Proceedings of 9th IOE Graduate Conference
Peer Reviewed
ISSN: 2350-8914 (Online), 2350-8906 (Print)
Year: 2021 Month: March Volume: 9

Study of Urban Vulnerability to Multi-hazards in Biratnagar Metropolitan City, Nepal

Suman Chapagain [a], Sumeet Moktan [b], Akhilesh Kumar Karna [c]

[a, c] *Department of Civil Engineering, Pulchowk Campus, IOE, TU, Nepal*
[a, b] *Himalayan Risk Research Institute, Bhaktapur, Nepal*
Corresponding Email: [a] sumanchapagain@hri.org.np

Abstract

Cities are exposed to different types of threats. They also consist of densely populated assets. Such asset is likely to get affected in any hazardous consequences resulting in huge loss in socio-economic values. Biratnagar metropolitan city is one of the rapidly urbanizing cities in the country and major economic center in the province 1. The increasing development activities have improved the city governance but also increased the number of urban assets that could be subjected to potential damage or loss during hazards. This research has presented the vulnerability of urban assets to multi-hazards scenario of Biratnagar metropolitan city. The research has looked into four types of vulnerabilities- physical, social, economic, and environmental vulnerability which can have significance contribution to increasing vulnerabilities of assets to different types of hazards. 19 variables for four types of vulnerabilities were identified for the study. Spatial information of such variables was collected on the field, analyzed using the GIS, and presented in the form of maps. The building features were distributed within vector grids and relative vulnerabilities of such grids was calculated using the standard normal distribution of observed data. The overall vulnerability of a city was calculated and categorized into different level of vulnerabilities using standard deviation approach. The overall vulnerability was presented in the form of map and chart.

Keywords

Urban, vulnerability, multi-hazard, indicators, Biratnagar Metropolitan City

1. Introduction

Development works in urban cities play a vital role in exposing urban assets to hazardous events which can result a huge loss in the economy and physical environment [1]. The vulnerability of such assets is likely to increase with their conditions over time. Vulnerability has been defined as a concept as well as a phenomenon by [2]. Vulnerability of infrastructures is hazard-dependent and a function of the susceptibility to damage [3], while the vulnerability of people is the function of coping capacity [4], depending upon the time, types, and intensity of events [5]. [6] has illustrated that the vulnerability is also dependent on the exposure, hazard, resilience, susceptibility and recovery.

Various types of vulnerability were identified and presented in three sides of a Rubik's cube [5]. One of the sides included physical, economic, environmental, and social factors. Vulnerabilities were defined as their existing condition which is a function of their characteristics like, age, strength, materials used, etc. Physical vulnerability is referred to as a degree of susceptibility of a built environment [7]. [8] has defined physical vulnerability as a potential damage to physical assets including built-up areas and infrastructures due to hazard. Similarly, the economic vulnerability is defined as a potential damage in economic sectors or obstruction of economic activities as an impact of hazard [9]. Same factors are also being used to determine the disaster resiliency of the city. Thus, [10] has conceptualized a dynamic but a complex relationship between vulnerability and resilience. The study of the vulnerability of urban assets can provide a basis for increasing resilience of a city by strengthening the vulnerable assets.

Study area: Biratnagar metropolitan city is one of the rapidly urbanizing cities in the country.During the preliminary study it was found that the indigenous settlements still exist in the city. There is also a high number of in-migration of people. Such in-migration have increased the number of urban assets like settlement areas and infrastructures. This might have contributed to the rapid urbanization in the city. Since the city is located in the region which is hit by different types of annual hazards, such assets are likely to be exposed to multi-hazards. With the null hypothesis that the vulnerabilities in indigenous and urbanizing areas are relative high, the following research objectives were set for the research:

- to identify the contextual hazards in the city, and
- to calculate the level of different types of vulnerabilities.

2. Methodology

2.1 Research method and variables:

The primary data has been used on the research. The data related to the indicators and variables were collected on the field by researchers. The collected information were analyzed and validated through another field visit. The findings were elaborated and described within the scope of the research. Thus, the research have adopted the exploratory research followed by the descriptive analysis. Four types of vulnerabilities- physical, economic, environmental, and social were assessed during the research. A total of 19 variables were selected from the literature review which has been frequently used in multi-hazards study. Vulnerabilities between housing grids were obtained and presented in the five-point scale of relative vulnerability.

2.2 Indicators and variables:

The selected 19 variables were related to 4 indicators. Such indicators and variables were related through their significance during contextual hazards.

Table 1: Indicator 1- Physical vulnerability

Variables	Significant hazards
House density	Seismic, flood, fire, epidemics
House types	Seismic, flood, fire
House storey	Seismic
Roof types	Seismic, fire
Wall types	Seismic, flood, fire
Ground slope	Seismic, flood
House compound	Seismic, flood
Foundation types	Seismic

Table 2: Indicator 2: Economic vulnerability

Variables	Significant hazards
Retail shop	Fire
Dealers	Fire
Institutions	Fire
Manufacturing	Fire
Agriculture	Fire

Table 3: Indicator 3: Environmental vulnerability

Variables	Significant hazards
Parks/recreation	Flood, epidemics
Protected areas	Flood

Table 4: Indicator 4: Social vulnerability

Variables	Significant hazards
Urban poor	Seismic, flood, fire, epidemics
Indigenous areas	Seismic, flood, fire, epidemics
Heritages	Fire, epidemics
Low education	Fire, epidemics

3. Data collection and processing

3.1 Data collection:

Spatial information of all variables was collected from the field visit to the Biratnagar metropolitan city as geo-referenced point data using KoBo Collect platform in android device. The field value noted on a point was considered to represent its surrounding. Thus, the value noted was based on the observation of its surrounding as a whole. In case of missing data in some points, the site was studied contextually and data were interpolated to the such points.

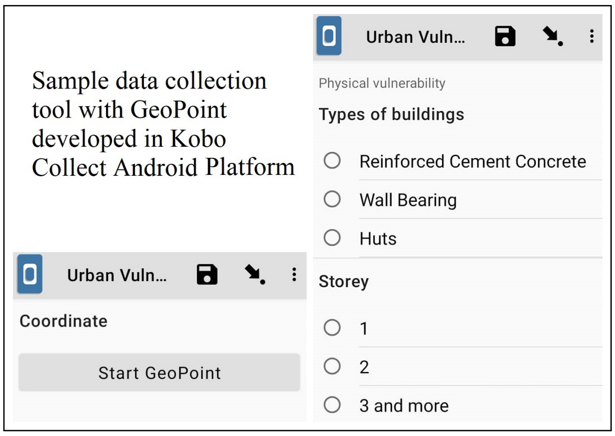

Figure 1: Sample of data collection tool used in the research.

Representative survey points are shown in the map below:

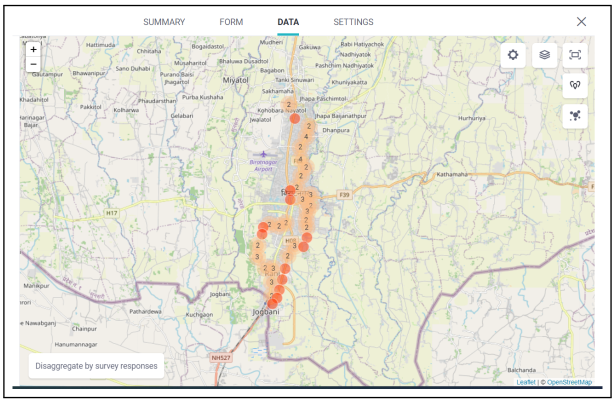

Figure 2: Field survey points displayed in the KoBo platform

3.2 Data processing and analysis:

The surveyed data were processed in the KoBo platform and Microsoft Excel to ensure the information related to each variables were collected from the field. Processed data were imported to the QGIS and the point data were assigned to the polygon dataset of building features. The values for the missing grids were calculated using the inverse distance weighted interpolation method.

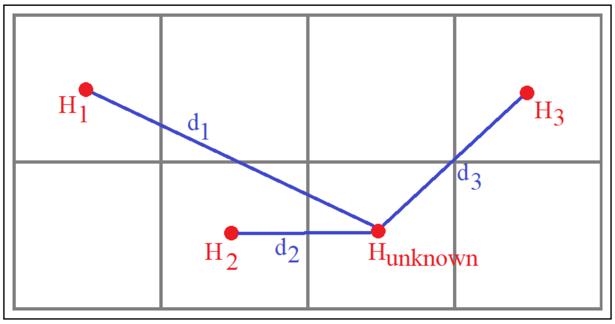

Figure 3: Inverse distance weighted interpolation process

The interpolation process was expressed as follows [11]:

$$H_{unknown} = \frac{\sum_{i=1}^{n} H_i/{d_i}^2}{\sum_{i=1}^{n} 1/{d_i}^2} \tag{1}$$

Where, $H_{unknown}$ is the interpolated value, H_i is the value of known points, d_i is the distance between known points and unknown points, and n is the number of points used in the interpolation procedure for estimating the unknown point.

The value of each variables was standardized using z-scores. Z score allows researchers to compare scores from different variables by normalizing the distribution to common scale [12]. Z-score was calculated by using the following equation:

$$z_i = \frac{u_i - \mu}{\sigma} \tag{2}$$

Where, z_i is the z-score of a grid for specific variable, u_i is the observed value of a grid, μ is the overall mean value, and σ is the standard deviation of observed values.

Normalized scores and total vulnerability are calculated using the following equation [10]:

$$\text{Normalized score, } N_i = \frac{\text{Value of a variable}}{\text{Maximum value}} \tag{3}$$

$$\text{Total vulnerability} = \sum_{i=1}^{19} N_i \tag{4}$$

Based on the calculated values, vulnerability maps were developed in the GIS. Vulnerabilities were categorized in five different classes using the standard deviation approach [13].

Table 5: Categorization of vulnerability classes

Range value	Level of vulnerability
>1.5σ	Very high
>0.5 to 1.5σ	High
>-0.5 to 0.5σ	Moderate
>-1.5 to -0.5σ	Low
<-1.5σ	Very low

4. Results and Discussions

After the processing and analysis of data the result was obtained in the form of a chart and maps.

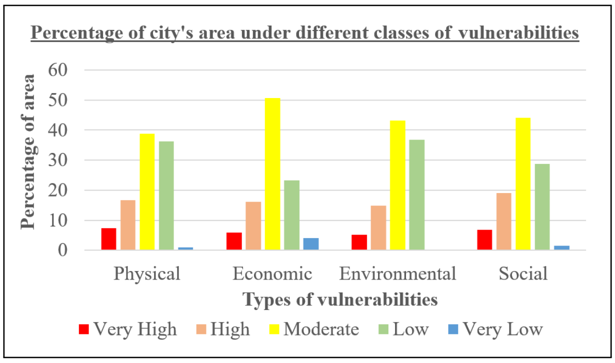

Figure 4: Percentage of area under different classes of vulnerabilities

The chart showed that only small areas were at very low vulnerabilities while most of areas were between low to high vulnerabilities and nearly 10 percentage of areas were at very high vulnerabilities classes. The indicator-wise maps were able to provide the spatial scenario of different types of vulnerabilities.

Physical vulnerability: Since, the city is one of the oldest urban cities in the country, it was found that old settlement areas still existed in the city. Such area consisted of older buildings and technology which have very high physical vulnerability. Similarly, core market areas also seem to have high physical vulnerability because of densely populated urban assets which are likely to be highly affected during hazards like earthquake and fire. Such areas are also likely to be affected by the urban flood and epidemics as a cascading hazard. Around 7.41 percentage of areas were found to be at very high physical vulnerability to multi-hazards.

Economic vulnerability: The city is considered to be one of the industrial capitals in the country and hence annually have high economic contribution to national economy. The areas like core market areas and areas having manufacture industries in the north have high economic vulnerability while the areas around the border checkpoint have medium economic vulnerability. The transition regions were found to have lower economic vulnerability. Around 5.96 percentage of areas were found to be at very high economic vulnerability to multi-hazards.

Environmental vulnerability: The areas in the west of the cities and some old settlement areas are found to have high environmental vulnerability. Such areas were abundant of vegetation, forest, and agriculture. Around 5.08 percentage of areas were found to be at very high environmental vulnerability to multi-hazards.

Social vulnerability: During the field visit, it was observed that still there was an existence of highly vulnerable communities such as settlements of indigenous ethnic groups, low-income communities, older settlement areas, communities of daily wage-based working groups, etc. in the city. Existence of such communities have resulted the higher social vulnerability at particular areas in the city. The study showed the higher social vulnerability across the areas where vulnerable communities have existed. Around 6.73 percentage of areas were found to be at very high social vulnerability to multi-hazards.

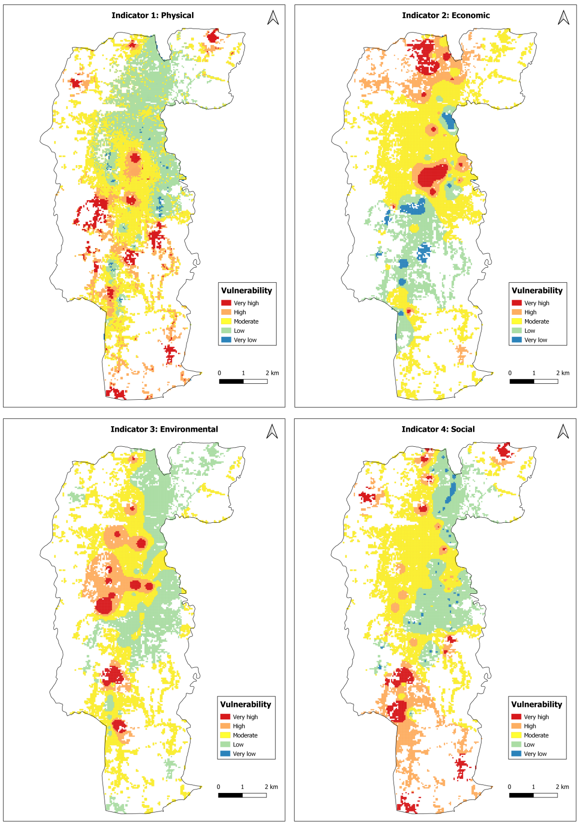

Figure 5: Indicator-wise vulnerability map

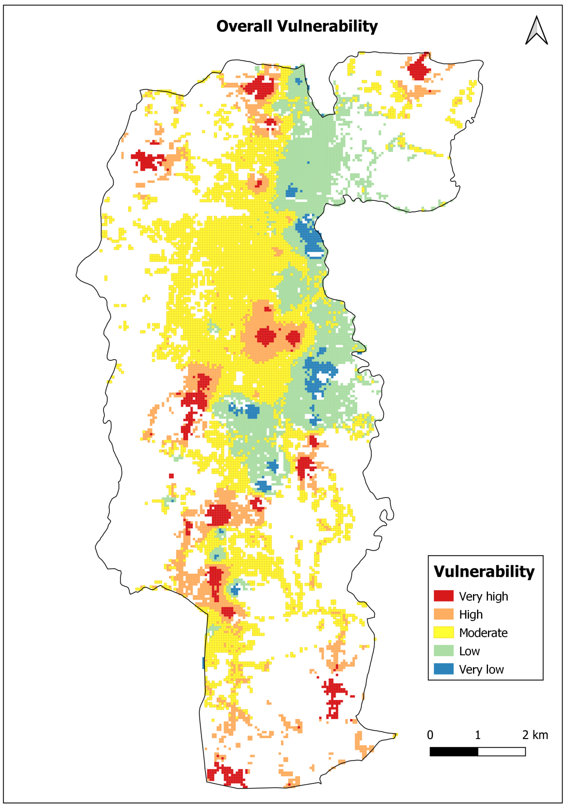

Figure 6: Overall vulnerability map

Overall vulnerability: The overall vulnerability map showed level of impact areas in the city can have during multiple hazards. Either of the aforementioned sectors or all sectors (mentioned earlier as indicators) are likely to be affected. Overall vulnerability was found to be high at either old settlements, core market areas, or areas consisting of manufacturing industries.

The value of overall vulnerability calculated as a whole as well as calculated as a cluster by dividing the city into parts was averaged around 6.58 percentage of total areas at very high level of vulnerability. Similarly, nearly 18 percentage of total area were highly vulnerable, 45.87 percent of total area were moderately vulnerable, 26.50 percent of area has low vulnerability, and 3.05 percent area has very low vulnerability. However, their level of vulnerability also depends upon the origin, frequency, intensity, and extent, and hence, the probabilistic level of impact due to any type of hazards was calculated and presented in the form of multi-hazards vulnerability curve.

Vulnerability curve:

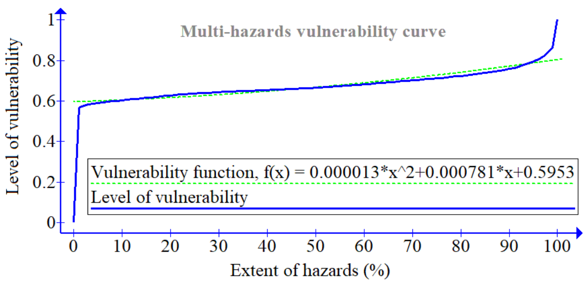

Figure 7: Multi-hazards vulnerability curve

The curve shows that the overall vulnerability of the city was over 0.6 even when the extent of hazard is very small. Such vulnerability gradually increased when the extent of hazard increases, and maximum when the extent of hazard is maximum i.e., when the hazard is affecting the whole city by regional level hazards like earthquake and flood.

5. Conclusions and Recommendations

Old, indigenous, and traditional settlements have higher vulnerability towards multi-hazards. The core market areas and newer settlements have lower physical vulnerability but their economic and environmental sector can be affected by hazards. The vulnerability curve shows that the whole city is highly vulnerable during the occurrence of large extent hazards which could affect the whole city. Thus, the city seems to have high vulnerability towards regional hazards. Thus, it is concluded that the higher vulnerability of vulnerable areas have contributed to higher overall vulnerability of the city. Similarly, the higher economic activities and unplanned environmental management at urban core might have contributed to higher economic and environmental vulnerabilities in such areas.

The method adopted in this research seems effective to identifying different levels of vulnerability within a city. Since not all the hazards affect all the sectors, the use of all four indicators is useful in identifying the indicator-specific vulnerability as well as the vulnerability to multi-hazard. The curve developed in this research can be useful in comparing the vulnerability level of different cities.

It is recommended that the city conducts an assessment to identify gaps and needs to decrease a vulnerability of vulnerable areas. Similarly, to reduce the vulnerabilities of new settlement, urban cores and developed ares, mainstreaming of disaster risk reduction activities is recommended in every development activities in such areas. Along with the strengthening activities, the city is recommended to develop and use the resiliency scorecard in real time to assess the resiliency achieved in the process.

6. Limitations and Justifications

The multi-hazards vulnerability is a complex process which depends on many variables and indicators from the multi-disciplinary fields. However, researchers have tried to use as many available variables whose first-hand information was collected, processed and analyzed on the field. Researchers have followed theoretical statistical processes for processing and analyzing data which might not be fully satisfiable on the real field scenario on some circumstances. However, the field validation was conducted multiple times for doubtful information. Vulnerability related values calculated through this research is not an absolute values but the relative values which is useful to comparing the scenario between two different areas.

Acknowledgments

The authors are thankful to the Himalayan Risk Research Institute for providing technical support on questionnaire development, integration into a mobile platform, and coordination on the field during the field study.

References

[1] Mark Pelling. Urbanization and disaster risk. *Cyberseminar on Population and Natural Hazards*, 2007.

[2] Alexander Fekete, Marion Damm, and Jörn Birkmann. Scales as a challenge for vulnerability assessment. *Natural Hazards*, 55(3):729–747, 2010.

[3] RL Ciurean, D Schröter, and T Glade. Conceptual frameworks of vulnerability assessments for natural disasters reduction. np: Intech, 2013.

[4] Sven Fuchs. Susceptibility versus resilience to mountain hazards in austria-paradigms of vulnerability revisited. *Natural Hazards and Earth System Sciences*, 9(2):337–352, 2009.

[5] Sven Fuchs and Thomas Thaler. *Vulnerability and resilience to natural hazards*. Cambridge University Press, 2018.

[6] Susan L Cutter. The vulnerability of science and the science of vulnerability. *Annals of the Association of American Geographers*, 93(1):1–12, 2003.

[7] W Neil Adger, Terry P Hughes, Carl Folke, Stephen R Carpenter, and Johan Rockström. Social-ecological resilience to coastal disasters. *Science*, 309(5737):1036–1039, 2005.

[8] Joern Birkmann, Omar D Cardona, Martha L Carreño, Alex H Barbat, Mark Pelling, Simon Schneiderbauer, Stefan Kienberger, Margreth Keiler, David Alexander, Peter Zeil, et al. Framing vulnerability, risk and societal responses: the move framework. *Natural hazards*, 67(2):193–211, 2013.

[9] Lino Briguglio, Gordon Cordina, Nadia Farrugia, and Stephanie Vella. Economic vulnerability and resilience: concepts and measurements. *Oxford development studies*, 37(3):229–247, 2009.

[10] Susan L Cutter, Lindsey Barnes, Melissa Berry, Christopher Burton, Elijah Evans, Eric Tate, and Jennifer Webb. A place-based model for understanding community resilience to natural disasters. *Global environmental change*, 18(4):598–606, 2008.

[11] GA Achilleos. The inverse distance weighted interpolation method and error propagation mechanism–creating a dem from an analogue topographical map. *Journal of spatial Science*, 56(2):283–304, 2011.

[12] Sukirty Jain, Sanyam Shukla, and Rajesh Wadhvani. Dynamic selection of normalization techniques using data complexity measures. *Expert Systems with Applications*, 106:252–262, 2018.

[13] Dipendra Gautam. Assessment of social vulnerability to natural hazards in nepal. *Natural Hazards and Earth System Sciences*, 17(12):2313–2320, 2017.