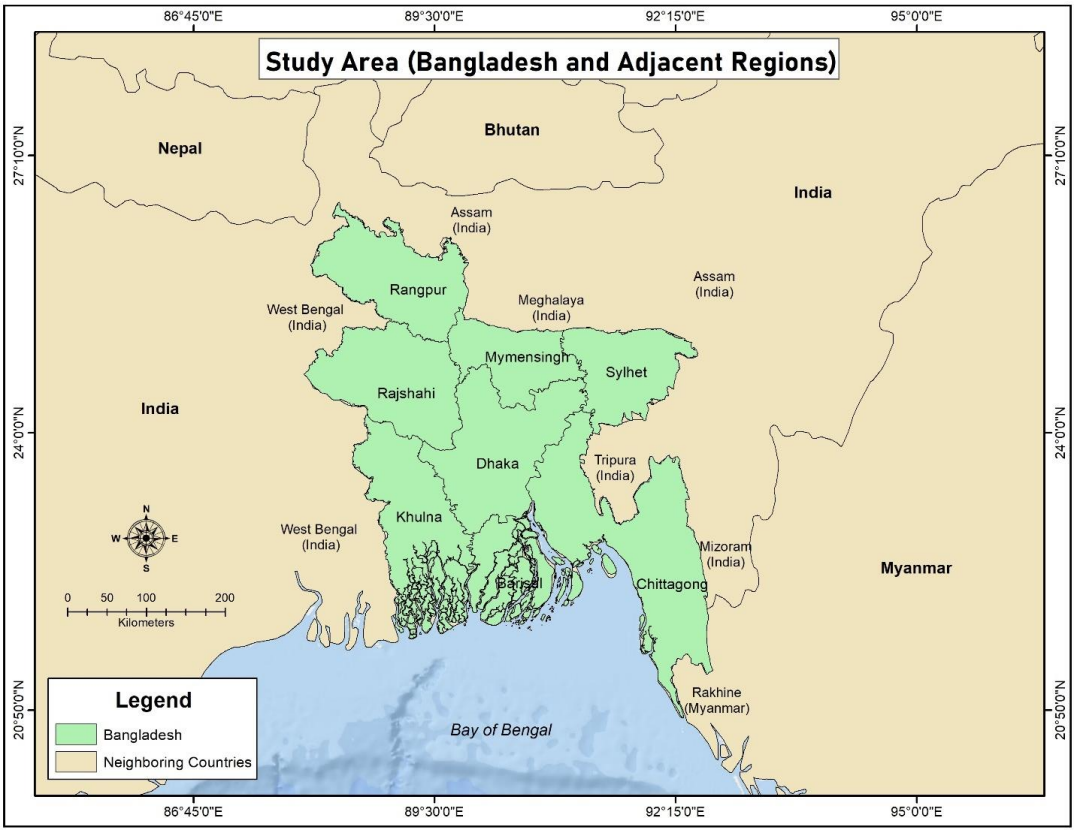
broader Indo-Burman range and Himalayan tectonic regime, which has been recognized for its complex fault systems and seismic vulnerability (Sapkota et al., 2013; Steckler et al., 2016).

Bangladesh, which lies within latitudes 20°34′N to 26°38′N and longitudes 88°01′E to 92°41′E, is bordered by the Indian states of West Bengal, Assam, Meghalaya, Tripura, and Mizoram to the west, north, and east; Rakhine State of Myanmar to the southeast; and the Bay of Bengal to the south. Internally, the study considers key administrative divisions of Bangladesh, including Dhaka, Chittagong, Sylhet, Mymensingh, Rajshahi, Rangpur, Khulna, and Barisal, which are both demographically and geographically significant (BANGLAPEDIA, 2024).

Figure 1: Study area map showing Bangladesh and its adjacent regions



The adjacent regions of Bangladesh are prone to earthquakes as seismically active regions, such as the Himalayan Arc, the Shillong Plateau, and the Burmese Arc, are very close to this region. (Sultana et al., 2013).

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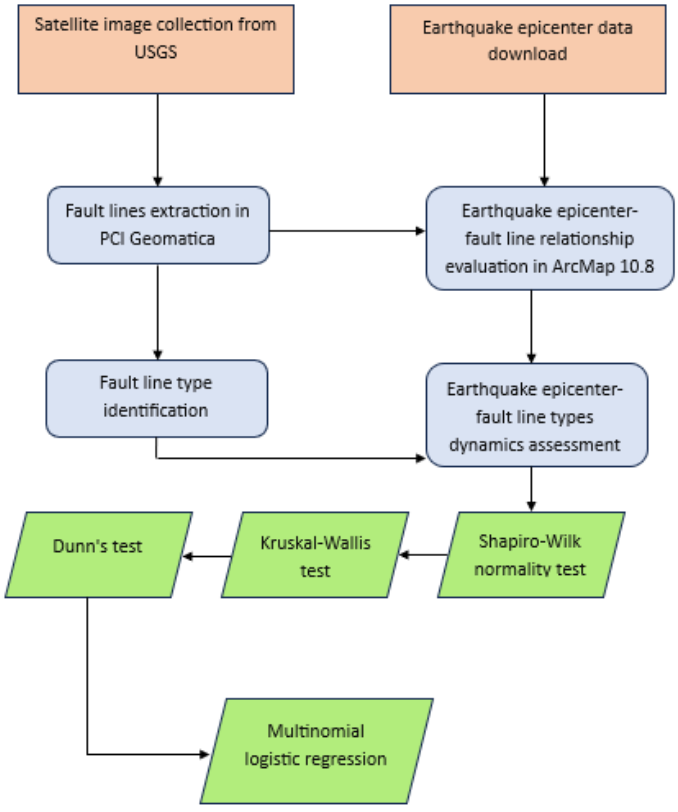
The incorporation of adjacent Indian states and Myanmar within the study is crucial, as numerous epicentral sources and fault systems that control seismic activity in Bangladesh are either sourced or extend outside its boundaries. Transboundary seismicity and fault processes are therefore crucial for accurate risk modeling and effective regional disaster planning measures (Nath & Thingbaijam, 2012).

Figure 2: Methodological framework of the study



2.2 Satellite image collection

Firstly, satellite images of Bangladesh and its adjoining areas were gathered from the USGS Earth Explorer for extracting fault lines for this region. Thermal information utilized in this study was obtained from Band 10 (10.6–11.2 μm) of the Thermal Infrared Sensor (TIRS) of Landsat 8. The

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data were gathered from the dry season (March 2025) to minimize atmospheric interference and maximize thermal surface contrast.

Landsat 8, a NASA-USGS collaborative mission, hosts both the Operational Land Imager (OLI) and TIRS. While OLI collects multispectral reflectance, this study only considered TIRS Band 10 because it has greater radiometric stability and less calibration uncertainty than Band 11 (Wulder et al., 2012; Roy et al., 2014). Although Band 10 possesses a native resolution of 100 meters, USGS resamples it to 30 meters through cubic convolution interpolation for a more accurate and higher-quality image.

2.3 Fault lines extraction

Systematic processing of the satellite images was conducted in PCI Geomatica software in order to identify and delineate the tectonic fault lines of Bangladesh and its adjacent regions. The processing workflow utilized the high-level modules of the software, i.e., the Algorithm Librarian, geological analysis, and lineament extraction utilities, specifically designed for lineament extraction in complex geological terrains.

The PCI Geomatica software's lineament extraction process is widely applied in the identification of geological structures from satellite imagery. The automatic method employs the LINE module in enhancing edge discontinuities and directional features. The directional convolution filters, such as high-pass directional filters (3×3, 5×5), were employed to enhance linear features with certain azimuthal directions (e.g., 45°, 90°, 135°). These filters strengthen pixel intensity gradients within desired directions to allow faint geological discontinuities, such as faults, joints, and fractures, to be identified. Finally, once the lineaments and fault lines are extracted, they are saved as a shapefile and opened with the ArcMap 10.8 software.

2.4 Fault line type identification

Extracted lineaments were categorized into four main fault types: normal faults, reverse faults, left-lateral faults, and right-lateral faults, as they are the main fault types (USGS, 2025). The classification was based on the assessment of length, curvature, intersection patterns, clustering, and orientation of the faults. Earlier studies in the Indo-Burma subduction zone and the United States Fault and Fold Database were used as reference templates to classify the faults (USGS, 2025).

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2.5 Earthquake epicenter data acquisition

A 100-year (1924–2024) earthquake catalog was extracted from the USGS Earthquake Catalog, a mature and continuously revised database of historic and real-time seismicity (Hayes et al., 2019). The catalog incorporates both early instrumental and modern seismic data from seismic and geodetic networks. For accuracy in analysis, events of magnitudes ≥ 3.0 only were extracted, as lower-magnitude micro-seismic events are often underreported in older records and provide minimal information on structural damage potential or regional stress distribution. The raw dataset was then exported in CSV format and opened in ArcMap 10.8 software, where it was converted into a geodatabase feature layer through the Add Data and Add XY Data tools.

Geospatial filtering was applied using a custom boundary polygon that covered tectonically relevant regions, including Bangladesh, West Bengal, parts of Nepal and Bhutan, the Bay of Bengal, northeast India (Assam, Meghalaya, Mizoram, and Tripura), and western Myanmar. There were 1541 earthquake epicenter data filtered from the process for the specific region.

2.6 Earthquake epicenter and fault line proximity analysis

To statistically investigate whether earthquake epicenters are correlated with fault lines or not, a proximity-based spatial analysis was performed using ArcMap 10.8 software. Specifically, the "Near" tool within the ArcToolbox > Analysis Tools > Proximity module was used to calculate the shortest Euclidean distance from the epicenter of each earthquake to its closest fault line. The distance from an earthquake epicenter to the closest fault line is then saved to the geodatabase of the earthquake epicenter shapefile.

After this, the geodatabase is converted into Excel data, which is based on fault line types and the distance from the nearest fault line to the earthquake epicenter. The Euclidean distance formula is,

$$\text{Distance}_{ij} = \sqrt{(X_i - X_j)^2 - (Y_i - Y_j)^2}$$

Here,

- (X_i, Y_i): coordinates of feature i in the input layer.
- (X_j, Y_j): coordinates of feature j in the near layer.

2.7 Spatial dynamics between fault lines and earthquakes

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After calculation of the shortest distance of earthquake epicenters to the nearest fault lines, spatial autocorrelation (Moran's I) was conducted in ArcMap 10.8 software. Moran's I, a global statistic, was utilized to determine the extent of spatial autocorrelation within the dataset through the provided variables. It attempts to test whether the pattern with which a variable is spread throughout space is significantly different from a random spatial process. Moran's I is a standard spatial autocorrelation measure where positive results would indicate clustering of similar values and negative results show dispersion (Zhang & Lin, 2007). The result of Moran's I shows whether there exists spatial dependency in a dataset or not.

Moran's I mathematical formula:

$$I = \frac{n}{W} \cdot \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_{i=1}^{n} (x_i - \overline{x})^2}$$ (Moran, 1950)

Where:

- I: Moran's I statistic
- n: Total number of spatial units
- x_i, x_j : Attribute values for features i and j
- $\overline{x}$: Mean of the attribute values
- w_{ij} : Spatial weight between features i and j
- W: Sum of all spatial weights

2.8 Fault line types and earthquake epicenter relationship assessment

2.8.1 Normality check and hypothesis test

To investigate the relationship between fault line types and their nearest distance from earthquake epicenters, it was crucial to ascertain whether the dataset was normally distributed. This would establish whether the data required a parametric or nonparametric statistical analysis.

In this study, the Shapiro-Wilk normality test was used to determine the distribution of the data. The test has long been established as being sensitive in detecting non-normality and is widely recognized as an effective tool for normality checking in samples. The analysis was conducted

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using the R programming language (version 4.3.2), applying the Shapiro-Wilk test () function from R's base statistical package.

The Shapiro-Wilk test gives a W statistic, and values considerably less than 1.0 indicate non-normality. The null hypothesis assumes that the data follow a normal distribution; thus, small p-values (<0.05) lead to null hypothesis rejection, indicating non-normality (Shapiro, 2019). In this study, the Shapiro-Wilk test output is W = 0.61438, p-value = 2.2e−16. The 0.61438 value of W is considerably less than 1, and the p-value is much lower than the conventional α level of 0.05, suggesting strong evidence against the null hypothesis (Fisher, 1925).

It can, therefore, be said that the aforesaid variable is not normally distributed. This finding necessitated the use of nonparametric statistical methods in future analysis of the dataset (Nahm, 2016). Therefore, the Kruskal-Wallis rank sum test was used to examine the spatial correlation of epicentral proximity with fault line classifications. The Kruskal-Wallis test is a nonparametric statistical method used in calculating differences between three or more independent groups based on one non-normally distributed continuous variable. (Kruskal & Wallis, 1952).

The result of the Kruskal-Wallis rank sum test for the dataset is $\chi^2 = 22.10$, p-value = 6.216×10^{-5}. The chi-squared statistic ($\chi^2 = 22.10$) on 3 degrees of freedom is used to test for a statistically significant difference between the distribution of shortest epicentral distances in the four types of faults. The p-value (< 0.0001) is significantly smaller than the significance level ($\alpha = 0.05$), leading to the rejection of the null hypothesis that all group medians are identical.

This result means that at least one fault type category has a different pattern of epicentral distance from the other fault categories. However, the Kruskal–Wallis rank sum test does not specify which groups are different, so a post-hoc pairwise comparison is required. For this purpose, Dunn's test with a Bonferroni correction was then applied. Dunn's test is a nonparametric multiple comparison procedure for pairwise comparisons after finding a significant Kruskal-Wallis test (Dinno, 2015).

2.8.2 Multinomial logistic regression

Multinomial logistic regression was used to determine which fault type is more likely to generate an earthquake around it. Here, the dependent variables were the fault types (reverse, right-lateral, left-lateral, and normal), and the independent variables were the distance from the earthquake epicenter to the nearest fault line. This statistical technique is suitable for describing relationships

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where the dependent variable has more than two categories and the independent variables are continuous or categorical. The method estimates various binary logistic regression models for each category of the dependent variable relative to a reference category (Aziz et al., 2016).

In this analysis, the reference category was the right-lateral fault lines, and the model estimates the log-odds of membership in each of the remaining categories relative to the reference category based on changes in the predictor variable. The software used to analyze the dataset was IBM SPSS Statistics 21.

3 Results

3.1 Fault lines in Bangladesh and its adjacent regions

Figure 3: Fault lines in Bangladesh and its adjacent regions

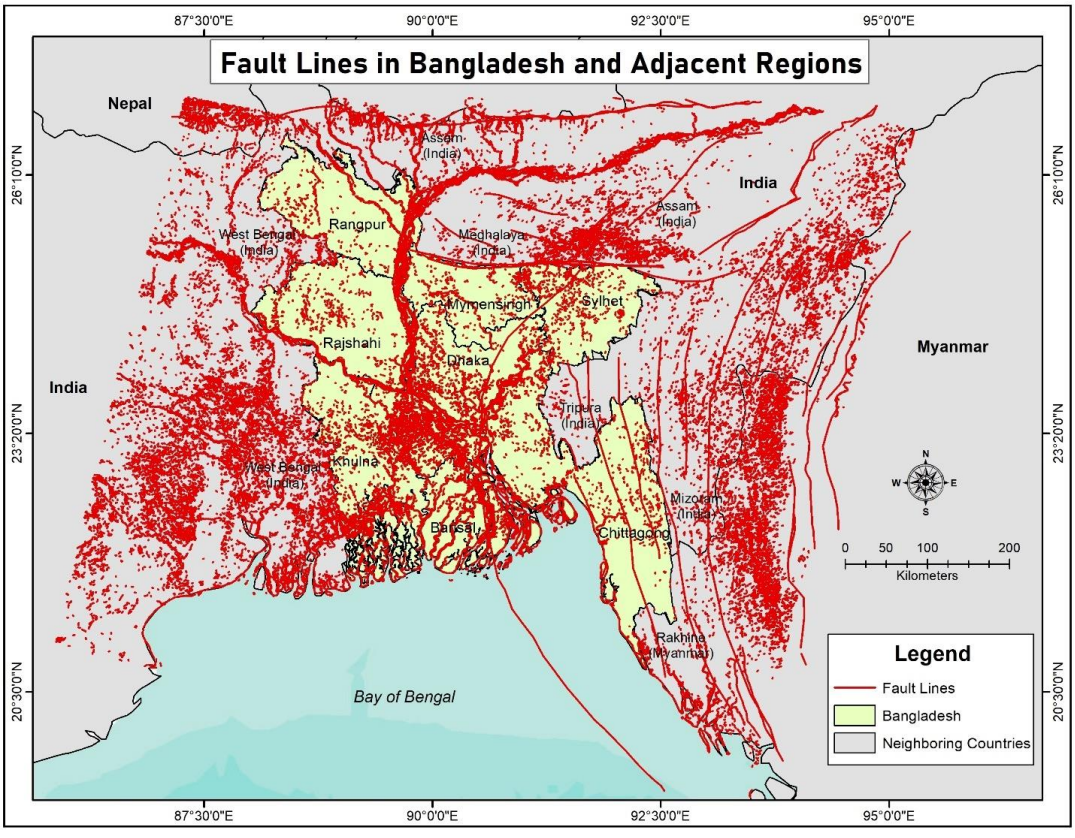

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Figure 3 displays a tectonic context of Bangladesh and its adjacent regions comprising approximately 40,000 mapped fault lines and lineaments derived from advanced remote sensing and geospatial analysis. Red linear items represent active faults and seismogenic lineaments.

3.2 Fault line types in Bangladesh and its adjacent regions

Figure 4: Fault line types in Bangladesh and its adjacent regions

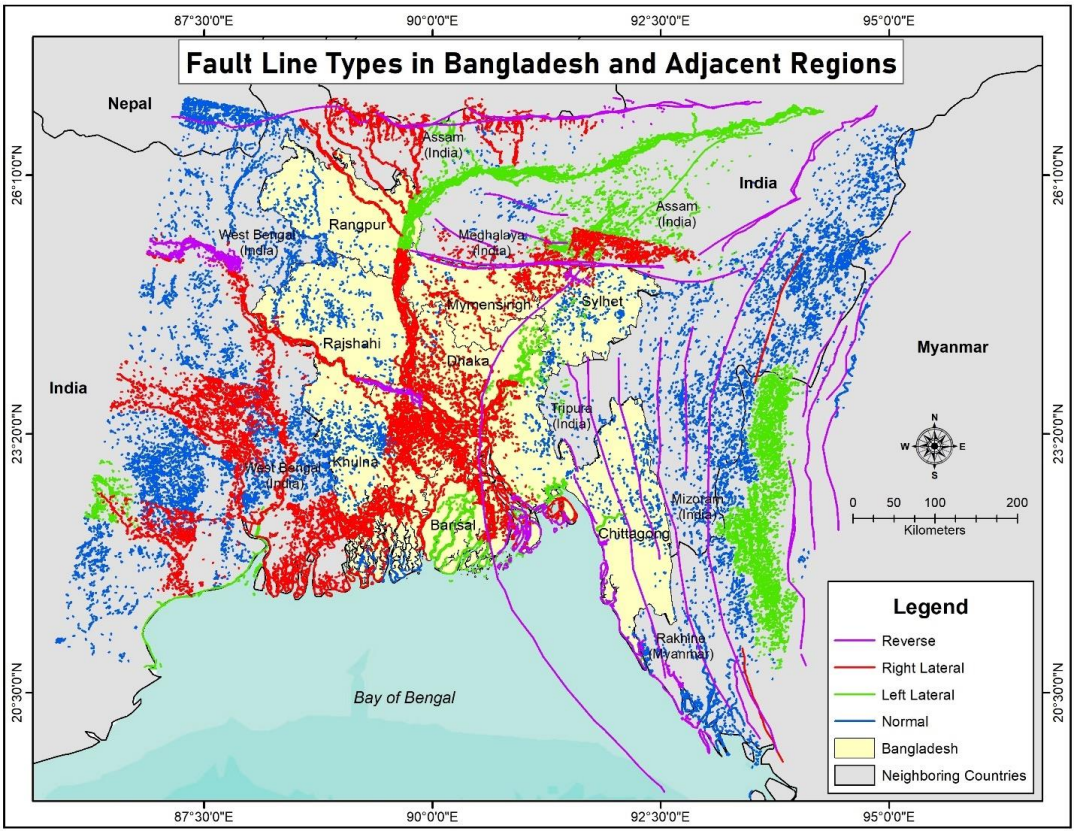

Figure 4 illustrates a more accurate spatial classification of tectonic structures in Bangladesh and the adjacent regions, delineating four major types of faults: reverse, right-lateral, left-lateral, and normal faults.

3.3 Earthquake epicenters in Bangladesh and its adjacent regions (1924-2024)

Figure 5: Earthquake epicenters in Bangladesh and its adjacent regions (1924-2024)

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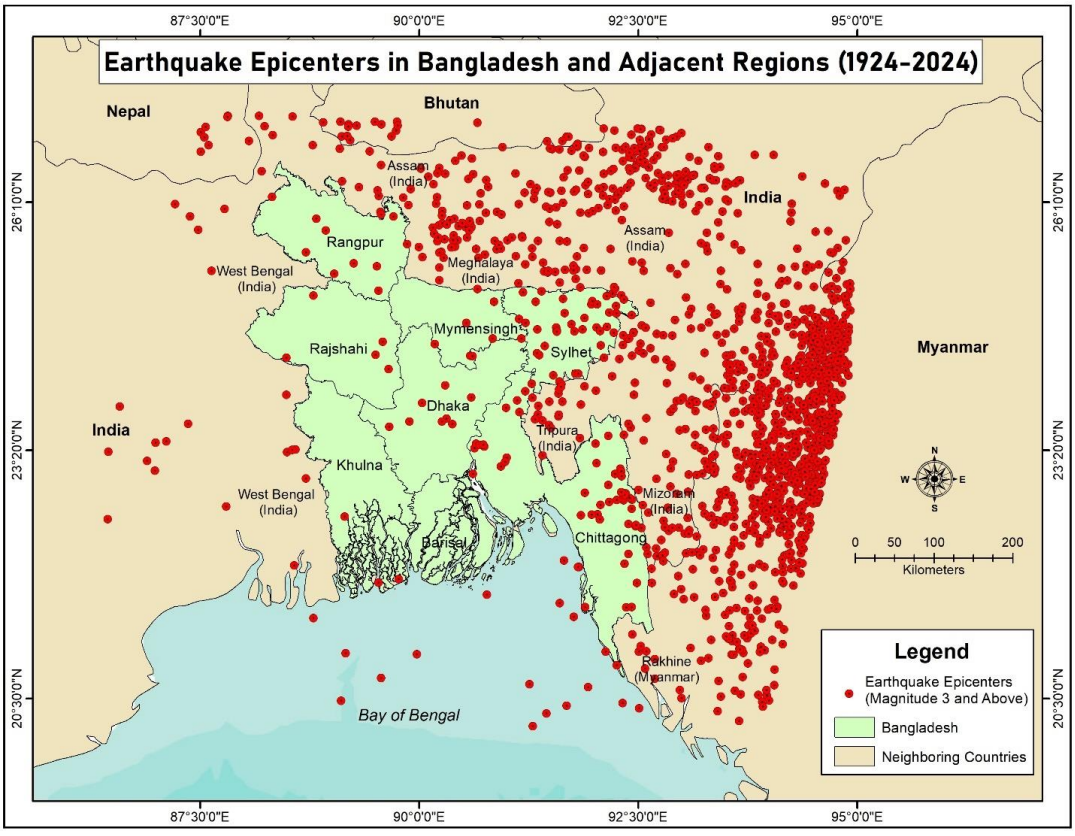

Figure 5 shows the epicentral spatial pattern of earthquake events (magnitudes ≥ 3.0) in Bangladesh and adjacent areas over the last one hundred years (1924–2024) based on seismic information offered by the USGS Earthquake Catalog. The red dots represent single earthquake events and indicate regional patterns of seismicity.

3.4 Earthquake epicenter and fault line relationship assessment

Figure 6: Spatial autocorrelation report between earthquake epicenters and fault lines

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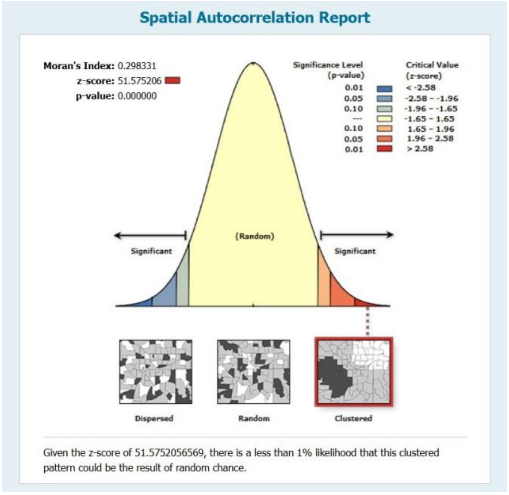

Global Moran's I Summary

Moran's Index:	0.298331
Expected Index:	-0.000649
Variance:	0.000034
z-score:	51.575206
p-value:	0.000000

Dataset Information

Input Feature Class:	EQ_Main
Input Field:	NEAR_DIST
Conceptualization:	INVERSE_DISTANCE
Distance Method:	EUCLIDEAN
Row Standardization:	False
Distance Threshold:	94786.3561 Meters
Weights Matrix File:	None
Selection Set:	False

The Moran's Index report shows the spatial autocorrelation between earthquake epicenters and fault lines, highlighting the degree to which their distribution exhibits a non-random spatial pattern.

3.5 Earthquake epicenter and fault line type relationship assessment

As the Kruskal-Wallis test showed significant differences, Dunn's test will help to identify which specific fault type pairs differ significantly in terms of their distance from epicenters. Interpretation of Dunn's test result as follows,

Table 1: Interpretation of the Dunn's test of fault line pairs with nearest distance to epicenters

Comparison	Mean rank difference	p-value	significance
Normal vs Left-lateral	17.09	1.00000	Not significant
Reverse vs Left-lateral	259.64	0.00021	Significant
Right-lateral vs Left-lateral	-92.00	0.40750	Not significant
Reverse vs Normal	242.55	0.00071	Significant
Right-lateral vs Normal	-109.09	0.19063	Not significant

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Right-lateral vs Reverse	-351.64	0.00003	Significant

3.5.1 Assessment of the influence of specific fault lines in earthquake epicenters

A multinomial logistic regression was conducted to assess the influence of distance from earthquake epicenters on the likelihood of different fault types. The right-lateral faults were used as the reference category.

Table 2: Multinomial logistic regression of fault line types and their nearest distances from earthquake epicenters

Parameter Estimates									
Nearest fault distance		B	Std. Error	Wald	df	Significance	Exp(B)	95% Confidence Interval for Exp(B)	
								Lower Bound	Upper Bound
Left-Lateral	Intercept	2.321	.137	288.871	1	.000			
	Near-Distance	-2.829	1.177	5.780	1	.016	.059	.006	.593
Normal	Intercept	2.151	.137	245.719	1	.000			
	Near-Distance	-2.364	1.164	4.124	1	.042	.094	.010	.921
Reverse	Intercept	-.520	.201	6.648	1	.010			
	Near-Distance	.571	1.367	.174	1	.676	1.769	.121	25.773
a. The reference category is: Right-lateral.									

The multinomial logistic regression model captured valuable information on spatial relationships between the locations of earthquake epicenters and fault types. Using fault types as the dependent variable and the distance from an epicenter to the nearest fault line (Near-Distance) as the

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independent variable, the model estimated the probability of the occurrence of earthquakes near different types of faults relative to right-lateral faults (the reference category).

4 Discussion

4.1 Fault lines in Bangladesh and its adjacent regions

In Fig. 3, active faults have long, continuous, and sharply defined geometries. They are most prominent along the eastern and northeastern boundary of Bangladesh, including zones around Myanmar, the Tripura-Mizoram fold belt, and the Dauki Fault zone along the Shillong Plateau in Meghalaya. These zones have been traditionally associated with great-magnitude seismic activities, including the 1897 Great Assam Earthquake (Mw ~8.0) (Morino et al., 2011)

In contrast, lineaments, which have linear orientation, do not necessarily all overlie currently active faults, but tend to define areas of tectonic weakness. They are highest in central and southern Bangladesh, the Sylhet trough, and West Bengal, India. Lineaments play a crucial role in shaping the region's morphology. Although lineaments may lack direct evidence for surface rupture, their alignment along with known stress orientations and seismic clusters suggests that the majority can be reactivated during subsequent seismic cycles. The significance of lineaments and faults in understanding seismic activity has gained emphasis through recent research. Lamontagne et al. (2020) mapped lineaments and faults in seismically active regions of Quebec and Ontario and provided a comprehensive overview of brittle structures.

4.2 Fault line types in Bangladesh and its adjacent regions

In Fig. 4, right-lateral faults are present with dense concentration in central and southern Bangladesh, from Dhaka to Khulna and the Meghna Delta. Right-lateral faulting is associated with horizontal shear and rotation of the blocks in a variety of tectonic regimes (Ron et al., 1984). The same faulting mechanisms were identified in the Sundarbans region, indicating active shearing on the delta front. The left-lateral faults are well-structured along the Meghalaya Plateau, Barisal division, and west of Myanmar near Mizoram. The left-lateral faults are anticipated in oblique convergent regimes, where the crustal shortening and lateral translation are co-temporal (Morino et al., 2011).

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Normal faults occur dominantly in the Rajshahi division, West Bengal, and northeast India. Normal faults are a widespread feature of extensional tectonic regimes, with downward movement of the hanging wall above the footwall (Jackson & McKenzie, 1983).

Reverse faults are focused in the Chittagong Hill Tracts, southern Mizoram, Meghalaya to the east of Sylhet, and Myanmar's Rakhine state. Reverse faults are a result of compressional stress, characteristic of convergent tectonic boundaries. This style is the one that best fits the forecasted tectonic response of the Indo-Burman subduction system, where the Indian Plate is being subducted under the Burma Plate (Steckler et al., 2008). The area has experience with megathrust earthquakes, e.g., the 1762 Arakan earthquake (Wang et al., 2014).

4.3 Earthquake epicenters in Bangladesh and its adjacent regions (1924-2024)

The distribution of earthquake epicenters in Fig. 5 displays distinct spatial clustering, with comparatively high concentrations in the Indo-Burma subduction zone, the Tripura-Mizoram fold belt, and northeastern India, particularly in Assam and Meghalaya. The clusters coincide with main active fault systems and known tectonic boundaries, for example, the Dauki Fault in Meghalaya, the Chittagong-Tripura-Mizoram thrust front. This is consistent with previous observations that the region has experienced deep oblique convergence of the Indian Plate and the Burma Microplate, resulting in an elevated level of moderate-to-large seismicity (Steckler et al., 2008; Wang et al., 2014). Seismicity in Bangladesh is most vigorous in the Chittagong Hill Tracts and Sylhet areas, where seismic hazard potential is increased by proximity to compressional and transpressional fault systems.

4.4 Earthquake epicenter and fault line relationship assessment

From Fig. 6, it can be seen that the spatial autocorrelation analysis produced Moran's Index of 0.298, indicating moderate and statistically significant positive spatial autocorrelation. This would suggest that earthquake occurrences with similar fault proximities are more likely to cluster spatially than they would be randomly distributed. The z-score of 51.575 and p-value of <0.000001 unequivocally support the assertion that such clustering is highly improbable by random chance. These are considerably above 99% critical levels of a typical significance curve with data distribution in the clustered tail of the curve. The trend shows that seismic activity is not randomly

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distributed over the area but rather tends to accumulate in regions where faults are in close alignment or tectonically active.

4.5 Earthquake epicenter and fault line type relationship assessment

Table 1 illustrates that reverse faults have appreciably different (larger) distances from left-lateral, normal, and right-lateral faults, as the p-value for reverse faults is appreciably lower than 0.05, grouping with the other three faults. Right-lateral, normal, and left-lateral faults are not appreciably different from each other, as no statistically significant difference was noted among these faults. Therefore, reverse fault types differ from the remaining types of faults in terms of distance from earthquake epicenters in this study.

4.5.1 Assessment of the influence of specific fault lines in earthquake epicenters

Table 2 shows that the distance to normal and left-lateral faults exerts a significant effect on earthquake occurrence probability. To be specific, distance to left-lateral faults was strongly negatively correlated ($B = –2.829$, $p = 0.016$), i.e., earthquakes have an extremely high chance of occurring near left-lateral faults compared to right-lateral faults. Similarly, for normal faults, the distance parameter was also negatively significant ($B = –2.364$, $p = 0.042$), revealing a higher likelihood that earthquakes would occur close to normal faults as well. These observations are evidence of spatial clustering of earthquake activity in the vicinity of these two fault types, and they conclude that their structural and tectonic character can be more seismically favorable in the region. Conversely, there was a non-significant statistical relationship between distance and reverse faults ($B = 0.571$, $p = 0.676$), and the wide confidence range of the odds ratio ($Exp(B) = 1.769$, 95% Confidence Interval: 0.121–25.773) suggests very high uncertainty in the relationship. This lack of relevance can result in a statement that reverse faults have decreased seismic productivity compared to left-lateral and normal faults.

The findings validate the usefulness of integrating statistical modeling, remote sensing, and geospatial data for exposing small fault-epicenter patterns. By identifying fault types more likely to trigger nearby earthquakes, the model helps to include a more realistic representation of seismic hazard distribution. The left-lateral and normal faults had the highest correlations with earthquake proximity, suggesting that the faults are likely to be more active or structurally better developed, in concordance with regional directions of stress. This approach enables probabilistic fault

https://doi.org/10.5194/egusphere-2025-3774
Preprint. Discussion started: 12 September 2025

behavior modeling in addition to deterministic fault mapping and provides a valuable tool for seismic risk area ranking.

5 Conclusions

This study conducts a rigorous geospatial and statistical analysis of fault lines, fault line types, and their spatial relationship with earthquake epicenters within Bangladesh and the adjacent regions. Using advanced remote sensing techniques, thermal infrared satellite imagery, and spatial characteristics of faults, the study was able to identify and classify fault lines into four broad categories: reverse, normal, left-lateral, and right-lateral, highlighting their geotectonic significance.

Through spatial autocorrelation analysis, the study demonstrated that earthquake epicenters are not randomly distributed but rather cluster near specific fault systems. Nonparametric statistical testing (Dunn's test, Kruskal-Wallis) verified that reverse faults differ significantly from the other fault types in epicentral proximity, establishing their distinct seismic behavior. Multinomial logistic regression also verified that earthquakes are more likely to occur at distances near normal faults and left-lateral faults in a detailed fault line system in and around Bangladesh.

These findings emphasize the fundamental requirement for incorporating fault type and their proximity to earthquake epicenters into regional earthquake hazard models. The methodology and results provide useful suggestions for disaster planning, infrastructure construction, and seismic hazard mitigation in Bangladesh and neighboring countries. Moreover, cross-border seismic source consideration confirms the importance of regional collaboration in sustainable earthquake resilience planning for Bangladesh.

Data availability

The data supporting this study are available from the corresponding author upon reasonable request.

Author contribution

MADL: conceptualization, data curation, methodology, supervision, software, formal analysis, validation, visualization, and writing (original draft preparation as well as review and editing). KHM: conceptualization, supervision, software, visualization, writing (review and editing).

https://doi.org/10.5194/egusphere-2025-3774
Preprint. Discussion started: 12 September 2025

Competing interests

The contact author has declared that none of the authors has any competing interests.

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