Earthquake Vulnerability Assessment through Spatial Multi-Criteria Analysis: A Case Study of Quetta City, Pakistan

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Abstract

Vulnerability assessment of an urban area to earthquake hazards is the requirement for attaining sustainable urban resilience. Quetta city is the capital of the province of Balochistan surrounded by mountains with the existence of many active faults. The main objective of the current study was to assess the earthquake vulnerability in Quetta valley. A total of 400 sample size was taken for the primary household survey. Secondary data was taken from the Geological Survey of Pakistan (GSP), the Pakistan Bureau of Statistics (PBS), and the United States Geological Survey (USGS). Data related to the socio-economic and structural components are performed in SPSS software and then transferred into the GIS environment to generate required maps. Whereas indicators related to hazard assessment like Peak Ground acceleration (PGA), Fault lines (FL), and Soil Type (ST) are performed in Arc-GIS to produce the expected maps and results. Analytical Hierarchal Process (AHP) & Weighted Linear Combination (WLC) methods are used to identify earthquake vulnerability. The results of the study reveal that Quetta is highly vulnerable to earthquake hazards in the future; its geology coupled with the human dimension indicates a more disastrous future in the next event. This research study has significant implications for urban planners and provides a risk reduction platform to reduce future earthquake losses and make Quetta city more resilient and sustainable.

1. Introduction

Natural hazards like cyclones, floods, forest fire, drought, volcanic eruption, landslides, tsunamis, and earthquakes are widespread in different regions of our globe (Rendall, 2020). The CRED database for disasters shows that from the beginning of the 19th century, till the present day the reported number of natural disasters has enormously increased. Geophysical and climate-related disasters killed more than one million people and left a further 4.5 Million displaced, injured, and homeless in the last two decades (UNDRR, 2021). Earthquakes are one of the most destructive natural hazards that can impose considerable economic and human losses on communities. Earthquakes have accounted for 12.3% of all-natural disasters, contributing to 25% of economic losses and 57% of all casualties around the world (UNDRR & CRED, 2020).

The world’s 55 percent population is living in cities in this current globalization era. Such a figure is estimated to increase by 67 percent in 2050 (UNDESA, 2020). Based on the latest seismic risk map of the world about 17 megacities around the globe are at high risk including Jakarta, Beijing, Manila, Tokyo, Delhi, Osaka, Chengdu, Istanbul, Lahore, Karachi, Nagoya, Lima, Dhaka, Mexico City, Tehran, Los Angeles, and Bogota. Lahore and Karachi are the two mega cities of Pakistan included in the list but both cities have low seismic rick as compared to Quetta. Though Quetta is not included in the list but still exists in the first seismic zone of the country because the population of the city is less than 10 million people. Enormous population displacement, environmental factors, poor economy, complex demographic nexus, and infrastructural and multifaceted functional systems are the significant contributing factors due to which urban areas are now exposed to various challenges including climate change and natural disasters, etc. (Bilham, 2019). At the global level, some international agreements including Paris

Agreement (2015), Sustainable Development Goals (2015–2030), and Sendai Framework for Disaster Risk Reduction (2015–2030) have been adopted to consider the challenges of an urban environment. These agreements aim to achieve urban resilience and a substantial reduction of losses due to natural disasters (Ji & Lee, 2021). Quantifying, understanding, analyzing, and visualizing the complex nature of vulnerabilities caused by various disasters is the most challenging job. Vulnerability assessments facilitate policymakers, planners, and managers to take judicious policies and actions to reduce the impact of emerging risks and natural disasters (Rendall, 2020).

Pakistan is located with active seismic faults in the region and faced various scale catastrophic earthquake events in history. The big earthquakes that hit the different parts of the country in the last century are Quetta (1935) earthquake, the Makran coast (1945) tsunami, Pattan (1974) earthquake, the Kashmir earthquakes (2005), and Ziarat (2008) earthquake. More than half of the country's population is vulnerable to constant earthquake hazards. More active faults exist in the southern and northern regions of the country. For millions of years, the Indian continental plate has been colliding with the Erosion plate boundary due to which more than (2000) kilometers of Continental lithosphere have been shortened to create huge mountain ranges in central Asia (Bollinger et al., 2004; Molnar and Tapponier, 1975). High seismic activities are produced in the region by continental-continental collision. Various massive mountain structures have been shaped as a result of such collision (for example, Kiether and Sulaiman ranges, Hindukush Mountains, Karakorum Mountains, and the Pamir ranges).

These catastrophic earthquake events in the last century justify the need for vulnerability assessment for implementing seismic risk mitigation strategies in the area. Considering Seismic vulnerability assessment, the formulation of appropriate mitigation strategies at the urban level should include all the relevant dimensions including geological, social, economic, physical, and systematic components. Various studies have been conducted on earthquake risk assessment in the recent past. The most relevant and recent efforts have been performed via a project from (2009–2018) in the shape of the Global Earthquake Model (GEM) on the global scale. The key purpose of the model was to provide a homogeneous global earthquake hazard and risk model by combining and developing various national and regional models. To minimize the multiple disaster risks including earthquake risk, the United Nations Office for Disaster Risk Reduction (UNISDR) developed a Global Assessment Report (GAR) which is another outstanding effort at the global level.

As the vulnerability to an earthquake hazard of any particular area involves various causative factors stemming from different dimensions of vulnerability, it is quite a complex and challenging task to find out an appropriate method that can broadly integrate multiple types of data. Various techniques and methods are available for Vulnerability assessment such as Non-Linear Dynamic Analysis (Peter, 2000), Failure Mechanism Identification and Vulnerability Evaluation (D'Ayala & Speranza, 2003), Capacity Spectrum Method (Daniell, 2011), Turkish Method (Alam & Haque, 2018) and Vulnerability Index Method (Lantada et al., 2010), etc. But all these models and methods require high-level expertise and are complicated. Therefore, multi-dimensional earthquake vulnerability requires an effective, simple, and flexible method of the study area. In earthquake studies, Multicriteria Decision Making (MCDM) methodology is mostly used by researchers (Flores, Escudero and Zamora-Camacho, 2021; Rezaie and Panahi, 2015; Walker et al., 2021; Alizadeh et al., 2018; Alam and Haque, 2018; Rahman, Ansary and Islam, 2015 and Yariyan et al., 2020) that encompasses qualitative and quantitative indicators to manage complication in decision making. Considering the wide acceptability, effectiveness and simplicity we have used the MCDM method in this study to assess the vulnerability of Quetta city to the earthquake by considering the geological, systematic, structural, and socio-economic components of earthquake vulnerability.

2. Study Area

Quetta the capital of the province is located in a very active seismic zone and frequently faced different scales of catastrophic earthquake events with various potential damages in history. In the earthquake zonation map of Pakistan, Quetta is situated in the first zone, which is a very high active zone in the context of the earthquake (PMD, 2007). The entire city was demolished in the (1935) Quetta earthquake with 7.6 magnitudes on the reactor scale (Ahmed 2008; PDMA 2007). Currently, Quetta city has an area of 176 km^2. With the occurrence of an earthquake, some of the other hazards like subsidence, surface fault, landslide, liquefaction, and secondary hazard like fire following are possible to occur. Therefore, it is important to see each vulnerable aspect of earthquake hazard (M. Hajibabaee, Hosseini, & Ghayamghamian, 2012). The study area is divvied into thirteen Zones based on their socioeconomic and demographic profile. The name of each Zone is given in Fig. 1.

3. Parameter’s Selection Of Earthquake Vulnerability Assessment

By analyzing the available data and with the help of a literature review (Cutter, Boruff, & Shirley, 2003; Ainuddin & Routray, 2012 and Alam & Haque, 2021) 24 vulnerability indicators have been chosen for this study based on four vulnerability components such as systematic, structural, socio-economic and geological vulnerability.

3.1.1. Systematic earthquake vulnerability

The accessibility to major facilities of an area such as healthcare services, fire services, emergency shelters, and open spaces are considered systematic vulnerability (Alam & Haque, 2021; Walker et al., 2021) indicators for assessing earthquake vulnerability of the systematic dimension are mentioned in Table 1.

3.1.2. Structural earthquake vulnerability

Based on the seismicity of the study area and geographical location 9 most important structural indicators such as poor buildings, masonry buildings with flexible roofs, building stories, building height, mean road width, building density, building with irregular shapes, pounding possibility, and heavy overhanging (Ainuddin & Routray, 2012a) are considered for the structural earthquake vulnerability shown in Table 2.

3.1.3. Socio-economic vulnerability indicators

The ratio of the vulnerable group such as children below 15 years of age, elderly population above 60 years of age disabled, and women population are taken as human social vulnerability indicators (*Cutter, 2003*). Similarly, literacy rate, the average income of the household, population density, family members in the household, and economically dependent population are considered for the socio-economic vulnerability in this study (Ainuddin, Routray, & Ainuddin, 2015). The indicators are shown in Table 3.

3.1.4. Geological earthquake vulnerability

Fault Lines, Peak Ground Acceleration, and Soil Type (Alam & Haque, 2021) are considered for the geological earthquake vulnerability in this study shown in Table 4.

Table 1
Systematic Earthquake Vulnerability Indicators

Indicators	Vulnerability Level			Supportive literature
	High	Medium	Low	
Distance to open spaces	> 300 m	200–300 m	< 200 m	(Nath, Adhikari, Devaraj, & Maiti, 2015; Rezaie & Panahi, 2015)
Distance to Healthcare center	> I km	500–999 m	< 500 m	(Jena & Pradhan, 2020; Alam & Haque, 2021)
Distance to Emergency Center	> I km	500–999 m	< 500 m	(Meghdad Hajibabaee, Amini-hosseini, & Reza, 2014)
Distance to Fire Services	> 1500 m	1000–1500 m	< 1000 m	(Ahasan, Alam, Chakraborty, & Hossain, 2020; (Alam & Haque, 2021)

Table 2
Structural Earthquake Vulnerability

Indicators	Vulnerability Level			Supportive literature
	High	Medium	Low	
Building with poor infrastructure (%)	> 50	25–50	< 25	(Ghajari, Alesheikh, Modiri, Hosnavi, & Abbasi, 2017; Ainuddin & Routray, 2012b).
Building with flexible roof (%)	> 50	25–50	< 25	(Alam & Haque, 2018; Rahman et al., 2015).
Mean Road Width	< 9 ft	9 ft-15 ft	> 15 ft	(Alam & Haque, 2021; Ghajari et al., 2017; Martins, 2018; Armaş, 2012)
Building with irregular shapes (%)	> 15	10–15	< 10	(Vicente et al., 2014; Alam & Haque, 2021)
Stories of the building	> 3 story	2 story	1 story	(Alizadeh et al., 2018; Nath, Adhikari, Devaraj, & Maiti, 2015)
Building density (acre)	> 15	10–15	< 10	(Armaş, 2012; Jena & Pradhan, 2020; Martins, 2018)
Building Age (year)	> 20	10–20	< 10	(Nath et al., 2015; Zebardast, 2013)
Possibility of pounding (%)	> 15	10–15	< 10	(Alam & Haque, 2018; Alam & Haque, 2021; (Ozmen et al., 2014)
Heavy overhanging (%)	> 20	10–20	< 10	(Alam & Haque, 2018; Ozmen et al., 2014; Alam & Haque, 2021)

Table 3
Socio Economic Vulnerability Indicators

Indicators	Vulnerability Level			Supportive literature
	High	Medium	Low	
Population above 60 years of age (%)	> 06	03–06	< 2	(Cutter & Finch, 2008; Vicente et al., 2014; Ainuddin & Routray, 2012b).
Children below 15 years of age (%)	> 10	06–10	< 5	(Alam & Haque, 2018; Rahman et al., 2015; Zebardast, 2013)
Female population (%)	> 45	30–45	< 30	(Alam & Haque, 2021; Ghajari et al., 2017; Martins, 2018; Armaş, 2012; Armaş, Toma-Danila, Ionescu, & Gavriş, 2017)
Illiteracy rate (%)	> 60	40–60	< 40	(Vicente et al., 2014; Alam & Haque, 2021;
Household income (Average)	Below poverty line	At poverty threshold	Above poverty line	(Alizadeh et al., 2018; Nath; Adhikari, Devaraj, & Maiti, 2015; Rahman et al., 2015)
Family Size (Average)	> 10	5–10	< 5	(Armaş, 2012; Jena & Pradhan, 2020; Martins, 2018)
Population density /(Acre)	> 160 pop/acre	100–160 pop/acre	< 100 pop/acre	(Nath et al., 2015; Zebardast, 2013; Martins, 2018)
Economically dependent families (%)	> 40	20–40	< 10	(Alam & Haque, 2018; Alam & Haque, 2021; (Ozmen et al., 2014)

Table 4
Geological Earthquake Vulnerability Indicators

Indicators	Vulnerability Level			Supportive literature
	High	Medium	Low	
Peak Ground Acceleration	> 0.410	0.351–0.410	0.311–0.350	(Alam & Haque, 2021; (Jena & Pradhan, 2020 and (Rezaie & Panahi, 2015).
Faults Line	< 1000 m	1000–1500 m	> 1500 m	(Jena & Pradhan, 2020; Alam & Haque, 2021)
Soil Type	Soft soil	Stiff soil	Hard soli	(Meghdad Hajibabaee, Amini-hosseini, & Reza, 2014 and Vicente, Ferreira, & Maio, 2014).

4. Methodology

As discussed in the background of the study, earthquake vulnerability is the function of four dimensions including systematic, structural, socio-economic, and geological vulnerability. A detailed overview of the components and methodology are summarized in the flowchart see Fig. 2. Multi-Criteria Decision Making (MCDM) process is used for earthquake vulnerability assessment in this study. Weighted Linear Combination and Analytical Hierarchy Process are widely used (MCDM) techniques by researchers to assess earthquake vulnerability (Armaş, 2012; Alam & Haque, 2018; Alizadeh et al., 2018; Alam & Haque, 2021). Thus, in this study, we used both AHP & WLC methods to identify earthquake vulnerability based on developed indicators mentioned in Fig. 2.

4.1. Analytical Hierarchal process

Assessing earthquake vulnerability, the AHP model involves the main steps are as follows: making a hierarchical process for indicators; designing a reciprocal matrix of the factors from pairwise comparison. Similarly, for the computation of eigenvector and eigenvalue (Saaty, 1980) developed a nine-point scale to identify the weight of indicators, and testing the consistency of the decisions through the following equations.

$$CI = \frac{\mathrm{max} - n}{\mathrm{n} - 1}$$

1

$$CR = \frac{CI}{RI}$$

2

Were, λ_{max} is the principle or maximum eigenvalue of the matrix and RI represents the inconsistency random index which depends on the numbers of indicators of vulnerability assessment.

Table 5
Pairwise comparison and preference scale in AHP (Saaty, 1980)

Relative intensity of Importance Decreasing	Equal Importance	Relative Intensity of Importance Increasing
1/9 1/8 1/7 1/6 1/5 1/4 1/3 1/2	1	2 3 4 5 6 7 8 9

Table 6
Saaty (1980) developed Random Index (RI) values for various number of indicators as shown in the below Table

Indicators	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	1.42	1.32	1.41	1.45

4.2. Weighted Linear Combination Method

Combining indicators by applying a weight to each indicator from the AHP model, WLC is an extensively used applied MCDM technique. Using a weighted overlay analysis in Arc-GIS all the weighted layers of vulnerability indicators and their sub-components are combined through the following equation as;

$$W = \sum_{J=1}^{n} (wi * xi)$$

3

In Eq. 3, W represents the index weight score of each Zone in the map, W_i represents the weight of each indicator, X_i and n represent the number of indicators.

For this study, 24 earthquake vulnerability indicators (4 systematic, 9 structural, 8 socioeconomic, and 3 Geological vulnerability indicators) are formed for a comparison matrix based on the three experts' opinions having relevant expertise in the field. The geometric mean is calculated from the expert's opinions to combine their opinions in a single matrix, as mentioned in Tables (7, 8, 9, and 10). The overall combined comparison matrix of the earthquake vulnerability assessment is presented in Table 11. The flow chart of vulnerability assessment is given in Fig. 2.

Table 7
Pair-wise Comparison Matrix, Weight & Consistency Ratio of Systematic Earthquake Vulnerability Indicators using AHP Model Based on the Expert's Opinion

Systematic Indicators	1	2	3	4	Weight	Consistency Ratio & Radom Index
1. Distance to open spaces	**1.00**	0.50	1.20	1.50	0.25	CR = 0.05, RI = 0.90
2. Distance to Healthcare center	2.00	**1.00**	1.80	1.30	0.28	
3. Distance to Emergency Center	0.83	0.55	**1.00**	0.70	0.19	
4. Distance to Fir Service	0.67	0.77	1.42	**1.00**	0.28	

Table 8
Pair-wise Comparison Matrix, W & C Ratio of Structural Earthquake Vulnerability Indicators using AHP Model Based on the Expert's Opinion

Structural Indicators	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**W**	**CR & RI**
1. Stories of the Building	**1.00**	0.30	0.60	0.30	0.70	0.70	0.65	1.80	1.25	0.076	CR = 0.03, RI = 1.42
2. Building with poor condition	3.33	**1.00**	1.25	0.69	1.10	1.20	0.80	1.25	1.10	0.120	
3. Masonry building	1.67	0.80	**1.00**	0.29	0.55	0.69	0.48	1.26	0.80	0.078	
4. Ponding	3.33	1.44	3.44	**1.00**	1.44	1.82	0.80	2.10	1.25	0.174	
5. Building with irregular shapes	1.42	0.90	1.81	0.69	**1.00**	0.90	0.69	1.55	1.25	0.110	
6. Overhanging	1.42	0.83	1.44	0.54	1.11	**1.00**	0.70	3.10	2.55	0.130	
7. Road Width	1.53	1.25	2.08	1.25	1.44	1.42	**1.00**	1.80	1.10	0.146	
8. Building density	0.56	0.80	0.79	0.47	0.64	0.32	0.55	**1.00**	1.00	0.068	
9. Building with basements	0.80	0.90	1.25	0.80	0.80	0.39	0.90	1.00	**1.00**	0.090	

Table 9
Pair-wise Comparison Matrix, W & C Ratio of Geological Earthquake Vulnerability Indicators using AHP Model Based on the Expert's Opinion

Geological Indicators	**1**	**2**	**3**	**Weight**	**CR & RI**
1. PGA	**1.00**	0.72	1.69	0.343	CR = 0.008, RI = 0.58
2. Nature of the soil	1.38	**1.00**	1.80	0.435	
3. Fault Lines	0.59	0.55	**1.00**	0.221	

Table 10
Pair-wise Comparison Matrix, W & Ratio of Socio-economic Earthquake Vulnerability Indicators using AHP Model Based on the Expert's Opinion

Structural Indicators	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**W**	**CR & RI**
1. Family income	**1.00**	2.29	1.33	0.70	0.70	1.25	0.80	1.29	0.123	CR = 0.01, RI = 1.41
2. Family size	0.43	**1.00**	0.40	0.40	0.40	0.90	0.55	0.80	0.065	
3. Population density	0.75	2.50	**1.00**	0.33	0.33	1.55	1.20	1.25	0.106	
4. Population above 60 years	1.42	2.50	3.03	**1.00**	1.00	2.55	1.77	3.00	0.209	
5. Population below 15 years	1.42	2.50	3.03	1.00	**1.00**	2.50	1.80	3.10	0.210	
6. Population with dependency	0.80	1.11	0.64	0.39	0.40	**1.00**	0.40	1.55	0.079	
7. Women population (%)	1.25	1.81	0.83	0.56	0.55	2.50	**1.00**	2.25	0.133	
8. Illiteracy rate (%)	0.78	1.25	0.80	0.33	0.32	0.64	0.44	**1.00**	0.071	

Table 11
Combined Pair-wise Comparison Matrix, W & C Ratio of Composite Earthquake Vulnerability using AHP Model Based on the Expert's Opinion

Geological Indicators	**1**	**2**	**3**	**4**	**Weight**	**CR & RI**
1. Geological	**1.00**	2.25	1.80	2.55	0.408	CR = 0.01, RI = 0.90
2. Structural	0.44	**1.00**	0.90	2.75	0.236	
3. Systematic	0.55	1.11	**1.00**	1.90	0.233	
4. Socio-economic	0.39	0.36	**0.52**	**1.00**	0.121	

4.3. Composite vulnerability index development

Each component of earthquake vulnerability has its significance but the integration of all components via a composite vulnerability index is very important for stockholders and policymakers for devising proper mitigation strategies and enhancing the resilience of urban areas (Armas, 2012; Walker et al., 2014). In this study a composite vulnerability index is developed, combining all the components of vulnerability.

Composite vulnerability index = Wsys*Ysys + Wstr*Ystr + Wgeo*Ygeo + Wsocio*Ysocio

Here Wi and Y_i denoted the weights and index values of systematic, structural, geological, and socio-economic vulnerability respectively.

4.4. Data collection

Data for this research study was collected from both primary and secondary sources, including the Pakistan Geological Survey (PGS), the Pakistan Bureau of Statistics (PBS), and the Pakistan Metrological Department (PMD). The socio-economic and structural earthquake vulnerability indicators are collected from the field. Similarly, systematic earthquake vulnerability is calculated through the point feature using ArcGIS.

5. Earthquake Vulnerability Maps Preparation And Data Analysis

Analytical Hierarchical Process (AHP) has determined the weights of various components and sub-indicators within the components of earthquake vulnerability. For data analysis and processing, the use of a Geographical Information System (GIS) is beneficial and plays a vital role in this stage (Alam & Haque, 2018). Similarly, Statistical Package for Social Sciences (SPSS) is also used as a supportive data analysis tool in this study. The collected data is processed in the following order sequentially. Initially, earthquake vulnerability scores and socio-economic data of Quetta city were stored in the SPSS software. Then, the ArcGIS environment is used for geo-processing the geological and structural earthquake vulnerability of Quetta city. In the next step, databases were combined with the study area map using ArcGIS. The systematic earthquake vulnerability score was joined and reclassified with the study area map of Quetta city using ArcGIS. Finally, WLC is used to prepare the composite earthquake vulnerability map of the study area based on the reclassified score using ArcGIS.

5.1. Systematic Vulnerability

The Geometric mean is used to identify the distances from the center of each Zone in the Arc-GIS environment to measure the systematic vulnerability of the study area. The four main indicators used for systematic vulnerability are open spaces, emergency centers, hospitals, and fire services. Results of Fig. 3 show that 4 out of 13 Zones (Hazar-Gungi, Quetta East, Quetta North, and Samungli) are found in high earthquake vulnerable Zones in terms of systematic vulnerability due to long distances among Zones and facilities available within the city. Similarly, 4 Zones of Quetta city (Satellite Town, Saryab, Hazara Town, and Quetta Cantt) fall in the medium systematic earthquake vulnerable Zones. Among the 13 Zones of the study area, only five Zones have low systematic earthquake vulnerability. These Zones have close spatial inks with four major facilities. Indicator-wise assessment is carried out on a scale of 0–1 of systematic earthquake vulnerability of Quetta city shown in Fig. 5.3. Based on the results of Fig. 8, most of the Zones in Quetta city are systemically have medium to high vulnerability due to their long spatial links from health care centers (0.29), fire services (0.28), open spaces (0.25), and emergency centers (0.18) respectively. In a destruction-type event like an earthquake hospital is the primary and significant facility for emergency response in an affected community. Only ten Government hospitals are available in

Quetta city. However, most of these hospitals are spatially located in the middle and core areas of the city, while 4 Zones are outside of these hospitals' Service Areas. The earthquake can also damage and destroy the gas lines, power stations of electricity, or other causative fire sources outside or inside of a building, which can cause the threat of fire hazards in the community after an earthquake disaster (Alam & Haque, 2021). But there are only 4 fire service stations located in the middle part of the city area of 1.16 million population. These four service stations are located only in two Zones (Centrum of Quetta and Jinnah Town). Some Zones have more than 10 Km long distances from the fire services, and thus it becomes difficult to provide efficient and timely rescue and fire services to these Zones during earthquake emergencies. Disaster emergency centers located within communities play a vital role in timely emergency response. In Quetta city, PDMA Balochistan had designed four emergency centers located only in two Zones (Centrum of Quetta city and Jinnah Town). Again these crucial services were not uniformly distributed in each Zone for earthquake emergency response. Most of the Zones have more than 8 Km long distances from emergency centers. All the four emergency centers are located in the middle part of Quetta city, which makes the remote Hazar Gunji, Samugli, Quetta East, and Quetta North Zones systematically high vulnerable.

5.2. Structural Earthquake Vulnerability

The indicators of structural earthquake vulnerability relate to the built-up environment factors such as bridges, buildings, roads, etc. indicators related to structural earthquake vulnerability have a potential influence on earthquake damage and the vulnerability of a community prone to earthquake hazards (Alam & Haque, 2021). In this research study, the nine most significant structural indicators are carried out to assess the structural earthquake vulnerability of Quetta city. Results of the structural earthquake vulnerability of Quetta city show that; five Zones among the thirteen are highly vulnerable in terms of structural earthquake vulnerability. These include (Hazraganji, Quetta East, Saryab, Pashtoon Abad, and Kharotabad). Similarly, Samungli, Quetta North, Centrum of Quetta, and Haazar Town have medium structural earthquake vulnerability. Only four Zones have low structural earthquake vulnerability as shown in Fig. 4.

Further the results of the analysis show that; about (40.53%) of buildings in the study area are made with poor quality infrastructure and most of these buildings are located in the eastern and northern parts of the city. Almost 40% and 13% of the buildings within Zones of Quetta city are built with flexible roofs and irregular shapes respectively. Road width is one of the influential indicators of structural earthquake vulnerability. The road and streets with more width have low vulnerability during emergency response, fire rescue, and evacuation process. Among the Zones, four Zones have less than 10 feet of road width, which makes the Zones vulnerable during earthquake response and emergencies.

Building story is also considered for structural earthquake vulnerability. Building with more stories has a high level of vulnerability. In each zone of the study area, the building exists with more than two stories, but the high-rise buildings with 6 stories and basements are observed in the centrum of Quetta city, Satellite Town, and Jinnah Town.

Building density per acre is also considered one of the important indicators of earthquake vulnerability. Zones with more than 15 households per acre are considered highly vulnerable in terms of structural earthquake vulnerability. Results of the analysis show that four Zones (Centrum of the city, Hazargunji, Hazara Town, and Samungli) are declared highly vulnerable Zones of the study area in terms of building density per acre.

Building age is also one of the important indicators in earthquake risk identification. Buildings with less than 10 years of age have a low level of vulnerability, between 10–20 years of age have a medium level of vulnerability, and buildings with more than 20 years of age are considered highly vulnerable. Three Zones (Centrum of Quetta, Quetta Cantt, and Quetta East) among the thirteen Zones have been found highly vulnerable in terms of building age.

Quetta city is one of the oldest cities in Balochistan, a large portion of the building were made before the designing of building codes. About 17% of the buildings in the study area have a very high chance of pounding during a quake. Three Zones (Saryab, Hazargungi, and Pashtoon Abad) are highly vulnerable in terms of the possibility of the pounding of buildings.

Identification of overhanging buildings in urban areas is one of the important aspects of earthquake risk quantification. Overhangs are the components of physical structures such as balconies, cantilevers, etc. these elements are hanging outside with less support and have a high chance of falling during an earthquake disaster. Centrum of Quetta, Hazargunji, and Hazar Town are highly vulnerable Zones in terms of heavy overhanging.

The map of the structural earthquake vulnerability is presented in Fig. 4. It is important to know which indicator has most influenced the structural earthquake vulnerability of Quetta city to prioritize urban planning and management implications. Indicator-wise assessment is carried out on a scale of 0–1 of structural earthquake vulnerability of Quetta city shown in Fig. 9. Results of the analysis of the overall structural earthquake vulnerability found that high pounding possibility (0.17), road width (0.14), the possibility of overhanging (0.13), building with poor condition (0.12), building with irregular shapes (0.11), and building with Flexible roofs (0.09), respectively are the significant contributing factors of structural earthquake vulnerability in Quetta city.

5.3. Socio-Economic Vulnerability

To identify the complete and comprehensive vulnerability condition of Quetta city, it is also important to know the socio-economic conditions of people living in various zones of the study area. In recent years, experts have not paid proper attention to socio-economic indicators therefore this study also focused on the socio-economic parameters for socio-economic earthquake vulnerability. In this research study, eight important indicators like the children's population, population above 60 years of age, women's population, dependent population, illiteracy rate, family members, family, income, and population density are considered for socio-economic earthquake vulnerability.

The identification of human vulnerable groups for effective disaster response is so important. Based on literature and past studies four special groups i.e. children, aged, women, and disabled people in a community are more vulnerable during the evacuation to any natural hazard like an earthquake, tsunami, and flood (Ainuddin et al., 2015b). Results of the analysis show that about 15% and 6% of the total population of Quetta city are children and aged population respectively. The higher ratios of children and aged people are mainly found in Saryab, Pashtoon Abad, Kharot Abad, Quetta East, and Quetta North. In these five Zones, the ratio of child population less than 10 years of age is more than 15% and the ratio of aged people more than 60 years of age is more than 6%, which makes the Zones highly vulnerable to earthquake hazards.

The overall ratio of the female to the male population in Quetta city is about 48:52. But these ratios vary from Zone to Zone. Zones with more than 45% women population are considered highly vulnerable. The ratio of women population of more than 45% has been found in the three Zones i.e. (Samungli, Hazara Town, and Quetta North). The literacy rate of Quetta city is about 59%. This is somewhat high in the context of Balochistan. This percentage varies from Zone to Zone across the study area. Zones with a more than 60% illiteracy rate are considered highly vulnerable Zones. Four Zones (Saryab, Quetta East, Pashtoon Abad, and Kharot Abad) of Quetta city are found highly vulnerable Zones in terms of an illiteracy rate of more than 60%.

Income is also one of the important indicators of socio-economic vulnerability. The average household income varies from Zone to Zone of Quetta city due to the long distances of Zones from proximity to central business markets, employment opportunities, industry, etc. In this study, income is categorized into three categories. The per capita income which is $1.25 per person per day is taken as a threshold level to assess the poverty level in the study area. Households with less than the given benchmark are considered highly vulnerable. Four Zones of the study area (Saryab, Kharot Abad, Pashtoon Abad, and Quetta east) are the most vulnerable in terms of economic conditions. The city of Quetta is the most highly populated in the province. The total population of the city is about 1.16 million. Three Zones (Centrum of Quetta, Quetta east, Pashtoon Abad, and Salim town) are the most vulnerable Zones due to the congested population.

Family size is also one of the influential social parameters in earthquake vulnerability. Households with large family sizes are more vulnerable in a disaster situation. Households with an average of more than 10 family members are considered highly vulnerable as shown in. In the study area, three Zones (Quetta east, Pashtoon Abad, and Kharot Abad) are highly vulnerable in terms of greater family size. Generally, children populations below 15 years of age and above 60 years of age are considered economically vulnerable and dependent populations. (Alam et al., 2019c). Results of the analysis show that about 31% of the population of Quetta city is economically dependent and the values of dependency vary from Zone to Zone of the study area. Six out of thirteen Zones (Quetta north, Quetta east, Hazargunji, Saryab, Pashtoon Abad, and Kharot Abad) are highly vulnerable Zones in terms of income dependency. Considering all the analysis and indicators of the aforementioned socio-economic vulnerability component, the result confirms that 6 out of 13 Zones of Quetta city are highly vulnerable to earthquake hazards in terms of socio-economic vulnerability as shown in Fig. 5.6. Whereas three out of thirteen Zones have a medium level of vulnerability and only 4 Zones (Quetta Cantt, Centrum of Quetta, Jinnah Town, and Satellite Town) are the low vulnerable Zones in terms of socio-economic vulnerability. The indicators-wise assessment of the Zones of Quetta city for socio-economic vulnerability is shown in Fig. 10. The study area is mainly vulnerable due to the high percentage of children population (0.21), elderly population (0.20), a high percentage of women (0.13), low family income (0.12), population density (0.10), dependent population, and illiteracy rate with (0.07), and family size with (0.06) are the aforementioned parameters which makes the city highly socio-economically vulnerable.

5.4. Geological Earthquake Hazard and Vulnerability Assessment

Geological vulnerability is based on three main components; fault lines, soil type, and PGA. Based on the results of geological dimensions; four out of thirteen Zones (Hazargunji, Samungli, Hazara Town, and Quetta North) are highly vulnerable, and four Zones (Quetta East, Kharot Abad, Salim Town, and Jinnah Town) as medium vulnerable, and five Zones (Satellite Town, Pashtoon Abad, Saryab, Centrum of the city, and Quetta Cantt) as low vulnerable in term of geological vulnerability in Quetta city as shown in Fig. 6. Similarly, Fig. 11 shows the influence of each geological dimension on a scale of 0–1 earthquake hazards. The highest influence of soil type (0.43) is observed, followed by Peak Ground Acceleration (0.34). Whereas, fault lines (0.22) have the least influence among the three geological dimensions used in the analysis. The soil of the study area is classified into three categories hard, swift, and soft. The energy quickly passes with a low level of amplitude through hard soil and thus causes minimum destruction to the buildings on the surface. But soft soil increases the amplitude and slows down the energy of the motion of a quack, which is the main cause of earthquake destruction to the infrastructure. The PGA value of Quetta city varies from 0.311 to 0.481 g. This range is declared a severe perceived shaking range by USGS, Instrumental Intensity Scale (Bendito et al., 2014). The highest PGA values are observed in the northern and western parts of Quetta city, which will cause huge destruction in the future. The fault lines are also considered one of the important dimensions of geological earthquake vulnerability. The two fault lines observed in the study area pass through different Zones. The closest Zones with fault lines are considered highly vulnerable.

5.5. Composite/Overall Earthquake Vulnerability

Results of the composite earthquake vulnerability are based on 24 important indicators jointly taken from four components (socio-economic, structural, geological, and systematic) of earthquake vulnerability. The combined result of the composite earthquake vulnerability shows that 7 out of thirteen Zones of Quetta city are highly vulnerable to all four components of vulnerability as shown in Fig. 7. Four Zones have a medium level of vulnerability and only two Zones are considered low earthquake vulnerable Zones in the study area. To identify the influence of each indicator on the overall earthquake vulnerability of Quetta city, indicator wise assessment is carried out on a scale of 0–1 as shown in Fig. 12. The policymakers, development agencies, and urban planners may prioritize the earthquake mitigation and disaster risk reduction strategies in Quetta city based on the aforementioned earthquake vulnerability indicators. Based on the results of Fig. 12, it is found that the soil type (0.43), PGA (0.34), distance to Hospitals (0.24), distance to fire service stations (0.22), Fault lines (0.22), open spaces (0.21), aged population (0.21), children population (0.20), and the possibility of overhanging (0.17) respectively are the significant and topmost influential indicators that make the Quetta city highly vulnerable to earthquake hazard. Whereas building with irregular shapes (0.11) and population density (0.10) have a medium-level influence on earthquake vulnerability in the study area. Similarly, illiteracy rate (0.07), dependent population (0.07), building stories (0.07), building with flexible roofs (0.07), family size (0.06), and building density (0.06) have to somewhat low influence on overall earthquake vulnerability in the study area as shown in Fig. 12.

6. Conclusion

The tragic consequences of major earthquakes in the recent past at various locations across the globe justify the seismic risk analysis and emergency need in the physical planning practices. Involving earthquake risk in urban planning in less developed countries like Pakistan is even more challenging due to resource lacking, deficiency of skills human resources and technological backwardness, etc. The current study presents a scientific approach, cost-effective and simple measurement of seismic vulnerability with the application of GIS and MCDM techniques for the comprehensive earthquake vulnerability assessment considering all aspects of seismic vulnerability. There are 24 distinct indicators of earthquake vulnerability included in this study as a whole from socio-economic, structural, systematic, and geological components. The results of this study may be helpful for urban planners and authorities to protect human life, mitigate seismic risk, and identify the risk zones, and resource allocation by targeting vulnerable locations and groups and deciding on development control interventions. Though 24 distinct indicators of vulnerability from four dimensions were used in this research study, some other important factors like a soft story, the slope of the earth, short columns, overflies, etc. are not included in this study due to the unavailability of data that can be targeted in further research. Spatial analysis of seismic vulnerability using MCDM and GIS is also beneficial for further hazard and risk assessment, especially in developing countries.

Declarations

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Data Availability

Not Applicable

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Not Available

Competing interests

There is no competing interest of authors

Consent to participate

The authors declare their full consent to the participation of this article.

Consent for publication

The authors declare their full consent to the publication of this article

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Figures

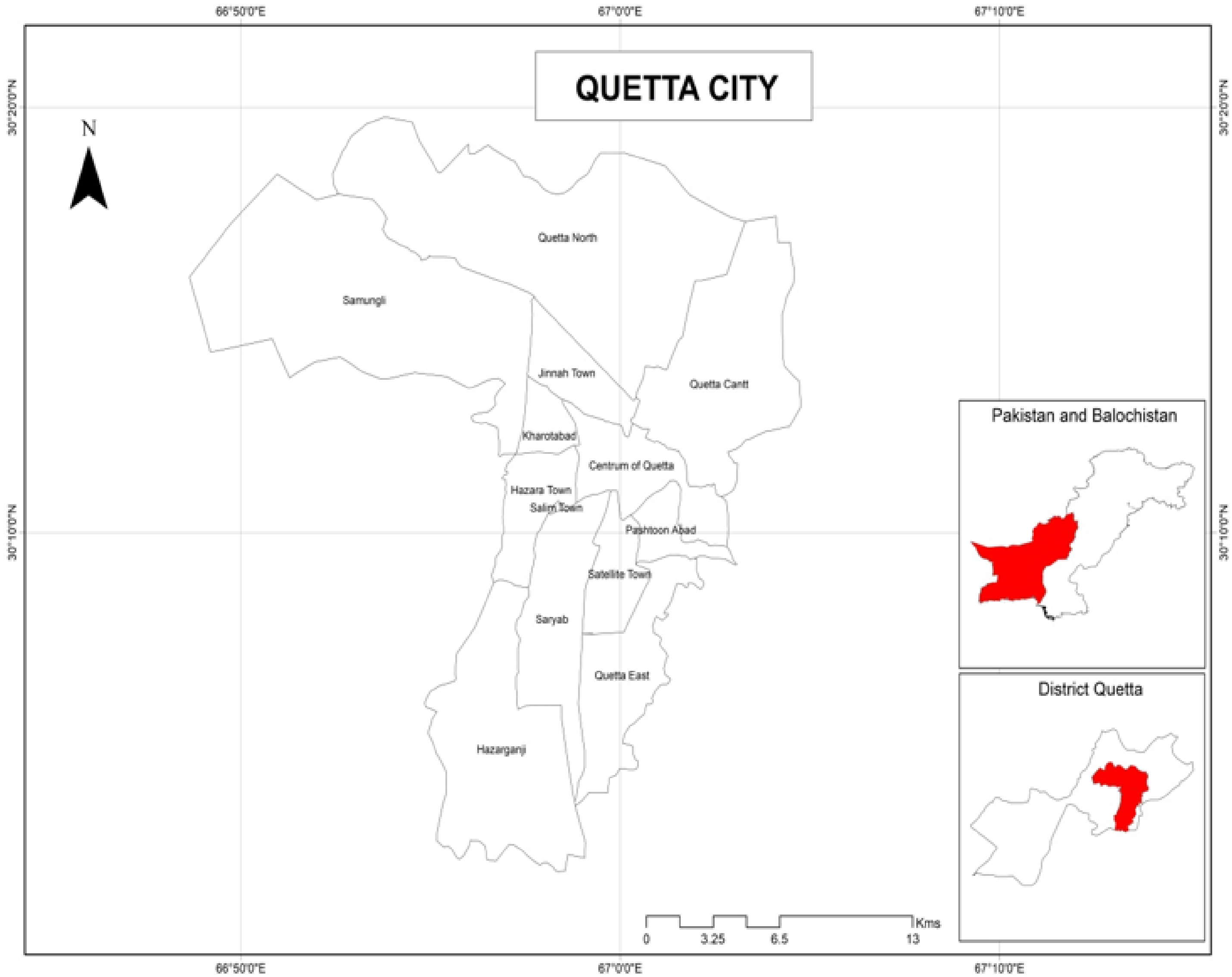

Figure 1

Study Area Map

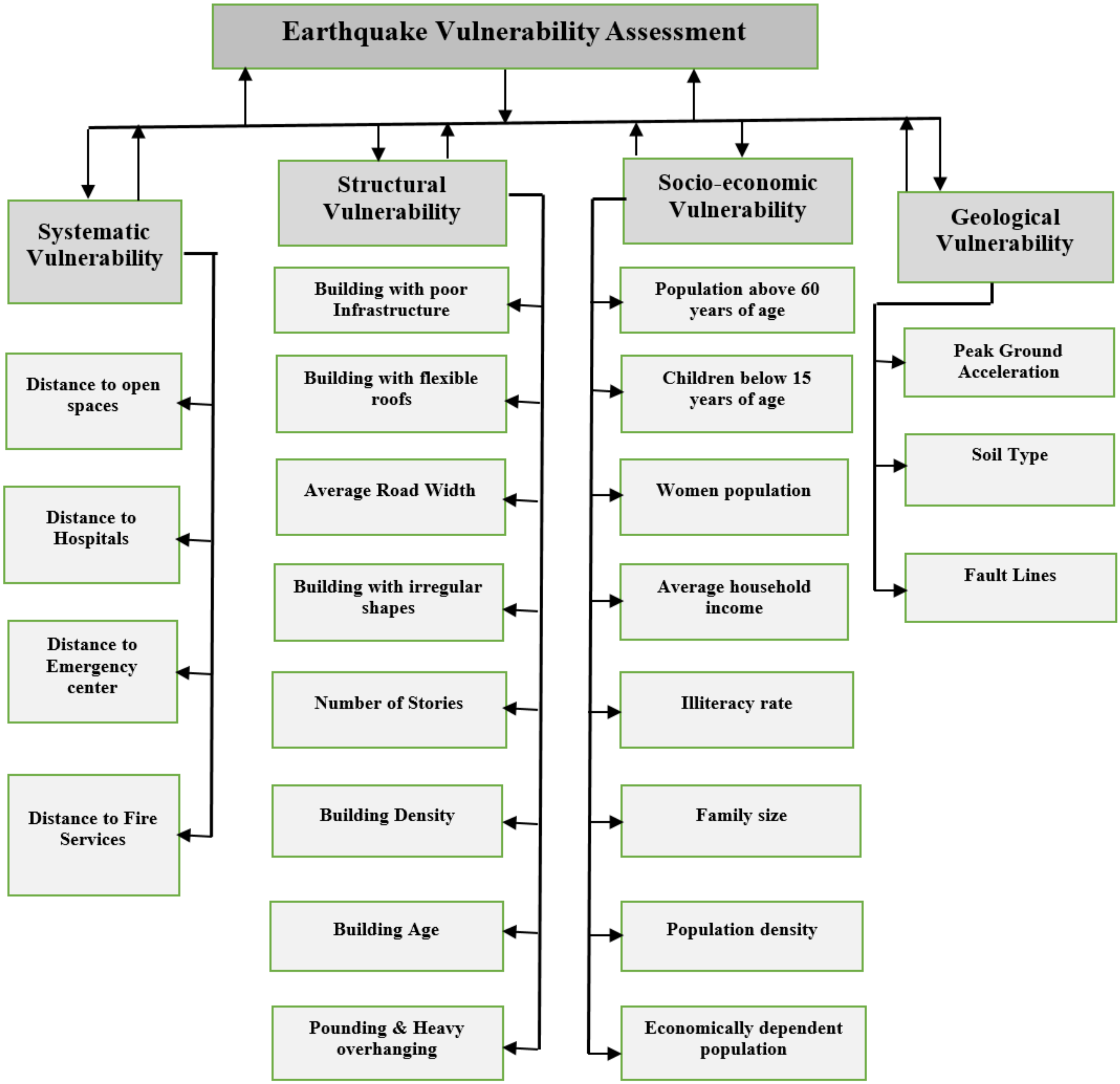

Figure 2

Flow Chart Representing Earthquake Vulnerability Assessment

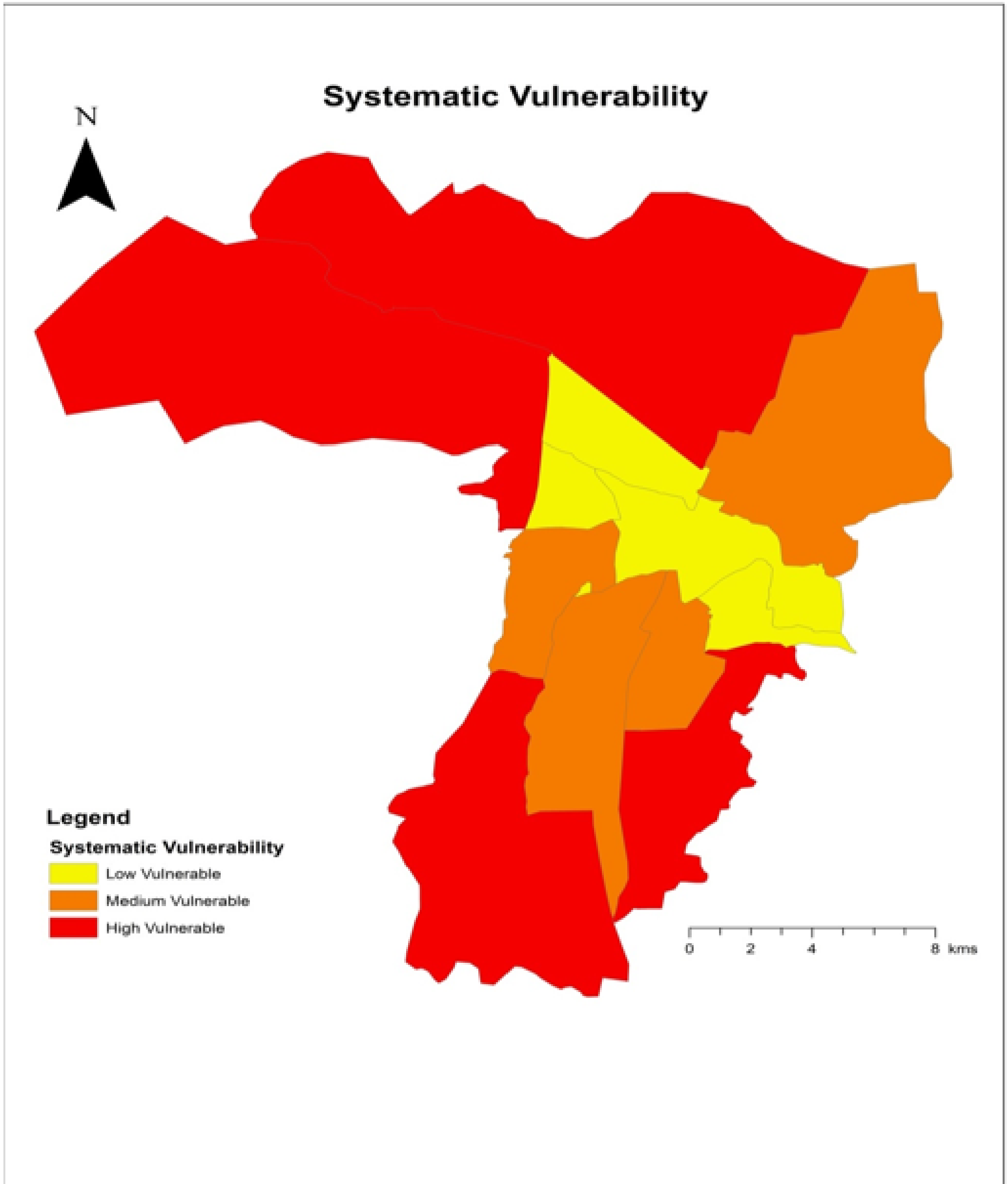

Figure 3

Systematic Earthquake Vulnerability Map

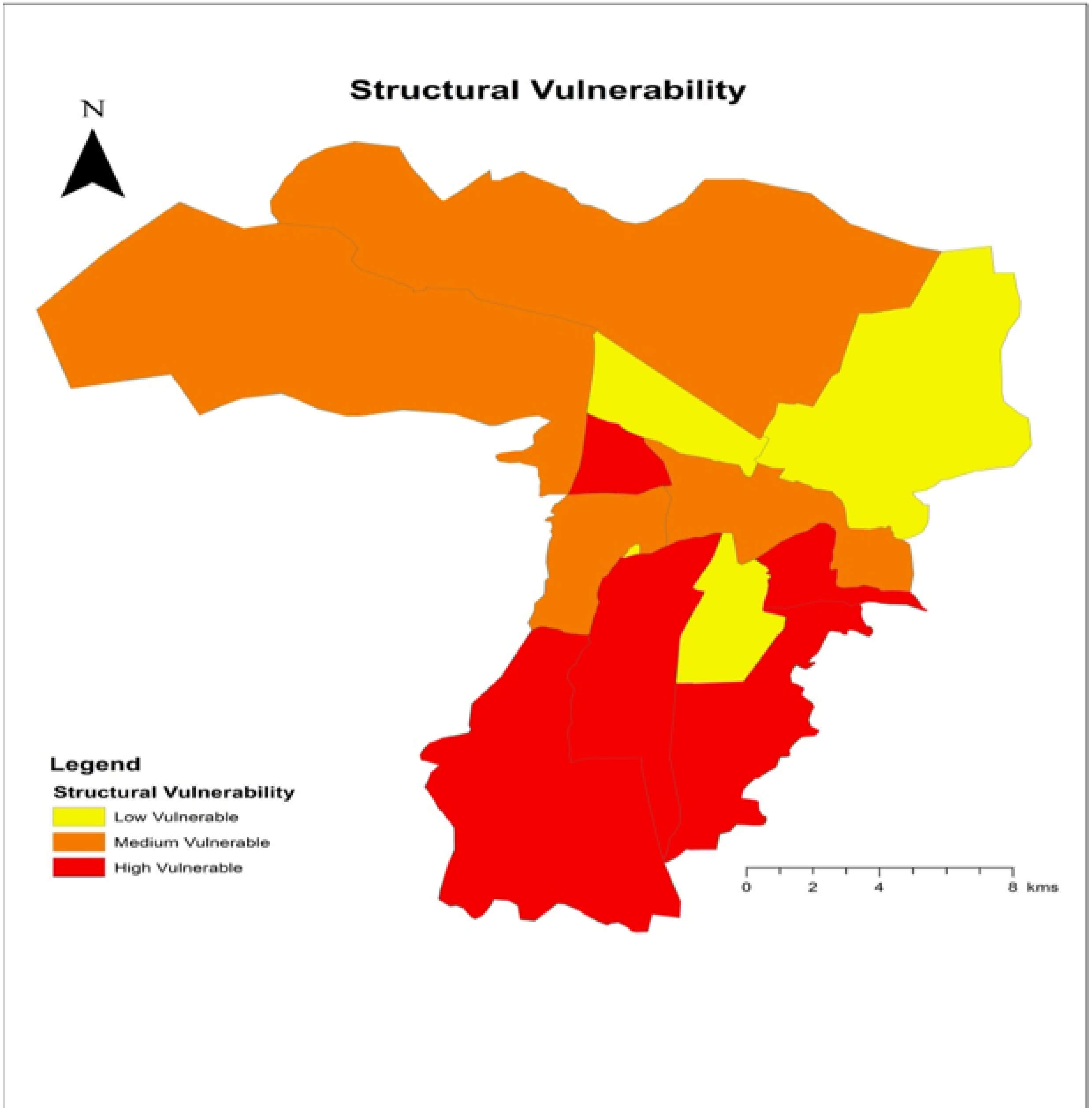

Figure 4

Structural Earthquake Vulnerability Map

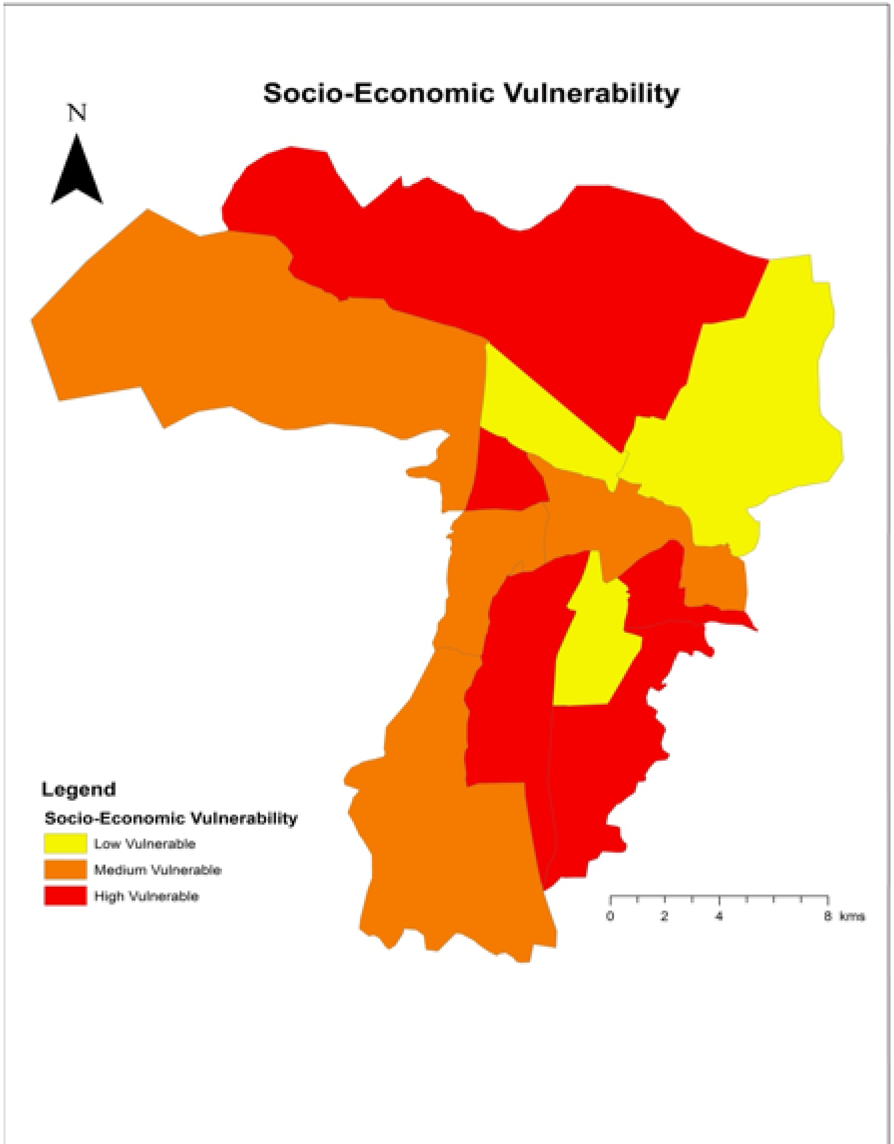

Figure 5

Socio-Economic Earthquake Vulnerability Map

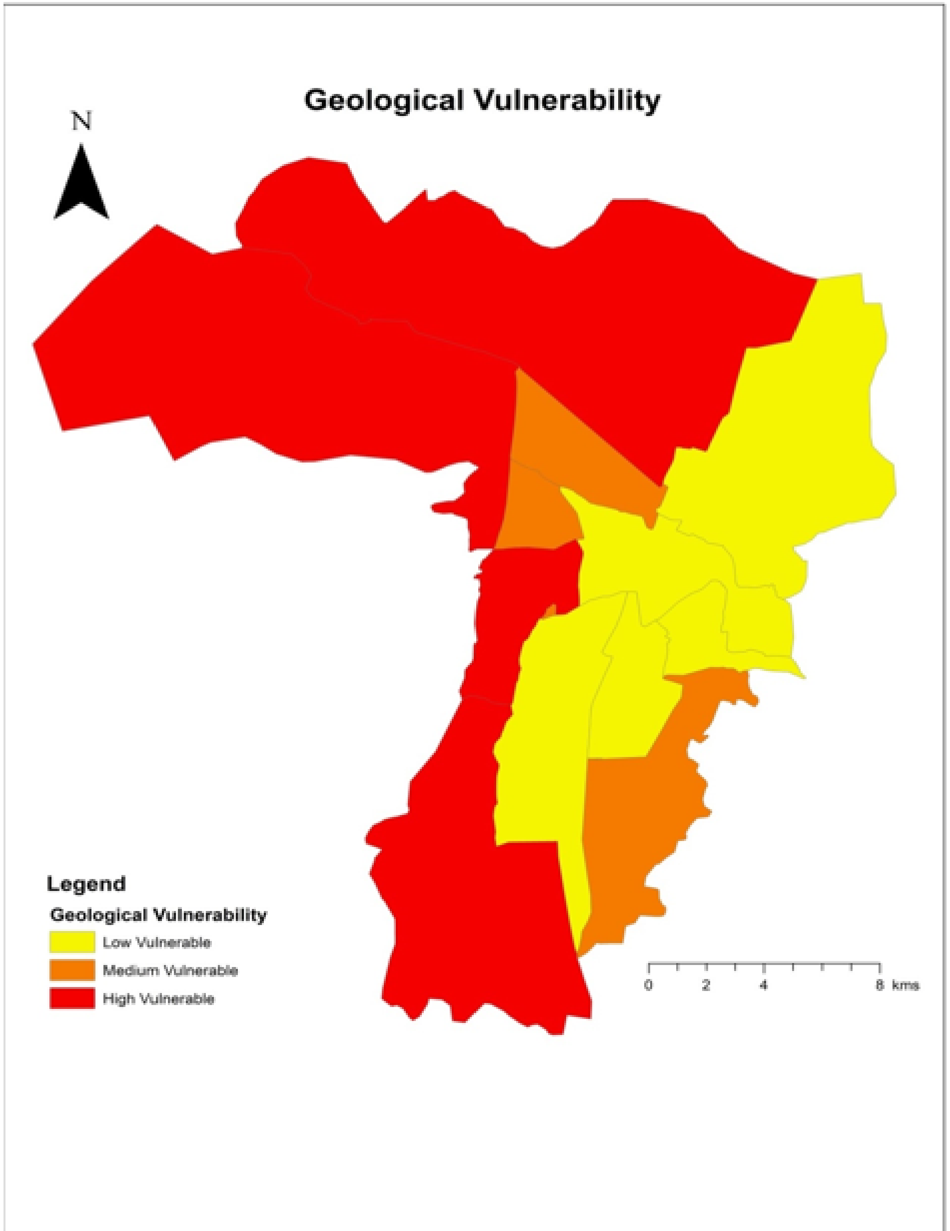

Figure 6

Geological Earthquake Vulnerability Map

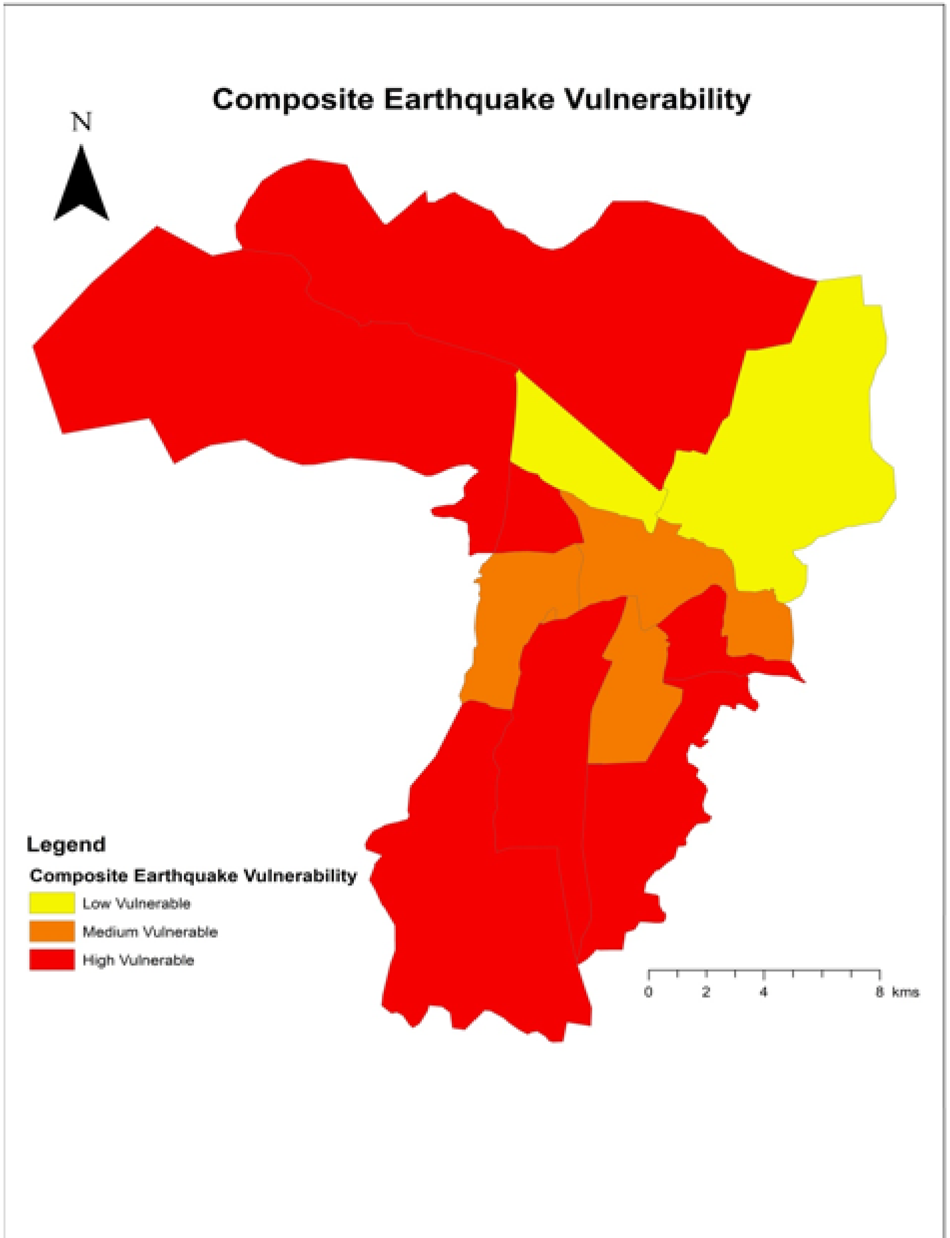

Figure 7

Composite Earthquake Vulnerability Map

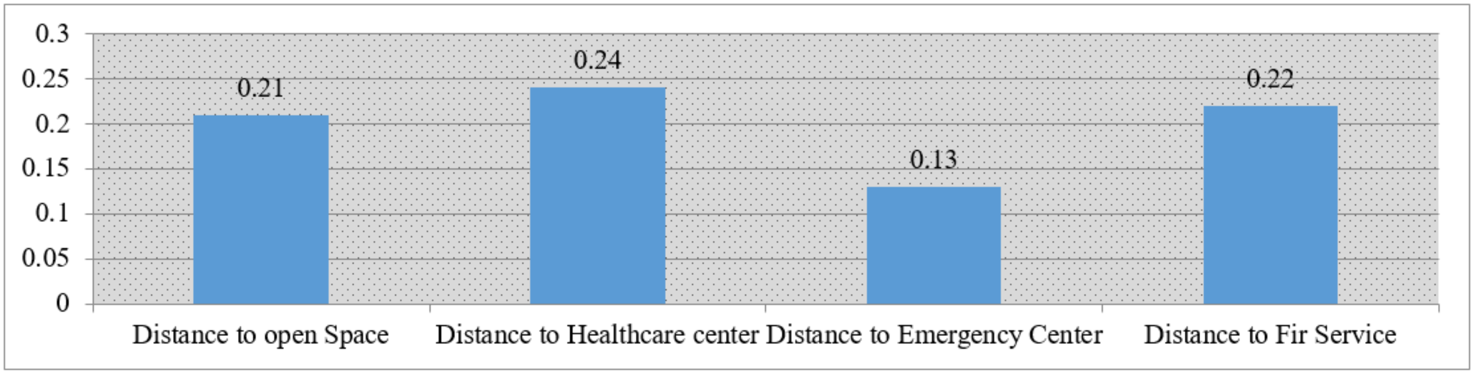

Figure 8

Influence of Systematic Indicators on Earthquake Vulnerability

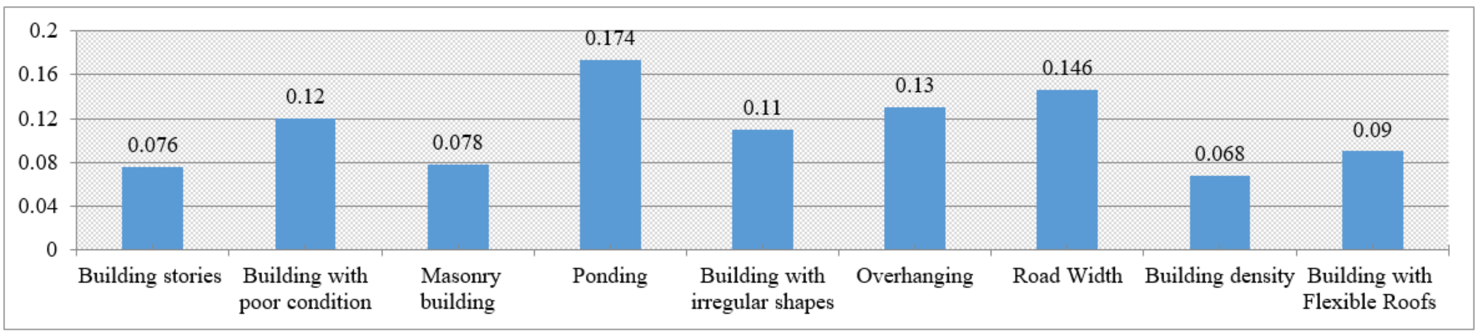

Figure 9

Influence of Structural Indicators on Earthquake Vulnerability

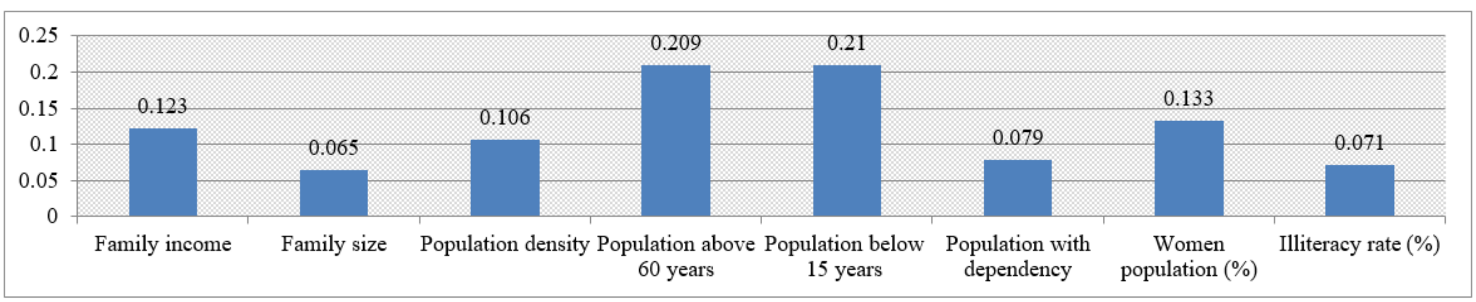

Figure 10

Influence of Socio-Economic Indicators on Earthquake Vulnerability

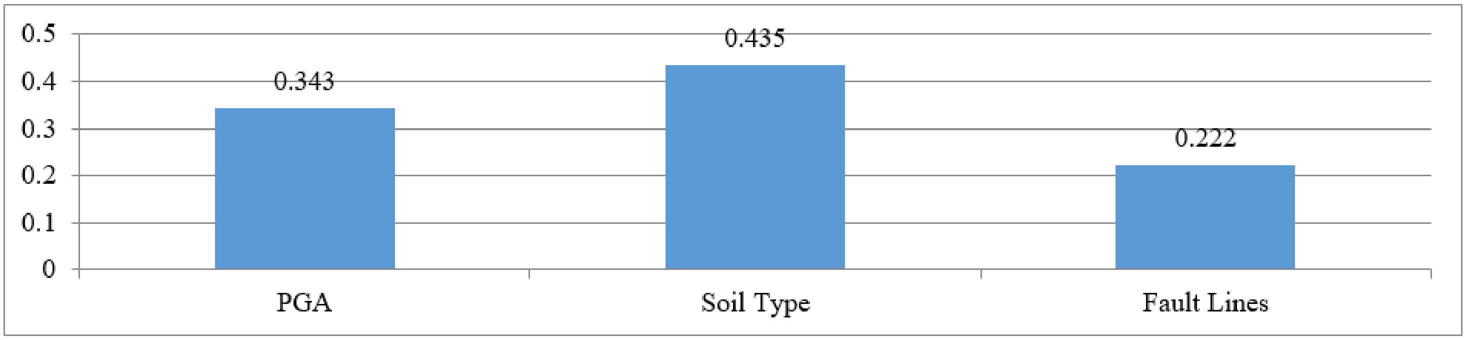

Figure 11

Influence of Geological Indicators on Earthquake Vulnerability

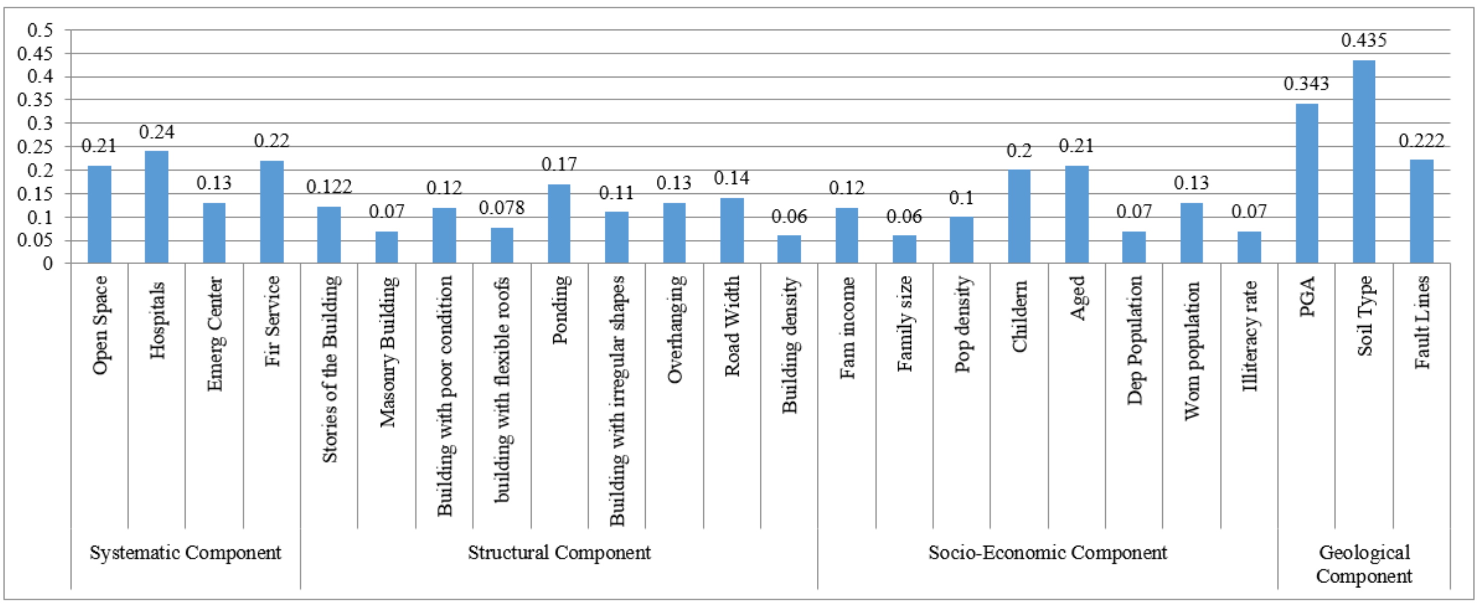

Figure 12

Influence of Composite Earthquake Vulnerability Indicators on Earthquake Vulnerability