Seismic vulnerability evaluation of educational buildings of Mymensingh city, Bangladesh using rapid visual screening and index based approach

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Abstract

Purpose – Seismic vulnerability evaluation of various public structures, especially school buildings, is very crucial for designing hazard mitigation initiatives in seismic prone areas. The city of Mymensingh is at great risk of earthquake because of its geographical location, geological structure and proximity to active faults. The city is famous for its ancient and renowned educational institutes that need to be evaluated for understanding the seismic performance of the building during an earthquake. This study aims to evaluate the seismic vulnerability of educational buildings of Mymensingh city using rapid visual screening (RVS) and index based approach.

Design/methodology/approach – RVS procedure includes field survey and secondary source assessment for evaluating structural vulnerability attributes. Analytical hierarchy process is applied to develop an index focusing on systematic attributes of vulnerability based on expert opinions. Then, a composite vulnerability map is developed combining both structural and systematic vulnerability score providing an equal weight.

Findings – This study evaluates the seismic vulnerability of 458 educational buildings of Mymensingh city and the result shows that 23.14% educational building has high, 46.29% has moderate and 26.86% has moderately low and only 3.71% buildings has the low seismic vulnerability. This study expected to be helpful in resource targeting and prioritizing seismic hazard mitigation activities for education buildings of Mymensingh city.

Originality/value – This study endeavors to present a comprehensive vulnerability assessment method by integrating RVS and index based approach that incorporates both structural and systematic dimensions of vulnerability. The result is expected to be helpful in the formulation of disaster prevention policy for vulnerable educational buildings and development of the earthquake-resistant building codes for the new building construction in Mymensingh city.

Keywords Seismic vulnerability, Rapid visual screening, Analytical hierarchy process, Index, Educational building, Geographic information system

Paper type Research paper

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1. Introduction

Damage and risk assessment before any disaster is very crucial for a better understanding of effective disaster prevention planning and designing emergency preparedness initiatives to reduce destructive consequences. Seismic vulnerability evaluation of physical infrastructures of an urban area is essential for any impact type phenomenon like an earthquake, which has capabilities to annihilate any area within few seconds. The seismic performance of schools deserves special attention because of their unique occupancy characteristics and important post-earthquake role. Past experience has shown that school buildings are especially vulnerable to earthquakes because of irregular structures, old buildings, inadequate exit way, non- structural falling objects, etc (Tischer, 2012). Rodgers (2012) reported more the 30 school building collapse in the different seismic events around the world, and 10,000 children lost their lives from 1963 to 2010. According to the report of ERRI (2005), the Kashmir earthquake of 2005 destroyed 67 per cent of educational institutes, and approximately 19,000 were children killed due to the collapse of school buildings. All this evidence indicates the necessity to evaluate the seismic vulnerability of the educational building of any spatial location to avoid unwanted tragedy in the future. Therefore, vulnerability assessment of buildings to earthquakes is the major steps to foster the structural mitigation strategies and preventive measures.

Bangladesh is characterized as one of the most tectonically active areas of the world as it lies on the junction of the Indian plate, Eurasian plate and Burmese microplate. The city of Mymensingh, one of the oldest municipalities and the latest administrative divisional city of Bangladesh, is located in the high-risk seismic zone of Bangladesh because of its proximity to three significant faults, namely, Madhupur fault, Dauki fault and Sylhet Assam fault, and high liquefaction soil type (Alam and Haque, 2018). The city undergoes through some tremendous seismic event in the past, including the 1762 earthquakes (7.5 magnitudes) originated from Madhupur tract in which the course of Brahmaputra River changed dramatically and the great Indian earthquake of 1897 (8.7 magnitudes) in which the whole Mymensingh city was collapsed (CDMP, 2014). The history and evergreen risk of an earthquake in Mymensingh city indicate that the city may be visited by an unwanted guest anytime and should be prepared early to face it. The infrastructures of Mymensingh city are at high risk of earthquake and needs to be evaluated for implementation of earthquake-resilient planning in the city. The city of Mymensingh is very advanced in education sector than other parts of the country because of its renowned educational institutes. The city is home to 193 educational institutes, including Bangladesh Agriculture University, Mymensingh Medical College, Mymensingh Girl Cadet College, Ananda Mohan College, etc (Haque, 2015). As Mymensingh is one of the oldest municipalities of the country, most of the educational institutes in the city are very old and built before the development of building code in Bangladesh without following proper rules and regulations. So, the educational buildings of Mymensingh city are vulnerable to any seismic event and badly needs to be assessed for earthquake-resilient planning and management.

The vulnerability of any structure in an earthquake sensitive area has two significant dimensions, which are the structural vulnerability and systematic vulnerability. Structural vulnerability refers to the vulnerability of buildings because of its structural elements such as construction type, construction material, pounding, plan and elevation irregularity and so on. On the other hand, systematic vulnerability refers to the vulnerability of a building because of its spatial location such as distance from the hospital, active faults, fire station, emergency shelter, the evacuation route and so on. For understanding the whole picture of seismic vulnerability, a comprehensive assessment needs to be applied using a multidisciplinary approach, which not only acknowledges the direct impact (i.e. structural damage, casualties or economic losses) but also includes the difficulties in accessing support services (Banica *et al.*, 2017; Walker *et al.*, 2014). This study attempts to assess both the structural and systematic vulnerability of educational buildings of Mymensingh city.

The major issue of conducting a comprehensive seismic vulnerability assessment is to find out the appropriate method, which can incorporate multidisciplinary dimensions of vulnerability. Over the past decades, the seismic risk of a building is evaluated using different methodologies by different researcher all over the world. Researchers applied capacity spectrum method (Barbat *et al.*, 2008; Kircher *et al.*, 1997), damage probability matrix (Ventura *et al.*, 2005; Calvi *et al.*, 2006), rapid visual screening (RVS) (FEMA, 2015; Srikanth *et al.*, 2010; Rahman *et al.*, 2015), nonlinear dynamic analysis (Fajfar, 2000; Fajfar and Gašperšič, 1996), failure mechanism identification and vulnerability evaluation method (Formisano *et al.*, 2010), etc., methodologies for earthquake vulnerability evaluation of infrastructure in seismic risk-sensitive area. All of the methods mentioned above, are only applicable to structural vulnerability assessment and assess the comprehension of the structural behavior of buildings for each level of impact when they are exposed to a seismic action (Ródenas *et al.*, 2018). Moreover, empirical methods such as vulnerability index method (Alam and Haque, 2018; Lantada *et al.*, 2010), Italian method (Cacace *et al.*, 2018), the Japan method (Japan Building Disaster Prevention Association, 2001), NZSEE guidelines (New Zealand Society for Earthquake Engineering, 2017) and so on, assess the performance of a specific building based on a statistical analysis of observed damage during past earthquakes, estimate the seismic susceptibility according to vulnerability classes based on qualitative variables or index based approach. Saputra *et al.* (2017) assessed the seismic risk of the residential building using logistic regression and geographic information system (GIS) based on the damage data of the last big earthquake in Java, Indonesia. However, in developing countries like Bangladesh is hardly equipped with the data of past earthquakes and expertise to analyze the data. Mück *et al.* (2013) assessed the building vulnerability to earthquake combining *in situ* building surveys and remote sensing data. Unavailability of commercial high-resolution satellite imageries, the complexity of extracting building details from the image, etc., limit the applicability of this approach in poor developing countries like Bangladesh. Many studies used Hazard US (HAZUS) software (Kircher *et al.*, 2006; Bendito *et al.*, 2014) based seismic vulnerability assessment but HAZUS cannot be readily used in other countries because of the unavailability of boundary characterization function outside the USA (Sarker *et al.*, 2010). Therefore, a less data, time and expertise consuming method is needed to be applied to assess the structural behavior of the educational building of Mymensingh city.

RVS is the most popular and viable method for probable seismic damage evaluation of any infrastructure in an earthquake risk area and to establish priorities of interventions for mitigating the seismic risk (Cocco *et al.*, 2019; Vicente *et al.*, 2011). Other methods of seismic damage evaluation are time and resource consuming and need high-level expertise, whereas RVS of a building can be easily done within half an hour. Moreover, the rapid visual screen method is widely used by researchers to assess the seismic vulnerability of buildings, especially school buildings. Gentile *et al.* (2019) evaluated the vulnerability of school buildings using INSPIRE method, modifying the rapid visual survey method. Zain *et al.* (2019) firstly screened the seismic vulnerability of school buildings of Kashmir using the RVS method and later applied incremental dynamic analysis for further analysis. School buildings of Sylhet city of Bangladesh are categorized into different vulnerability categories using RVS method (Ahmed *et al.*, 2012). De Angelis and Pecce (2015) assessed the seismic vulnerability of nonstructural elements in school buildings of Italy by developing a non-structural index using RVS methodology. Rajarathnam and Santhakumar (2015) evaluated the seismic vulnerability of buildings of Chennai city to earthquake based on RVS aided by aerial photographs in the GIS platform. Considering the popularity, time and resource effectiveness and simplicity of RVS method, this study aims to evaluate the structural seismic vulnerability of educational buildings of Mymensingh city using RVS methodology.

Buildings are identified as resistant to earthquake considering its accessibility parameters, which is broadly known as the systematic dimension of vulnerability (Mück *et al.*, 2013). Though the RVS method is very simple and well-performed, it cannot incorporate the systematic dimension of the seismic vulnerability, which induced the necessity of integrating another method with the RVS. A comprehensive search of the literature shows that researchers (Banica *et al.*, 2017; Walker *et al.*, 2014; Rezaie and Panahi, 2015; Rashed and Weeks, 2003) focus on developing an index based on multiple-criteria decision analysis for assessing systematic dimensions of seismic vulnerability. The study will develop an index based approach using a multi-criteria decision-making analysis method to evaluate the systematic vulnerability of educational buildings of Mymensingh city in the GIS environment. Finally, the score of the structural and systematic vulnerability of educational buildings are combined to develop a composite vulnerability map.

While significant progress has been noticed in the research of structural seismic vulnerability assessment, the systematic dimension of earthquake vulnerability assessment is continuously undervalued by the researchers and few attempts have been taken to integrate them into a comprehensive index (Walker *et al.*, 2014). This study endeavors to present a comprehensive vulnerability assessment method by integrating the RVS and index based approach that incorporates both structural and systematic dimensions of vulnerability. The result is expected to be helpful in the formulation of disaster prevention policy for vulnerable educational buildings and development of the earthquake-resistant building codes for the new building construction in Mymensingh city.

2. Methodology

The objective of this research is to evaluate the seismic vulnerability of educational buildings of Mymensingh city with the combination of RVS and index based approach to identify the earthquake-vulnerable educational buildings in terms of structural and systematic factors, etc. To achieve this aim, the subsequent steps are done.

2.1 Understanding the study area

2.1.1 Geographic location. Mymensingh, earlier known as Nasirabad, established in 1897 as one of the oldest municipalities of Bangladesh on the west bank of the old Brahmaputra River. The city located in the northern part of the country at 24°45′22″ N latitude and 90° 24′23″ E longitude with an elevation of 62 ft above sea level. Mymensingh city covers an area of 21.73 sq. km and divided into 21 wards. It has an estimated present population of 258,040 and growing at a rate of 1.28 per cent (BBS, 2011). The city of Mymensingh is considered as one of the major economic hubs of the central north of the country because of its proximity to the capital, good road, and water and railway connection and for having many major industries of Bangladesh. The map of the study area is shown in Figure 2.

2.1.2 Seismic history of the study area. The city of Mymensingh had faced some major earthquake events in the past. Mymensingh had experienced a tremendous earthquake of 7.5 magnitudes in 1762, which the course of Brahmaputra River drastically changed. The city also faced the great India earthquake with a magnitude of 8.7 and epicenter at Shillong

Platea, which destroyed the whole Mymensingh town. On July 27, 2008, the city of Mymensingh again felt an earthquake of 5.1 magnitudes on Richter scale and the epicenter was located 12 km northeast of Mymensingh city and 120 km north of Dhaka. The Nepal earthquake of 2015 also jolted the city and caused tremendous panic among the city dwellers. The past earthquake history and its distribution along with the existing fault line are shown in Figure 1.

2.1.3 Geology of the study area. The city of Mymensingh is positioned in the northeastern portion of the Indian plate within the old Brahmaputra flood plain, which comprises low-lying alluvial plain. The city of Mymensingh is located in zone IV (seismic coefficient 0.36 g)

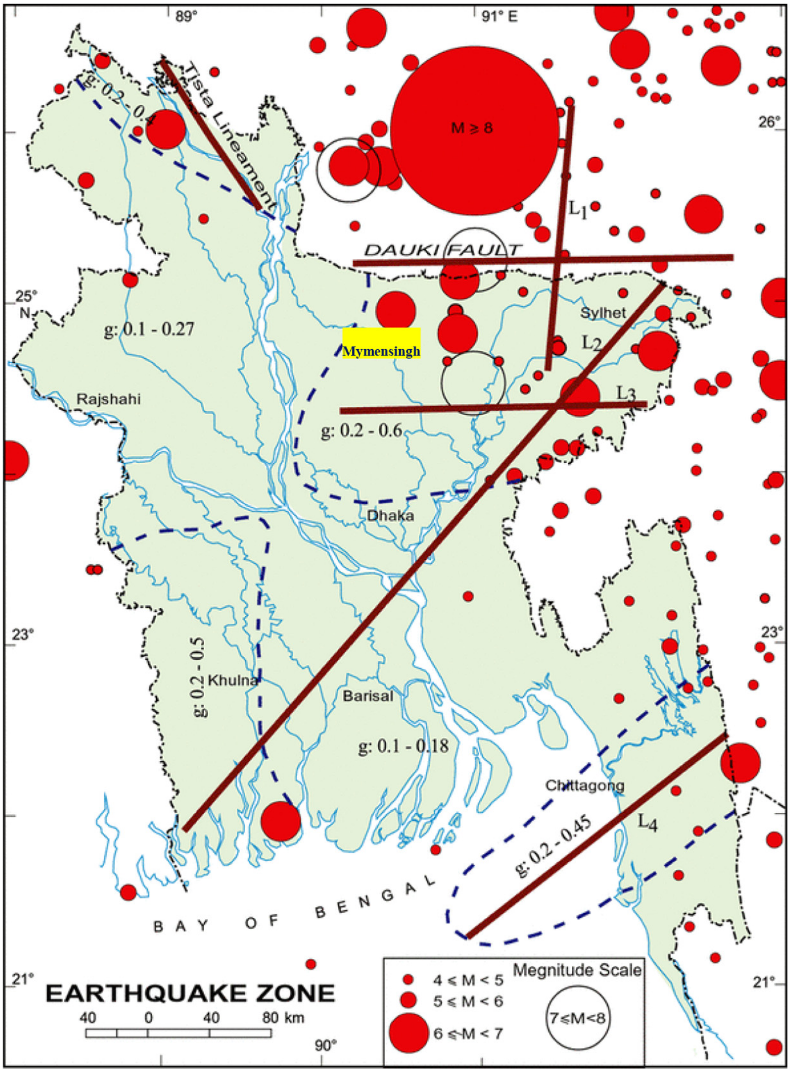

Figure 1.
Past earthquake history and fault line of the study region (IEER, 2020)

of the seismic zonation map of Bangladesh (Sarker *et al.*, 2010; BNBC, 2015). Mymensingh city is surrounded by Dauki fault from the northern side and Madhupur blind fault from the western side of the country. The city possesses almost 90 per cent high liquefaction susceptible loose/soft soil, which has very poor seismic behavior and structure built on this loose soil may collapse at any medium seismic event (CDMP, 2014).

2.2 Sample selection

The research aims to evaluate the probable seismic vulnerability of educational buildings using the RVS and an index based approach. The city of Mymensingh is well-known for its ancient and renowned educational institutes such as Bangladesh Agricultural University, Jatiya Kabi Kazi Nazrul Islam University, Mymensingh Medical College, Mymensingh Ananda Mohan College, Mymensingh Girls' Cadet College, Mymensingh Zilla School, Notre Dame College, Mymensingh, and Shahid Syed Nazrul Islam College and so on. There are 193 educational institutes, which consist of approximately 2,000 infrastructure in Mymensingh city. This study includes 458 academic buildings of different educational institutes of Mymensingh city and excludes all other non-academic buildings such as the student hostel, administrative building, religious buildings and so on. Two major educational institutes, namely, Bangladesh Agriculture University and Mymensingh girl's cadet college are excluded from this study because of the time issue, resource constraint and restrictions, respectively. The spatial distribution of educational buildings in Mymensingh city is shown in Figure 2.

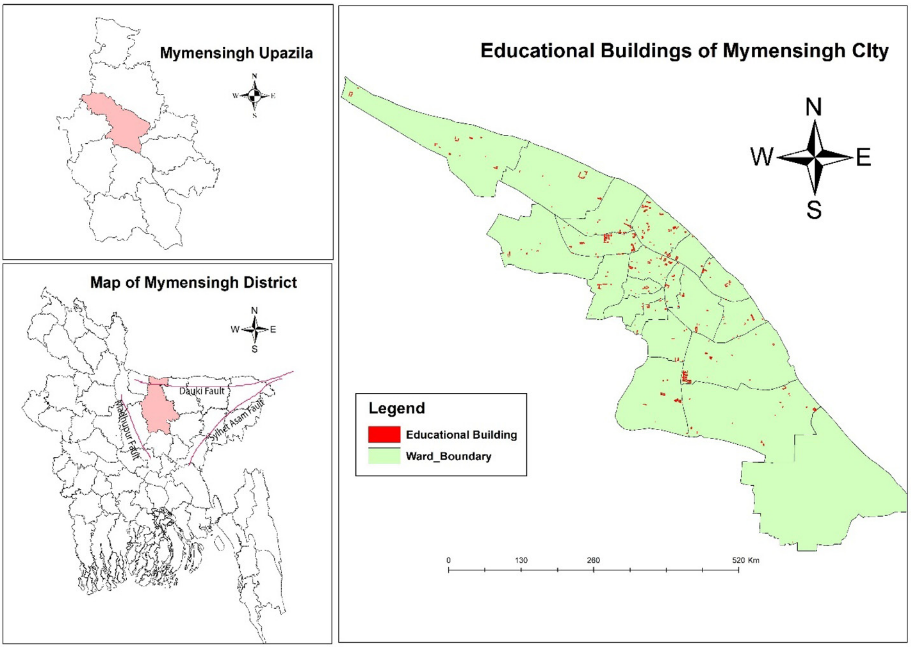

Figure 2.
Location map of the study area

2.3 Data analysis

The structural vulnerability assessment of the educational buildings of Mymensingh city has been conducted in this current study by using the RVS method. Then, the final RVS score of each educational building is inputted in ArcGIS for mapping of structural vulnerability. The distance-based data of systematic vulnerability factors are estimated using the closed facility function of the network analysis tool in the ArcGIS environment. The analytical hierarchy process (AHP) is applied to determine the weights of the systematic vulnerability factors through the opinion of three experts by the researcher. Then, the systematic vulnerability score of educational buildings is calculated by the weighted linear combination (WLC) method. Finally, the physical and systemic vulnerability scores were normalized, equally weighted and combined to produce the composite earthquake vulnerability map. The framework used for composite earthquake vulnerability assessment, comprising both structural and systematic dimensions of educational buildings of Mymensingh city is shown in Figure 3.

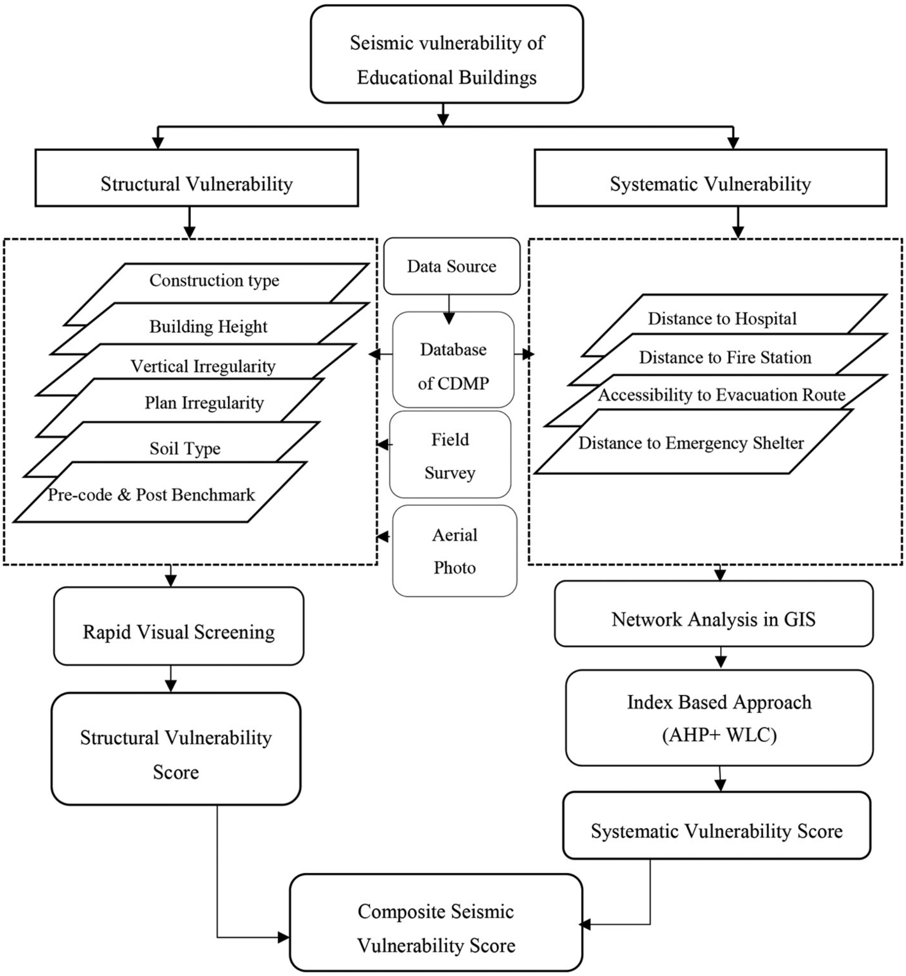

Figure 3. The framework of composite vulnerability assessment of educational buildings of Mymensingh city

2.4 Structural vulnerability assessment-rapid visual screening

RVS method is used to identify, screen and evaluate the damage of buildings that are potentially seismically vulnerable without any structural calculation. The RVS method follows a damageability grading system based on a field survey form developed by Federal Emergency Management Agency (FEMA, 2015), which assists users in rapidly identify vulnerability and score buildings according to their damage probability if hit by major earthquakes (FEMA, 2015). To detect potential earthquake-vulnerable buildings, the RVS method follows several steps as follows.

2.4.1 Determination of seismicity region. It is essential to determine the seismic coefficient of the study area to know the seismic proneness of the area as the values in survey form of RVS varies for the different seismic zone. Global seismic hazard assessment program (GSHAP) has classified the earth into for seismic hazard category (low, moderate, high and very high) and the city of Mymensingh fall in high seismic risk category (Giardini *et al.*, 1999). The city of Mymensingh is located in zone IV (seismic coefficient 0.36 g) of the seismic macro-zonation map of Bangladesh and is demarcated as one of the most earthquake-vulnerable cities of the country (BNBC, 2015) (Figure 4). So, the RVS form for high seismicity is used in this study to evaluate the probable seismic damage of the educational buildings of Mymensingh city.

2.4.2 Data collection of building vulnerability attributes. After selection of data collection form based on the seismicity level of the study area, each building needs to be screened by identifying its size and shape and drawing a plan and elevation view; defining occupancy class and soil type, identifying potential nonstructural falling hazards, lateral-load resisting system and other characteristics. The data of buildings vulnerability indicators are primarily collected based on shapefiles of the physical feature of the Mymensingh strategic development plan (MSDP) database and field survey. The vulnerability attributes of educational buildings and their data source are described below in Table I.

2.4.3 Determination of final score. To determine the final score of a building, the basic score, score modifier and minimum score of the abovementioned all the attributes (Table I) need to be determined. This score varies along with the seismicity region and each type of buildings has a unique basic score, assigned by FEMA (2015). The soil type needs to be determined as different soil type has different score modifiers. FEMA (2015) and Fajfar and Gašperšič (1996) has provided three score modifiers for soil type A or B and for soil type E. The final structural score (Level 1), S, is determined for a given building by adding (or subtracting) the score modifiers for that building to the basic structural hazard score for the building. The result is documented in the section of the form entitled final score. The basic score, score modifier and final score for high seismic vulnerability region is shown in Table II. For example, If a two-storied reinforced masonry (RM2) school building of high seismic region has plan irregularity, then, according to Table II, the basic score of the building is 1.7 and the sum of score modifier will be −0.8 (−0.7 for plan irregularity and −0.1 for two stories). Then, the final score of the building is 0.9, which greater than the minimum score. If the final score is less than the minimum score, then the minimum score should be considered as the final building score.

The steps of RVS survey is mentioned in the following Figure 5.

2.5 Systematic vulnerability assessment-index based approach

Systematic vulnerability refers to the vulnerability, which may influence the emergency response and management activities following the earthquake. This study aims to assess

Figure 4. Seismic risk zonation of Bangladesh (BNBC, 2015)

the systematic vulnerability of school buildings by developing an index based approach. For the indexing purpose, the combination of two multicriteria decision-making techniques, namely, AHP and WLC are applied in this study.

2.5.1 Systematic earthquake vulnerability factors. Earthquake vulnerability of an urban area largely depends on absence or presence, strength or weakness and proximity or distance of some major factors. In this study, four most influential systematic vulnerability factors (Table III) are selected for assessment of the systematic seismic vulnerability of educational buildings of Mymensingh city based on a comprehensive literature review and experts' judgments. The data of four systematic vulnerability

Attributes of building	Interpretation	Data source
Number of stories	Building damage probability largely depends on the height of the building and tall building experience more shaking than shorter building on soft soil	Field survey and MSDP database
Year built	Building age is tied directly to design and construction practices and older buildings have more damage probability in any seismic event	Field survey and MSDP database
Total floor area	The total floor area is estimated by multiplying the estimated area of one story by the total number of stories in the building, and it is useful for estimating occupancy load	MSDP physical feature shape file or aerial photograph
Plan and elevation view	Plan and elevation view may also be useful in indicating significant features and reveals many building attributes	Field survey and aerial photograph
Soil type	There are six different types of soil, namely, hard rock, average rock, dense soil, stiff soil, soft soil and poor soil. Soft or poor soil amplify the seismic wave and causes building damage	MSDP geological survey database
Occupancy	Occupancy refers to the use of the building and this study is bound to only school occupancy class	MSDP land use database
Occupancy load	Occupancy load refers to the number of occupants per square unit and occupancy load varies 1 person per 50 per 100 sq. ft for educational buildings	Field survey and MSDP database
Nonstructural falling hazards	Nonstructural falling hazards such as chimneys, parapets, cornices, veneers, overhangs and heavy cladding can pose life-safety hazards if not adequately anchored to the building	Field survey
Building type	RVS procedure includes 15 types of building to be screened, which can be classified as RCC building (C1 and C2 type), masonry building (URM, RM1, RM2 and C3), wooden building (W1 and W2 type), steel frame building (S type) and others	Field survey, MSDP physical feature database
Lateral force resisting system	The screener should identify it from the field survey and all other alphanumeric values are depended on it	Field survey, MSDP physical feature database
Mid/high rise building	Building with the four-seven floor is considered as midrise building and more than seven-floor buildings are regarded as high rise	Field survey, MSDP physical feature database
Vertical irregularity	If the building is irregularly shaped in elevation or if some walls are not vertical, then this modifier is applied	Field survey, MSDP physical feature database
Plan irregularity	If buildings are irregular in plain view (E, L, T, U and + shape), this modified score can be applied for those buildings	Aerial photograph
Pre-code	Pre-code refers to the year(s) in which seismic codes were initially adopted and enforced for the various model building types	Bangladesh national building code, 1993
Post-benchmark	Post-benchmark refers to the year in which major improvements were adopted of seismic code	BNBC (2015)

Table I.
Attributes of buildings seismic performance and their data source (FEMA, 2015)

factors are estimated for each educational building of Mymensingh city using a network analysis tool in the proprietary ArcGIS environment. Some other crucial systematic vulnerability factors such as distance from the gas station, electric station, capacity of emergency shelter and so on, are excluded from this study because of data unavailability, time and resource constraints.

Table II. Basic score, modifiers and final score of RVS for high seismic region (FEMA, 2015)

FEMA building type do not know	Basic score, modifiers and final Level 1 score and S_{L1}																
	W1	W1A	W2	S1 (MRF)	S2 (BR)	S3 (LM)	S4 (RC SW)	S5 (URM INF)	C1 (MRF)	C2 (SW)	C3 (URM INF)	PC1 (TU)	PC2	RM1 (FD)	RM2 (RD)	URM	MH
Basic score	*3.6*	*3.2*	*2.9*	*2.1*	*2.0*	*2.6*	*2.0*	*1.7*	*1.5*	*2.0*	*1.2*	*1.6*	*1.4*	*1.7*	*1.7*	*1.0*	*1.5*
Severe vertical irregularity, V_{L1}	– 1.2	– 1.2	– 1.2	– 1.0	– 1.0	– 1.1	– 1.0	– 0.8	– 0.9	– 1.0	– 0.7	– 1.0	– 0.9	– 0.9	– 0.9	– 0.7	NA
Moderate vertical irregularity, V_{L1}	– 0.7	– 0.7	– 0.7	– 0.6	– 0.6	– 0.7	– 0.6	– 0.5	– 0.5	– 0.6	– 0.4	– 0.6	– 0.5	– 0.5	– 0.5	– 0.4	NA
Plan irregularity, P_{L1}	– 1.1	– 1.0	– 1.0	– 0.8	– 0.7	– 0.9	– 0.7	– 0.6	– 0.6	– 0.8	– 0.5	– 0.7	– 0.6	– 0.7	– 0.7	– 0.4	NA
Pre-code	– 1.1	– 1.0	– 0.9	– 0.6	– 0.6	– 0.8	– 0.6	– 0.2	– 0.4	– 0.7	– 0.1	– 0.5	– 0.3	– 0.5	– 0.5	0.0	– 0.1
Post-benchmark	1.6	1.9	2.2	1.4	1.4	1.1	1.9	NA	1.9	2.1	NA	2.0	2.4	2.1	2.1	NA	1.2
Soil type A or B	0.1	0.3	0.5	0.4	0.6	0.1	0.6	0.5	0.4	0.5	0.3	0.6	0.4	0.5	0.5	0.3	0.3
Soil type E (1-3 stories)	0.2	0.2	0.1	– 0.2	– 0.4	0.2	– 0.1	– 0.4	0.0	0.0	– 0.2	– 0.3	– 0.1	– 0.1	– 0.1	– 0.2	– 0.4
Soil type E (>3 stories)	– 0.3	– 0.6	– 0.9	– 0.6	– 0.6	NA	– 0.6	– 0.4	– 0.5	– 0.7	– 0.3	NA	– 0.4	– 0.5	– 0.6	– 0.2	NA
Minimum score, S_{MIN}	*1.1*	*0.9*	*0.7*	*0.5*	*0.5*	*0.6*	*0.5*	*0.5*	*0.3*	*0.3*	*0.3*	*0.2*	*0.2*	*0.3*	*0.3*	*0.2*	*1.0*

Notes: Final Level 1 score and $S_{L1} \geq S_{MIN}$

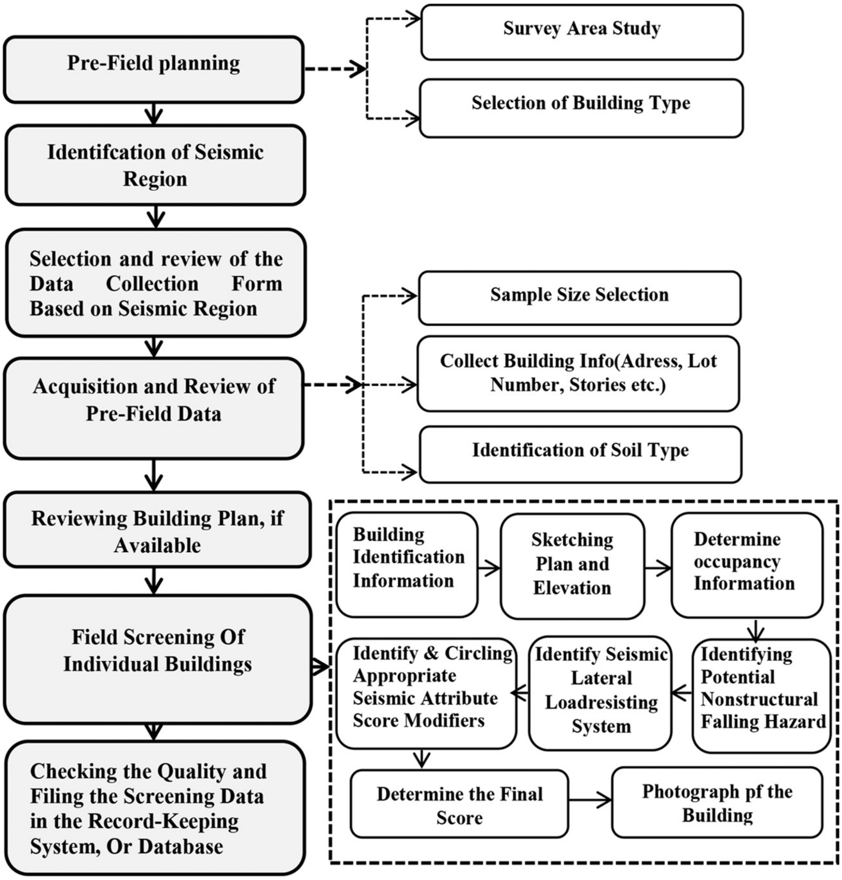

Figure 5.
Steps of RVS survey for seismic vulnerability assessment (FEMA, 2015)

Systematic vulnerability factors	Data type	Vulnerability level Low	Moderate	High	Data source	Source of classification
Distance to hospital	Continuous	>500 m	500-1,000 m	<1 km	MSDP database	Alam and Haque (2018), Aliabadi *et al.* (2015) and Moradi *et al.* (2014)
Accessibility to evacuation route	Continuous	>500 m	500-1,000 m	<1 km	MSDP database	Alam and Haque (2018), Rezaie and Panahi (2015) and Islam *et al.* (2013)
Distance to fire station	Continuous	<1 km	1-2 km	<2 km	MSDP database	Alam and Haque (2018), Aliabadi *et al.* (2015) and Moradi *et al.* (2014)
Distance to emergency shelter	Continuous	>1 km	1-2 km	<2 km	MSDP database	Rezaie and Panahi (2015), Moradi *et al.* (2014) and Maleki *et al.* (2016)

Table III.
List of systematic vulnerability factors

2.5.2 Analytical hierarchy process. In this study, AHP, a renowned tool for decision-making because of its simplicity and rationality (Alam and Mondal, 2018), is applied to develop a matrix for measuring the systematic vulnerability of educational buildings of Mymensingh city. The AHP follows three steps in developing an index for vulnerability evaluation. Step 1 is the generation of binary comparison matrices on a scale of 1-9 developed by Saaty (1980) in which 1 indicating that the two parameters are equally important and 9 implying that one parameter is more important than another. The scale of importance is shown in Table IV.

In Step 2, the weight of different parameters is calculated from row-multiplied value, unnormalized and normalized value using the following equations (1) and (2):

$$\text{Unnormalized value, mi} = \sqrt[n]{RMV} \tag{1}$$

$$\text{Normalized value} = \frac{\text{mi}}{\sum_{i=1}^{n} mi} \tag{2}$$

Here mi refers to the unnormalized value of the *i*-th parameter and *n* represents the total influential parameters.

In Step 3, the weight of each and estimation of consistency between judgments are measured in the third step. The consistency is measured using the consistency index and consistency ratio using equations (3) and (4). If the consistency ratio <0.1, the pairwise comparison matrix has consistency and if the CR value exceeds 0.1, pairwise comparison must be iterated between indicators and sub-indicators until it shows good consistency:

$$\text{Consistency index, CI} = \frac{L-n}{n-1} \tag{3}$$

$$\text{Consistency ratio, CR} = \frac{CI}{RI} \tag{4}$$

L represents the eigenvalue of the pairwise comparison matrix and RI is the random inconsistency index, has some developed value and depends on the number of vulnerability

Intensity of importance	Definition
1	Equal importance
2	Weak or sight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrate the importance
8	Very very strong
9	Extreme importance

Table IV. Magnitude of importance for pairwise comparison (Saaty, 1980) assessment parameters (N). The RI values for the different number of factors are shown in Table V.

In this study, a comparison matrix of four systematic vulnerability factors is developed based on the expert opinion. Judgment of five experts has been collected with reasonable consistency and integrated into one pairwise matrix using the geometric mean. The overall consistency ratio of the comparison is 0.004 (less than 0.1), which indicates the consistency of the matrix. According to this method, four systematic vulnerability parameters are weighted on a scale of 0-1 and categorized under low (0.167), medium (0.333) and high (0.500) and assign their respective scores. The comparison matrix is shown in Table VI.

2.5.3 Weighted linear combination. WLC technique is an additive weighting method in which a weight is assigned to each factor at the initial stage. The weight is determined using the AHP method based on expert opinions, which is used with their corresponding individual standardized criteria as input for the WLC aggregation method. The final weight is gained according to the linear addition of given weights to parameters and their sub-categories [Equation (5)]:

$$\mathrm{W} = \sum_{j=1}^{n} \mathrm{Wjwij} \tag{5}$$

Here W shows the index value of each area in the vulnerability map, Wj shows the normalized weight of each parameter, wij is the weight of i-th sub-category with respect to the j-th parameters and n the total influential parameters.

2.6 Constructing a composite vulnerability index

Constructing a composite index with a combination of different vulnerability dimensions is not a new phenomenon. Researchers (Rahman *et al.*, 2015; Islam *et al.*, 2013; Rashed and Weeks, 2003; Aliabadi *et al.*, 2015; Moradi *et al.*, 2014) used to combine many vulnerability dimensions such as structural, social, geotechnical and many other dimensions into one composite index to assess earthquake vulnerability. However, the integration of the systematic vulnerability dimension into the traditional composite index is a new phenomenon and very few researchers (Walker *et al.*, 2014; Rezaie and Panahi, 2015; Moradi *et al.*, 2014) advocate for the integration of systematic vulnerability components in natural hazard research. As the integration of the

Table V. The value of random inconsistency indices (RI) for $n = 1, 2, \ldots, 12$ (Saaty, 1980)

N	1	2	3	4	5	6	7	8	9	10	11	12
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54

Table VI. Pairwise comparison matrix of systematic vulnerability factors

Systematic parameters	Hospital	Fire service	Shelter	Route	Weight
Distance to hospital	1.00	1.30	0.97	1.24	0.275
Distance to fire service	0.77	1.00	0.77	1.40	0.235
Distance to emergency shelter	1.03	1.30	1.00	1.61	0.299
Distance to evacuation route	0.81	0.72	0.62	1.00	0.191

Notes: Consistency ratio = 0.004; and random inconsistency = 0.9

systematic vulnerability dimension in earthquake research is a new phenomenon, there exists no clear guideline on the weight of this dimension in comparison to other vulnerability dimensions and researchers tend to use subjective judgment in providing weights. In this current study, we endeavor to integrate systematic vulnerability with the structural dimension of a building to develop a composite vulnerability index. To avoid the subjectivity and biases, the vulnerability dimensions are rescaled through normalization in a linear scale of 0-1 and summed them to produce an equally weighted combined vulnerability score for each educational building. As structural vulnerability score or RVS scores vary from 0.7 to 4.4, where lower value means high vulnerability, the score is first normalized on a linear scale of 0-1. Finally, providing equal weight to both structural (0.5) and systematic (0.5) dimensions, a composite vulnerability index is developed in this study.

3. Result and discussion

3.1 Analysis of structural seismic vulnerability

In this research, 458 educational buildings have been analyzed using the RVS method (FEMA, 2015; Fajfar and Gašperšič, 1996), and spatial mapping of the probable seismic damage is done in the GIS platform. From the field survey, information about various attributes of the building of earthquake hazard, i.e. type of construction, number of stories, vertical irregularity and plan irregularity, etc., have been collected and then examined to develop a score for each building. According to the field survey, it is found that the maximum educational building of Mymensingh city is unreinforced reinforced masonry (URM) building (49.4 per cent) and concrete frame building with unreinforced masonry infill (30.1 per cent), which shows poor seismic behavior during any earthquake (Figure 6). The other building types are reinforced masonry building (15.9 per cent), building with light metal (3.9 per cent) and wooden building (0.7 per cent) in Mymensingh city.

The floor height of educational institutes of Mymensingh city varies from one to seven-storey buildings where one-storey buildings are the highest with 64.2 per cent occupancy. Educational buildings of seven storeys are very limited (0.2 per cent) and there are no high rise educational buildings in the study area. Among the others, two storey buildings are 18.3 per cent; three-storey, four-storey, five-storey and six-storey buildings are 8.7, 3.1, 1.1 and 0.9 per cent, respectively.

Buildings with irregularity in plan and elevation views are more likely to collapse during any seismic event than regular buildings. According to the field survey, it has been found that only 10 per cent of the buildings in the study area are vertically irregular and contain irregularity in the setback, soft storey, short column, etc. About 38.2 per cent of buildings of the study area have irregularity in their plan view and contain L, E and T shape buildings.

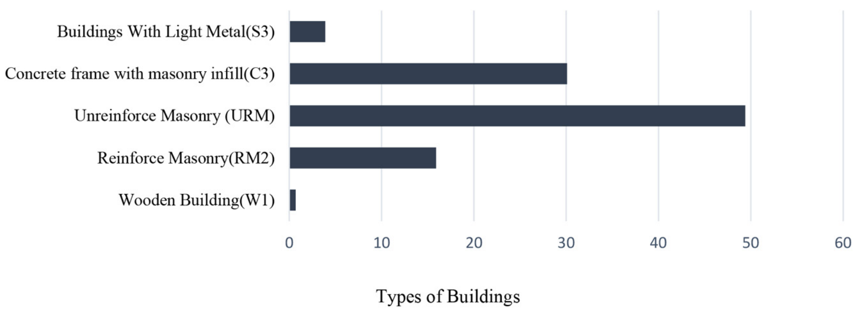

Figure 6. Different building types in educational institutes of Mymensingh city

Buildings with irregularity in plan and elevation views are more likely to collapse during any seismic event than regular buildings. According to the field survey, it has been found that only 10 per cent of the buildings in the study area are vertically irregular and contains irregularity in the setback, soft storey, short column, etc. About 38.2 per cent of buildings of the study area have irregularity in their plan view and contain L, E and T shape buildings.

The educational buildings of Mymensingh city also contain non-structural falling hazard elements such as chimneys, parapets, cornices, veneers, overhangs, heavy cladding and so on, and cause a significant threat to life and property if not adequately anchored to the building. The statistics of field survey data shows that eight educational building out of 458 has heavy overhanging elements (that hangs outside of the building with less support), which has the high possibility of falling early during an earthquake.

When an earthquake occurs, a huge amount of energy spread through the ground and seismic waves are being amplified to maintain the same energy, which creates stronger shaking in stiff or soft soil (Alam and Haque, 2018). Nonlinear behavior of the soil response also has a strong influence on the intensity change of seismic events (Ranguelov, 2011), which is evident from the analysis of several earthquake events conducted by Midorikawa and Miura (2008). The city of Mymensingh possesses extensive area coverage of stiff and soft soil, which constitutes 90 per cent of the total area. The school buildings in stiff (D type) and soft soil (E type) are shown in Figure 7.

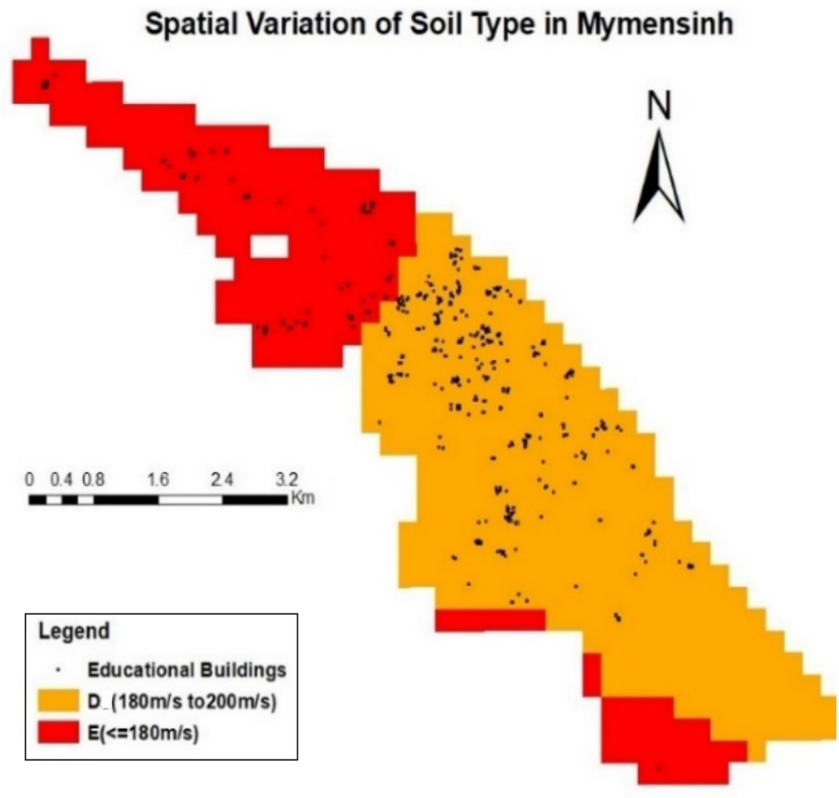

Figure 7.
Spatial variation of soil type and location of the educational building

3.2 Result of rapid visual screening

This study aims to categorize the educational buildings based on seismic vulnerability using RVS and index based approach. After finishing the field survey and calculation of score modifier, the final RVS score is found and the score is categorized into four categories, namely, high, moderate, moderately low and low. The result shows that 27.7 per cent (127 buildings) educational buildings of Mymensingh city have high earthquake vulnerability, where only 0.4 per cent (2 building) are in very low vulnerability category. Moderate and moderately low vulnerable educational buildings constitute about 68.6 per cent (314 buildings) and 3.3 per cent (15 buildings) of the entire building, respectively. The structural vulnerability classification of educational buildings of Mymensingh city is shown in Figure 8.

It is also essential to identify, which building type has the most structural vulnerability in an earthquake to prioritize seismic risk mitigation activities. Among the educational buildings of Mymensingh city, it is seen that URM and C3 category buildings have high structural vulnerability than other building types. On the contrary, wooden buildings and light metal buildings have low structural vulnerability than other types in Mymensingh city. The building type-wise distribution of structural vulnerability is represented in Table VII.

3.3 Analysis of systematic seismic vulnerability

The systematic seismic vulnerability of educational buildings in the context of Mymensingh city depends on the distance of four important elements including hospital, fire station, emergency shelter and evacuation route, which are described below:

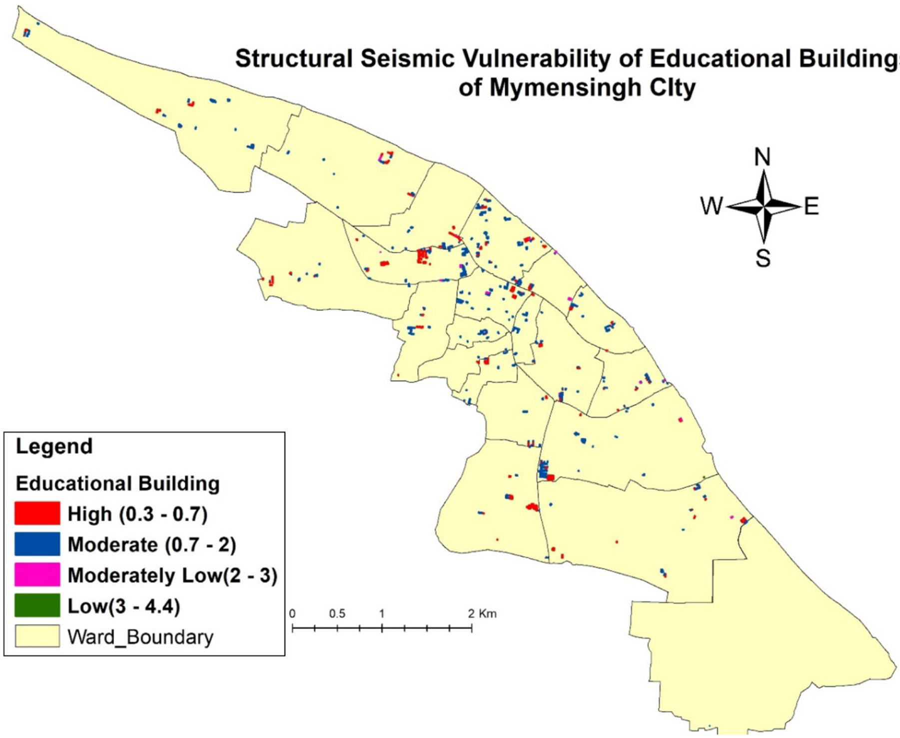

Figure 8. The structural vulnerability of educational buildings of Mymensingh city

3.2.1 Distance to the hospital. As the frequency of causality because of the earthquake in the daytime is always high in school buildings, the hospital plays a crucial role in emergency response planning after an earthquake. According to the comprehensive disaster management program (CDMP, 2014) of Mymensingh city, there are 54 major hospitals (private and government) in Mymensingh town, which are spatially concentrated in the middle part of the city. The distance of major hospitals from the selected educational buildings is measured using a network analysis tool in the ArcGIS environment. Then, the distance of each school building is classified into three vulnerability levels, namely, high, moderate and low based on Table III. The result shows that 63.1 per cent (289 buildings) educational buildings have proximity to the hospital, whereas 8.1 per cent (37 buildings) fall in the highly vulnerable category because of its long-distance from hospital service. About 28.8 per cent (132 buildings) educational building falls in the moderate vulnerable category.

3.2.2 Accessibility to the evacuation route. As Mymensingh is one of the most seismic vulnerable cities of Bangladesh, an attempt had been made by the Government of Bangladesh to design a disaster management contingency planning for Mymensingh city and a contingency evacuation route has been designed for Mymensingh city under CDMP-II. To measure the distance of each school building from the evacuation route, the shapefile (polygon) of the evacuation route is converted into point feature using the data management tool and then the closest facility function of the network analysis tool is performed. The result shows that about 98.9 per cent (453 buildings) educational buildings of Mymensingh city are located within the 500 m buffer of the evacuation route, which makes the majority of school buildings low vulnerable. The remaining 1.1 per cent (five-building) educational building of Mymensingh city falls in the moderate vulnerable category.

3.2.3 Distance to the fire station. The seismic wave of an earthquake damages the electrical power, gas lines or other fire sources badly, which triggers the risk of fire hazard in an area after a seismic activity (Alam and Haque, 2018). Though Mymensingh is one of the oldest municipalities of the country, there exists only one fire station in the whole city, which is incapable of providing service if any catastrophe occurs in the city. The distance of educational buildings of Mymensingh city to fire station are estimated using network analyst tool in ArcGIS environment, and the result indicates that majority of the educational building of the city are highly vulnerable to an earthquake because of its remote location from the fire station. According to the result, high, moderate and low vulnerable educational buildings because of the long distance from the fire station are 43.4 per cent (199 buildings), 30.6 per cent (140 buildings) and 26 per cent (119 buildings), respectively.

3.2.4 Distance to the emergency shelter. CDMP-II has also identified 21 emergency shelters for displaced people of Mymensingh city if an earthquake occurs. Emergency shelter is an important element of post-earthquake planning, and distance of every educational building needs to be estimated for measuring the vulnerability of the buildings.

Table VII. Distribution of structural vulnerability among different types of buildings in Mymensingh

	Type of construction					
RVS score	W1 (%)	S3 (%)	C3 (%)	URM (%)	RM2 (%)	Total
$0.3 < RVS < 0.7$	0.22	0.44	10.26	14.63	2.18	27.73
$0.7 < RVS < 2.0$	–	1.53	19.86	34.06	13.10	68.55
$2.0 < RVS < 3.0$	–	1.96	–	0.66	0.66	3.28
$RVS > 3.0$	0.44	–	–	–	–	0.44
Total	0.66	3.93	30.12	49.35	15.94	100

For this purpose, the shapefile (polygon) of the evacuation route is converted into point feature using a data management tool, and then the closest facility function of network analysis tool is performed to measure the distance of educational buildings from its nearest emergency shelter. The result shows that 39.1 per cent (179 buildings) educational buildings located outside of the service area of emergency shelter and 38.7 per cent (177 buildings) educational buildings fall in the moderate vulnerability category.

3.2.5 Systematic vulnerability score. There are two primary ways to measure systematic vulnerability, which includes distance based vulnerability measurement and area-based vulnerability measurement. Distance-based measures focus on the time required for people at risk to reach a care facility, whereas area-based measures describe the ratio of population to services in an area (Walker *et al.*, 2014; McLafferty, 2003). This study follows distance-based vulnerability measurement as the area-based measurement has some drawbacks such as the modifiable areal unit problem (Walker *et al.*, 2014). The systematic vulnerability of educational buildings of Mymensingh city is assessed in this study using the AHP and GIS technology. The result shows that 14.85 per cent educational buildings (68 buildings) are highly earthquake vulnerable in Mymensingh city because of its spatial location. Only 26.42 per cent of educational buildings (121 building) of Mymensingh city has proximity to major emergency facilities and fall in low vulnerability category. Moderate and moderately low vulnerability category, respectively, constitutes about 27.07 per cent (124 buildings) and 31.66 per cent (145 buildings) educational buildings of Mymensingh city. The systematic vulnerability (Figure 9) displays a pattern in the spatial distribution of seismic vulnerable educational buildings in Mymensingh. Figure 9 shows that high and moderate systematic vulnerable educational buildings are spatially distributed in the outer urban peripheral area, whereas moderately low and low vulnerable educational buildings are spatially concentrated in the center area of the city. As mentioned in the sections (Sections 3.2.1 and 3.2.3) above, high spatial concentration of hospital in the center area, the insufficient fire station in the periphery area act as a positive factor for schools in the center area and negative factor for the schools in the periphery, thus, causes this spatial distribution.

3.3 Composite seismic vulnerability

In this study, the vulnerability of educational buildings of Mymensingh city has been investigated according to structural and systematic factors by using a combination of RVS and an index based approach. Earthquake vulnerability of a building not only depends on the structural attributes but also depends on its systematic attributes. The educational buildings of Mymensingh city are investigated in this study using RVS methodology to assess the structural vulnerability. An index has been developed in this study using the AHP model-based on four systematic vulnerability factors to estimate the systematic vulnerability of educational buildings. The result of structural and systematic vulnerability is normalized and combined in the last step providing equal weight to achieve a composite vulnerability map of educational buildings of Mymensingh. The final map obtained from processing the structural vulnerability and systematic vulnerability are divided into four categories of high, moderate, moderately low and low. The results showed that 21.40 per cent (98 buildings) educational buildings of Mymensingh city have high, 42.36 per cent (194 buildings) have moderate and 29.91 per cent (137 buildings) have the moderately low vulnerability. Only 6.33 per cent (29 buildings) educational buildings of Mymensingh have low vulnerability against earthquakes, which is an element of major concern for city management authorities and planning agencies. The city authority should take special concentration on renovation or destruction of the highly vulnerable buildings of the city to reduce the loss of life and property. The distribution of composite seismic vulnerable

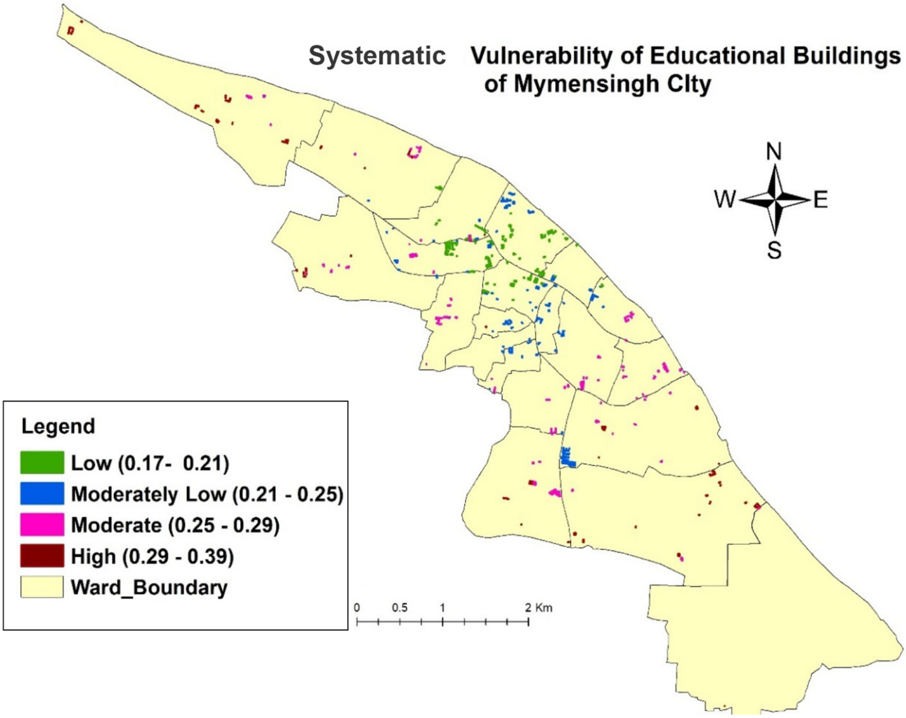

Figure 9. Systematic seismic vulnerability of educational buildings of Mymensingh city

educational buildings of Mymensingh city is shown in Figure 10. The composite vulnerability map shows a very different pattern from systematic seismic vulnerability, shown in Figure 9. The composite vulnerability map shows that most of the high and moderate seismic vulnerable educational buildings are located in the center part of the city, similar to the distribution of structural vulnerability map shown in Figure 8. As the central part is the oldest area of the city, most of the educational buildings are old and most of them were designed and built before the introduction of modern building codes, which justifies the distribution of structural vulnerability. In connection to it, the inadequacy of emergency shelter and the existence of narrow road width factors of systematic vulnerability in the center old part of the city added extra weight to the composite vulnerability score. As a result, most of the educational buildings in the old center part of the city is marked as high and moderate earthquake vulnerable in the composite vulnerability map.

4. Conclusion

Evaluation of vulnerability of educational buildings induced by an earthquake is of paramount importance for ranking the buildings based on vulnerability to assess seismic habitation needs and hazard mitigation planning. This research develops a composite index based seismic vulnerability assessment methodology and evaluates the seismic vulnerability of educational buildings in Mymensingh city in an integrative manner, combining RVS method with multi-criteria analysis based index based approach, by taking into consideration not only the structural vulnerability but also the accessibility to emergency services following an earthquake. The proposed integrated methodology shown in this study has some limitations

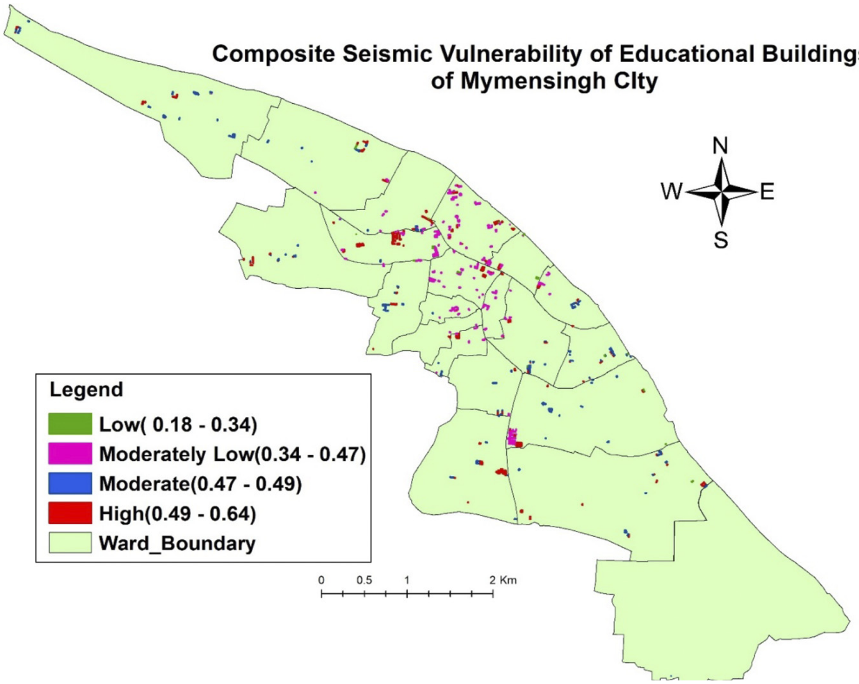

Figure 10.
Composite seismic vulnerability map of educational buildings of Mymensingh city

such as less number of systematic indicators and expert opinion, overlooking societal and economic dimension, dimension, ignoring resilience and preparedness of students and so on, which need to be improved and reiterated. As for the contribution of the work, this proposed integrated methodology comprehensively assesses the vulnerability of the education buildings to seismic hazard at the city scale and presents it in a way that will enable researchers, concerned city planning authority in detailed assessments of vulnerability and adaptation strategies.

5. List of abbreviation

AHP Analytical hierarchy process
CDMP Comprehensive disaster management program
FEMA Federal emergency management authority
GIS Geographic information system
MSDP Mymensingh strategic development plan
RVS Rapid visual screening
WLC Weighted linear combination

6. Declaration

- *Availability of data and material*: The data used in this manuscript is uploaded on the website of MSDP (2011-2031) project Website: www.msdp.gov.bd/

- *Competing interest*: The authors declare that they have no competing interests.
- *Funding*: This research received no external funding.
- *Authors contribution*: Md. Shaharier Alam collects and analyzes the data with the guidance of Prof. Shamim Mahabubul Haque. The whole research is designed and guided by Prof. Shamim Mahabubul Haque.

References

Ahmed, M., Khaleduzzaman, K.M., Siddique, N.A. and Islam, S. (2012), "Earthquake vulnerability assessment of schools and colleges of Sylhet, a North-Eastern city of Bangladesh", *SUST Journal of Science and Technology*, Vol. 19 No. 5, pp. 27-34.

Alam, M.S. and Haque, S.M. (2018), "Assessment of urban physical seismic vulnerability using the combination of AHP and TOPSIS models: a case study of residential neighborhoods of Mymensingh city, Bangladesh", *Journal of Geoscience and Environment Protection*, Vol. 6 No. 2, pp. 165.

Alam, M.S. and Mondal, M. (2018), "Assessment of sanitation service quality in urban slums of Khulna city based on SERVQUAL and AHP model: a case study of railway slum, Khulna, Bangladesh", *Journal of Urban Management*, Vol. 8 No. 1, pp. 20-27, doi: 10.1016/j.jum.2018.08.002.

Aliabadi, S., Fallah, A., Sarsangi, E. and Modiri, (2015), "The social and physical vulnerability assessment of old texture against earthquake (case study: Fahadan district in Yazd city)", *Arabian Journal of Geosciences*, Vol. 8 No. 12, pp. 10775-10787.

Banica, A., Rosu, L., Muntele, I. and Grozavu, A. (2017), "Towards urban resilience: a multi-criteria analysis of seismic vulnerability in Iasi city (Romania)", *Sustainability*, Vol. 9 No. 2, p. 270.

Barbat, A.H., Pujades, L.G. and Lantada, N. (2008), "Seismic damage evaluation in urban areas using the capacity spectrum method: application to Barcelona", *Soil Dynamics and Earthquake Engineering*, Vol. 28 Nos 10/11, pp. 851-865.

BBS (2011), *Bangladesh Bureau of Statistics, Bangladesh Population Census: Mymensingh Zila Series*, Planning Commission, Ministry of Planning, Dhaka.

Bendito, A., Rozelle, J. and Bausch, D. (2014), "Assessing potential earthquake loss in Mérida State, Venezuela using Hazus", *International Journal of Disaster Risk Science*, Vol. 5 No. 3, pp. 176-191.

BNBC (2015), "Bangladesh national building code", HBRI-BSTI. Draft Version, available at: www.scribd.com/document/339174596/Bangladesh-National-Building-Code-2015-Vol-2-3-Draft-pdf

Cacace, F., Zuccaro, G., De Gregorio, D. and Perelli, F.L. (2018), "Building inventory at national scale by evaluation of seismic vulnerability classes distribution based on census data analysis: BINC procedure", *International Journal of Disaster Risk Reduction*, Vol. 28, pp. 384-393.

Calvi, G.M., Pinho, R., Magenes, G., Bommer, J.J., Restrepo-Vélez, L.F. and Crowley, H. (2006), "Development of seismic vulnerability assessment methodologies over the past 30 years", *ISET Journal of Earthquake Technology*, Vol. 43 No. 3, pp. 75-104.

CDMP (2014), *Scenario-Based Earthquake Contingency Plan for Mymensingh Municipality*, Government of Bangladesh, Dhaka.

Cocco, G., D'Aloisio, A., Spacone, E. and Brando, G. (2019), "Seismic vulnerability of buildings in historic centers: from the "urban" to the "aggregate" scale", *Frontiers in Built Environment*, Vol. 5, p. 78.

De Angelis, A. and Pecce, M. (2015), "Seismic nonstructural vulnerability assessment in school buildings", *Natural Hazards*, Vol. 79 No. 2, pp. 1333-1358.

ERRI (2005), Earthquake Engineering Research Institute Special Earthquake Report, available at: www.eeri.org/lfe/pdf/kashmir_eeri_2nd_report.pdf

Fajfar, P. (2000), "A nonlinear analysis method for performance-based seismic design", *Earthquake Spectra*, Vol. 16 No. 3, pp. 573-592.

Fajfar, P. and Gašperšič, P. (1996), "The N2 method for the seismic damage analysis of RC buildings", *Earthquake Engineering and Structural Dynamics*, Vol. 25 No. 1, pp. 31-46.

Fema, P. (2015), "Rapid visual screening of buildings for potential seismic hazards: a handbook", Federal Emergency Management Agency Report, FEMA. P. 154.

Formisano, A., Mazzolani, F.M. and Indirli, M. (2010), "Seismic vulnerability analysis of a masonry school in the Vesuvius area", in *Proceeding of the COST Action C26 Final Conference "Urban Habitat Constructions under Catastrophic Events", Naples*, pp. 16-18.

Gentile, R., Galasso, C., Idris, Y., Rusydy, I. and Meilianda, E. (2019), "From rapid visual survey to multi-hazard risk prioritisation and numerical fragility of school buildings", *Natural Hazards and Earth System Sciences Discussions*, Vol. 19 No. 7, pp. 1365-1386.

Giardini, D., Grünthal, G., Shedlock, K.M. and Zhang, P. (1999), "The GSHAP global seismic hazard map", *Annals of Geophysics*, Vol. 42 No. 6.

Haque, S.M. (2015), *Seismic Risk Assessment in Bangladesh for Bogra, Dinajpur, Mymensingh, Rajshahi*, Rangpur and Tangail City Corporation/Paurashava Areas, Bangladesh.

IEER (2020), "History of earthquakes in Bangladesh, institute of earthquake engineering research (IEER)", CUET, available at: http://ieercuet.weebly.com/uploads/2/0/6/5/20658532/2170823_orig.gif

Islam, M.S., Swapan, M.S.H. and Haque, S.M. (2013), "Disaster risk index: how far should it take account of local attributes? ", *International Journal of Disaster Risk Reduction*, Vol. 3, pp. 76-87.

Japan Building Disaster Prevention Association (2001), *Seismic Evaluation and Retrofits*, Japan Building Disaster Prevention Association, Tokyo, Japan.

Kircher, C.A., Whitman, R.V. and Holmes, W.T. (2006), "HAZUS earthquake loss estimation methods", *Natural Hazards Review*, Vol. 7 No. 2, pp. 45-59.

Kircher, C.A., Nassar, A.A., Kustu, O. and Holmes, W.T. (1997), "Development of building damage functions for earthquake loss estimation", *Earthquake Spectra*, Vol. 13 No. 4, pp. 663-682.

Lantada, N., Irizarry, J., Barbat, A.H., Goula, X., Roca, A., Susagna, T. and Pujades, L.G. (2010), "Seismic hazard and risk scenarios for Barcelona, Spain, using the Risk-UE vulnerability index method", *Bulletin of Earthquake Engineering*, Vol. 8 No. 2, pp. 201-229.

McLafferty, S.L. (2003), "GIS and health care", *Annual Review of Public Health*, Vol. 24 No. 1, pp. 25-42.

Maleki, S., Meshkini, A., Ebrahimi, M., Kloraghan, A., Moin Mehr, A. and Omidipoor, M. (2016), "Modeling of urban vulnerability probability (supposition) using logistic regression model; case study: Tehran city", *Journal of Civil Engineering Urban*, Vol. 6 No. 6, pp. 94-100.

Midorikawa, S. and Miura, H. (2008), "Nonlinear behavior of soil response observed in strong-motion records from recent Japanese earthquakes", *Proceedings of the 14WCEE*. Beijing, China.

Moradi, M., Delavar, M. and Moshiri, B. (2014), "A GIS-based multi-criteria decision-making approach for seismic vulnerability assessment using quantifier-guided OWA operator: a case study of Tehran, Iran", *Annals of Gis*, Vol. 21 No. 3, pp. 209-222.

Mück, M., Taubenböck, H., Post, J., Wegscheider, S., Strunz, G., Sumaryono, S. and Ismail, F.A. (2013), "Assessing building vulnerability to earthquake and tsunami hazard using remotely sensed data", *Natural Hazards*, Vol. 68 No. 1, pp. 97-114.

New Zealand Society for Earthquake Engineering (2017), *The Seismic Assessment of Existing Buildings*, Technical Guidelines for Engineering Assessment, Wellington, New Zealand, available at: www.eq-assess.org.nz/

Rahman, N., Ansary, M.A. and Islam, I. (2015), "GIS based mapping of vulnerability to earthquake and fire hazard in Dhaka city, Bangladesh", *International Journal of Disaster Risk Reduction*, Vol. 13, pp. 291-300.

Rajarathnam, S. and Santhakumar, A.R. (2015), "Assessment of seismic building vulnerability based on rapid visual screening technique aided by aerial photographs on a GIS platform", *Natural Hazards*, Vol. 78 No. 2, pp. 779-802.

Ranguelov, B. (2011), *Natural Hazards–Nonlinearities and Assessment*, Acad. Publ. House (BAS), ISBN 978-954-332-419-7.

Rashed, T. and Weeks, J. (2003), "Assessing vulnerability to earthquake hazards through spatial multicriteria analysis of urban areas", *International Journal of Geographical Information Science*, Vol. 17 No. 6, pp. 547-576.

Rezaie, F. and Panahi, M. (2015), "GIS modeling of seismic vulnerability of residential fabrics considering geotechnical, structural, social and physical distance indicators in Tehran using multi-criteria decision-making techniques", *Natural Hazards and Earth System Sciences*, Vol. 15 No. 3, pp. 461-474.

Ródenas, J., García-Ayllón, S. and Tomás, A. (2018), "Estimation of the buildings seismic vulnerability: a methodological proposal for planning ante-earthquake scenarios in urban areas", *Applied Sciences*, Vol. 8 No. 7, pp. 1208.

Rodgers, J.E. (2012), "Why schools are vulnerable to earthquakes", in *Proceedings, 15th world conference on earthquake engineering*, Lisbon, pp. 24-28.

Saaty, T.L. (1980), *The Analytic Hierarchy Process*, McGraw-Hill, New York, NY, McLafferty SL (2003) GIS and health care. Ann Rev Public Health 24:25–42.

Saputra, A., Rahardianto, T., Revindo, M.D., Delikostidis, I., Hadmoko, D.S., Sartohadi, J. and Gomez, C. (2017), "Seismic vulnerability assessment of residential buildings using logistic regression and geographic information system (GIS) in Pleret Sub District (Yogyakarta, Indonesia)", *Geoenvironmental Disasters*, Vol. 4 No. 1, p. 11.

Sarker, J.K., Ansary, M.A., Rahman, M.S. and Safiullah, A.M.M. (2010), "Seismic hazard assessment for Mymensingh, Bangladesh", *Environmental Earth Sciences*, Vol. 60 No. 3, pp. 643-653.

Srikanth, T., Kumar, R.P., Singh, A.P., Rastogi, B.K. and Kumar, S. (2010), "Earthquake vulnerability assessment of existing buildings in Gandhidham and Adipur cities, Kachchh, Gujarat (India)", *European Journal of Scientific Research*, Vol. 41 No. 3, pp. 336-353.

Tischer, H. (2012), *Rapid Seismic Vulnerability Assessment of School Buildings in Québec*, McGill University, Canada.

Ventura, C.E., Finn, W.L., Onur, T., Blanquera, A. and Rezai, M. (2005), "Regional seismic risk in British Columbia classification of buildings and development of damage probability functions", *Canadian Journal of Civil Engineering*, Vol. 32 No. 2, pp. 372-387.

Vicente, R., Parodi, S., Lagomarsino, S., Varum, H. and Silva, J.A.R.M. (2011), "Seismic vulnerability and risk assessment: case study of the historic city center of Coimbra, Portugal", *Bulletin of Earthquake Engineering*, Vol. 9 No. 4, pp. 1067-1096, doi: 10.1007/s10518-010-9233-3.

Walker, B.B., Taylor-Noonan, C., Tabbernor, A., Bal, H., Bradley, D., Schuurman, N. and Clague, J.J. (2014), "A multi-criteria evaluation model of earthquake vulnerability in Victoria, British Columbia", *Natural Hazards*, Vol. 74 No. 2, pp. 1209-1222.

Zain, M., Usman, M., Farooq, S.H. and Mehmood, T. (2019), "Seismic vulnerability assessment of school buildings in seismic zone 4 of Pakistan", *Advances in Civil Engineering*, Vol. 2019.

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