

## **MULTI-CRITERIA EARTHQUAKE RISK MAPPING USING GEOSPATIAL TECHNIQUES AND AHP IN THE CHITTAGONG HILL TRACTS**

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### **ABSTRACT**

Bangladesh lies in a tectonically active zone, making it highly vulnerable to earthquakes. The Chittagong Hill Tracts (CHT), located near major fault lines like the Tripura and Dauki faults, face significant seismic risk. Past events, including the 1997 and 2003 earthquakes, caused notable damage in this region. Despite ongoing preparedness programs, due limited scientific assessment and lack of awareness in rural hilly areas necessitates updated, spatially-informed risk mapping to guide mitigation and planning. The goal of the study is to assess the earthquake risk in the Chittagong Hill Tracts (CHT) using geospatial techniques and the Analytic Hierarchy Process (AHP) by integrating hazard, vulnerability, and capacity indicators. This research analyzed the Earthquake Risk in the CHT region on the basis of potential hazard, vulnerability and capacity. The hazard component includes peak ground acceleration, proximity to fault lines, past earthquake events, soil characteristics, slope. For vulnerability mapping 3 parameters including proximity to buildings, buildings and population density. Capacity assessment was done through the evaluation of accessibility to services like roads, education, healthcare. The weightage of these parameters were calculated by Analytic Hierarchy Process (AHP) and a weighted overlay analysis was done for mapping the three major factors. The result shows the high hazard prone areas are mainly concentrated in the north eastern part of CHT. Vulnerability assessment shows that Mahalchhari and Alikadam contains the most highly vulnerable areas. The periphery areas of CHT have the lowest capacity because of lack of access to essential services. The final integrated risk map shows the areas under earthquake risk on a scale from high to low risk. This map identifies Mahalchhari and Alikadam as high risk areas while north western regions including Lakshmichhari, Manikchhari, Kawkali, Kaptai are in low risk. This study will help in further research regarding earthquake risk assessment, planning and will benefit the urban planners, researchers, government agencies and NGOs working disaster management and earthquake resilience in Bangladesh.

**Keywords:** *AHP, Hazard, Vulnerability, Capacity, Earthquake Risk.*

## **1. INTRODUCTION**

Earthquake is a natural calamity which occurs suddenly because of the rapid shaking of the ground caused by the shifting of rocks deep underneath the earth's surface (*Earthquakes | Ready.Gov*, n.d.). Earthquake risk can be defined as the probability of losses occurring due to earthquakes within a given period of time which include human lives, social and economic disruption as well as material and infrastructural damage (*Seismic Risk Assessment — MCM Group*, n.d.). Bangladesh is facing a high risk of moderate to strong earthquakes that may result in widespread damage and loss of thousands of lives as five geological fault lines run through the country and can generate tremors of over 7 magnitudes (Islam et al., 2016). Bangladesh's geotectonic location at the boundary between the Indian plate and Burma subplate has led to numerous earthquake events and recent seismic hazard assessment has signified the importance of sustainable earthquake resilient development in the region (Rahman et al., 2025). The hilly regions of Bangladesh near the Chittagong-Myanmar fold and thrust belt is at the risk of a Mw 8.5 earthquake, with the nearby Tripura fault being highly active and posing threats of seismic events and landslides in areas like Rangamati (Shanto et al., 2024). Chittagong Hill Tracts (CHT) are affected by natural disasters like earthquake and landslide, causing severe casualty and loss of property. The tribal inhabitants are tackling this hazard with age old construction technique gained from everyday experiences and without any theoretical knowledge (Ching & Suravi, 2019). The aim of the study is to assess earthquake risk in the Chittagong Hill Tracts using geospatial techniques and the Analytic Hierarchy Process (AHP) by integrating hazard, vulnerability, and capacity indicators.

## **2. METHODOLOGY**

The selected study area is Chittagong Hill Tracts (CHT) which is located in south-eastern Bangladesh, consisting of three districts: Rangamati, Khagrachari and Bandarban. The area experiences a tropical monsoon climate with high rainfall, together with complex geology and diverse soil type, contributes to susceptibility of natural hazards such as earthquakes and landslides (Hossain et al., 2025). This study adopts a GIS based analysis for identifying the earthquake risk in CHT as there is probability of frequent natural hazard due to its location. Three indicators named Hazard, Vulnerability and Capacity were assessed and integrated to determine the risk. The study used the formula: *Seismic Hazard* × *Vulnerability* / *Capacity* (MrGeogWagg, 2015).

### **2.1 Data collection**

The data used were peak ground acceleration (pga), geological fault lines, geology, soil properties, past earthquake event data for hazard mapping. PGA values were collected from Global Earthquake Model (GEM), fault line and geology data were collected from USGS Science Data Catalogue, soil data were collected from Food and Agriculture Organization (FAO). Past earthquake data from 1908 to 2025 including event location, magnitude and focal depth were collected from USGS Earthquake Catalogue. Dem data from slope determination was collected from USGS Earth Explorer. For vulnerability mapping the building polygon data and populated places point data were collected from Humanitarian Data Exchange. For capacity assessment proximity to roads, education and health facilities were analysed and these datasets were collected from Humanitarian Data Exchange.

### **2.2 Data processing**

All the vector datasets were converted into raster layers with a 30-meter cell size to ensure uniform spatial resolution and facilitate overlay analysis in ArcGIS. This standardization allows for consistent comparison among different spatial variables. Subsequently, the raster data were reclassified into five categories ranging from very low to very high, using the equal interval method, which divides the data range into equal segments. This classification helps in simplifying data interpretation and enables clearer visualization of spatial patterns and gradients across the study area.

#### **2.2.1 Hazard**

The proximity to fault lines was determined using the Euclidean distance tool to measure the shortest distance from each location to the nearest fault. Slope was extracted from the DEM using the Slope tool in ArcGIS to represent variations in terrain steepness. Geology was classified according to rock type

and soil composition to capture differences in ground stability. Past earthquake magnitude and depth were interpolated using the Inverse Distance Weighted (IDW) method to create a continuous surface of seismic activity. Together, these parameters serve as essential inputs for analysing spatial variations in earthquake susceptibility.

Table 1: Hazard Parameters Impact Classification

Parameters	Hazard Level					Supporting Literature
	Very low	Low	Medium	High	Very high	
Peak Ground Acceleration	0.20-0.27	0.27-0.34	0.34-0.40	0.40-0.47	0.47-0.54	(Zhuang et al., 2019)
Distance from Fault lines	42.02 km-52.52 km	31.51 km-42.02 km	21.01 km-31.51 km	10.5 km – 21.01 km	0 km – 10.5 km	(Alizadeh et al., 2018)
Slope	0-14.75°	14.57°-29.14°	29.14°-42.73°	42.73° - 58.29°	58.29°-72.86°	(Alizadeh et al., 2018; Toyfur et al., 2018)
Geology	Hard rock	Consolidated	Semi-consolidated	Loose Alluvium	Soft soil	(Alizadeh et al., 2018; Jena et al., 2019; Toyfur et al., 2018)
Earthquake Magnitude (M)	4.9 - 5.06	5.06 - 5.23	5.23 - 5.39	5.39 - 5.56	5.56 - 5.72	(Hasan et al., 2025)
Earthquake depth	30 km - 35 km	25 km -30 km	20 km -25 km	15 km -20 km	10 km -15 km	(Hasan et al., 2025)

### 2.2.2 Vulnerability

The building data (polygons) were converted into point data by using Feature to Point and then analysed using Kernel Density and Euclidean Distance for obtaining building density and proximity to buildings respectively. The population density was determined by using kernel density from the populated places point data.

Table 2: Vulnerability Parameters Impact Classification

Parameters	Vulnerability Level					Supporting Literature
	Very low	Low	Medium	High	Very high	
Building density	0 - 4.1	4.1 - 8.3	8.3 - 12.46	12.46 - 16.62	16.62 – 20.78	(Jena et al., 2020; Vicente et al., 2008)
Population density	0 - 64	64 - 129	129 - 193	193 - 258	258 - 322	(Tate, 2012; Zhuang et al., 2019)
Distance from buildings	0 km - 5.17 km	5.174 km -10.35 km	10.35 km -15.5 km	15.5 km - 20.7 km	20.7 km - 25.8 km	(Neves et al., 2012)

### 2.2.3 Capacity

The road network data and point data of both educational and health facilities were analyzed using the Euclidean Distance tool to determine proximity to these essential services and infrastructure. This analysis helps identify areas with better accessibility and those lacking adequate service coverage. The resulting distance maps were later reclassified to evaluate the relative accessibility levels within the study area.

Table 3: Capacity Parameters Impact Classification

Parameters	Capacity Level					Supporting Literature
	Very low	Low	Medium	High	Very high	
Distance from roads	17.26 km - 21.57 km	12.97 km - 17.26 km	8.6 km - 12.97 km	4.3 km - 8.6 km	0 km - 4.3 km	(Alizadeh, et al., 2018; Hasan et al., 2025)
Distance from education facilities	36.69 km - 49.61 km	29.76 km - 39.69 km	19.84 km - 29.76 km	9.92 km - 19.84 km	0 km - 9.92 km	(Sendai Framework for Disaster Risk Reduction 2015 - 2030, n.d.)
Distance from health facilities	44.71 km - 55.89 km	33.53 km - 44.71 km	22.35 km - 33.53 km	11.17 km - 22.35 km	0 km - 11.17 km	(Hasan et al., 2025; Sendai Framework for Disaster Risk Reduction 2015 - 2030, n.d.)

### 2.3 Weight assigning and Analysis

The Analytical Hierarchy Process (AHP) was used to assign the weighted values to all the parameters of the three factors based on literature review and experts' opinion. Then the raster calculator was used to integrate the hazard, vulnerability, capacity layers by using the risk formula to generate the final earthquake risk map for CHT.

Table 4: Weight Assignment of Hazard Parameters

Hazard Parameters	PGA	Faults distance	Slope	Geology	EQ Mag	EQ Depth	Weightage
PGA	1	1	6	1.5	1	5	24.39
Faults distance	1	1	6	1.5	1	5	24.39
Slope	1/6	1/6	1	0.25	0.14	1/3	3.46
Geology	0.66	0.66	1.33	1	0.2	2	10.98
EQ Mag	1	1	7	5	1	4	30.1
EQ Depth	0.2	0.2	3	0.5	0.25	1	6.68

Consistency Ratio:  $0.02 < 0.1$  Acceptable

Source: (Al-Dogom et al., 2018; Rehman et al., 2024)

Table 5: Weight Assignment of Vulnerability Parameters

Vulnerability Parameters	Building Density	Population Density	Building Distance	Weightage
Building Density	1	2	3	54
Population Density	0.5	1	2	29.7
Building Distance	0.33	0.5	1	16.3

Consistency Ratio:  $0.009 < 0.1$  Acceptable

Source: (Jena et al., 2021; Rehman et al., 2024)

Table 6: Weight Assignment of Capacity Parameters

Capacity Parameters	Road	Hospital	Education	Weightage
Road	1	0.5	0.33	16.3
Hospital	2	1	0.5	29.7
Education	3	2	1	54

Consistency Ratio:  $0.009 < 0.1$  Acceptable

(Rehman et al., 2024)

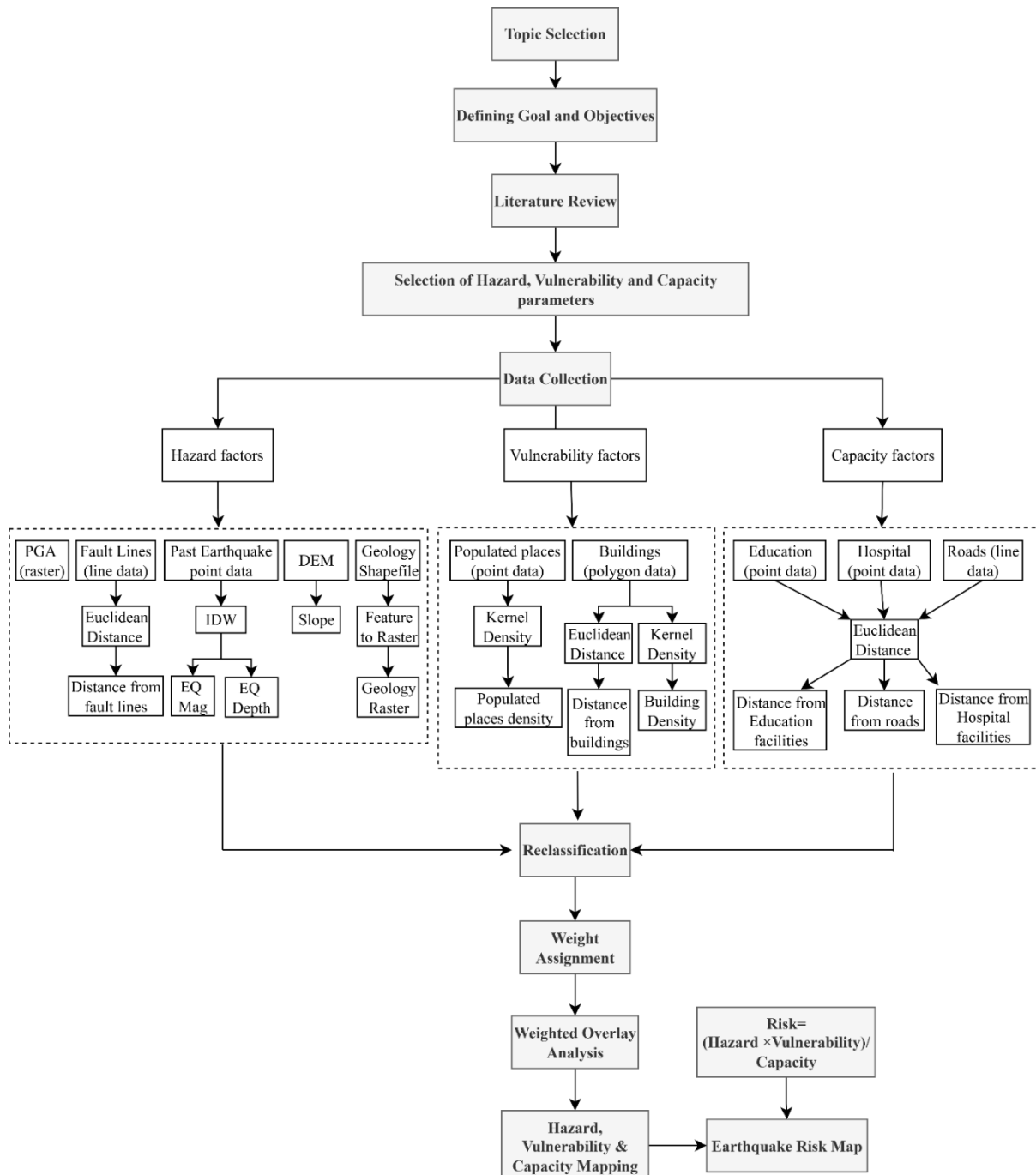


Figure 1: Methodology Flowchart

### 3. RESULTS AND DISCUSSION

This chapter presents the analysis and interpretation of spatial data to identify earthquake-prone zones in the Chittagong Hill Tracts. It integrates hazard, vulnerability, and capacity factors through GIS-based mapping and weighted overlay techniques to generate the final risk map. The results illustrate spatial variations in risk levels across different upazilas.

#### 3.1 Hazard Assessment

This section presents the spatial analysis of earthquake hazard distribution across the Chittagong Hill Tracts. The hazard map (Figure 3) classifies the area into five categories, ranging from very high to very low hazard levels. Findings indicate that the north-eastern region, particularly the upazilas of Baghai Chhari and Langadu, exhibits the highest concentration of hazard-prone zones, covering approximately 92 sq. km. Conversely, about 3,296 sq. km fall within low hazard zones, while around 651 sq. km represent the lowest hazard category, encompassing parts of Bandarban Sadar, Rowangchari, Ruma, Lama, Thanchi, Alikadam, and Naikhongchhari. Among these, Thanchi appears to be the least susceptible to earthquake hazards.

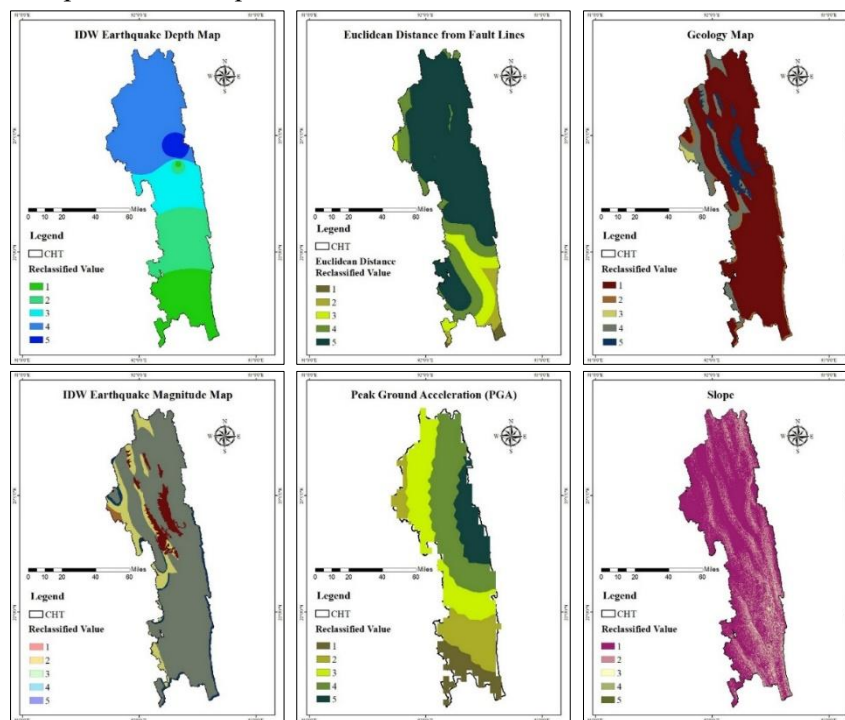


Figure 2: Hazard Parameters Map

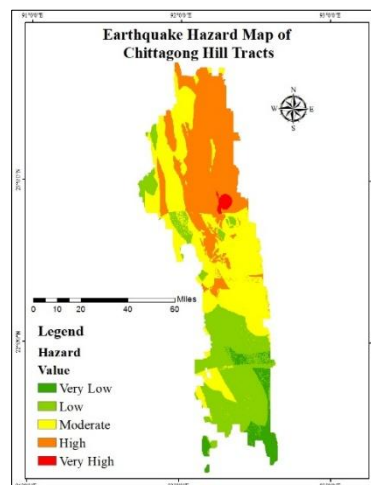


Figure 3: Hazard Map

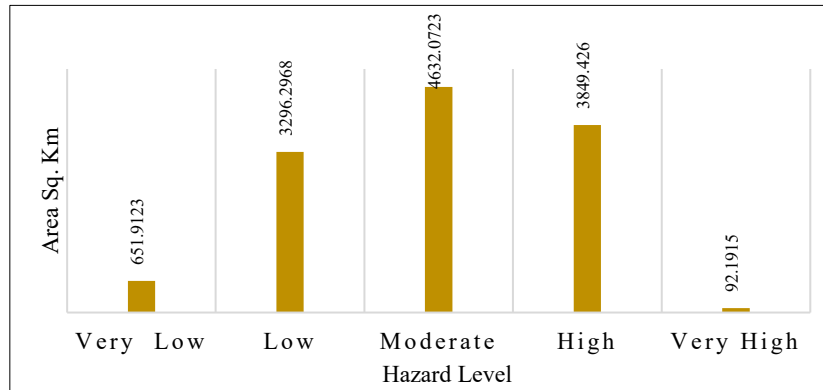


Figure 4: Earthquake Hazard Prone Areas (sq. km)

### 3.2 Vulnerability Assessment

In this section, the areas vulnerable to earthquakes in the Chittagong Hill Tracts are analyzed. The vulnerability map (Figure 6) classifies the region into five categories, ranging from very high to very low vulnerability levels. The results show that Mahalchhari and Alikadam are the most highly vulnerable upazilas. Moderate vulnerability is observed in portions of Matiranga, Khagrachari Sadar, Langadu, Ruma, Rowangchari, Thanchi, and Naikhongchhari. In contrast, about 3,241 sq. km fall under the very low vulnerability zone, covering most parts of Lakshmichhari, Kawkhali (Betbunia), Naniarchar, and Belaichhari.

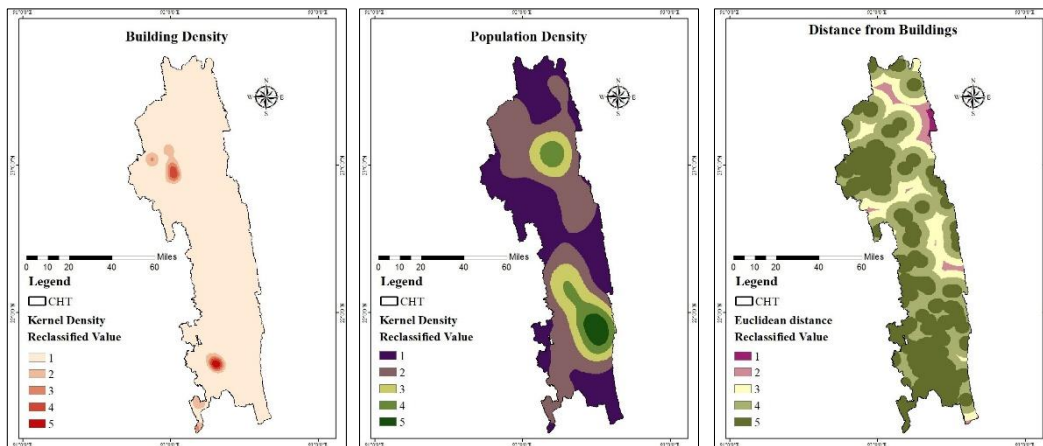


Figure 5: Vulnerability Parameters Map

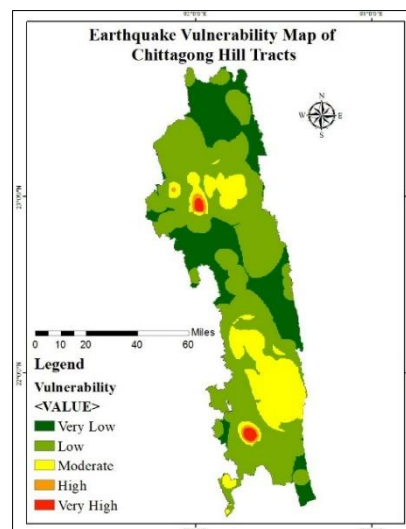


Figure 6: Vulnerability Map

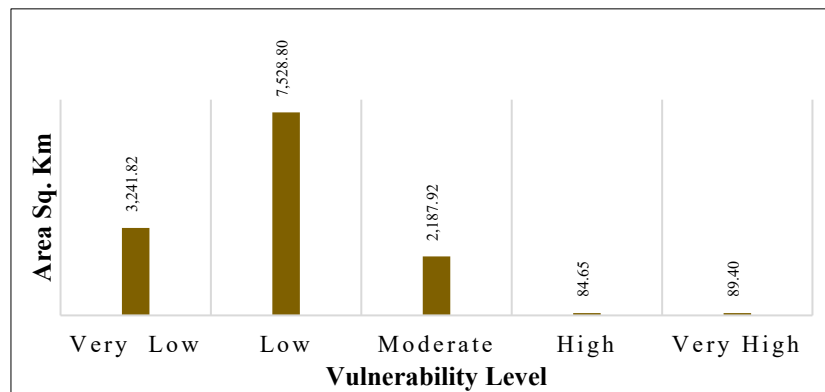


Figure 7: Earthquake Vulnerable Areas (sq. km)

### 3.3 Capacity Assessment

Mostly the areas that are located at the outer portion of CHT show comparatively low capacity as these areas lack essential services such as roads, hospitals, education centers due to their distance from main city centers. This reduces their capacity to respond quickly during an earthquake emergency. About 202 sq. km and 948 sq. km areas have very low and low capacity respectively to handle the earthquake risk including little portions of Thanchi, Belaichhari, Dighimala (Figure 9).

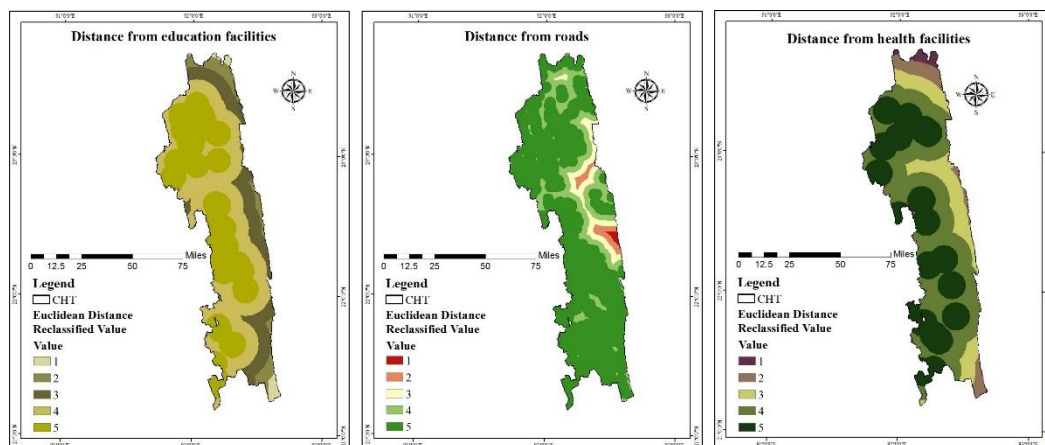


Figure 8: Capacity Parameters Map

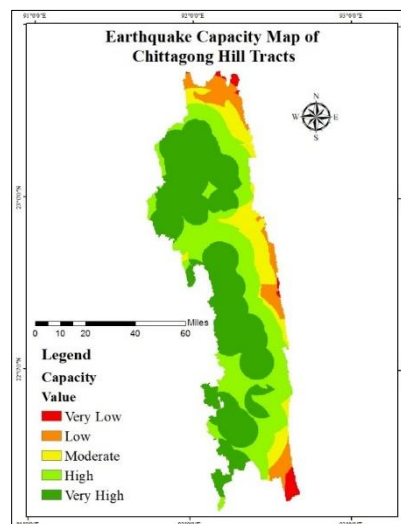


Figure 9: Capacity Map

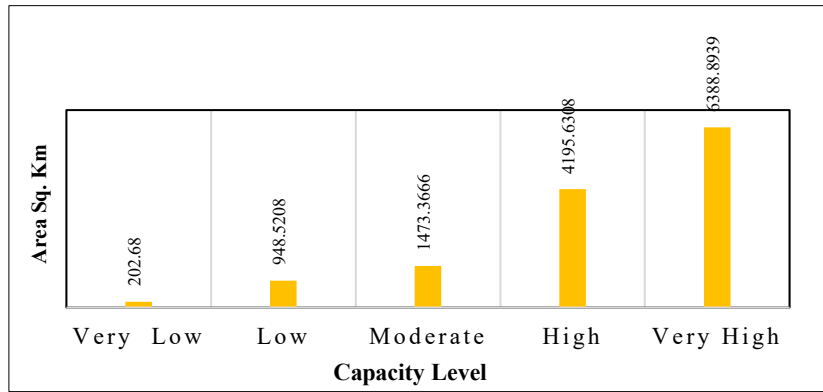


Figure 10: Earthquake Response Capacity Areas

### 3.3 Risk Assessment

The final earthquake risk map (Figure 11) shows the risk level within the Chittagong Hill Tracts based on the combined effect of hazard, vulnerability, capacity. Most of the areas of Mahalchhari and Alikadam are in high risk. Though these upazilas have higher capacity but due to highest building density, closer to the fault line these areas fall within the high-risk zone. Some areas of Bagai chhari, Barkal, Belai chhari Jurai chhari, Thanchi fall under moderate to very high-risk zone. Some of these areas have high peak ground acceleration, some are closer to fault lines and some has very low capacity to handle earthquake. The very low risk zone covers about 6545 sq. km areas of the north western part. This is the safest side of the CHT including Manikchhari, Lakshnichhari, Kawkhali, Kaptai, Nagorchhari. Also, Bandarban Sadar, Lama, Rowangchhari, Rajasthali, Rangamati Sadar, Ramgar, Khagrachari Sadar, Panchhari have low to very low risk of earthquake.

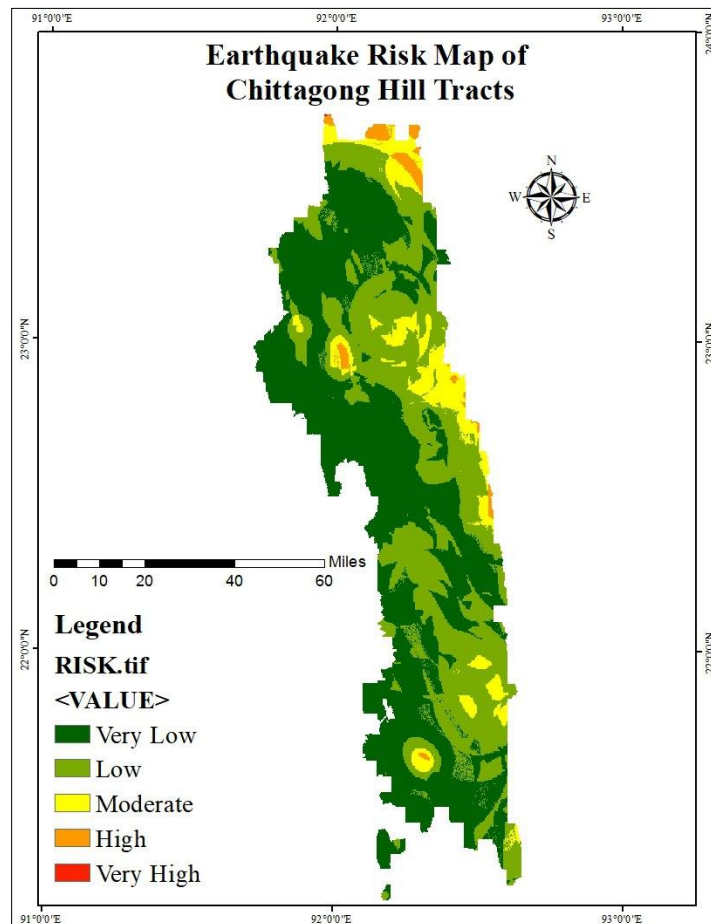


Figure 11: Final Earthquake Risk Map

Table 7: Areas Under Earthquake Risk (sq. km)

Level	Area
Very Low	6545.663
Low	4759.759
Moderate	998.6778
High	203.4882
Very High	1.1088

The most areas in each upazila fall under earthquake risk levels 1-3, indicating very low to moderate risk shown in Figure 12. In contrast, Figure 13 highlights pockets of very high risk (level 5) in Barkal. Bagai Chhari, Jurai Chhari, Mahalchhari, Langdu, Ruma, and Thanchi are in level 4 indicating high risk. Although these high-risk zones are limited, they may affect nearby areas, while the majority of land remains at low risk (level 2).

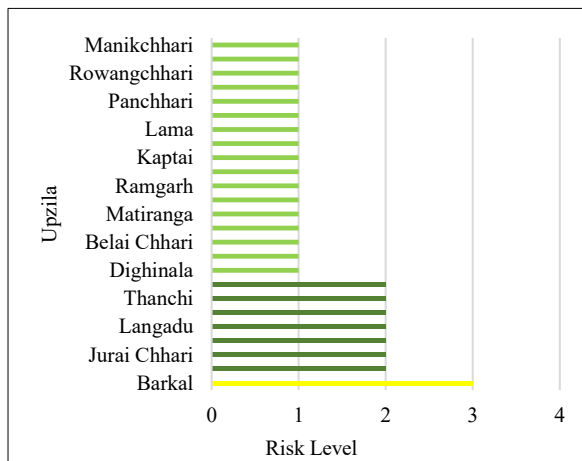


Figure 2: Majority Earthquake Risk Level at Each Upazila in CHT

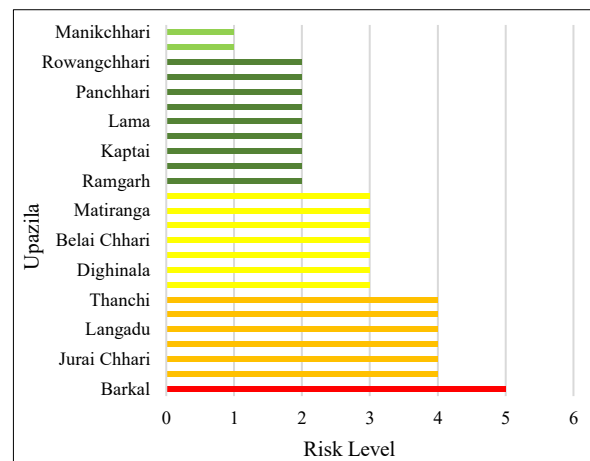


Figure 1: Maximum Earthquake Risk Level at Each Upazila in CHT

#### 4. CONCLUSIONS

This study conducts a multi-criteria earthquake risk assessment of the Chittagong Hill Tracts, covering Bandarban, Khagrachari, and Rangamati, integrating hazard, vulnerability, and capacity indicators. The northeastern region, especially Bagai Chhari and Langdu, is highly hazard-prone, while Mahalchhari and Alikadam are highly vulnerable. Peripheral areas lack basic services, reducing coping capacity. Integrated risk mapping shows high-risk zones in areas with dense buildings near fault lines, even where capacity is higher, whereas low-capacity areas face elevated risk. High-risk, low-capacity zones, including parts of Bagai Chhari and Barkal, need targeted development and mitigation. Strengthening infrastructure, improving service access, and enforcing zoning near fault lines are critical. For reducing the earthquake risk, specific policy measures should be enforced such as implementing earthquake resistant building code according to local geology, restricting development in high-risk areas and promoting community-based disaster preparedness and awareness. The framework aids policymakers, stakeholders, and researchers in prioritizing mitigation and enhancing disaster preparedness.

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## DECLARATION OF USE OF AI

The authors declare that no artificial intelligence (AI) tools were used in the research methodology, data analysis or research process; only standard software was used for formatting or language editing.

## REFERENCES

- Al-Dogom, D., Schuckma, K., & Al-Ruzouq, R. (2018). *GEOSTATISTICAL SEISMIC ANALYSIS AND HAZARD ASSESSMENT; UNITED ARAB EMIRATES*.
- Alizadeh, M., Hashim, M., Alizadeh, E., Shahabi, H., Karami, M. R., Beiranvand Pour, A., Pradhan, B., & Zabihi, H. (2018). Multi-Criteria Decision Making (MCDM) Model for Seismic Vulnerability Assessment (SVA) of Urban Residential Buildings. *ISPRS International Journal of Geo-Information*, 7(11), 444. <https://doi.org/10.3390/ijgi7110444>
- Alizadeh, M., Ngah, I., Hashim, M., Pradhan, B., & Pour, A. B. (2018). A Hybrid Analytic Network Process and Artificial Neural Network (ANP-ANN) Model for Urban Earthquake Vulnerability Assessment. *Remote Sensing*, 10(6), 975. <https://doi.org/10.3390/rs10060975>
- Ching, S. W., & Suravi, R. H. (2019, January). *INDIGENOUS DISASTER RESILIENCE: AN OBSERVATION OF BAWM HOUSES, BANDARBAN, CHITTAGONG*. International Conference on Disaster Risk Management At: Dhaka, Bangladesh.
- Earthquakes | Ready.gov*. (n.d.). <https://www.ready.gov/earthquakes>
- Hasan, M., Hoque, M. A.-A., & Pradhan, B. (2025). Mapping seismic risk in Rangpur Division, Bangladesh: An integrated geospatial approach. *Spatial Information Research*, 33(5), 40. <https://doi.org/10.1007/s41324-025-00643-y>
- Hossain, M. I., Ferdous, M. N., Bhattacharjee, S., & Rahman, M. (2025). Remote sensing and GIS-driven landslide susceptibility mapping using machine learning for sustainable land management: A study from the Chittagong Hill Tracts of Bangladesh. *Discover Sustainability*, 6(1), 1200. <https://doi.org/10.1007/s43621-025-02084-x>
- Islam, R., Islam, N., & Islam, M. N. (2016, December). *EARTHQUAKE RISKS IN BANGLADESH: CAUSES, VULNERABILITY, PREPAREDNESS AND STRATEGIES FOR MITIGATION*.
- Jena, R., Pradhan, B., & Beydoun, G. (2020). *Earthquake vulnerability assessment in Northern Sumatra province by using a multi-criteria decision-making model*. 46. <https://doi.org/10.1016/j.ijdr.2020.101518>
- Jena, R., Pradhan, B., Beydoun, G., Nizamuddin, Ardiansyah, Sofyan, H., & Affan, M. (2019). *Integrated model for earthquake risk assessment using neural network and analytic hierarchy process: Aceh province, Indonesia*. 11, 613–634.
- Jena, R., Pradhan, B., Naik, S. P., & Alamri, A. M. (2021). *Earthquake risk assessment in NE India using deep learning and geospatial analysis*.
- MrGeogWagg. (2015, September 7). Lesson 2 Measuring Risk. *MrGeogWagg*. <https://mrgeogwagg.wordpress.com/2015/09/07/lesson-2-measuring-risk/>
- Neves, F., Costa, A., Vicente, R., Oliveira, C. S., & Varum, H. (2012). Seismic vulnerability assessment and characterisation of the buildings on Faial Island, Azores. *Bulletin of Earthquake Engineering*, 10(1), 27–44. <https://doi.org/10.1007/s10518-011-9276-0>
- Rahman, M. M., Bai, L., Li, H., & Liu, C. (2025). Probabilistic Seismic Hazard Map for Bangladesh Including the Smoothed Background Seismicity and Local Site Effects. *Pure and Applied Geophysics*. <https://doi.org/10.1007/s00024-025-03894-w>
- Rehman, A., Sajjad, M., & Song, J. (2024). *Integrated frequency ratio-analytical hierarchy and geospatial techniques-based earthquake risk assessment in mountainous cities: A case from the Northwestern Himalayas*.
- Seismic Risk Assessment—MCM Group*. (n.d.). Retrieved June 20, 2025, from <https://mcmdev.com/stories/risk>
- Sendai Framework for Disaster Risk Reduction 2015—2030*. (n.d.).
- Shanto, S. A., Hossain, A. S. M. F., Fariha, A. S., & Ansari, M. (2024). *Assessment of seismic slope stability of Rangamati Hill Tracts (Vols. 1–2)*.

- Tate, E. (2012). Social vulnerability indices: A comparative assessment using uncertainty and sensitivity analysis. *Natural Hazards*, 63(2), 325–347. <https://doi.org/10.1007/s11069-012-0152-2>
- Toyfur, M. F., Pribadi, K. S., Wibowo, S. S., & Sengara, I. W. (2018). Vulnerability factor in earthquake risk assessment model for roads in Indonesia. *MATEC Web of Conferences*, 229, 03009. <https://doi.org/10.1051/mateconf/201822903009>
- Vicente, R., Parodi, S., Lagomarsino, S., & Varum, H. (2008). *SEISMIC VULNERABILITY ASSESSMENT, DAMAGE SCENARIOS AND LOSS ESTIMATION*.
- Zhuang, J., Peng, J., Zhu, X., & Huang, W. (2019). Scenario-Based Risk Assessment of Earthquake Disaster Using Slope Displacement, PGA, and Population Density in the Guyuan Region, China. *ISPRS International Journal of Geo-Information*, 8(2), 85. <https://doi.org/10.3390/ijgi8020085>