international DESIGN JOURNAL
Print ISSN 2090-9632
Online ISSN 2090-9640

The Role of Vulnerability Assessment in Urban Planning for Mitigating Seismic Risk

Fatima Nadi
Department of Architectural Engineering, Faculty of Engineering, Aswan University, Aswan, Egypt, fatimanadi@eng.aswu.edu.eg
Omar Hamdy
Department of Architectural Engineering, Faculty of Engineering, Aswan University, Aswan, Egypt, omar.hamdy@aswu.edu.eg

Abstract:

The proportion of people living in cities has been increasing in recent years due to urbanization's relentless acceleration. Recently, the rate of urban growth is at its highest point in history around the world (Labaka et al., 2019). The urban area is still expanding. As a result of this rapid urbanization which, on occasion, is unplanned, cities are facing a range of abrupt shocks brought and chronic stressors. Natural hazards are one of the greatest threats facing humanity. (UNDRR(a), 2015). Natural hazards are devastating events that often cause many casualties, huge economic losses and great destruction. One of the greatest challenges of human society over the years has always been adapting and living in the constant presence of natural hazards.Between 2000 and 2019, the Emergency Event Database EM-DAT reported 7,348 disaster incidents, globally (EM-DAT, 2023). Approximately 1.23 million people died as a result of natural disasters worldwide, which is about 60,000 every year on average, and over 4 billion people were affected. Additionally, disasters caused global economic losses of about US$ 2.97 trillion. In 2022, as a result of 387 natural hazards worldwide was recorded by the EM-DAT, it affected 185 million people and caused the loss of 30,704 lives (Centre for Research on the Epidemiology of Disasters (CRED), 2023), and total losses were around US$ 270 billion (Munich Re, 2023). Over the past two decades, geophysical disasters, particularly earthquakes and tsunamis, have emerged as the deadliest natural hazards. Despite constituting only 8% of all recorded disasters, they have been responsible for 59% of disaster-related fatalities, as highlighted by the EM-DAT report. Seismic dominates the list of the most catastrophic events, with six of the ten deadliest disasters attributed to them. Notable examples include the 2004 Indian Ocean seismic and Tsunami, which claimed over 226,000 lives, the 2005 Pakistan earthquake that resulted in 73,300 deaths, the 2008 China earthquake with 87,500 fatalities, and the devastating 2010 Haiti earthquake, which killed over 222,000 people and left millions homeless. In addition to their staggering human cost, earthquakes inflict widespread infrastructure damage and lead to immense economic losses. For instance, the 2011 earthquake and tsunami in Japan caused unprecedented damages estimated at USD 239 billion, marking it as one of the costliest disasters ever recorded (Centre for Research on the Epidemiology of Disasters (CRED), 2023). In fact, not all seismic hazards have the potential to cause disasters; rather, catastrophes are caused when a hazard is combined with vulnerable aspects of the built environment. It is necessary to examine not just the hazard features but also those of the built environment and all of its constituent parts in order to provide answers to these issues. A disaster can occur in two scenarios: the first is a lack of awareness about the presence of a hazard, and the second is insufficient preparedness for the hazard. The first stage in creating a community resilience strategy and reducing disaster risk is conducting a disaster risk assessment (DFID, 2012). International organizations such as the WHO and UNDRR emphasize that disaster risk arises when the frequency, intensity, and impact of a hazard intersect with the number of people and assets exposed, as well as their vulnerability to damage, **Error! Reference source not found.** (SADC DRM IMS | Risk Components | SADC - DRM IMS, n.d.). Risk is composed of three components: hazard, exposure, and vulnerability (UNDRR(C), 2015),. So, finding causative factors for disaster outcomes means examining risk factors in these areas". Risk increases as more people and assets are exposed. Factors such as population growth, migration, and unplanned urban expansion, commonly referred to as urban sprawl, have led to an increasing concentration of people in areas prone to various hazards (UNDRR(C), 2015). Furthermore, community characteristics significantly define their "vulnerability" to hazards. This means that while cities may be exposed to hazards, there is no risk if vulnerabilities are absent (Yong et al., 2001). The study of 'vulnerability' is inherently complex (Schneiderbauer & Ehrlich, 2004). Consequently, research often prioritizes 'hazard' and 'exposure' over an in-depth examination of ‘vulnerability’. Despite being a

fundamental component of risk assessment, a recent review study highlighted the scarcity of research on vulnerability assessment in Africa, particularly in the context of seismic vulnerability, this study aims to conduct a theoretical review of the literature to identify the role of vulnerability assessment in urban planning for seismic risk mitigation.

Objectives and Methods: This study aims to conduct a theoretical review of the literature to identify the role of vulnerability assessment in urban planning for seismic risk mitigation. This study was conducted in three stages. In the first stage, a general review of the concept of risk assessment was carried out based on definitions and guidelines provided by international organizations such as the Federal Emergency Management Agency (FEMA), the United Nations Office for Disaster Risk Reduction (UNDRR), and the World Health Organization (WHO). In the second stage, by examining the relevant literature, the study examined the concept of the main elements of risk, which are hazard, exposure, and vulnerability. This stage of the study involved examining the relevant literature to analyze the methods and requirements for evaluating each element. In the last stage, the study conducted a deep theoretical review of the literature focusing on seismic vulnerability assessment and determined the role of seismic vulnerability assessment in mitigating seismic risks. The research also examined studies that conducted earthquake vulnerability assessments with the aim of enhancing disaster preparedness in order to extract the factors that increase seismic vulnerability. This study examines how seismic vulnerability affects mitigation and adaptation strategies, providing a deeper understanding of the mechanisms that contribute to amplifying or reducing risks in the urban environment. Overall, the study highlights the importance of proactive measures in disaster management and the role of seismic vulnerability assessments in effectively reducing the impact of seismic events.

Results; The results indicate that vulnerability assessment is a fundamental component of risk assessment, as it encompasses a wide range of social, cultural, economic, institutional, political, and else that interact with each other. The complexity of vulnerability arises from the dynamic interactions between these factors, which vary considerably across different communities. Understanding and identifying the factors that cause seismic vulnerability, and their interactions can help direct efforts towards addressing these aspects, thus increasing the resilience of cities and urban areas.

In assessing seismic vulnerability, a multi-dimensional approach is essential. The physical dimension focuses on the structural integrity of buildings and the influence of geotechnical factors, such as soil composition and topography, which directly impact a structure’s ability to withstand seismic events. The built environment dimension further explores urban components, including building density, street widths, and proximity to critical infrastructure, all of which affect a city's resilience to disasters. Additionally, social vulnerability plays a crucial role in determining a community's capacity to adapt and recover, with demographic and economic indicators serving as key determinants of sensitivity and adaptive capacity. A comprehensive vulnerability assessment helps identify the most at-risk communities, infrastructure, and urban elements, allowing for the implementation of targeted interventions.

This paper relied on open and freely available sources. Utilizing papers from different sources may contribute to greater diversity in results. Additionally, this study focused on seismic vulnerability assessment only. Vulnerability assessment for other hazards may involve different aspects; therefore, examining vulnerability factors and indicators across various natural hazards and dimensions would be beneficial. For future research, it may be beneficial to expand the scope of the study to include other hazards such as floods or hurricanes. By considering a wider range of hazards, researchers can gain a more comprehensive understanding of vulnerability factors and indicators. This would allow for a more holistic approach to disaster risk reduction and management.

Paper History:

Paper received December 09, 2024, Accepted February 29, 2025, Published on line May 1, 2025

Keywords:

Vulnerability, Seismic hazard, Risk assessment, Natural disasters, Exposure

References:

1- 2009 UNISDR terminology on disaster risk reduction | UNDRR. (n.d.). Retrieved January 28, 2025, from https://www.undrr.org/publication/2009-unisdr-terminology-disaster-risk-reduction
2- Afsari, R., Nadizadeh Shorabeh, S., Bakhshi Lomer, A. R., Homaee, M., & Arsanjani, J. J. (2023a). Using Artificial Neural Networks to Assess Earthquake Vulnerability in Urban Blocks of Tehran. Remote Sensing, 15(5), 1248. https://doi.org/10.3390/rs15051248
3- Afsari, R., Nadizadeh Shorabeh, S., Bakhshi Lomer, A. R., Homaee, M., & Arsanjani, J. J. (2023b). Using artificial neural networks to assess earthquake vulnerability in urban blocks of Tehran. Remote

Sensing, 15(5), 1248.
4- Alam, M. S., & Haque, S. M. (2022). Multi-dimensional earthquake vulnerability assessment of residential neighborhoods of Mymensingh City, Bangladesh: A spatial multi-criteria analysis based approach. Journal of Urban Management, 11(1), 37–58.
5- Alizadeh, M., Ngah, I., Hashim, M., Pradhan, B., & Pour, A. B. (2018). A hybrid analytic network process and artificial neural network (ANP-ANN) model for urban earthquake vulnerability assessment. Remote Sensing, 10(6), 975.
6- Alizadeh, M., Zabihi, H., Rezaie, F., Asadzadeh, A., Wolf, I. D., Langat, P. K., Khosravi, I., Beiranvand Pour, A., Mohammad Nataj, M., & Pradhan, B. (2021). Earthquake vulnerability assessment for urban areas using an ann and hybrid swot-qspm model. Remote Sensing, 13(22), 4519.
7- Centre for Research on the Epidemiology of Disasters (CRED), U. C. de L. (UCLouvain), U. S. A. for I. D. (USAID). (2023). 2022 Disasters in numbers | PreventionWeb. https://www.preventionweb.net/publication/2022-disasters-numbers
8- Columbro, C., Eudave, R. R., Ferreira, T. M., Lourenço, P. B., & Fabbrocino, G. (2022). On the use of web mapping platforms to support the seismic vulnerability assessment of old urban areas. Remote Sensing, 14(6), 1424.
9- DFID. (2012). Multi-Hazard Disaster Risk Assessment (v2).
10- Diaz-Sarachaga, J. M., & Jato-Espino, D. (2020). Analysis of vulnerability assessment frameworks and methodologies in urban areas. Natural Hazards, 100(1), 437–457. https://doi.org/10.1007/s11069-019-03805-y
11- Dilley, M., & Boudreau, T. E. (2001). Coming to terms with vulnerability: a critique of the food security definition. Food Policy, 26(3), 229–247.
12- Disaster Classification System | EM-DAT Documentation. (n.d.). Retrieved January 29, 2025, from https://doc.emdat.be/docs/data-structure-and-content/disaster-classification-system/
13- Duzgun, H. S. B., Yucemen, M. S., Kalaycioglu, H. S., Celik, K., Kemec, S., Ertugay, K., & Deniz, A. (2011). An integrated earthquake vulnerability assessment framework for urban areas. Natural Hazards, 59, 917–947.
14- Eastman, J. R. (1999). Multi-criteria evaluation and GIS. Geographical Information Systems, 1(1), 493–502.
15- EM-DAT. (2023). EM-DAT - The international disaster database. https://www.emdat.be/
16- FEMA. (n.d.). Natural Hazards | National Risk Index. Retrieved July 13, 2023, from https://hazards.fema.gov/nri/natural-hazards
17- FEMA, P. (2015). 154: Rapid visual screening of buildings for potential seismic hazards: a handbook. Federal Emergency Management Agency Report, FEMA. P, 154.
18- Fordham, M., Lovekamp, W. E., Thomas, D. S. K., & Phillips, B. D. (2013). Understanding social vulnerability. Social Vulnerability to Disasters, 2, 1–29.
19- Freire, S., & Aubrecht, C. (2012). Integrating population dynamics into mapping human exposure to seismic hazard. Natural Hazards and Earth System Sciences, 12(11), 3533–3543.
20- Frigerio, I., Ventura, S., Strigaro, D., Mattavelli, M., De Amicis, M., Mugnano, S., & Boffi, M. (2016). A GIS-based approach to identify the spatial variability of social vulnerability to seismic hazard in Italy. Applied Geography, 74, 12–22. https://doi.org/10.1016/J.APGEOG.2016.06.014
21- Garatwa, W., & Bollin, C. (2002). Disaster risk management: Working concept. In Disaster risk management: Working concept (p. 48).
22- Global assessment report on disaster risk reduction 2019 | UNDRR. (n.d.). Retrieved January 29, 2025, from https://www.undrr.org/publication/global-assessment-report-disaster-risk-reduction-2019
23- Grünthal, G., & Schwarz, J. (n.d.). European Macroseismic Scale 1998 EMS-98 Editor.
24- Hamdy, O., & Alsonny, Z. (2022). Assessing the Impacts of Land Use Diversity on Urban Heat Island in New Cities in Egypt, Tiba City as a Case Study. International Design Journal, 12(3), 93–103. https://doi.org/10.21608/idj.2022.128425.1040
25- Hamdy, O., Gaber, H., Abdalzaher, M. S., & Elhadidy, M. (2022). Identifying exposure of urban area to certain seismic hazard using machine learning and GIS: A case study of greater Cairo. Sustainability, 14(17), 10722.
26- Hamdy, O., Zhao, S., A. Salheen, M., & Eid, Y. (2016). Identifying the Risk Areas and Urban Growth by ArcGIS-Tools. Geosciences, 6(4), 47. https://doi.org/10.3390/geosciences6040047
27- Hanberry, B. B. (2023). Urban Land Expansion and Decreased Urban Sprawl at Global, National, and City Scales during 2000 to 2020. Ecosystem Health and Sustainability, 9, 0074. https://doi.org/10.34133/ehs.0074

28- Hardoy, J., & Satterthwaite, D. (2023). Urban Growth as a Problem. In The Earthscan Reader in Sustainable Development (pp. 197–199). Routledge. https://doi.org/10.4324/9781003403432-28
29- Harrison, C. G., & Williams, P. R. (2016). A systems approach to natural disaster resilience. Simulation Modelling Practice and Theory, 65, 11–31. https://doi.org/https://doi.org/10.1016/j.simpat.2016.02.008
30- Hosseinpour, V., Saeidi, A., Nollet, M.-J., & Nastev, M. (2021). Seismic loss estimation software: A comprehensive review of risk assessment steps, software development and limitations. Engineering Structures, 232, 111866. https://doi.org/https://doi.org/10.1016/j.engstruct.2021.111866
31- Hua, W., Ye, J., & Ye, J. (2023). Resilience assessment and seismic risk assessment of reticulated shell structures considering multiple uncertainties. Structures, 55, 1584–1594. https://doi.org/10.1016/J.ISTRUC.2023.06.129
32- Kassem, M. M., Mohamed Nazri, F., & Noroozinejad Farsangi, E. (2020). The seismic vulnerability assessment methodologies: A state-of-the-art review. Ain Shams Engineering Journal, 11(4), 849–864. https://doi.org/10.1016/J.ASEJ.2020.04.001
33- Labaka, L., Maraña, P., Giménez, R., & Hernantes, J. (2019). Defining the roadmap towards city resilience. Technological Forecasting and Social Change, 146, 281–296. https://doi.org/https://doi.org/10.1016/j.techfore.2019.05.019
34- Lee, S., Yoo, C., Im, J., Cho, D., Lee, Y., & Bae, D. (2023). An innovative method to investigate the altering urban thermal environment by dynamic land cover change: A case study of Suwon, Republic of Korea. EGU General Assembly Conference Abstracts, EGU-13594.
35- Li, S.-Q. (2023). Empirical resilience and vulnerability model of regional group structure considering optimized macroseismic intensity measure. Soil Dynamics and Earthquake Engineering, 164, 107630. https://doi.org/https://doi.org/10.1016/j.soildyn.2022.107630
36- Li, X., & Gong, P. (2016). Urban growth models: progress and perspective. Science Bulletin, 61(21), 1637–1650. https://doi.org/https://doi.org/10.1007/s11434-016-1111-1
37- Munich Re. (2023). Climate change and La Niña driving losses: the natural disaster figures for 2022 | Munich Re. https://www.munichre.com/en/company/media-relations/media-information-and-corporate-news/media-information/2023/natural-disaster-figures-2022.html
38- Nations, U. (2014). World urbanization prospects: The 2014 revision, highlights. department of economic and social affairs. Population Division, United Nations, 32, 1–517. https://population.un.org/wup/publications/files/wup2014-report.pdf
39- Nations, U. (2018). The World's Cities in 2018: Data Booklet. https://doi.org/10.18356/C93F4DC6-EN
40- Noby, M., Elattar, M. E., & Hamdy, O. (2023). A Machine Learning Model to Predict Urban Sprawl Using Official Land-use Data. Urbanism. Arhitectura. Constructii, 14(3), 249–258.
41- Nugroho, F., & Al-Sanjary, O. I. (2018). A Review of Simulation Urban Growth Model. International Journal of Engineering & Technology, 7(11), 17–23. https://doi.org/10.14419/ijet.v7i4.11.20681
42- Ozegbe, K. C. (2022). Earthquake Response, Vulnerability Assessment, and Rehabilitation of Water Conveyance Tunnels in High Seismic Hazard Regions: Whitewater Tunnel No. 2 Seismic Resilience Study. Lifelines 2022: 1971 San Fernando Earthquake and Lifeline Infrastructure - Selected Papers from the Lifelines 2022 Conference, 1, 356–368. https://doi.org/10.1061/9780784484432.032
43- Peril Classification and Hazard Glossary. (n.d.). Retrieved January 29, 2025, from https://council.science/wp-content/uploads/2019/12/Peril-Classification-and-Hazard-Glossary-1.pdf
44- SADC DRM IMS | Risk Components | SADC - DRM IMS. (n.d.). Retrieved January 29, 2025, from https://drmims.sadc.int/en/sendai-framework/risk-components
45- Samuel, M. A., Xiong, E., Haris, M., Lekeufack, B. C., Xie, Y., & Han, Y. (2024). Assessing Seismic Vulnerability Methods for RC-Frame Buildings Pre-and Post-Earthquake. Sustainability, 16(23), 10392.
46- Schneiderbauer, S., & Ehrlich, D. (2004). Risk, hazard and people's vulnerability to natural hazards. A Review of Definitions, Concepts and Data. European Commission Joint Research Centre. EUR, 21410, 40.
47- Silva, V., Crowley, H., Varum, H., Pinho, R., & Sousa, R. (2014). Evaluation of analytical methodologies used to derive vulnerability functions. Earthquake Engineering & Structural Dynamics, 43(2), 181–204.
48- Social Vulnerability Index | Place and Health - Geospatial Research, Analysis, and Services Program (GRASP) | ATSDR. (n.d.). Retrieved January 24, 2025, from https://www.atsdr.cdc.gov/place-health/php/svi/index.html

49- UNDRR(a). (2015). Sendai Framework for Disaster Risk Reduction 2015-2030 | UNDRR. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030
50- UNDRR(C). (2015). Disaster Risk | Understanding Disaster Risk. https://www.preventionweb.net/understanding-disaster-risk/component-risk/disaster-risk
51- UNIDSR. (2017). Disaster Resilience Scorecard for Cities. Preliminary Level Assessment. United Nations Office for Disaster Reduction Geneva.
52- Van Westen, C. J. (2013). Remote sensing and GIS for natural hazards assessment and disaster risk management. Treatise on Geomorphology, 3(15), 259–298.
53- Waly, N. M., Ayad, H. M., & Saadallah, D. M. (2021). Assessment of spatiotemporal patterns of social vulnerability: A tool to resilient urban development Alexandria, Egypt. Ain Shams Engineering Journal, 12(1), 1059–1072.
54- Wang, Y., Sun, Y., Cao, X., Wang, Y., Zhang, W., & Cheng, X. (2023). A review of regional and Global scale Land Use/Land Cover (LULC) mapping products generated from satellite remote sensing. ISPRS Journal of Photogrammetry and Remote Sensing, 206, 311–334. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2023.11.014
55- Ward, P. J., Blauhut, V., Bloemendaal, N., Daniell, J. E., de Ruiter, M. C., Duncan, M. J., Emberson, R., Jenkins, S. F., Kirschbaum, D., & Kunz, M. (2020). Natural hazard risk assessments at the global scale. Natural Hazards and Earth System Sciences, 20(4), 1069–1096.
56- What is remote sensing and what is it used for? | U.S. Geological Survey. (n.d.). Retrieved January 26, 2025, from https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used
57- Yong, C., Qi-fu, C., & Ling, C. (2001). Vulnerability Analysis in Earthquake Loss Estimate. Natural Hazards, 23(2), 349–364. https://doi.org/10.1023/A:1011181803564
58- Ziraoui, A., Kissi, B., Aaya, H., & Azdine, I. (2023). The State of the Art on Seismic Protection Technologies for Structures: A Review. International Conference on Advanced Materials for Sustainable Energy and Engineering, 68–74.

CITATION Fatima Nadi, Omar Hamdy (2025), The Role of Vulnerability Assessment in Urban Planning for Mitigating Seismic Risk, International Design Journal, Vol. 15 No. 3, (May 2025) pp 195-206