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Assessment of Urban Physical Seismic Vulnerability Using the Combination of AHP and TOPSIS Models: A Case Study of Residential Neighborhoods of Mymensingh City, Bangladesh

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Abstract

Mymensingh, one of the oldest municipalities of Bangladesh, is at great risk against earthquakes because three major faults *viz.* Dauki fault, Madhupur fault, and Sylhet-Assam fault are located around it, and possesses liquefaction susceptible soil type. The city has great significance from the economic and administrative point of view and recently declared as the 8th administrative division of Bangladesh which directly stimulates the unplanned future expansion. Considering the potentiality of haphazard development and high seismic risk, it is crucial to assess the seismic vulnerability for taking the judicious decision regarding risk reduction measures for the city. The study combines Technique for Order Preference by Similarity to Ideal Solution method (TOPSIS) and Analytical Hierarchical Process (AHP) models to assess the seismic vulnerability of residential neighborhoods of Mymensingh city as the probability of death and damage is remarkable in residential neighborhoods than other land use types. A combined quantitative methodology of AHP-TOPSIS is used in this study to quantify 13 important qualitative and quantitative factors of earthquake vulnerability, decided on expert opinions. The data of 13 vulnerability factors are collected from the Mymensingh Strategic Development Plan (MSDP, 2011-2031) database, done under Comprehensive Disaster Management Programme (CDMP)-II during 2012-2014. Geographic Information System is used in this study to analyze and mapping of seismic vulnerability. Results indicated that 37 residential neighborhoods are very highly vulnerable, 55 neighborhoods are highly vulnerable, 75 neighborhoods are moderately vulnerable and 74 neighborhoods are in the low vulnerable category.

Keywords

AHP, GIS, Physical Seismic Vulnerability, TOPSIS

1. Introduction

Cities are growing fast all over the world as a process of urbanization and more than half of the world population lives in urban area. Formation of new urban areas creating new facilities as well as new risk to its citizen and natural disasters is one of the most lethal threats to the life and property of citizens of an urban area. Natural disaster such as: flood, earthquake, cyclone etc. are major hindrance in the way of achieving sustainable urban development which causes immense losses of lives and damage to properties, livelihoods and economic infrastructures. So, it is major challenges to assess disaster risk and mainstreaming disaster risk reduction strategies in the development policy of an urban area. Assessing earthquake vulnerability is crucial for a city located on earthquake risk zone for better understanding the inherent weakness of the city against earthquake to prioritize preparedness and risk mitigation activities. Physical earthquake vulnerability refers to a combination of factors related to weakness of the built environment, geology and lack of access to emergency services of an urban area. Earthquake has been at the top of the disaster management agenda for quite some time in Bangladesh after the discovery of hidden megathrust under Bangladesh, India and Myanmar which can shake the south Asia at a magnitude 9.0, placing up to 140 million at risk in most densely populated place on earth [1]. The city of Mymensingh is highly earthquake vulnerable due to its poor geological setting. The city is surrounded by three major faults *viz.* Dauki fault, Madhupur fault and Sylhet-Assam fault and has close proximity to the newly found megathrust. The city also possesses 90% liquefaction susceptible soil type, which has very poor seismic behavior [2]. On the other hand, the importance of the city is significantly increasing in Bangladesh since the city has economic potentiality, administrative importance, good transportation system and close proximity to the capital. Recently the city of Mymensingh got declared as the 8th administrative division which is expected to stimulate unplanned future expansion and random development. It is very crucial to assess earthquake vulnerability of residential neighborhoods because it is the place where we live and, death and damage ratio of residential land use is significantly higher than other land-use types [3], especially if an earthquake hits at night time. As Mymensingh is an old and historic city of Bangladesh, people started to live in this city nearly about the year of 1869; most of the residential neighborhoods grew organically without following any physical plan or building code for the construction of buildings. Besides, there exists a socio-economic, cultural variation among the neighborhoods. In this circumstance, assessing earthquake vulnerability of Mymensingh city for prioritizing risk reduction activities is the most urgent task to reduce earthquake vulnerability of the city.

Many methods and tools are developed for assessing earthquake vulnerabilities in different contexts and at different spatial scales. Zaheri, Hir and Miab [4] combines Analytical Hierarchical Process (AHP) and Technique for Order Preference by Similarity to Ideal Solution method (TOPSIS) to assess earthquake vulnerability of 74 villages of the central district of Marand County, Iran. A combined method of RADIUS, TOPSIS and AHP Models are developed by Sarvar, Amini and Laleh-Poor [5] to assess seismic risk region 1 of Tehran, where in various variables such as the buildings location in proportion to faults, type of materials, oldness of the buildings, number of floors, population density, soil type, slope of the region, and pathway network were used to evaluate seismic vulnerability. Nwe and Tun [3] identified seismic vulnerability zones of Mandalay city, Myanmar based on land use condition using AHP. Spatial variation of earthquake vulnerability of residential neighborhoods are assessed by Alam and Haque [6], using AHP, where soil type, peak ground acceleration, percentage of BFL (Brick in cement mortar masonry with flexible roof) building, poor conditioned building, irregular shape building, building with pounding possibility, buildings with heavy overhanging, building density (number of building per acre) and road width are taken as assessment criteria. Farajzadeh, Ahadnezhad and Amini [7] used fuzzy TOPSIS method for vulnerability assessment of urban housing against earthquake in Tehran municipality and the result shows that urban areas are highly earthquake vulnerable. This study aims to investigate and estimate residential land use specific seismic vulnerability of Mymensingh city using TOPSIS and AHP models and ranks the residential neighborhoods into four levels (low, moderate, high, very high) of earthquake vulnerability based on vulnerability score. Geographic Information System (GIS) is used to analyze and mapping of the spatial variation of physical vulnerability. This study is expected to be helpful in resource targeting for prioritizing risk mitigation activities and development of safe, sustainable and earthquake resilient infrastructure, built environment and housing in residential neighborhoods of Mymensingh city.

2. Study Area

The city of Mymensingh is located in the northern part of the Bangladesh (24˚45'N latitude and 90˚23'E longitude) on the bank of old Brahmaputra River. The city was established in 1869 with an area of 2.73 sq·km and 21 administrative wards. It is the home of 258,040 (Male—132,123, Female—125,917) population with an annual population growth rate of 1.82% [8]. The city was completely collapsed in the Great Indian earthquake of 1897 (8.7 Magnitude) originated from the epicenter at Shillong Plateau [9]. In 27 July 2008, Mymensingh faced another earthquake, known as Mymensingh earthquake, originated from Madhupur fault at 5.1 magnitudes on Richter scale. The epicenter was located 12 km northeast of Mymensingh city [10]. There are 241 small residential neighborhoods in Mymensingh city delineated by mental mapping during preparation of Mymensingh Strategic Development Programme [2]. The residential neighborhoods of Mymensingh city grew organically from the British colonial period and the physical conditions of the neighborhoods are very poor. Most of the infrastructures of the neighborhoods are old, deteriorated and oriented in a haphazard manner in earthquake risk zone. This study only takes into account the residential neighborhoods of Mymensingh city as the study area to assess physical seismic vulnerability (Figure 1).

3. Physical Seismic Vulnerability Factors

Earthquake vulnerability of an urban area largely depends on absence or presents, strength or weakness, proximity or distance of some major factors. Physical earthquake vulnerability factors are related to inherent weakness of built environment, geology and accessibility to emergency services etc. In this study, 13 most influential vulnerability factors are selected for assessment of seismic vulnerability based on a literature review and on experts' opinions. Some other most important structural vulnerability parameters such as-soft storey, short column, age of building, lateral stiffness etc. are excluded from this study due to data unavailability or rare existence in residential neighborhoods of Mymensingh city. The list of selected physical seismic vulnerability parameters are shown in Table 1.

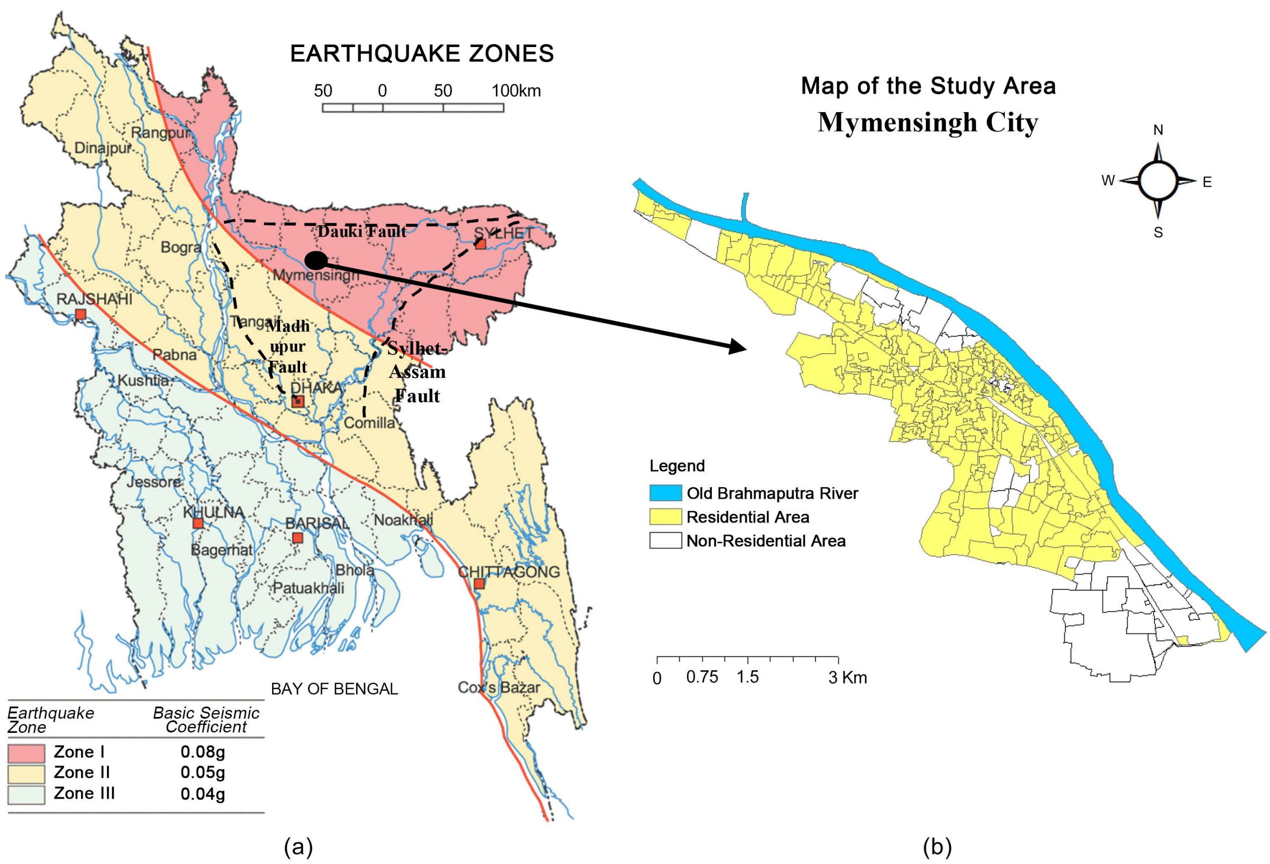

Figure 1. (a) Seismic zonation map of Bangladesh; (b) Map of Mymensingh City.

Table 1. Physical seismic vulnerability factors.

Physical Seismic Vulnerability Factors	Vulnerability Level		
	Low	Moderate	High
Average Floor Height	1 floor	2 floor	≥3 floor
Poor Conditioned Building (%)	0% - 25%	25% - 50%	More than 50%
Masonry Building (%)	0% - 25%	25% - 50%	More than 50%
Pounding Possibility (%)	0% - 10%	10% - 25%	More than 25%
Irregular Shape Building (%)	0% - 10%	10% - 25%	More than 25%
Heavy Overhanging (%)	0% - 10%	10% - 25%	More than 25%
Average Road Width (ft.)	More than 16 ft.	8 - 16 ft.	0 - 8 ft.
Building Density/Acre	0 - 10	10 - 15	More than 15
Soil Type	Hard Soil	Stiff Soil	Soft Soil
Peak Ground Acceleration (PGA)	0.346485 - 0.369287	0.369288 - 0.392051	0.392052 - 0.410747
Distance to Hospital	Less than 500 m	500 - 1000 m	More than 1 km
Distance to Fire Station	Less than 1 km	1 km - 2 km	More than 2 km
Accessibility to Evacuation Route	Less than 500 m	500 - 1000 m	More than 1 km

4. Methodology

This study used a combined methodology of AHP model and TOPSIS model to assess the physical seismic vulnerability of residential neighborhoods of Mymensingh city. This combined methodology follows three major phases (Figure 2). In the first phase, weights of each vulnerability factors are assigned based on pair wise comparison of expert's opinion in AHP model. Then evaluation of best alternatives depicted in a simple mathematical calculation and finally residential neighborhoods are ranked using TOPSIS method. In the final phase, the weighted and best alternative evaluated data of physical vulnerability factors from AHP and TOPSIS model are inputted in GIS environment to produce physical seismic vulnerability map of residential neighborhoods of Mymensingh city.

4.1. Analytical Hierarchical Process (AHP)

AHP is a powerful tool, developed by Saaty [11], for decision making among multiple criteria by pair wise comparisons among the criteria based on expert opinion. AHP incorporates both qualitative and quantitative aspects of a decision and assigns weight to each criterion. AHP follows three major steps of vulnerability assessment. In the first step, a comparison matrix has been developed based on expert opinion on a scale of 1 - 9 where 1 means two factors are equally important and 9 indicates that one parameter is extremely important than other.

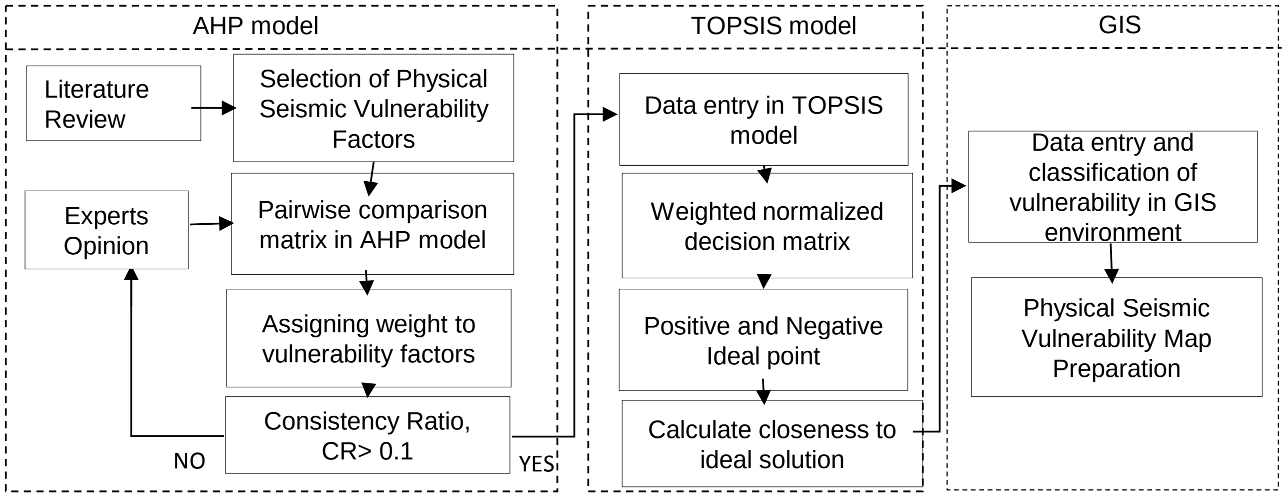

Figure 2. Framework of physical seismic vulnerability assessment.

The scale of importance developed by Saaty [11] is shown in **Table 2**. In the second step, the weight of each factor is calculated from row-multiplied value (RMV), unnormalized and normalized value using Equations (1) and (2).

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

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

here m_i refers to the unnormalized value of i_{th} parameter and n represents the total influential parameters. In the third step, weight consistencies between judgments are measured using Equations (3) and (4). If consistency ratio > 0.1, the matrix has inconsistency and pair wise comparison must be reperformed between indicators and sub-indicators.

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

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

L represents the Eigen value of pair wise comparison matrix and RI is the random inconsistency index which depends on the number of vulnerability assessment parameters (N). The variations of RI value for different number of parameters are shown in **Table 3**.

In this study, a comparison matrix of 13 seismic vulnerability factors is developed based on judgments of 3 experts. Then the geometric mean of 3 expert's opinion is calculated to aggregate the opinions into one matrix (shown in **Table 4**). According to the method, the factors are weighted and ranked on the scale 0 to 1. The value of CR is 0.014, which indicates consistency in pair wise comparison of vulnerability factors. The level of vulnerability of each factor (shown in **Table 1**) is also weighted in this method where the score of low medium and high vulnerabilities are 0.167, 0.333 and 0.500 respectively.

Table 2. Magnitude of importance for pairwise comparison [11].

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 importance
8	Very, very strong
9	Extreme importance

Table 3. Random inconsistency indices (RI) for $n = 1, 2, \cdots, 15$. [12].

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56	1.57	1.59

Table 4. Pairwise comparison matrix and weights of each factors using AHP model based on geometric mean of expert's opinion.

Physical Seismic Vulnerability factors	1	2	3	4	5	6	7	8	9	10	11	12	13	Weight
1) Average floor height	1	0.55	0.44	0.38	1.00	1.00	1.59	1.00	0.28	0.28	0.33	0.33	0.38	0.037
2) Poor Building (%)	1.82	1	0.79	0.63	2.00	2.00	1.59	1.00	0.28	0.28	0.50	0.44	0.55	0.052
3) Masonry Building (%)	2.29	1.26	1	0.63	3.00	3.00	2.00	1.26	0.38	0.44	0.63	0.55	0.69	0.068
4) Pounding Possibility (%)	2.62	1.59	1.59	1	4.00	3.63	2.29	2.00	0.40	0.40	0.63	0.55	1.00	0.085
5) Irregular Building (%)	1.00	0.50	0.33	0.25	1	1.00	0.50	0.50	0.22	0.23	0.33	0.30	0.35	0.029
6) Heavy overhanging (%)	1.00	0.50	0.33	0.28	1.00	1	0.50	0.50	0.22	0.23	0.33	0.30	0.35	0.029
7) Road Width	0.63	0.63	0.50	0.44	2.00	2.00	1	0.69	0.28	0.28	0.40	0.37	0.55	0.040
8) Building Density	1.00	1.00	0.79	0.50	2.00	2.00	1.44	1	0.38	0.38	0.50	0.50	0.55	0.052
9) Soil type	3.64	3.64	2.62	2.52	4.64	4.64	3.56	2.62	1	1.00	2.00	1.26	2.29	0.158
10) Peak ground acceleration	3.64	3.64	2.29	2.52	4.31	4.31	3.56	2.62	1.00	1	2.00	1.26	2.29	0.155
11) Distance to Hospital	3.00	2.00	1.59	1.59	3.00	3.00	2.52	2.00	0.50	0.50	1	0.63	1.26	0.095
12) Distance to Fire Station	3.00	2.29	1.82	1.82	3.30	3.30	2.71	2.00	0.79	0.79	1.59	1	2.29	0.121
13) Accessibility to evacuation route	2.62	1.82	1.44	1.00	2.89	2.89	1.82	1.82	0.44	0.44	0.79	0.44	1	0.079

(Random consistency index, RI = 1.56, Consistency ratio = 0.014)

4.2. Technique for Order Preference by Similarity to Ideal Solution Method (TOPSIS)

TOPSIS is one of the renowned multi criteria decision-making (MCDM) method, which chose alternatives, based on distance from positive and negative ideal point. The basic concept of TOPSIS is the chosen Alternative should have the shortest distance from the ideal solution and the farthest from the negative-ideal solution [13]. TOPSIS model follows five major steps.

Step 1: Construct normalized decision matrix using Equation (5) where x_{ij} score of option *i* with respect to criterion *j*.

$$\text{Normalize score,}\quad r_{ij} = x_{ij} \Big/ \left(\sum x_{ij}^2\right) \tag{5}$$

Step 2: Construct the weighted normalized decision matrix using Equation (6) where w_j is weights for each criteria.

$$v_{ij} = w_j \times r_{ij} \tag{6}$$

Step 3: Identify the Positive and Negative Ideal Solution. The positive ideal (A^+) and the negative ideal (A') solutions are defined according to the weighted decision matrix via Equations (7) and (8) below

$$A^+ = \left\{V_1^+, V_2^+, \cdots, V_n^+\right\}$$

$$\text{where,}\quad V_j^+ = \left\{\max\left(V_{ij}\right) \text{ if } j \in J;\ \min\left(V_{ij}\right) \text{ if } j \in J'\right\} \tag{7}$$

$$A' = \left\{V_1', V_2', \cdots, V_n'\right\}$$

$$\text{where,}\quad V_j' = \left\{\min\left(V_{ij}\right) \text{ if } j \in J;\ \max\left(V_{ij}\right) \text{ if } j \in J'\right\} \tag{8}$$

Step 4: Calculate the separation distance of each alternative from the positive ideal and negative ideal solution (Equations (9) and (10)).

$$S^+ = \sqrt{\sum_{j=1}^{n}\left(V_j^+ - V_{ij}\right)^2}$$

$$\text{where,}\quad i = 1, \cdots, m \tag{9}$$

$$S^- = \sqrt{\sum_{j=1}^{n}\left(V_j' - V_{ij}\right)^2}$$

$$\text{where,}\quad i = 1, \cdots, m \tag{10}$$

Here S_i^+ is the distance from the i^{th} alternative from the positive ideal point for the j^{th} feature and S_i^- is the distance between the i^{th} alternative and the negative ideal point for the j^{th} feature. The negative and positive ideal point for each physical seismic vulnerability factors are shown in **Table 5**. Positive and negative ideal point used in TOPSIS model.

Step 5: Measure the relative closeness of each location to the ideal solution using Equation (11).

$$\text{Closeness,}\quad C_i^* = S^- \Big/ \left(S^- + S^+\right) \tag{11}$$

C_i^* is a value between 0 and 1 and when the value is closer to 1, that alternative is closer to the ideal condition. In this study, highest physical seismic vulnerability

Table 5. Positive and negative ideal point used in TOPSIS model.

Vulnerability Factors	Positive	Negative	Factors	Positive	Negative	Factors	Positive	Negative
Average Floor Height	0.00507	0.00170	Building Density	0.00392	0.00131	Pounding Possibility	0.00919	0.00307
Poor Building	0.00614	0.00205	Soil type	0.01342	0.00886	Irregular Building	0.00297	0.00099
Masonry Building	0.00542	0.00181	PGA	0.01358	0.00454	Heavy overhanging	0.00338	0.00169
Road Width	0.00113	0.00337	Distance to Hospital	0.00843	0.00282	Distance to Fire Station	0.00907	0.00303
			Accessibility to evacuation route	0.01110	0.00371			

point represents the positive ideal point and the negative ideal point is the one with the lowest physical seismic vulnerability. The positive and negative ideal point for each parameter In addition, the closeness of alternative value is to 1, the more vulnerable those limits are and the closer they are to 0, the less vulnerability these limits will have.

5. Data Source and Analysis

5.1. Data Source

The weight of factors and sub-factors of physical seismic vulnerability of residential neighborhood of Mymensingh city has been determined by Analytical Hierarchical Process through expert's judgment. All the data of 13 physical seismic vulnerability factors of Mymensingh city are collected from the physical and geological feature database of Mymensingh Strategic Development Plan (MSDP, 2011-2031) under Comprehensive Disaster Management Programme (CDMP)-II of the Ministry of Disaster Management and Relief and Urban Development Directorate (UDD), Ministry of Housing and Public Works. The physical and geological feature survey and database preparation was done during CDMP phase-II period from 2012-2014.

5.2. Analysis of Physical Seismic Vulnerability Factors

Earthquake vulnerability of an urban area largely depends on the vulnerability of its built up environment as the structures are mainly responsible for the death and damage in any earthquake hazard. There exists a remarkable diversity in the infrastructure of residential neighborhoods of Mymensingh city because of its antiquity and significance. In this study, 13 physical seismic vulnerability factors are analyzed using AHP and TOPSIS model based on expert opinion to assess the seismic vulnerability of residential neighborhoods of Mymensingh city.

5.2.1. Average Floor Height

Building height has a very significant influence on earthquake vulnerability of an area. Tall or high-rise buildings are affected most during the earthquake than low-rise building. In this study, Average building height of every residential area is calculated to assess the spatial variation of earthquake vulnerability of Mymensingh town. In Mymensingh City, 86% of total residential buildings has only 1 floors where 7% building are 2 floors and 7% building has more than 3 floors. The main risk of building height in Mymensingh city is its spatial concentration. Some residential neighborhoods have a high concentration of high-rise buildings, which makes them vulnerable to earthquake. Residential neighborhood wise average building height data of Mymensingh city have been extracted from the physical feature survey data of MSDP using the geo-processing tool in Arc GIS environment. The spatial distribution of residential buildings floor height is shown in Figure 3(a).

5.2.2. Poor Conditioned Building

Earthquake vulnerability of any structure greatly depends on its apparent quality and a structure with poor apparent quality has poor seismic behavior. As Mymensingh is an old city of Bangladesh, most of the buildings in this city are antique and are in a poor condition now. In Mymensingh city, 27% residential buildings are now in very poor condition, which has a high probability to fall or damage in very small seismic activity. The residential neighborhood wise data of poor buildings are extracted in this study from physical feature survey data of MSDP using the geo-processing tool in GIS environment to assess the earthquake vulnerability. The spatial distribution of poor buildings in residential neighborhoods of Mymensingh city is shown in Figure 3(b).

5.2.3. Masonry Building

The construction material of buildings also determines the earthquake vulnerability of any urban area. Building with different construction material behave differently in an earthquake shaking and masonry buildings (buildings constructed

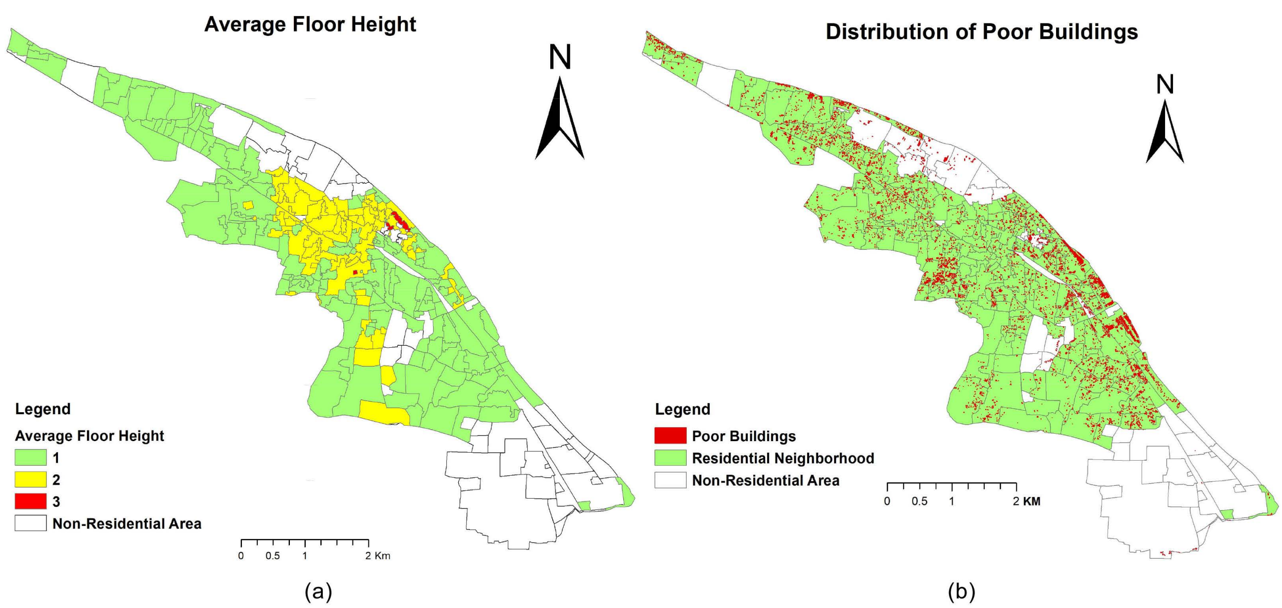

Figure 3. Distribution of (a) average floor height; (b) Poor buildings in residntial neighborhoods of Mymensingh city.

with of brick and cement block or stone) have a very poor seismic behavior. The city of Mymensingh is highly earthquake vulnerable because about 47% residential buildings of the residential neighborhoods of the city are masonry building. It is essential to assess the spatial concentration of masonry building in residential neighborhoods of Mymensingh city. In this study, the residential neighborhood wise data of masonry building are extracted and analyzed from the physical feature survey database of MSDP, using the geo-processing tool in GIS environment. The spatial distribution of masonry buildings in Mymensingh city is shown in **Figure 4(a)**.

5.2.4. Pounding Possibility

Insufficient separation between buildings causes collision of one building with adjacent buildings and causes great damage to the buildings during an earthquake. This collision is commonly called as pounding. As an ancient city of Bangladesh, the buildings are densely oriented in the residential neighborhood of Mymensingh city. About 12% buildings in Mymensingh city has the possibility of pounding during an earthquake. The data of pounding are extracted from the physical feature survey database of MSDP and shown in **Figure 4(b)**.

5.2.5. Irregular Shape Building

Irregularity in building plan is a deviation from a rectangular plan, having orthogonal axis systems in two directions. Such deviation from plan irregularity leads to irregularities in stiffness and strength distributions, which in turn increase the risk of damage localization under strong ground excitations [14]. In Mymensingh city, almost 10% residential building has either vertical or horizontal irregularity. The residential neighborhood wise data of irregularity are extracted from the physical feature survey database of MSDP using the geo-processing tool in Arc GIS. The spatial distribution of irregularity is visually represented in **Figure 4(c)**.

5.2.6. Heavy Overhanging

Heavy overhangs are the part of a building that hangs outside with less support, which has the high possibility of falling early during an earthquake and cause damage and death. In Mymensingh city, 2% residential buildings have heavy overhanging and most of the buildings are located in the middle part of the city. The data of overhanging of each neighborhood are extracted from physical feature database of MSDP using the geo-processing tool in Arc GIS and shown in **Figure 4(d)**.

5.2.7. Road Width

Road width has a great significance in the movement of emergency vehicles in response and recovery phase after an earthquake. In this study, the road with less than 8 ft width is considered as vulnerable and most of the road of residential neighborhoods are in vulnerable category. The data of average road width of each neighborhood are collected and analyzed from the road network database of MSDP and shown in **Figure 4(e)**.

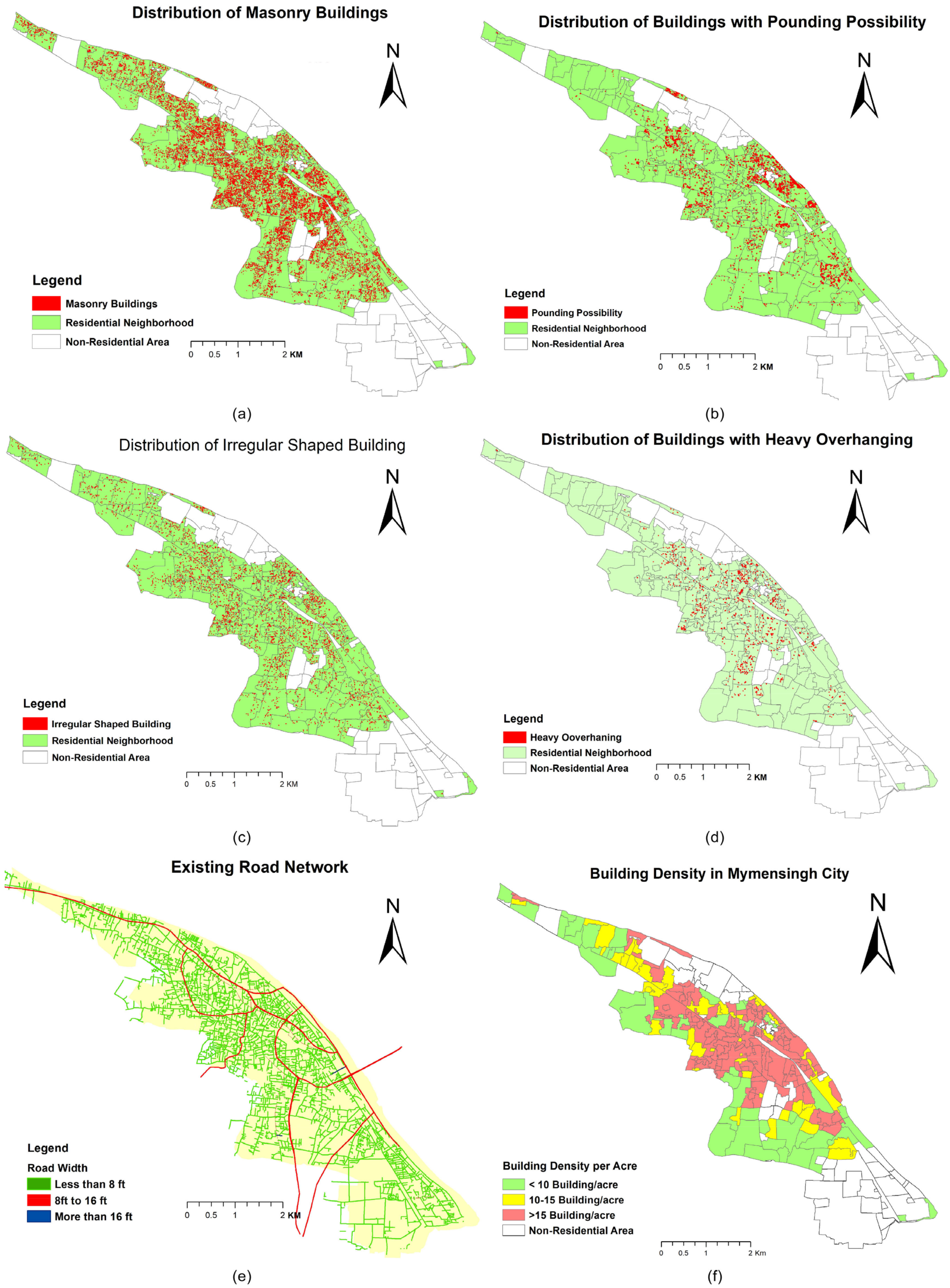

Figure 4. Distribution of (a) Masonry buildings; (b) Buildings with pounding possibility; (c) Irregular shaped buildings; (d) Buildings with heavy overhanging; (e) Road width; and (f) Building density in residential neighborhoods of Mymensingh city.

5.2.8. Building Density

Building density refers to the number of buildings that are located per unit area and the area, which has a high building density, has a high earthquake and fire vulnerability. In this study, the density of building per acre in every residential neighborhood of Mymensingh is calculated in GIS environment and shown in **Figure 4(f)**.

5.2.9. Soil Type

When an earthquake occurs, a huge amount of energy spread through the ground and hard soil are the faster modes of spreading than stiff or soft soil. In stiff or soft soil, the seismic waves are being amplified to maintain the same energy, which creates stronger shaking. The city of Mymensingh is in great earthquake risk as 90% soil of the city is either stiff or soft soil [2]. **Figure 5(a)** shows the distribution of soil type in residential neighborhoods of Mymensingh and the data soil type are collected from MSDP geological survey database and analyzed in GIS environment using the geo-processing tool.

5.2.10. Peak Ground Acceleration

Peak Ground Acceleration (PGA) expresses the intensity of ground shaking and used for creating shake map for an area to design emergency response and planning. The PGA values of Mymensingh city vary from 0.41 g to 0.38 g, which is in "Severe" perceived shaking category in Instrumental Intensity scale developed by United States Geological Survey (USGS). The PGA values of each neighborhood of Mymensingh City are extracted from geological survey database of MSDP using the geo-processing tool in GIS environment and shown in **Figure 5(b)**.

5.2.11. Distance from Hospital

Hospital is an important element of emergency response planning after an earthquake occurs and there is 64 hospitals (private and govt.) hospital in Mymensingh town. But most of the hospitals are spatially concentrated in the middle part of the city and some neighborhoods are located outside of service area of these hospitals. The spatial distribution of hospital is shown in **Figure 5(c)**. The distance of nearest hospital from the center of each neighborhood of Mymensingh city are calculated using closest facility function under network analysis tool in Arc GIS software. For calculation of distance, road network dataset is created from road network database of MSDP and the center of each neighborhood is identified using data management tool in Arc GIS software.

5.2.12. Distance from 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. It is irony of fate that there is only one fire station (**Figure 5(c)**) in Mymensingh city for 258,040 population and 37,674 residential buildings. The location of fire station is shown in figure and the distance of each neighborhoods from the fire station are calculated in the similar procedure like hospital distance calculation.

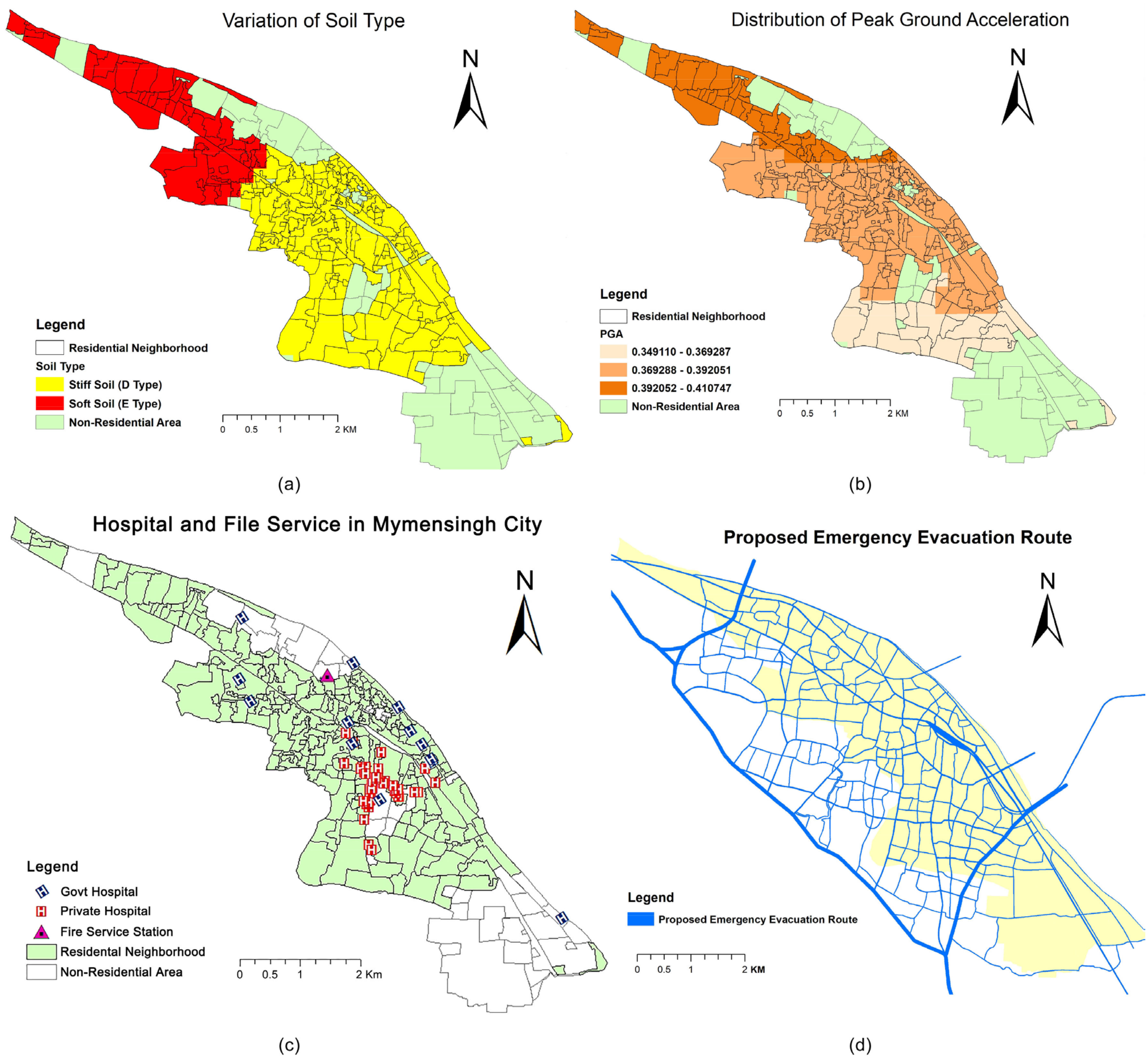

Figure 5. Distribution map of (a) Soil type; (b) Peak ground accelartion; (c) Hospital and Fire Service; and (d) Evacuation route in residential neighborhoods of Mymensingh city.

5.2.13. Accessibility to Evacuation Route

As Mymensingh is an earthquake vulnerable city, emergency evacuation route after an earthquake has been designed for the city under Comprehensive Disaster Management Program (CDMP-II). In this study, the distance of nearest node of the evacuation route from the center of each neighborhoods are calculated using closest facility function under network analysis tool in Arc GIS environment to assess the accessibility of each para to evacuation route. The evacuation route designed for Mymensingh city under CDMP-II are shown in Figure 5(d).

In the next step, the neighborhood wise database of aforementioned 13 factors are joined with the residential area map of Mymensingh city map in vector based

GIS. The weights of each factors are assigned and ranked using AHP model to calculate the score of each factors based on expert opinion. The positive ideal point and negative ideal point of each factors are identified in TOPSIS model. Then, the residential neighborhoods are ranked based on relative closeness score, calculated in TOPSIS model in Excel environment, and the score are reclassified using natural break (Jenks) and joined with residential area map of Mymensingh city map in vector based GIS. Finally, physical seismic vulnerability map of residential neighborhoods of Mymensingh city is produced based on reclassified relative closeness vulnerability score.

6. Result

The GIS based analysis of physical seismic vulnerability, using a combination of AHP and TOPSIS model, classified the residential neighborhoods into four level of seismic vulnerability. The result shows that 37 residential neighborhoods are very highly seismic vulnerable, 55 residential neighborhoods are highly seismic vulnerable, 75 residential neighborhoods are moderately seismic vulnerable and 74 neighborhoods are in low vulnerable category. The spatial distribution of seismic vulnerability of residential neighborhoods of Mymensingh town is visually represented in **Figure 3** using GIS. The vulnerability map shows that the same vulnerability categorized neighborhoods locate very close to each other, which indicates a pattern of vulnerability residential neighborhoods of Mymensingh city. The north-western part of the city is very high seismic vulnerable whereas the southern part of the city is mostly moderate and low vulnerable. This result indicates that development of any type in the very high and high vulnerable zone should follow the seismic code of building construction Act of Bangladesh, considering the soil type and PGA value and exiting vulnerable building needs to be removed or renovated in this zone. Provision for emergency services needs to be provided in this very high and high vulnerable zone for developing a safe, sustainable and seismic resilient urban place in Mymensingh city.

7. Discussion

Understanding the spatial variation of earthquake vulnerability and related methodologies of vulnerability assessment helps to design appropriate risk mitigation policies and action plans for an urban area. In this study, the physical seismic vulnerability of residential neighborhoods of Mymensingh city has been investigated according to geotechnical and structural factors by using a combination of AHP and TOPSIS model in GIS environment. Not all the factors have the same importance in earthquake vulnerability of an area. Therefore, to achieve the relative importance of each factor, weights have been given to each factors using AHP based on expert's judgment. The vulnerability map of Mymensingh city identifies that most of the high and very high vulnerable zone is located in the northwestern neighborhoods of the city (**Figure 6**) where the soil are mainly

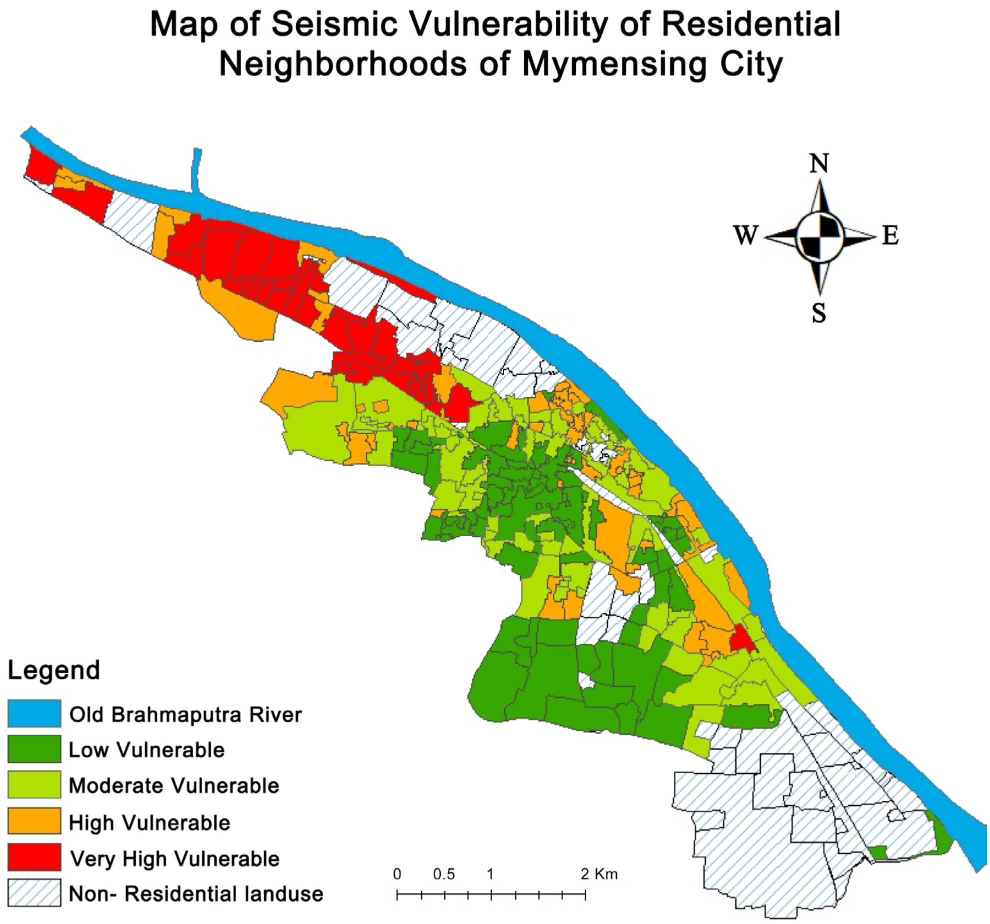

Figure 6. Physical seismic vulnerability of residential neighborhoods of mymensingh city.

soft (**Figure 5(a)**) and PGA value are very high (**Figure 5(b)**). These neighborhoods are very high vulnerable because of inaccessibility to fire and hospital service (**Figure 5(c)**). On the other hand, most of the moderate and high vulnerable neighborhoods are located in the middle part of the city where buildings are densely oriented with heavy over hangings and high risk of pounding (**Figure 6**). Spatial concentration of masonry, poor and irregular buildings are high in these neighborhoods, which makes them high or moderately vulnerable to earthquake.

To validate the result of this study, it is important to find out similar works done in Mymensingh city previously and compare the result of this paper with that previous works. Comprehensive Disaster Management Program phase-II (2012-2014) had developed earthquake sensitivity map for Mymensingh city during the preparation of Mymensingh Strategic Development Plan (MSDP) using Hazus (a multi hazard risk assessment tool developed by Federal Emergency Management Agency) methodology. The earthquake sensitivity map of Mymensingh city is shown in **Figure 7**. Comparison between **Figure 6** and **Figure 7** shows more or less the same areas of Mymensingh town, which are earthquake vulnerable.

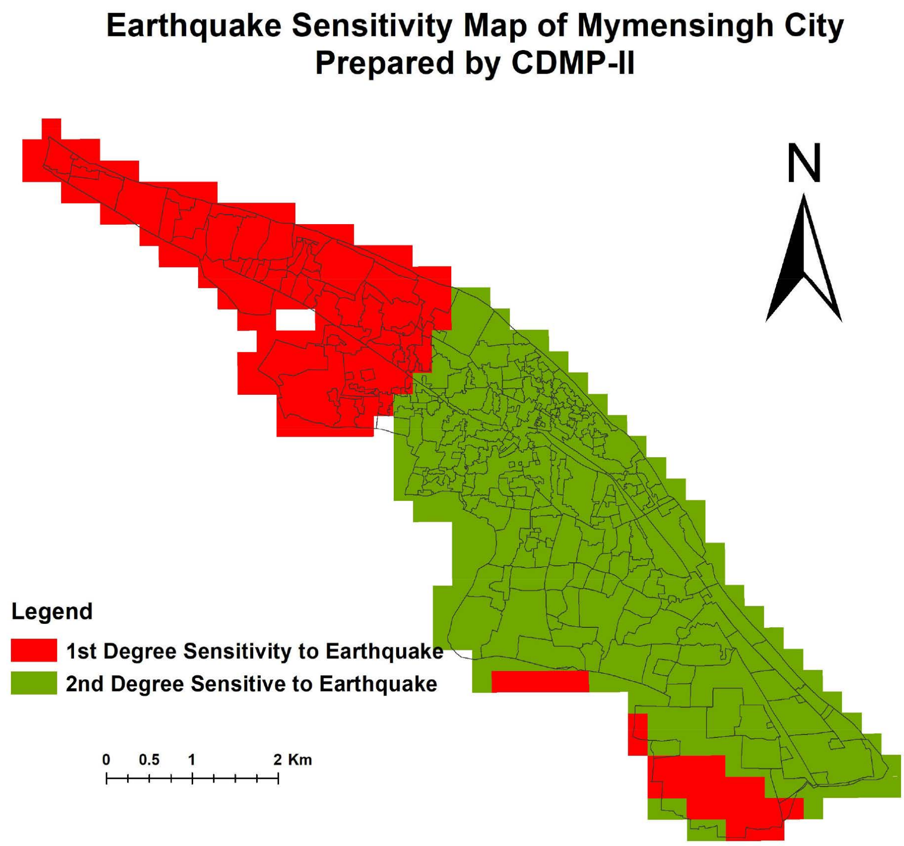

Figure 7. Earthquake sensivity map prepared by CDMP-II.

8. Conclusion

It is very important to assess the seismic vulnerability of a city to build up a safe, sustainable and earthquake resilient place for living. This paper introduced micro-level land-use specific physical seismic vulnerability assessment using combined methodology of AHP and TOPSIS model for Mymensingh city, which is expected to help the policy makers to prioritize special city planning initiatives to reduce earthquake risk. The method used in this paper can be applied in any geographic location, which is earthquake vulnerable. These findings are consistent with the empirical knowledge of the study area and are expected to be helpful in identifying appropriate seismic risk reduction interventions by the local authorities. Socio-economic aspects of vulnerability are overlooked in this study, which can be integrated into further research to develop a more accurate assessment to help in city planning and disaster management.

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Conflicts of Interest

The authors declare no conflict of interest.

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