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## Article

Multi-dimensional earthquake vulnerability assessment of residential neighborhoods of Mymensingh City, Bangladesh: A spatial multicriteria analysis based approach

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**Research Article** 

# Multi-dimensional earthquake vulnerability assessment of residential neighborhoods of Mymensingh City, Bangladesh: A spatial multi-criteria analysis based approach

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#### ABSTRACT

The assessment of the vulnerability of a city to different natural hazards is the prerequisite to achieving sustainable urban resilience. The city of Mymensingh is located in the most earthquake vulnerable zone of Bangladesh and surrounded by multiple fault lines including the Madhupur Blind Fault, Dauki Fault, and Sylhet-Assam Fault lines. The city also achieved the title of the 8th divisional city in 2015, thereby opening the door to unrestrained future development. Therefore, it is of paramount importance to assess the earthquake vulnerabilities of Mymensingh city and this research is envisioned to evaluate this vulnerability by combining 23 parameters derived from four major dimensions-geological, socio-economic, structural and systematic dimensions. The MCDM techniques of Analytical Hierarchy Process and Weighted Linear Combination coupled with GIS-based spatial analysis were applied in this study to assess the residential neighborhoodlevel earthquake vulnerability. The findings show that out of the 241 residential neighborhoods of Mymensingh city, 51 are observed to be highly vulnerable, while 123 are exposed to medium vulnerability and 67 to low vulnerability. According to the analysis, the topmost factors that make Mymensingh City highly earthquake-vulnerable are the soil type, proximity to the fire station, elderly population levels, Peak Ground Acceleration, child population levels and distance to healthcare facilities. The simplistic, efficient, and reasonably accurate methodology and findings of this research are expected to be helpful for policymakers in low-income countries to prioritize special consideration areas, resource targeting, and deciding on appropriate planning and development control interventions for disaster management.

#### 1. Introduction

In this era of globalization, cities are expanding very fast and 55 percent of the world's population is now living in cities. This figure is projected to increase by 68 percent in 2050 (UNDESA, 2018). Due to the dynamics of massive population displacement, multifaceted functional systems, complex nexus of demographic, economic, infrastructural, and environmental factors, cities are now exposed to multiple challenges including natural disasters, climate change, etc. (Atun, 2014; Pelling, 2011). Considering the challenges of an urban environment, the world has adopted several milestone international agreements including the Sustainable Development Goals (2015–2030), Paris Agreement (2015), Sendai Framework for Disaster Risk Reduction (2015–2030) which advocates for sustainable

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urban resilience through the substantial reduction the number of global losses due to disasters (Kelman, 2017). Understanding, analyzing, quantifying and visualizing the complexity of the vulnerabilities caused by various natural disasters is the most challenging task of disaster risk reduction. It facilitates emergency managers, planners, and policymakers to take judicious actions and policies to minimize the impact of natural hazards and other emerging risks (Alam, Chakraborty, & Islam, 2019a; Alam & Chakraborty, 2021; Papathoma-Köhle, Schlögl, & Fuchs, 2019).

Bangladesh sits atop three active and shoving tectonic plates along with shallowly dipping megathrust with mega-earthquake unleashing capacity (Apu & Das, 2020; Sarker, Ansary, Rahman, & Safiullah, 2010; Steckler et al., 2016). Moreover, the cities of Bangladesh is facing unplanned urban growth, high population density, and environmental degradation which exposing the urban populations to earthquake hazard. The city of Mymensingh, one of the four oldest municipalities of Bangladesh (established in 1787 during the British Colonial period), was conferred the title of the 8th divisional city in 2015 that can lead to unplanned development in the future. Considering the administrative and economic importance as a divisional city and its easy accessibility to the capital, Mymensingh city is one of the fastest urbanizing cities of Bangladesh and there is a scope for devising disaster risk-sensitive urban planning to ensure sustainable development. Along with all the potentiality, the city also falls in the most severe earthquake vulnerable zone (Zone IV with. a 36 g seismic coefficient) of Bangladesh (BNBC, 2021) and is surrounded by major faults including Madhupur Blind Fault, Dauki Fault, and Sylhet-Assam Fault (Alam and Hague, 2017, 2018; Apu & Das, 2020; Morino et al., 2011). Moreover, almost ninety percent soil of the city is highly liquefaction susceptible that can amplify the seismic waves, and cause mass destruction. Though the city hasn't experienced any major earthquakes in recent time, some major earthquakes in the past century including the 7.5 Richter scale magnitude earthquake of 1762 and the 8.7 Richter scale magnitude earthquake in 1897 caused massive destruction of the city (Alam & Haque, 2020; Apu & Das, 2020; Sarker et al., 2010). Specifically, the earthquake of 1762 had changed the course of the adjacent Brahmaputra River, one of the longest transboundary rivers of the world (Das & Saraf, 2007). Such evidence from the past centuries justifies the need for vulnerability assessment of the Mymensingh city for implementing risk mitigation actions in the city.

Vulnerability to disasters like earthquakes is a complex nexus among the social, economic, geological, systematic, and physical dimensions (Armaş, Toma-Danila, Ionescu, & Gavriş, 2017; Arouq, Esmaeilpour, & Sarvar, 2020; Rezaie & Panahi, 2015). Therefore, the formulation of appropriate risk reduction strategies at the city level should incorporate all of these dimensions (Alizadeh et al., 2018; Walker et al., 2014). However, most of the previously conducted research on earthquake vulnerability predominantly focuses on the prediction of the magnitude, structural or geological aspects and minimally incorporates the others dimensions of vulnerability. Most of the studies including those by Nath, Adhikari, Devaraj & Maiti (2015); Ishita & Khandaker (2010); Jena and Pradhan (2020); Sarris, Loupasakis, Soupios, Trigkas, & Vallianatos (2010) strived to assess the structural or geological dimension of earthquake vulnerability. Some studies are focused on the prediction of the magnitude of the earthquake (Adeli & Panakkat, 2009; Alarifi, Alarifi, & Al-Humidan, 2012; Erzin & Cetin, 2012). On the other hand, some studies only incorporate the social dimension of earthquake vulnerability but undervalued the other dimensions (Armaş & Gavris, 2013; Martins, e Silva, & Cabral, 2012; Shirley, Boruff, & Cutter, 2012; Walker et al., 2014). Even though remarkable developments are observed in the physical and social aspects of vulnerability research, no significant endeavor has been undertaken to assess the systematic dimension of earthquake vulnerability and incorporate it into a comprehensive index by the researchers so far (Alam & Haque, 2020; Walker et al., 2014). Few studies have been done that evaluate the earthquake vulnerability of a city combining all major dimensions of vulnerability. Therefore, this research is envisioned to evaluate the vulnerability of Mymensingh city to earthquake hazards combining four major dimensions of vulnerability namely geological, structural, socioeconomic, and systematic dimensions.

As the vulnerability of a city to an earthquake involves multiple causative factors stemming from multiple dimensions of vulnerability, it is quite challenging to find an appropriate method that can comprehensively incorporate various types of data. There are several other methods such as Capacity Spectrum Method (Freeman, 1998), Non-linear Dynamic Analysis (Fajfar, 2000), Vulnerability Index Method (Lantada et al., 2010), Turkish method (Alam, Alam, & Tesfamariam, 2012), Failure Mechanism Identification and Vulnerability Evaluation (D'Ayala & Speranza, 2003), Rapid Visual Screening (Federal Emergency Management Agency, 2017), etc. available for seismic vulnerability evaluation. But all these methods are complicated, require high-level expertise and data support, and most importantly, all of them are structural vulnerability component biased. Therefore, a simpler, flexible, and effective method is required to assess the multi-dimensional earthquake vulnerability of a city. Based on a comprehensive literature review, it is identified that Multicriteria Decision Making (MCDM) is the most used methodology in earthquake studies to manage the complexity in decision making that encompasses quantitative and qualitative indicators (Flores, Escudero, & Zamora-Camacho, 2020; Rezaie & Panahi, 2015; Walker, Schuurman, Swanlund, & Clague, 2020; Yariyan, Zabihi, Wolf, Karami, & Amiriyan, 2020). Since the assessment of earthquake vulnerability encompasses multiple factors, the MCDM method is widely used by researchers including Alizadeh et al. (2018), Rashed and Weeks (2003), Alam and Haque (2018), Armas (2012), Rahman, Ansary, and Islam (2015), Jena and Pradhan (2020), Rezaie and Panahi (2015), Yariyan et al. (2020) for earthquake risk assessment as well as in risk-sensitive land use planning spheres due to their relative ease of implementation. Considering the simplicity, effectiveness, and wide acceptability, this study has used the MCDM method to evaluate the vulnerability of Mymensingh city to the earthquake by incorporating the structural, geological, systematic, and socio-economic dimensions of earthquake vulnerability. Finally, a composite index is developed using the MCDM method combining all four dimensions based on expert opinions, and the extent of vulnerability in each residential neighborhood is analyzed and visually presented in the map using ArcGIS software. The result of this research is expected to provide a useful means of earthquake risk micro-zonation, resource targeting and may prove to be a useful tool for devising risk-sensitive land-use planning in earthquake-prone areas.

#### 2. Study area

Though earthquakes cause damage to all types of land use in a city, the previous occurrence of earthquakes in different regions of the world show that casualties, death, and destruction are highest in the residential areas due to its high spatial concentration of life and property (Alizadeh et al., 2018; Saputra et al., 2017). Therefore, this research endeavors to evaluate the vulnerabilities of the residential neighborhoods of Mymensingh city to an earthquake hazard. Mymensingh city, declared as the 8th divisional city of Bangladesh in 2015, was established on the bank of the old Brahmaputra River. During the British colonial period, Mymensingh city, formerly known as Narsirabad, was founded in 1787 and was conferred the title of municipality in 1869. Presently, the city has an area of 21.73 sq.km., including 21 administrative wards and 241 small residential neighborhoods, which are home to 258,040 people (BBS, 2011; CDMP, 2014). The population of the city is growing at a rate of 1.82% and the literacy rate is 73.9% (BBS, 2011). The 241 residential neighborhoods, locally known as para, were chosen as the study areas for this earthquake vulnerability assessment (Shown in Fig. 1).

#### 3. Selection of parameters of earthquake vulnerability assessment

In this study, 23 influential earthquake vulnerability parameters have been selected based on diligent literature review, expert



Fig. 1. Residential neighborhoods of the Mymensigh City, Bangladesh.

opinion, and by analyzing available data, under four vulnerability dimensions, viz., and geological, systematic, structural and socioeconomic vulnerability.

#### 3.1. Geological earthquake vulnerability parameters

Based on an inclusive literature review, the three most used geological parameters have been identified for this study which are shown in Table 1.

#### 3.2. Systematic earthquake vulnerability parameters

The accessibility of an area to major emergency facilities including healthcare service, open spaces, evacuation route, fire service, emergency shelter, etc. is often denoted as systematic vulnerability (Alam & Haque, 2020; Rashed & Weeks, 2003; Walker et al., 2020). Parameters considered for assessing systematic earthquake vulnerability are shown in Table 2.

#### 3.3. Structural earthquake vulnerability parameters

In this study, the eight most influential structural parameters are considered to evaluate the structural dimension of earthquake vulnerability which are displayed in Table 3.

#### 3.4. Socio-economic earthquake vulnerability parameters

The socio-economic vulnerability parameters that are considered in this study are mentioned in Table 4.

#### Table 1

Geological earthquake vulnerability parameters.

Parameter	Vulnerability Leve	el		Supporting Literature
	Low	Medium	High	
Soil Type	Hard Soil	Stiff Soil	Soft Soil	(Ishita & Khandaker, 2010; Sarvar, Amini, & Laleh-Poor, 2011; Vicente, Parodi, Lagomarsino, Varum, & Silva, 2010)
Peak Ground Acceleration	0.346485 - 0.369287	0.369288 - 0.392051	0.392052 - 0.410747	(Jena & Pradhan, 2020; Moradi, Delavar, & Moshiri, 2014; Rezaie & Panahi, 2015)
Shear Wave Velocity	More than 360 m/s	180 m/s to 360 m/s	less than 180 m/ s	(Chandler, Lam, & Tsang, 2006; Jena, Pradhan, & Beydoun, 2020)

#### Table 2

Systematic earthquake vulnerability parameters.

Parameter	Vulnerabilit	y Level		Supporting Literature
	Low	Medium	High	
Distance to hospital Distance to Fire Service Distance to Emergency center Distance to Evacuation Route	<500 m <1 km <500 m <500 m	500 m to 1 km 1 km–1 km 500 m to 1 km 500 m to 1 km	>1 km >2 km >1 km >1 km	(Alam & Haque, 2020; Arouq et al., 2020; Rezaie & Panahi, 2015) (Armaş, 2012; Arouq et al., 2020; Scawthorn, Eidinger, & Schiff, 2005) (Alam & Haque, 2020; Arouq et al., 2020; Rezaie & Panahi, 2015) (Jena & Pradhan, 2020; Rezaie & Panahi, 2015)

#### Table 3

Structural earthquake vulnerability parameters.

Parameter	Vulnerabilit	y Level		Supporting Literature
	Low	Medium	High	
% of poor building	<25%	25–50%	>50%	(Ghajari, Alesheikh, Modiri, Hosnavi, & Abbasi, 2017; Jena & Pradhan, 2020; Moradi et al., 2014)
% of masonry building with flexible roof	<25%	25-50%	>50%	(Alam & Haque, 2018; Ishita & Khandaker, 2010; Rahman et al., 2015)
Average Building Storey	1 Storey	2 Storey	$\geq$ 3 Storey	(Alizadeh et al., 2018; Ishita & Khandaker, 2010; Nath et al., 2015; Sarris et al., 2010; Vicente et al., 2010)
Average Road Width(ft.)	>16 ft	8 ft–16 ft	<8 ft	(Ghajari et al., 2017; Ishita & Khandaker, 2010; Martins et al., 2012)
Building Density/acre	<10 building	10 to 15 building	>15 building	(Armaş, 2012; Jena & Pradhan, 2020; Martins et al., 2012; Zebardast, 2012)
Irregular Shape Building (%)	<10%	10–15%	>15%	(Ferreira, Vicente, Mendes da Silva, Varum, & Costa, 2013; Maio, Ferreira, Vicente, & Estêvão, 2015)
Pounding Possibility (%)	<10%	10–15%	>15%	(Alam & Haque, 2020; Jena & Pradhan, 2020; Jeng & Tzeng, 2000; Papathoma-Köhle et al., 2019)
Heavy Overhanging (%)	<10%	10–15%	>15%	(Alam & Haque, 2018, 2020; Inel, Ozmen, & Bilgin, 2008)

#### Table 4

Socio-economic earthquake vulnerability parameters.

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Parameter	Vulnerability Lev	vel		Supporting Literature				
	Low	Medium	High					
Percentage of child population(<5 yr)	<5%	5% to 10%	>10%	(Ferreira et al., 2013; Rahman et al., 2015)				
Percentage of elderly population $(65 + yr)$	<2.4%	2.4%-4.8%	>4.8%	(Armaș & Gavriș, 2013; Zebardast, 2012)				
Women population (%)	<25%	25%-50%	>50%	(Armaş et al., 2017; Schmidtlein, Shafer, Berry, & Cutter, 2011)				
Literacy Rate	>70%	35%-70%	<35%	(Fatemi, Ardalan, Aguirre, Mansouri, & Mohammadfam, 2017; Islam, Swapan, & Haque, 2013)				
Average Household income	>16475BDT	8238 BDT to 16475 BDT	<8238BDT	(Armaş & Gavriş, 2013; Duzgun et al., 2011; Rahman et al., 2015)				
Population Density/acre	<100 person/ acre	100 to 150 person/acre	>150 person/ acre	(Armaș & Gavriș, 2013; Nath et al., 2015)				
Average Household size	<2.21	2.21 to 4.41	>4.41	(Armaş, 2012; Schmidtlein et al., 2011)				
Economically dependent population (%)	<25%	25%-50%	>50%	(Armaș et al., 2017; Martins et al., 2012; Moradi et al., 2014; Walker et al., 2014)				

#### 4. Methodology

The Multicriteria decision-making methods (MCDM) are privileged with the ability to incorporate all types of data and maintain an equilibrium among ease-of-use and inclusiveness of decision criteria (Alizadeh et al., 2018; Flores et al., 2020; Walker et al., 2014, 2020). This equilibrium is very critical for judicious decision making in the context of sustainable hazard preparedness and mitigation planning, especially resource-starved cities of poor countries with high-risk settings (Nyimbili, Erden, & Karaman, 2018). According to the literature review of similar studies, the Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC) are the most widely used MCDM techniques in disaster studies (Alam & Haque, 2018; Alam & Mondal, 2019; Alizadeh et al., 2018; Ishita & Khandaker, 2010). Thus, this research uses both the AHP method and WLC method to develop indices to identify how earthquake vulnerabilities are spatially varied among the residential neighborhoods of Mymensingh city.

#### 4.1. Analytical Hierarchy Process (AHP)

The major steps followed by the AHP model in assessing earthquake vulnerability are: developing a hierarchy for factors; developing a reciprocal matrix from pairwise comparison of the factors based on Saaty (Saaty, 1980) developed nine-point scale (Table 5), computation of eigenvector and eigenvalue, identify the weight of the factors, and testing the consistency of the judgments following equations (1) and (2).

The consistency ratio value of the matrix has to be less than 0.1 to prove consistency, otherwise, the whole process must be iterated until the consistency is achieved. To measure the consistency index (CI) and consistency ratio (CR) defined by Saaty (1980), the following equations needs to be applied;

$$CI = \frac{\lambda max - n}{n - 1}$$
(1)

$$CR = \frac{CI}{RI}$$
(2)

Here,  $\lambda_{max}$  is the highest or principal eigenvalue of the pair-wise comparison matrix and RI denotes the random inconsistency index (Presented in Table 6).

#### Table 5

Preference scale for pairwise comparisons in AHP (Saaty, 1980).

Decreasing Relative Intensity of Importance						Equally Impo	rtant	Increasing Relative Intensity of Importance											
<b>4</b> 1/9	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1		2	3	4	5	6	7	8	9	$\rightarrow$	•

#### Table 6

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RI	value	for	different	number	t of	parame	ters o	leve.	loped	by	Saaty	(1	98	0	).
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Number of Parameter	1	2	3	4	5	6	7	8	9	10
RI Value	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

#### 4.2. Weighted Linear Combination (WLC) method

Weighted Linear Combination, an extensively applied MCDM technique, is used for combining parameters by applying a weight, derived from the AHP model, to each parameter. All the weighted layers of vulnerability parameters and their sub-categories are combined using a weighted overlay analysis tool in the proprietary ArcGIS software using the following equation;

$$W = \sum_{i=1}^{n} w i^* x i$$
(3)

In the above-mentioned equation, W denotes the index score of the neighborhood in the earthquake vulnerability map,  $w_i$  is the weight of each parameter,  $x_i$  and n indicate the number of parameters.

In this study, comparison matrices of 23 earthquake vulnerability parameters (3 Geological, 8 Structural, 8 Socio-economic, and 4 Systematic vulnerability parameters) are created according to the opinion of three experts from the relevant field of expertise. To combine multiple opinions into a single matrix, the geometric mean of the expert's opinion is calculated (Shown in Table 7, Table 8, Table 9, and Table 10). The aggregated comparison matrix of earthquake vulnerability assessment used in this study is shown in Table 11. According to the AHP and WLC coupled technique, 23 earthquake vulnerable parameters derived from four umbrella dimensions are weighted on a scale of 0–1. It is essential to assign a weight to every sub-category of the above mentioned 24 parameters. Providing different weights to every sub-factor is a complex and time-consuming task. This study classifies each of the vulnerability parameters into three categories viz., low, medium, and highly vulnerable. Based on the recommendation of the experts and literature review (Alizadeh et al., 2018; Islam, Swapan, & Haque, 2013), the sub-categories are weighted on a scale of 0–1 where the weight of the highly vulnerable category is 0.500, the medium vulnerable category is 0.333, and the low vulnerable category is 0.167. The framework used for the earthquake vulnerability assessment of Mymensingh city is shown in Fig. 2.

Table 7

Pair-wise comparison matrix, weight and consistency ratio of Geological earthquake vulnerability parameters based on the expert's opinion.

Geological Parameters	PGA	Soil Type	SWV	Weight	
Peak Ground Acceleration (PGA)	1.00	0.63	1.59	.318	CR = 0.003, RI = 0.58
Soil type	1.59	1.00	2.00	.466	
Shear Wave Velocity (SWV)	0.63	.50	1.00	.216	

#### Table 8

Pair-wise comparison matrix, weight and consistency ratio of Systematic earthquake vulnerability parameters based on the expert's opinion.

Systematic Parameters	Hospital	Fire service	Shelter	Route	Weight	
Distance to hospital	1.00	0.55	1.82	1.26	0.253	CR = 0.014, RI = 0.9
Distance to fire service	1.82	1.00	1.82	1.82	0.374	
Distance to emergency shelter	0.55	0.55	1.00	0.69	0.162	
Distance to Evacuation route	0.79	0.55	1.44	1.00	0.211	

#### Table 9

Pair-wise comparison matrix, weight and consistency ratio of Structural earthquake vulnerability parameters based on the expert's opinion.

Structural Parameters	1	2	3	4	5	6	7	8	Weight	
1.Building Storey	1.00	0.29	0.55	0.29	0.69	0.69	0.63	1.82	0.074	CR = 0.034, RI = 1.41
2.Poor conditioned building	3.44	1.00	1.44	0.69	1.14	1.25	0.87	1.25	0.143	
3.Masonry building	1.81	0.69	1.00	0.31	0.48	0.63	0.5	1.82	0.088	
4.Pounding	3.44	1.44	3.22	1.00	1.59	2.62	1.00	2.28	0.213	
5.Irregular shaped building	1.45	0.88	2.08	0.63	1.00	1.00	0.55	1.26	0.116	
6.Overhanging	1.45	0.8	1.59	0.38	1.00	1.00	0.55	3.12	0.118	
7.Road width	1.59	1.15	2.00	1.00	1.82	1.82	1.00	2.88	0.178	
8.Building Density	0.55	0.8	0.55	0.44	0.79	0.32	0.35	1.00	0.068	

#### Table 10

Pair-wise comparison matrix, weight and consistency ratio of Socio-economic earthquake vulnerability parameters based on the expert's opinion.

Socio-economic parameters	1	2	3	4	5	6	7	8	Weight	
1.Household income	1.00	2.62	1.26	0.19	0.19	1.26	0.32	1.26	0.072	CR = 0.024, RI = 1.41
2.Household size	0.38	1.00	0.33	0.18	0.18	0.44	0.26	0.38	0.034	
3.Population density	0.79	3.00	1.00	0.28	0.28	1.26	0.40	1.26	0.077	
4. Elderly population	5.19	5.59	3.56	1.00	1.00	3.00	2.00	3.56	0.258	
5.Child Population	5.19	5.59	3.56	1.00	1.00	3.00	2.00	3.30	0.255	
6.Dependent population	0.79	2.29	0.79	0.33	0.33	1.00	0.32	1.44	0.073	
7. Women (%)	3.11	3.91	2.52	0.50	0.50	3.11	1.00	2.08	0.162	
8. Literacy rate (%)	0.79	2.62	0.79	0.28	0.30	0.69	0.48	1.00	0.068	

#### Table 11

Aggregated Pair-wise comparison matrix, weight and consistency ratio of composite earthquake vulnerability parameters based on the expert's opinion.

Composite index	Geo-logical	Structural	Systematic	Socio-economic	Weight	
Geo-logical	1.00	2.29	2.29	3.92	0.459	CR = 0.01, RI = 0.9
Structural	0.45	1.00	1.00	2.62	0.223	
Systematic	0.45	1.00	1.00	2.62	0.223	
Socio-economic	0.26	0.38	0.38	1.00	0.095	



Fig. 2. Framework of composite earthquake vulnerability assessment.

4.3. Development of composite earthquake vulnerability index

Each of the earthquake vulnerability dimensions has its significance in disaster research, but developing a composite index integrating all the dimensions is highly important for the policymakers for resource targeting, devising proper prediction and mitigation strategies, and enhance the resilience of cities (Armaş, 2012; Walker et al., 2014). In this study, a separate index has been developed for geological, structural, social, and systemic dimensions of vulnerability using the weights from the AHP method and equation of the WLC method. Finally, using the following equation 4, a generalized version of the WLC equation, this study develops a composite earthquake vulnerability index combining all dimensions, approaching an all-inclusive evaluation of vulnerability.

Composite Earthquake Vulnerability Index = 
$$W_{geo}^* X_{geo} + W_{str}^* X_{str} + W_{svs}^* X_{sys} + W_{soc}^* X_{soc}$$
 (4)

Here,  $W_{geo}$ ,  $W_{str}$ ,  $W_{sys}$  and  $W_{soc}$  denote the weight of geological, structural, systematic and socio-economic vulnerability dimensions respectively (Table 11).  $X_{geo}$ , Xstr, Xsys and  $X_{soc}$  represents the index value of geological, structural, systematic and socio-economic vulnerability respectively.

#### 4.4. Data source

All the data of this research were collected from secondary sources, including the Mymensingh Strategic Development Plan (MSDP), 2011–2031 database, and Bangladesh Bureau of Statistics (BBS) database. The data of structural and geological parameters are collected from the physical feature survey, geological investigation database of MSDP respectively. Socio-economic data of this research was collected from both the MSDP database and the BBS database. To calculate systematic vulnerability index, distances of each of the neighborhoods from important facilities are calculated through the employment of a Network Analyst tool of proprietary ArcGIS, using the point feature database of MSDP.

#### 4.5. Data analysis and vulnerability maps preparation

This study, using the Analytical Hierarchical Process, has determined the weights of different factors and sub-factors of seismic vulnerability. GIS software such as ArcGIS plays a vital role in this stage as it is incredibly beneficial for data processing and analysis (Ahasan, Alam, Chakraborty, & Hossain, 2020). All the gathered data has been processed in the following sequential order: Firstly, the socio-economic data and vulnerability scores of earthquake vulnerability of Mymensingh city were stored in the SPSS environment. Secondly, neighborhood-wise data of structural and geological earthquake vulnerability of Mymensingh city was extracted using geo-processing in the ArcGIS environment. Then, the databases were joined with the neighborhood map in ArcGIS. The center points of individual residential neighborhoods were delineated using the conversion tool in ArcGIS. In the next step, the maps were reproduced, for determining systematic vulnerability parameters employing Network Analyst tool ArcGIS, to identify neighborhoods that were inaccessible or possess less accessibility to the hospital service, fire service, temporary emergency shelter, and existing evacuation routes. The score of systematic earthquake vulnerability was



Fig. 3. Steps in GIS analysis.

reclassified and joined with the neighborhood database of Mymensingh city in ArcGIS. At the final stage, the composite earthquake vulnerability map of the residential neighborhoods of Mymensingh city was prepared using the WLC method according to the reclassified score in the ArcGIS environment (Fig. 3).

#### 5. Result

The spatial variations of vulnerabilities are analyzed and depicted in maps in three vulnerability zones, viz., high, medium, and low. From the city planning context, for a better understanding of the priorities of risk mitigation activities, it is essential to identify the relative importance of vulnerability parameters influencing earthquake vulnerability of the neighborhoods and therefore, have also been discussed in the following section as well.

#### 5.1. Geological vulnerability

According to the geological dimensions, vulnerability analysis identified 44 residential neighborhoods as highly vulnerable, 175 neighborhoods as medium vulnerable, and only 22 neighborhoods as low vulnerable zones in Mymensingh City. The geological earthquake vulnerability map is shown in Fig. 4. Besides, Fig. 5 shows the influences of different geological parameters on earthquake vulnerability (on a scale of 0-1). It is observed that soil type has the highest (0.5) influence among the parameters, followed by PGA (0.32). Shear Wave Velocity (0.18) has the least influence among the three parameters used in this analysis. Soil type is a critical factor because the density of the ground has a direct effect on the amount of motion the ground will experience during a quake. The soil of Mymensingh city is classified into three categories including hard soil, stiff soil and soft soil. During an earthquake, hard soil propels the energy quickly with a very small amplitude and thus causes less damage to the infrastructure on the surface. But soft ground slows the energy down and increases the amplitude of the motion, which is the primary cause of earthquake damage to man-made structures. The geological analysis shows that the soft soil covers the north-western part of the city which makes the neighborhood of that area highly vulnerable. The PGA value of Mymensingh city varies from 0.38 g to 0.41 g, which is in the "Severe" perceived shaking category in the Instrumental Intensity scale developed by the United States Geological Survey (USGS). The investigations show in the case of activity in any fault, the amount of PGA in the north-western neighborhoods will be around 0.41 g which will cause massive destruction. The value of shear wave velocity is measured in 0-30 m depth of soil and the lower the value of shear wave velocity, the higher the scale of vulnerability. The value of shear wave velocity of Mymensingh city is measured at 30 m depth, and the value is categorized into three vulnerability categories viz. less than 180 m/s, 180 m/s to 360 m/s and greater than 360 m/s. Based on the geological investigation, the north-western neighborhoods have soft soil properties, high PGA value and shear wave velocity which makes them highly geologically vulnerable to earthquake.

#### 5.2. Systematic vulnerability

The distances of four systematic vulnerability parameters from the geometric center of each neighborhood are considered and analyzed in the ArcGIS environment to measure the systematic vulnerability. The result shows that 88 residential neighborhoods are found in the high earthquake-vulnerable zone as far as it is concerned with feeble connections with these four emergency facilities. About 90 residential neighborhoods of Mymensingh city fall in the medium systematic vulnerable zone. Only 63 residential neighborhoods, which have close spatial links with the above-mentioned facilities, are in the low systematically earthquake-vulnerable zone (Fig. 6). The parameter-wise assessment of systematic earthquake vulnerability of Mymensingh City on a scale of 0–1 is shown in Fig. 7. According to Fig. 7, most of the residential neighborhoods in Mymensingh City are highly vulnerable due to their long distances from fire service stations (0.43), hospitals (0.24), and emergency shelter (0.2) respectively.

In an impact-type event like the earthquake, the hospital is an essential element of emergency response planning in an affected area. There are 64 hospitals (private and govt.) hospital in Mymensingh town. But most of the hospitals are spatially distributed in the middle part of the city near to the central business district(CBD) area, and some neighborhoods are located outside of the service area of these hospitals. The seismic wave of an earthquake can destroy or damage the electrical power station, gas lines or other fire sources inside or outside of a building, which can trigger the risk of fire hazard in a neighborhood after a temblor (Alam et al., 2019b; Alam and Haque, 2017, 2018, 2020). Unfortunately, there is only one fire station in Mymensingh city, located in the middle CBD area, for 258,040 populations and 37,674 residential buildings. Some residential neighborhoods are located at more than 5 km distant from the fire station, and it is difficult to provide timely fire and rescue service to these neighborhoods after an earthquake. In the Earthquake Contingency Plan of Mymensingh city (CDMP, 2014), 21 major emergency shelters had been designed for immediate evacuation which is not optimally distributed within the city. It is observed that 178 residential neighborhoods are located at a distance of more than 1 km. All these emergency services are located in the middle part of the city which makes the remote north-western areas and southern areas are systematically high vulnerable.



Fig. 4. Geological earthquake vulnerability of residential neighborhoods of Mymensingh city.



Fig. 5. Influence of Geological-Parameters on Earthquake vulnerability in Mymensingh city.







Fig. 7. Influence of Systematic Parameters on Earthquake vulnerability in Mymensingh city.

#### 5.3. Structural vulnerability

Structural earthquake vulnerability parameter refers to the factors that relate to the built-up environment such as buildings, bridges, roads etc. Structural parameters have a great influence on earthquake vulnerability and damage potential of a neighborhood. In this study, eight most influential structural parameters are considered to assess the earthquake vulnerability of Mymensingh city. Based on the analysis of structural parameters of Mymensingh city, it is identified that;

• 27.32% residential building of the residential neighborhoods are old and has an apparent poor quality. About 14.95% (36 neighborhood) residential neighborhoods in Mymensingh city have more than 50% poor quality buildings which are located in the middle part of the city.



Fig. 8. Structural earthquake vulnerability of residential neighborhoods of Mymensingh city.

- About 47% of the residential buildings of Mymensingh city are built of masonry buildings with flexible roof which are densely concentrated in some residential neighborhoods in the middle part of the city. About 48.55% (117 neighborhoods) residential neighborhoods in Mymensingh city has more than half masonry buildings which are highly vulnerable to earthquake.
- Though maximum buildings of Mymensingh city is low rise, there still exists some high-rise buildings in the middle part of the city. About 33.61% (81 neighborhoods) residential neighborhoods have an average building height of more than one Storey in Mymensingh city.
- During preparation of the Earthquake contingency plan of different cities of Bangladesh, it is measured that if the road width is more than 8 ft, there will be enough space for emergency vehicle movement after an earthquake occurrence considering the debris generated on both sides of the road. This study considers residential neighborhoods with less than 8 feet wide roads are highly earthquake-vulnerable and 32.37% (78 neighborhoods) residential neighborhoods of Mymensingh city fall in this category.
- In this study, building density per acre is considered as a parameter of earthquake risk, and residential neighborhoods with more than 15 buildings per acre are demarked as highly vulnerable to earthquakes. The analysis reveals that 61.41% (148 out of 241) residential neighborhoods are highly vulnerable due to high building density.
- In Mymensingh city, 13.24% of the residential buildings and 9.54% of the residential neighborhoods (23 out of 241) of the city are irregularly shaped which are unevenly distributed within the city and some residential neighborhoods have a higher percentage of the irregular shaped building.
- As Mymensingh city is one of the oldest cities of Bangladesh, a substantial portion of the buildings of the city was built before the development of the national building construction code. As many as 12.17% of the residential buildings and 11.62% of the residential neighborhoods (28 out of 241) of the city have a very high possibility of pounding during an earthquake which is unequally distributed.
- Overhangs are the elements of a structure such as a cantilever, balcony etc. which hang outside with less support and have a high probability of falling during a quake. About 2.13% residential building of Mymensingh city has a heavy overhang which is erratically distributed within the city.

Considering all these aforementioned factors and analysis from structural vulnerability index, it is found that 8 out of 241 residential neighborhoods are highly structurally vulnerable, 54 neighborhoods are medium structurally vulnerable and 179 neighborhoods are low structurally vulnerable. It is interesting to observe that in Mymensingh city neighborhoods, which are structurally vulnerable, are not geologically vulnerable. The reason behind this difference is the location of the CBD area in the middle part of the city which is medium geologically vulnerable. In Mymensingh city, the vulnerability parameters that make a city structurally vulnerable are comparatively high in the residential neighborhoods within or close to the CBD area than the neighborhoods of other parts of the city. The structural earthquake vulnerability map is portrayed in Fig. 8. It is critical to know which parameter has the most influence on the structural vulnerability to prioritize city planning implications. Fig. 9 illustrates that the influence of 8 structural vulnerability parameters on overall structural vulnerability (measured on a scale 0–1) and it is found that high pounding possibility (0.21), low road width (0.17), a high percentage of the poor building (0.13), irregular (0.13) and masonry buildings (0.13) respectively are the primary reasons behind structural vulnerability in Mymensingh city.



Fig. 9. Influence of structural factors on structural earthquake vulnerability.

#### 5.4. Socio-economic vulnerability

To get a complete picture of the vulnerability situation of Mymensingh city, it is also essential to understand the socio-economic characteristics of people living in different neighborhoods of the city. Unfortunately, during recent years, earthquake experts have not paid enough attention to socio-economic dimensions of earthquake vulnerability and therefore only a handful of studies have been conducted in this regard. Based on the analysis of structural parameters of Mymensingh city, it is identified that;

- Children are the most susceptible to earthquake hazards as they are incapable of defending themselves and the population under 5 years of age is defined as the child population in this study. About 7.8% of the total population of Mymensingh city are children (BBS, 2011). About 7.05% of the total residential neighborhood (17 out of 241 neighborhoods) has more than 10 percent of the child population which is considered as high earthquake-vulnerable.
- Elderly population (aged more than 65 years) consists of 3.6% of the total population of Mymensingh city (BBS, 2011). About 6.22% residential neighborhoods (15 out of 241 neighborhood) of Mymensingh city has more elderly population (more than 65 years) than the national average of 4.8%.



Fig. 10. Socio-economic earthquake vulnerability of residential neighborhoods in Mymensingh city.

- In Mymensingh city, about 48.8% of the total population is women population but this percentage fluctuates from neighborhood to neighborhood and almost half of the residential neighborhoods (105 out of 241 neighborhoods) have a higher percentage of women population.
- Though the overall literacy rate of Mymensingh city is 73.9% which is quite high in the Bangladeshi context, it varies across neighborhoods, and some residential neighborhoods have a low literacy rate (BBS, 2011). Residential neighborhoods with less than 35% literacy rate are considered highly earthquake-vulnerable in this study and 9.13% residential neighborhoods (22 out of 241 neighborhood) falls in this category. Neighborhoods near central CBD areas have high literacy rate than other areas of Mymensingh city.
- There exists a significant disparity in average household income among the residential neighborhoods of Mymensingh city due to the distance from the central business district, proximity to industry, employment opportunities, literacy rate etc. The average national household income in the urban area of Bangladesh is 16475 taka (BBS, 2011) which is taken as a benchmark in this study. About 20.16% of the residential neighborhoods (51 out 241 neighborhoods) with household income below the national average are considered vulnerable to earthquakes. Residential neighborhoods in the north-western and southern areas have a lower income average than the neighborhoods in the middle CBD areas of Mymensingh city.
- The city of Mymensingh is one of the highly populated cities of Bangladesh with a population density of 11875 people per square kilometer and also possesses a high population growth rate (BBS, 2011). As there exist many small-scale residential neighborhoods in Mymensingh city, the population density is calculated in per acre. About 34.85% residential neighborhoods (84 out of 241 neighborhood) has a population density over 150 people per acre and thus considered as highly earthquake-vulnerable.
- The average household size of Mymensingh city is 4.7, and some residential neighborhoods have a higher household size also. As the national urban area average household size of Bangladesh is 4.41, residential neighborhoods with an average household size of more than 4.41 people are considered as highly earthquake-vulnerable in this study. About 31.54% of the residential neighborhoods have an average household size of more than 4.41 and most of these neighborhoods are located in the middle part of the city.
- In General, the population group under the age of 15 years and over 60 years is considered as economically dependent population (Alam et al., 2019c). About 34.6% of the population of Mymensingh city is economically dependent, and the percentage varies across residential neighborhoods of Mymensingh city. About 19.62% residential neighborhood (42 out of 241 neighborhood) in Mymensingh city has more than 50 percent economically dependent population and marked as highly earthquake-vulnerable.

Considering all these aforementioned factors and analysis from socio-economic vulnerability index, the result shows that 75 neighborhoods out of 241 are highly socio-economically vulnerable to earthquake hazard whereas 158 residential neighborhoods are medium economically earthquake-vulnerable. Only eight residential neighborhoods are found as low socio-economically vulnerable in Mymensingh City. The spatial distributions of socio-economic earthquake vulnerability in Mymensingh City are visually represented in Fig. 10. The parameter wise socio-economic vulnerability analysis (Fig. 11) of the residential neighborhoods of Mymensingh City shows that mainly the city is socio-economically earthquake-vulnerable due to the high percentage of the elderly population (0.32), a high percentage of the child (0.24) and women population (0.16) and population density (0.07). Other parameters' contribution to socio-economic vulnerability is less than 0.05. The percentage of the elderly population, child and women are higher in the neighborhoods more socio-economically vulnerable.







Fig. 12. Composite earthquake vulnerability of residential neighborhoods of Mymensingh city.

#### 5.5. Composite earthquake vulnerability

The result of the composite earthquake vulnerability index shows that 51 residential neighborhoods of Mymensingh are highly earthquake-vulnerable from all four dimensions of vulnerability. About 123 residential neighborhoods are medium earthquake-vulnerable, and 67 neighborhoods are marked as low earthquake-vulnerable. The composite earthquake vulnerability map is displayed in Fig. 12. In this study, 23 most important earthquake vulnerability parameters are considered to evaluate the multi-dimensional vulnerability to earthquake hazard, and the influence of the parameters on the composite earthquake vulnerability of Mymensingh City are analyzed and shown on a scale of 0–1. The concerned city planning and development agencies may prioritize their earthquake risk reduction activities in Mymensingh City based on the influence of each of the parameters on earthquake vulnerability as shown in Fig. 13.

According to the analysis, it is found that soil type (0.52), distance to the fire station (0.46), the elderly population (0.35), Peak Ground Acceleration (0.34), child population (0.27), and distance to the hospital (0.25) respectively are the topmost factors that make Mymensingh City highly earthquake-vulnerable. To be more specific, the existence of 90% soft soil, only one fire station, high PGA value, a high percentage of elderly and child population than national urban area average, spatial concentration of hospitals in the



Fig. 13. Influence of vulnerability parameters on composite earthquake vulnerability.

middle part of the city is the main reason behind the earthquake vulnerability of Mymensingh city. On the contrary, household size (0.04), building storey (0.05), literacy rate(0.05), income per household (0.06), and overhanging (0.06) have less influence on the high earthquake vulnerability of Mymensingh city. Explicitly, small household size, high percentage of low rise buildings, high literacy rate and income, etc. parameters are responsible for the low and medium earthquake vulnerability of some residential neighborhoods in Mymensingh city.

#### 6. Discussion

Earthquake vulnerability is inherently a multi-dimensional problem that varies along with the physical space and within social groups (Alizadeh et al., 2018). Therefore spatial modeling of earthquake vulnerability and analysis is crucial at the individual, household and regional scale to expedite the formulation of development policies and action plans for hazard mitigation (Alam & Haque, 2020; Walker et al., 2014). In this study, the MCDM techniques coupled with GIS-based spatial analysis were applied to develop a residential neighborhood-wise seismic micro-zonation of Mymensingh city in Bangladesh. Twenty-three major earthquake vulnerabilities stemming from four major dimensions, including structural, geological, socio-economic, and systematic dimensions, were used as input to enable the development of an earthquake risk map of the city. In developed countries, earthquake vulnerabilities are precisely determined by the application of the Federal Emergency Management Agency (FEMA) developed HAZUS software which follows several steps including study region definition, hazard characterization, development of fragility function, and damage and loss estimation, etc. (FEMA, 2011).But using HAZUS in resource starving countries like Bangladesh is not feasible as it requires an enormous amount of data and expertise, unavailability of standardized infrastructure information, USA centric boundary characterization issue, fragility function development, etc. (Bendito, Rozelle, & Bausch, 2014; Sarker et al., 2010). Urban Planning and policy-making authorities of low-income countries are merely facilitated by that amount of monetary support and expertise, and consequently, the incorporation of seismic vulnerability assessment and micro-zonation mapping is frequently found unavailable in their city planning exercise. Considering this issue, this study showed that the MCDM method coupled with the GIS technique provides a simple, low-cost, and efficient way to measure the vulnerability of any location to earthquake hazards.

This study comprehensively classified the residential neighborhood based on earthquake vulnerabilities from structural, geological, socio-economic, and systematic dimensions. This dimension-wise analysis of seismic vulnerability assessment has important planning and development implications which will help policymakers to formulate a risk-sensitive sustainable urban space. According to the analysis and map are shown in Fig. 4, geological earthquake vulnerability is high in the north-western areas in the upper portion of the Mymensingh city which gradually reduced in the center and other parts of the city. About 20% area (4.36 sqkm; 44 neighborhood) of the Mymensingh city is highly vulnerable from the geological perspective. The micro-zonation pattern of geological vulnerability follows the pattern of soil type as most of the soil in the north-western areas is soft soil and highly liquefaction susceptible. Therefore, it is important to impose some legal restrictions considering the pattern of geological vulnerability. But in highly populated and less land holding countries like Bangladesh, it is not feasible to impose a complete restriction on building construction in these areas. Considering the need, the city planning authorities should consider imposing an effective engineering solution including soil compaction, changing foundation type, pilling, etc. in the building construction in these areas. Moreover, Mymensingh is one of the oldest municipalities of Bangladesh which expanded in a linear pattern along with the river bank. As the city first started to grow from the center point, therefore, the building density, old and poor quality masonry buildings are high in the CBD area rather than other places. The structural vulnerability analysis also shows that the residential neighborhoods in the middle part of the city are highly vulnerable than other areas of the city (Fig. 8). About 1.52% area (0.33 sqkm, 8 neighborhoods) of the Mymensingh city is high structural vulnerable to earthquake hazards. The city planning authority should identify the old dilapidated building, irregularly shaped buildings in these areas and take necessary action according to their condition. Considering the resource and expertise constraint of the city planning authorities, more emphasis should be provided on the high structural vulnerable neighborhoods rather than the whole city. In contract with the structural

vulnerability pattern, residential neighborhoods in the north-western areas and southern areas are systematically high vulnerable as most of the hospitals, schools, and fire service, are spatially placed in the middle areas of the city (Fig. 6). More specifically, 29.9% area (6.5 sqkm; 88 neighborhoods) of the Mymensingh city has poor access to emergency services which makes them high systematic vulnerable. These findings can help the policymakers to make a relocation plan for existing services and propose new emergency services in deprived neighborhoods. It is also identified that, except for some residential neighborhoods, most of the areas are either high



Fig. 14. Seismic hazard intensity mapping of Mymensingh city. (Source: Sarker et al., 2010).

or medium socio-economically vulnerable to the earthquake in Mymensingh city. As an earthquake is an impact type event and occurs without any warning, therefore the findings of this socio-economic vulnerability are expected to help the concerned authorities in resource targeting to the highly socio-economic vulnerable areas to increase resilience to natural hazards. Combining all dimensions of earthquake vulnerability, 16.25% area (3.53sqkm) of Mymensingh city is highly vulnerable, 26.14% area (5.68 sqkm) are medium vulnerable and 18.45% area (4.01 sqkm) are low vulnerable to earthquake hazard. More importantly, 20 neighborhoods (6.73% of the total area; 1.46sqkm) in the north-western part of the city are vulnerable to three types of vulnerability, including geological, systematic and socio-economic earthquake vulnerability. These areas need to be marked as most vulnerable and prioritized for risk-sensitive measures to reduce the damage during an earthquake. Such results provide an appropriate guide for city managers and decision-makers to perceive the influence of each dimension and can become an important tool for confronting crises resulting from future earthquake incidences.

#### 7. Validation

Validation of earthquake risk assessment study can be done accurately with the previous earthquake impact database. But the historic earthquake impact database of Mymensingh city is not available as the city didn't face any major earthquake in recent time. In the absence of the historic earthquake database, many earthquake research studies recommended and validate the result by comparing it with the result of previously published studies (Jena & Pradhan, 2020; Jena, Pradhan, & Beydoun, 2020). Thus, the results of this study were validated using the previously published works. For validating the methodology and findings of this study, Cohen's kappa statistics methods were used to compare the result of this current study with other similar studies. The Cohen kappa statistic, a well-recognized accuracy assessment algorithm mostly used to assess the performance of the classifier, is a metric that compares an Observed Accuracy with an Expected Accuracy and illustrates the agreement between two accuracy results on a scale of 0-1 (Cohen, 1968; Gao, Ding, Huang, & Hu, 2020). Cohen kappa score of 1 indicates complete agreement and values 0 indicate no agreement between the two results. Pontius (2002) suggested that a kappa score below 0.4 indicates low agreement, 0.4 to 0.6 denotes moderate agreement, 0.6 to 0.8 means good agreement, and more than 0.8 signify very good agreements amid the expected and observed dataset. The literature review shows that another study of seismic micro-zonation of Mymensingh city was conducted by Sarker et al. (2010), which considered the geological data (SPT, PGA, site amplification, liquefaction) and the earthquake of 1897 as a scenario event (Shown in Fig. 14). Thus a comparison was conducted between the result of this study and Sarker et al. (2010) using the equation of Cohen Kappa. The kappa score was found to be 0.53 indicating 53% agreement between the two results and which could be considered fair according to the scale of Pontius (2002). This justifies the ability of this method to provide a relatively accurate result for wider application in developing and underdeveloped nations. The agreement or disagreement between the result of this study and the result of Sarker et al. (2010) is also analyzed using a confusion matrix. The comparison of these two results is done only for residential cells. The confusion matrix score shows that there exists 71% agreement in defining the highly vulnerable zones and 90% agreement in determining low vulnerable zones (Fig. 15). The normalized confusion matrix shows that there exists 57% disagreement in defining a medium vulnerable area which slightly misclassified as low vulnerable in the result.



Fig. 15. Confusion matrix (a) without normalization and (b) Normalized confusion matrix.

#### 8. Conclusion

Major Earthquakes and their tragic consequences in recent times at different locations across the world justify the emergency need for the inclusion of earthquake risk analysis in the physical planning practice. Integrating earthquake risk in the city-planning practice for developing countries like Bangladesh is even more challenging due to resource constraints, technological backwardness, deficiency of trained workforce, etc. This study presents a simple, cost-effective, and scientific approach for the inclusive measurement of earthquake vulnerability of a space considering every aspect of vulnerability with the application of the MCDM technique and GIS-based geospatial analysis. The findings of this study are expected to help the city planning authorities, especially in developing countries in identifying the risk zone, visualize the hazard risk for easier interpretation, resource optimization by targeting the vulnerable, and deciding on appropriate planning and development control interventions. Though twenty-three distinct parameters stemming from four dimensions of vulnerability were used in this study, there are some other factors including earth slope, the existence of soft story and short column in the buildings, the age of a building, etc were excluded in this research considering the data unavailability and inapplicability in the study area, which can be incorporated in further research. The main benefits of using this MCDM method coupled with GIS-based geospatial analysis for earthquake vulnerability assessment are its cost, time, and resource efficiency along with reasonably accurate results for assistance in city planning and management in developing countries. This methodology can be applied in any earthquake-vulnerable geographic location and is expected to be helpful for policymakers in low-income countries to prioritize special consideration areas or hotspots for disaster management.

#### Availability of data and material

The data used in this research is uploaded in the public domain (http://www.msdp.gov.bd/) of the government of the People's Republic of Bangladesh and can also be found from the corresponding author by request.

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#### Declaration of competing interest

None.

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