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Understanding Urban Vulnerability of the Built Environment in Kathmandu Valley, Nepal

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ABSTRACT

Kathmandu Valley in Nepal faces increasing resource competition and associated conflict, often resulting in exploitative practices and amplified vulnerability among urban populations. The high intensity of natural and human-induced hazards is further compounding these vulnerabilities. Understanding the socio-physical vulnerability of the built environment assists in identifying at-risk communities and strengthening community resilience. This study explores the urban vulnerability in eighteen municipalities of Kathmandu Valley, Nepal, shaped by housing conditions, built environment, and service-infrastructure accessibility. The Social Vulnerability Index (SoVI) was used alongside Focus Group Discussions (FGDs), Key Informant Interviews (KIIs), and consultations with local authorities. Geo-spatial tools were used to analyze the spatial dimensions of urban vulnerability. The findings reveal that among eighteen urban municipalities, Shankarapur municipality is very highly vulnerable, and six other municipalities are highly vulnerable. In comparison to housing conditions and the built environment, service and infrastructure accessibility emerged as the most variable component, with SoVI scores ranging from 0.03 to 0.91. The research highlights that recognizing critical gaps helps policymakers create more inclusive and effective urban resilience strategies. Ensuring equitable access to resources and services is essential for building resilient urban communities.

Introduction

The imbalance between population and resource distribution has two-fold effects: environmental (physical) degradation and social vulnerability (Cutter et. al., 2000). Rapid urbanization, accompanied by increasing sprawl, alters the built environment and socio-demographic composition, thereby intensifying urban vulnerability (UV). UV encompasses the challenges and risks caused by natural and human-induced hazards, decreasing resource base, degrading built environments and housing conditions, socio-physical marginalization, inequality, and infrastructure strain (Meerow & Newell, 2016). Natural resources are finite and spread unevenly, while service provisions are established based on fixed population estimates.

The limited and uneven distribution of resources and service provisions results in competition for use, leading to exploitive practices and vulnerability (Shrestha & Paudel, 2023). Thus, vulnerability is becoming more complex with increasing risk due to exposure to poor housing conditions, marginal locations, like informal settlements, river banks, and higher slopes (KVDA, 2016; Sengupta, 2018).

Various studies on UV Assessment (UVA) include social and physical dimensions of vulnerability and analyze how they are intertwined and induced at the local level (Armas & Gavris, 2016; Arunachalam et al., 2023; Ge et al., 2017). UV refers to the susceptibility of social groups to the adverse impacts of natural hazards and the disruption of livelihood (Otto et al., 2017; Siagian et al., 2014). It is emphasized that the ultimate focus of UVA should be on a community-centered approach (Bennett et. al., 2016) because communities with differential capacities, and distinct socio-economic and bio-physical contexts have to cope and adapt to varying scales and paces. It is argued that UVA should address interlinked socio-ecological systems as an important element of resilience (Tyler & Moench, 2012). Vulnerability studies in urban contexts have also centered on exploring exposure to risk and hazards in particular (Fatemi et al., 2017). Such assessment aids in decision-making and improves policy and practice decisions (Metzger & Schroter, 2006). In the recent urban planning context, lack of or limited access to resources, and social exclusion reflect social marginality. Poorly managed resource allocation is also regarded as one of the underlying drivers of vulnerability (Cutter et al., 2003).

The growing population and the activities and interactions that come with it are key factors in transforming the urban landscape. The urban environment of the Kathmandu Valley is under the pressures of rapid urbanization, depleting environmental resources, and living conditions (Muzzini & Aparicio, 2013; Singh & Dhakal, 2023). Increasing urbanization and haphazard growth, an informal settlement with increasing population, inadequate infrastructure, and traffic congestion have remained genuine urban issues of Kathmandu Valley in Nepal (Shrestha & Paudel, 2023). It is the country's most urbanized region, undergoing a rapid urbanization process, confronting socio-demographic territorialization and escalating vulnerability. Urban-bound migration has been a major determinant of rapid urban growth in the Valley, with a 4.45% growth rate in contrast to the national growth rate of 1.34% (Central Bureau of Statistics [CBS], 2011), and it has the highest proportion of migrants compared to other urban areas of the country (KVDA, 2016; NSO, 2023). The increasing population, coupled with increasing demand for resources and services, has constrained access, simultaneously escalating vulnerability in different parts of the Valley. Lack of efficient planning and implementation, increasing urban sprawl, with priorities like economic profitability and maximum built-up ratio, depleting vegetation, and resources like land and water, pollution and waste generation, and decreasing carrying capacity, results in ecological imbalances, adding further misery to the urban environment (Adhikari, 2021). Besides, road infrastructure development creates proximity, inducing rapid suburbanization with consequent adverse impacts on peri-urban and rural environments (Adamiak, 2016).

Studies about urban social vulnerability in the context of Nepal have been limited and have adopted a few indicators and variables, mostly focusing on hazards (Aksha et al., 2019; Gautam, 2017; Mesta et al., 2022). Major gaps exist in information on the interface between urbanization and natural and human-induced hazards and disaster risk in terms of built environment, housing conditions, and accessibility to services and infrastructure (Hossain et al., 2017). Being a high receiver of the migrant population and haphazardly built-up growth, studies of UV in Nepal are imperative for sustainable urban development and a better quality of life. This study explores the spatial pattern of UV shaped by housing conditions, built environment, including hazard susceptibility, and access to services and infrastructure, which aids in addressing at-risk populations and strengthening community resilience.

Data and Methods

Study Area

Kathmandu Valley is located at an average elevation of 1,300 meters above mean sea level. It is one of the earliest settlements, concentrated within compact clusters with a population density of 3585 persons/km^2. It occupies 665 km^2 and has a total population of 29,96,341 comprising 787,725 households (NSO, 2023). It shares only 1.58% of the total urban area but encompasses 12.5% of the total urban population. Bagmati is the major river that passes through the Valley along with its fourteen tributaries. The urban form of Kathmandu Valley represents a radial pattern with a hinterland extending from the traditional core of Kathmandu city. Suburban market centers surround the core urban area and extend to the foothills and lower slopes, while rural settlement clusters are outspread to the middle and higher slopes.

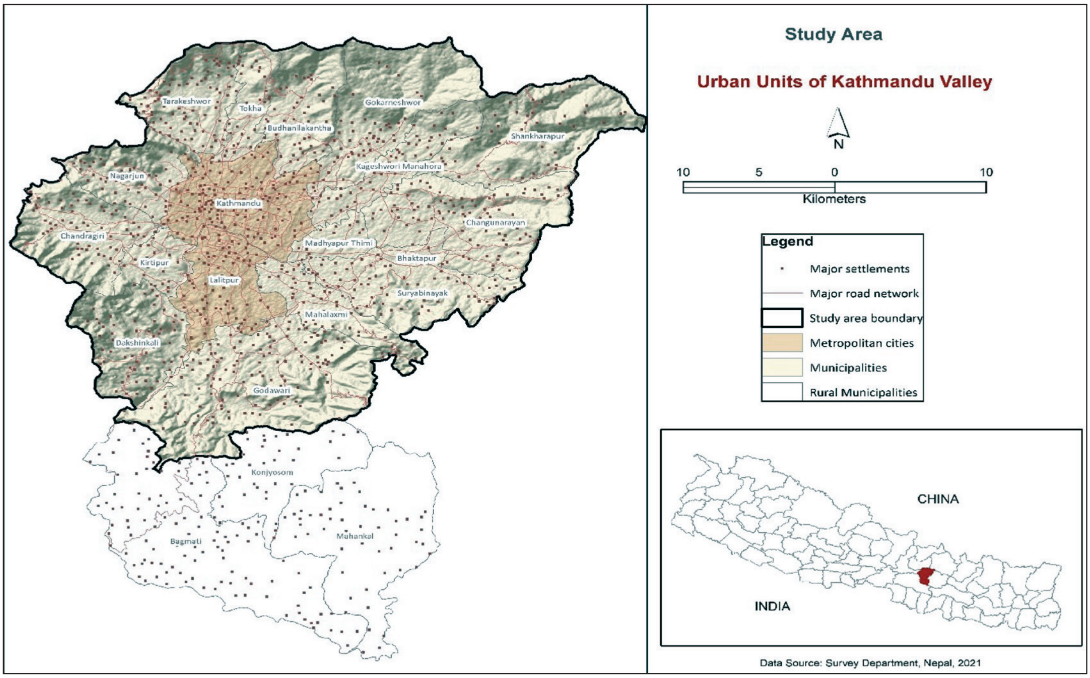

Figure 1. Location map of the study area, Kathmandu Valley, Nepal

Data

This study followed the integrated approach and adopted mixed methods. The social vulnerability index (SoVI) was adopted to assess the vulnerability condition at the municipal level. Table 1 presents the indicators and variables employed to analyze the social vulnerability. It has three sets of indicators with twenty-five variables representing: housing and housing conditions with seven variables, a built environment (spatial) with twelve variables, and access and utility services with six variables. Remote sensing and GIS tools were applied to assess spatial indicators such as topographical factors, multi-hazard susceptibility, river environment, and squatter settlements. The built-up change was done using Landsat data from 2001 to 2021. Besides field-based mapping and observation, 36 key informant interviews and 18 focus group discussions (FGD)s were carried out. A total of 53 wards (the lowest administrative units) were also consulted.

Table 1: Selected indicators and variables for urban social vulnerability assessment

Indicators	**Variables**
Housing condition (#7)	1) Population density (Km^2)[1 and 2]
	2) Building density (Km^2)[1 and 2]
	3) Average household (HH) size[1]
	4) % Rented households[1]
	5) % of HH without piped drinking water[1]
	6) % of HH without toilet facilities[1]
	7) % of HH without RCC foundation[1]
Built Environment(#12)	1) Number of HH in squatters/slums [#]
	2) % of Public Open Space (POS)[2]
	3) POS ratio to built-up area[2]
	4) % Vegetation coverage[2]
	5) % Water body coverage[2]
	6) % of built-up area in flood zone[2]
	7) % of built-up area in landslide-prone zone[2]
	8) % of the area under high liquefaction zone[2]
	9) Waste generation/day/Ton[5]
	10) % of built-up area[2]
	11) % of agricultural land[2]
	12)% of unsafely managed excreta[5]
Services and Infrastructure Access (#6)	1) Road density (motor road)[2]
	2) % Daily public bus flow[#]
	3) Number of Public health facilities[3]
	4) % of HH with a telephone[1]
	5) Per-capita economic establishment[3]
	6) % of the population who completed a Bachelor's degree[1]

Note: Variables representing + indicate high vulnerability and - indicate low vulnerability

Data Sources: [1] Population census, Central Bureau of Statistics (2078 BS), [2] Computed/GIS mapping (2022/23),[3] Local Human Development Report. Province Policy and Planning Commission, Bagmati Province, Nepal (2019),[4] Flash Report I, 2021-022, Center for Education and Human Resource Development, Ministry of Education, Science and Technology, Sanothimi, Bhaktapur, (2022),[5] SFD Lite Report of Kathmandu Valley, South Asia/ENPHO and KVWSMB (2020), [#] Municipal Profiles and Field survey, (2023)

Methods

This study has analyzed indicators pertinent to UV to assess the vulnerability condition. UV analysis was carried out at the municipal level using the Social Vulnerability Index (SoVI), as developed by Cutter et al. (2000, 2003) and further refined by Cutter and Morath (2014) and Cutter (2024).The index was first used to assess vulnerability in an urban disaster context and regarded as a common and appropriate technique to explain all variances in the set of measured variables and for data reduction where there are several factors (Holand et al., 2011). To calculate SoVI, each variable (V_m) value was normalized (NV_m) and expressed in a standard scale ranging from 0 to 1, in which 0 indicates the low and 1 indicates the high vulnerability. The normalization procedure consisted of comparing each variable to the corresponding minimum (V_{min}) and maximum values (V_{max}) as follows,

$$NMv = \frac{Vm - Vmax}{Vmin - Vmax} \quad \text{..........................} \; \textit{Equation 1}$$

where, NM_v *= normalized value,* V_m *=individual variable,* V_{max} *= maximum value,* V_{min} *= minimum value*

To calculate the score per indicator (I_n), an arithmetic mean of the corresponding normalized value (NM_v) was calculated to determine each indicator's aggregate value. The final score was calculated using *Equation 2*:

$$SoVI = I_1 + I_2 + I_3 /n \quad \text{..............................} \; \textit{Equation 2}$$

Overall composite SoVI value is classified into five class levels from very low to very high vulnerability based on Jenk's natural break optimization classification (Jenk, 1967) in the GIS environment for spatial pattern mapping.

Built-up area change was analyzed using the supervised classification method and field verification. Landsat imagery from 2001, 2006, 2011, 2016, and 2021 was obtained from the USGS website for built-up area mapping, and the GoogleEarth platform was used for building growth in 2006, 2022, 2026, and 2021. Susceptibility mapping of flood, landslide, and liquefaction risk was carried out using the frequency-ratio method as adopted by Nohani et al. (2019) and the Government of Nepal (2010). Accessibility to services utilities is assessed using a linear distance approach and population-to-service ratio. The percentage share of landuse classes (forest/vegetation, open space, water bodies, and agriculture to the total area, road density, building to built-up ratio, and population density was also calculated using the GIS tool.

Results

Housing Conditions

The analysis of housing condition indicators involves examining the physical characteristics, socioeconomic, and environmental contexts of housing. Seven variables, as listed in Table 1 are analyzed and ranked accordingly for SoVI calculation. The calculated SoVI is presented in Figure 2. The SoVI values range from 0.26 to 0.67. Among the 18 municipalities, four exhibit lower vulnerability scores that range from 0.26 to 0.29, whereas three municipalities display high vulnerability scores that vary from 0.50 to 0. 67. Bhaktapur is highly vulnerable (0.67), followed by Madhyapur Thimi (0.51) and Mahalaxmi (0.50). Kritipur has the lowest vulnerability (0.26), followed by Nagarjun and Dakshinkali (0.28).

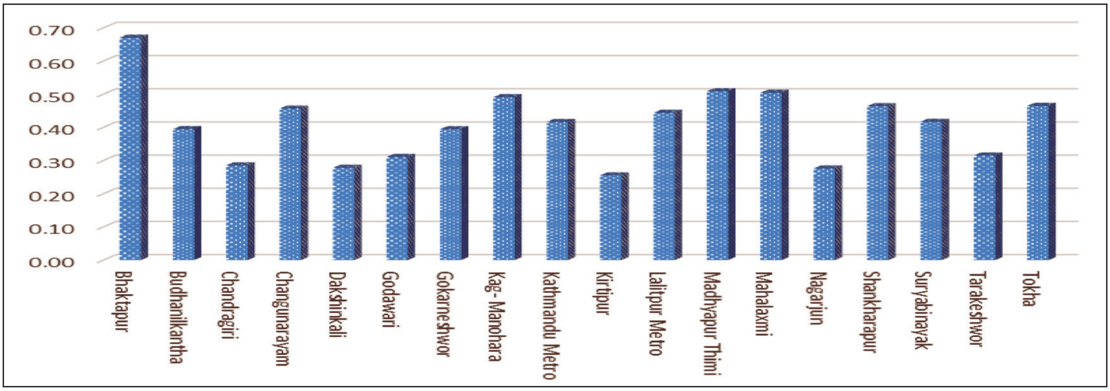

Figure 2. Vulnerability in terms of Housing Conditions

Built-up density (score 1) and HH size (Score 1) are dominant factors in Bhaktapur, whereas HH without RCC foundation (0.95) and HH without piped drinking water (0.67) are dominant in Madhyapur Thimi and Mahalaxmi municipality. The spatial pattern of housing condition vulnerability is presented in Figure 5 (A).

Built Environment

To offer insights into how physical structures and urban environmental factors affect a community's vulnerability and resilience, this study employed twelve variables (Table 1). Calculated SoVI values demonstrate that among 18 municipalities, the highly vulnerable municipalities are Bhaktapur and Kathmandu with a score of 0.63. it is followed by Madhyapur Thimi and Mahalaxmi with scores of 0.50. Godawari is the least vulnerable municipality (0.28), followed by Kritipur (0.31). Eleven municipalities have SoVI scores between 0.4 and 0.47, indicating moderate vulnerability, while two municipalities ranged between 0.31 and 0.37, indicating relatively lower vulnerability (Figure 3).

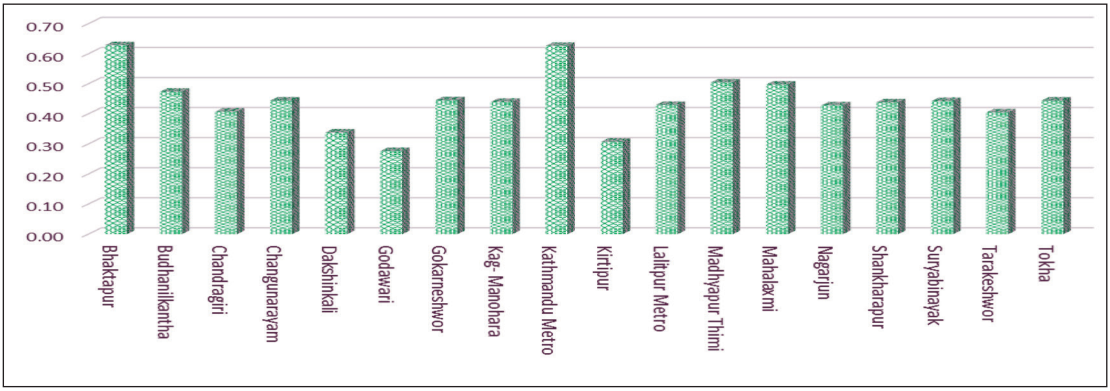

Figure 3. Vulnerability in terms of the built environment

Limited public open space, low vegetation cover, and large built-up areas within high flood and liquefaction zones are major determinants in Bhaktapur. A higher percentage of squatter settlements, a higher percentage of waste generation, low vegetation cover, and a higher percentage of the built-up area within a high liquefaction zone are major factors in Kathmandu. Madhyapur Thimi is highly vulnerable due to low vegetation cover, limited public open space, and a higher percentage of built-up within a high liquefaction zone. In contrast, Mahalaxmi has limited open space and water bodies. The spatial pattern of housing condition vulnerability is presented in Figure 5 (B).

Access to Services and Infrastructure

A total of five variables were incorporated under this indicator (Table 1). A calculated SoVI score is presented in Figure 4. In comparison to housing conditions and built environment, service accessibility reveals a distinct pattern with values ranging from 0.03 to 0.91. Kathmandu Metropolitan City has the lowest vulnerability (0.03), followed by four traditional urban cores, namely Madhyapur Thimi and Bhaktapur (0.44), and Lalitpur and Kirtipur (0.47). Shankarapur is highly vulnerable (0.91) followed by Dakshinkali (0.87) and Godawari (0.76). The other ten municipalities are moderate in terms of service and utilities accessibility.

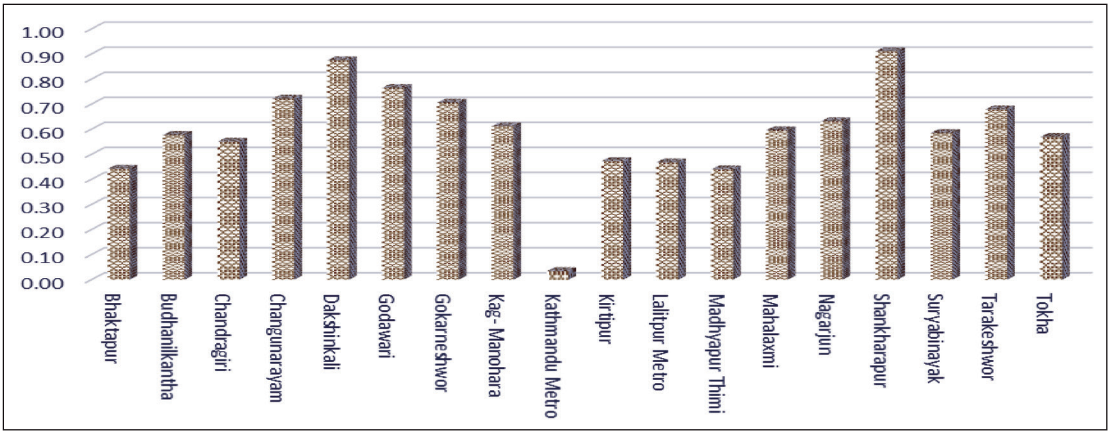

Figure 4. Vulnerability in terms of Services and Infrastructure Access

Low per capita economic establishment, limited motor road access, limited public bus service, and a lower percentage of the population with graduate-level education are major determinants of the very high vulnerability in Shankarapur. Dakshinkali is also vulnerable due to limited access to motor roads, less public bus service, and a lower percentage of the population with smartphones. Lower per capita economic establishment and limited motor road accessibility are the major causes in Godawari. The spatial pattern of housing condition vulnerability is presented in Figure 5 (C).

Overall Vulnerability

In this study, twenty-five variables ranging from six (housing condition) to twelve (built environment) under three thematic indicators were included based on a review of the relevant literature regarding the geographic/ spatial condition and socio-economic and development context of cities in developing countries. The composite social vulnerability score for eighteen municipalities is presented in Figure 5.

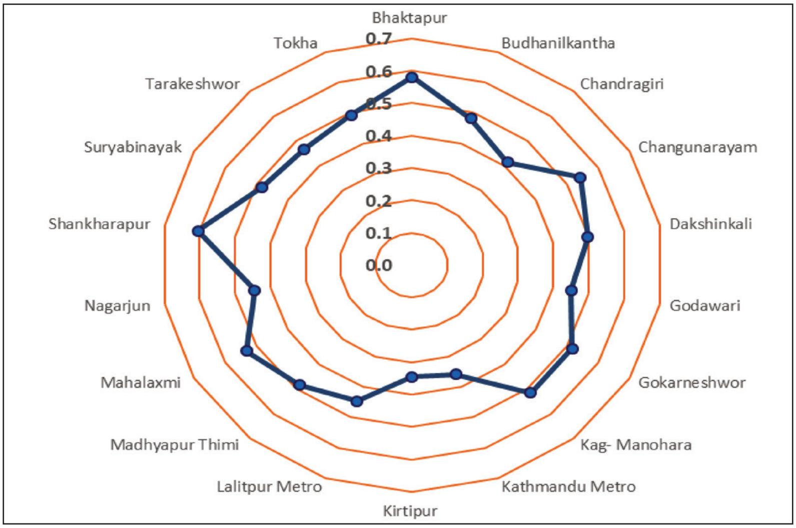

Figure 5. Overall Vulnerability of Kathmandu Valley Municipalities

Shankarapur has the highest level of UV (0.604), and Kirtipur has the lowest vulnerability (0.345) followed by Kathmandu. The overall SoVI index value was reclassified into four groups, namely low, medium, high, and very high vulnerability (Table 2). One municipality is very highly vulnerable, five municipalities are highly vulnerable, and there are ten municipalities with moderate levels of UV.

Table 2: Composite Social Vulnerability Level of Municipalities

Vulnerability level	Municipalities	#
Low (0.345-0.359)	Kirtipur and Kathmandu	2
Moderate (0.414-0.497)	Chandragiri, Nagarjun, Lalitpur, Godawari, Tarakeshwor, Suryabinayak, Budhanilkantha, Madhyapur Thimi, Tokha, and Dakshinkali	10
High (0.514-0.58)	Kageshwori-Manohara, Gokarneshwor, Mahalaxmi, Changunarayan, and Bhaktapur	5
Very High (0.604)	Shankharapur	1

Source: Author's calculation based on the SoVI index

Municipalities are clustered with similar social vulnerability status (Figure 6). The traditionally core municipalities located in the central part of the valley are comparatively less vulnerable than new municipalities in the outer areas. North-eastern municipalities have relatively higher vulnerability. The spatial pattern of vulnerability in terms of housing conditions mirrors the overall vulnerability. However, regarding the built environment, traditionally, core municipalities have higher vulnerability. The random pattern is visible in the case of vulnerability to service and infrastructure accessibility.

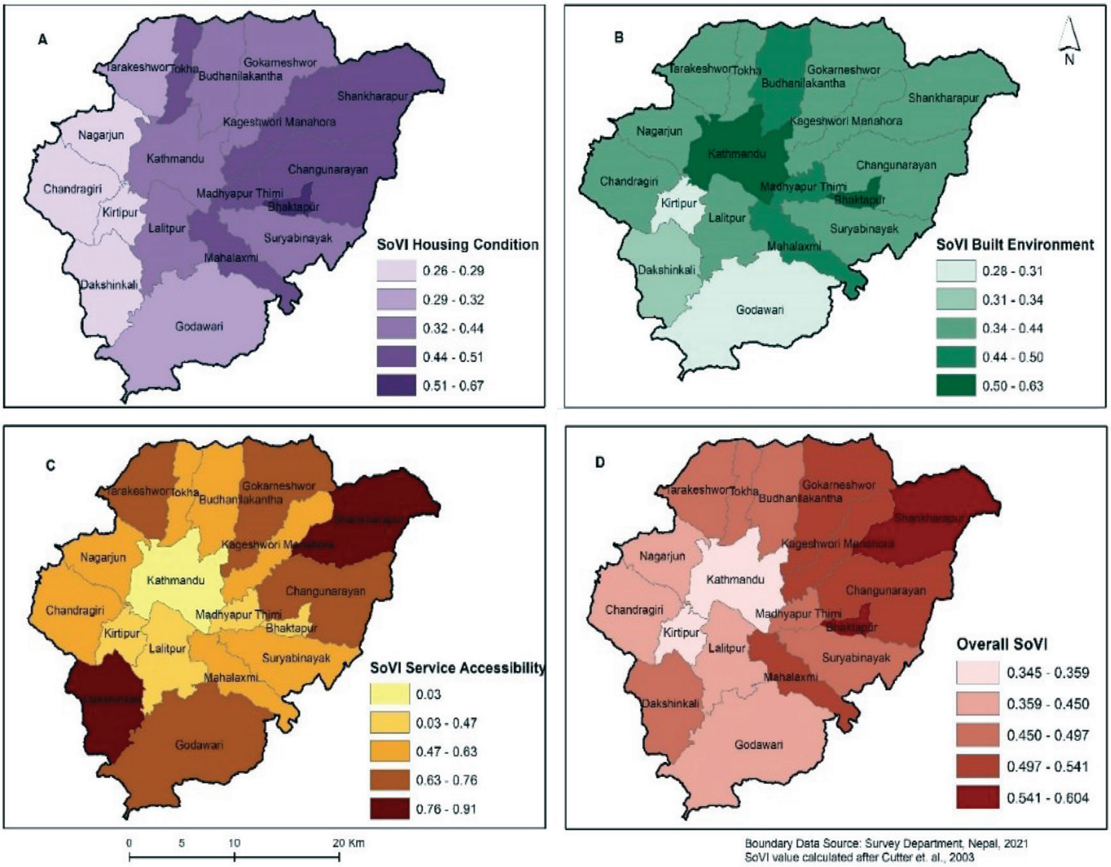

Figure 6. Spatial pattern of Urban municipal vulnerability in Kathmandu Valley

Discussion

The field-based assessment carried out in this study through FGD, KII, and local authority consultation reveals that UV in the Valley is the product of socio-spatial relations, developed in area-specific physical, social, economic, and cultural settings. Eighty percent of the participants of FGD and KII reveal that the haphazard growth, spatial clustering of migrants creating socio-demographic territoriality, degrading urban environment, increasing population in slums and squatter settlements, and inadequate infrastructure are genuine issues of Kathmandu Valley. According to them, inadequate coordination and cooperation among urban institutions with overlapping jurisdictions and weak links are major challenges to mitigating UV. Hossain et al. (2017) also reported that vulnerability is fundamentally linked to disaster risks such as floods, landslides, liquefaction, and fires, as groups that are highly socially vulnerable tend to experience more significant impacts and greater losses.

Singh & Dhakal (2024) reported that the vulnerability is intensified by haphazard spatial growth, increasing migrants and population density, poor access to services and infrastructure, limited economic opportunities, and conflict over resources. This study found that in 2001 built-up area occupied less than 10% of the valley area, which increased to 16.5% in 2011 and 35% in 2021. The highest spatial growth was in Godawari, Suryabinayak, and Changunarayan. Between 2006 and 2021, the growth of buildings was rapid in Gokarneshwor, Suryabinayak, and Tarakeshwor. The population growth rate was also very high in these municipalities: 5.1 in Nagarjun, 5.5 in Suryabinayak, and 5.9 in Tarekeshwor (NSO, 2023). These municipalities fall under moderate to high levels of vulnerability. Mesta et al., (2022) also asserted that 29% of the future built-up growth will be in the most socially vulnerable settlements, resulting in 11% higher vulnerability than the current level.

The housing characteristics of the study area indicate that only 46% of the population has piped water suply within their premises, and 10% do not have toilets within their premises (NSO, 2023). Likewise, 43% of the valley population were migrants in 2011, which increased to 53% in 2021 (NSO 2023). Shrestha et al. (2024) revealed that the spatial distribution of the migrants shows a distinct clustering with five northern municipalities sharing the highest percentage of migrants (60%), and building growth has surpassed population growth. The increasing migrants, building construction, and clustering significantly affect housing options (crowding), access to resources and services, and social cohesion, leading to increased vulnerability with potentially calamitous consequences for the low-income population (Bajracharya et al., 2015; Shrestha & Paudel, 2023). Aksha et al. (2019) reported that the spatial concentration of higher social vulnerability is found among disadvantaged and minority ethnic groups and mountain communities with poor infrastructure and critical service access. This study did not find any ethnic and minority clusters of specific vulnerable groups. Moreover, Mesta et al. (2023) stated that building growth toward environmentally sensitive areas will increase vulnerability, and financial losses are estimated to increase up to 16% in 2031.

Haphazard urbanization has caused disruption of natural waterways, rapid surface runoff, and river course shift, and infrastructures are exposed to hazard risk (Zachariah et al., 2024). This finding accords with the current study. The frequency and severity of floods have increased in recent years, causing greater damage to property and human life (Figure 7A-7D). The role of institutions is criticized regarding the approval of major structures like public markets and health facilities in hazard-risk areas (Figure 7A, AB, and 7C).

A: 08 August 2023: Nakkhu

B:28 September 2024:Nakkhu

C:24 July 2024: Inundated vegetable wholesale market at the bank of the Bagmati River (Public land)

D:28 September 2024: Inundated squatter settlement along the Bagmati River

Figure 7. Damage caused by inundation and flooding due to extreme monsoon rain, Kathmandu Valley 2022-2024

The growth of squatter settlements and slums is one of the significant urban challenges in Kathmandu Valley (MoUD, 2017) which highlights unplanned urban development and the growth of marginalized communities. In the 1980s, there were seventeen squatter settlements, which grew to forty-five (40 squatters and 5 slums) by 2008. Currently, forty-nine informal settlements with more than 4000 HH and 27000 populations are listed by the National Informal Settlement Union, as listed in Table 3. Among 18 municipalities, twelve municipalities have squatters located along the banks of different rivers. Kathmandu has the highest concentration of informal settlements (28) and mostly along the Bagmati and Manohara Rivers. It is followed by Budhanilkantha Municipality with six settlements along the Dhobikhola. However, there is no formal published record on the number of informal settlements, but it is emphasized that the number has increased with time (Shrestha et al., 2020). Adhikari (2021) reported that there are 63 slums and squatter settlements, which is growing at a rate of 24% and the housing condition is meager with 15% without toilets, and 48% direct sewerage discharge to the river. Based on the satellite image mapping and field survey, this study found a total of fifty-two squatter settlements along the river banks of the valley with 4065 temporary houses. Forty squatter settlements are located along three major rivers namely, Bagmati (#19), Manohara (#16), Dhobikhola (#6), and Bishnumati (#5).

Table 3: Distribution of Informal Settlement

SN	Municipality	House	Population	No of Settlement	% share
1	Budhanilkantha	160	1121	6	12.24
2	Chandragiri	15	210	1	2.04
3	Godawari	235	1600	1	2.04
4	Gokarna	19	80	1	2.04
5	Kageshwori Manahara	93	506	3	6.12
6	Kathmandu	2640	14926	28	57.14
7	Kirtipur	5	25	1	2.04
8	Lalitpur	42	168	1	2.04

9	Madhyapur Thimi	728	4940	2	4.08
10	Mahalaxmi	40	240	1	2.04
11	Suryabinayak	56	300	1	2.04
12	Tokha	32	161	2	4.08
	Total	4065	24277	49	100.00

Source: National Informal Settlement Union, Nepal, 2024

The spatial distribution of informal settlements and slums is presented in Figure 8. It is evident from the figure that most of the settlements are concentrated in three major rivers namely, Bagmati, Manahara, Dhobikhola, and Bishnumati. A total of nineteen settlements

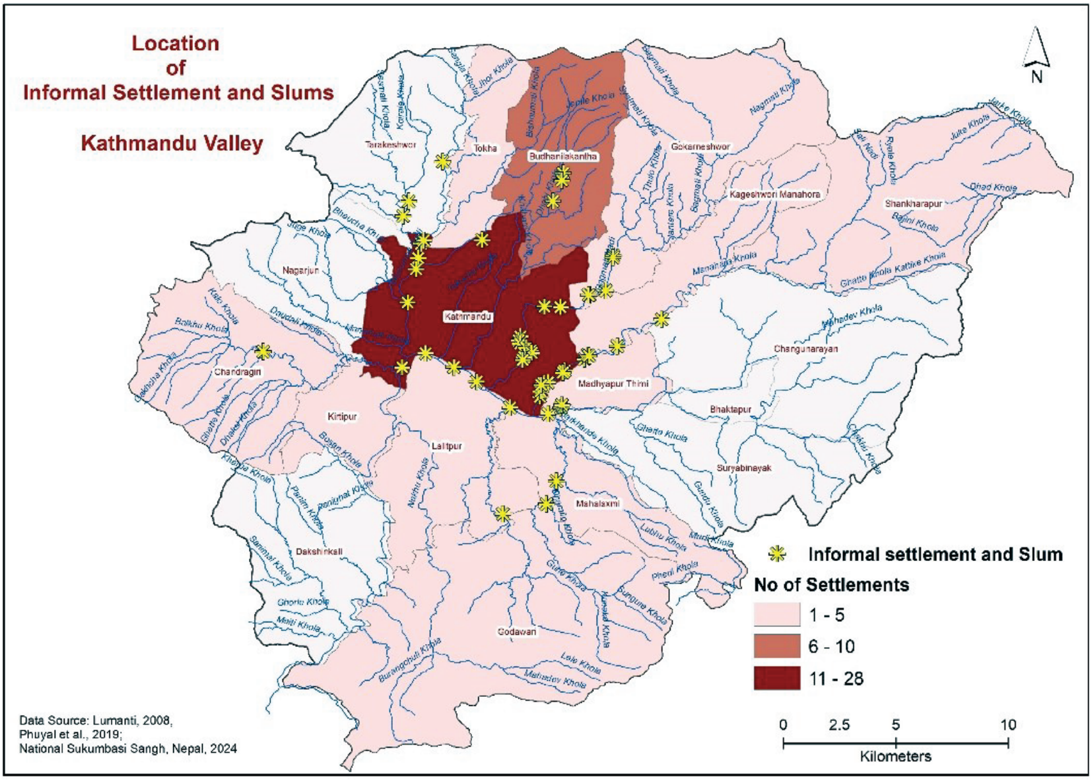

Figure 8. Spatial distribution of informal settlements and slums (Data Source: Nepal Informal Settlement Union, 2024
Source: Author's GIS mapping of time series GoogleEarth Images 2005-2024)

are found along the Bagmati River followed by 16 settlements located along the Manohara River. Bishnumati River has five, and Dhobikhola has three informal settlements. Besides, informal settlement is also found along the Godawari, Seshmati, Balkhu, Kodku, Sangla, and Samakhusi rivers. These informal settlements have contributed to river pollution and a negative visual impression along the river. On the contrary, with the changing river course and regular flooding and inundation occurrence, these settlements are at high hazard risk. Changes in landuse structure and solid waste management are other reported spatial impacts of ongoing urbanization (Flacke et al., 2022). Multihazard risk assessment depicted that 22.29% of the valley area has a very high seismic hazard risk, 13.6% is under very high flood risk, and around 9% is under a very high landslide risk area within densely populated settlements, indicating high vulnerability and greater potential damage and loss (Khatakho et al., 2021).

The availability and accessibility of basic services and infrastructure greatly influence a community's ability to function, respond to challenges, and recover from human and natural hazard risks (Gautam, 2017; Mesta et al., 2022). Analyzing the access to services and infrastructure helps to identify disparities within a community and highlights areas that require improvement to enhance resilience and reduce vulnerability. Migration significantly impacts settlement development and resource accessibility, especially triggering urbanization and spatial expansion. Internal migration drives city growth, often leading to overcrowding and informal settlement growth. It increases pressure on housing, raising demand and prices, while infrastructure struggles to keep pace in the cities. This study found that 49% of the migrated population chose the Valley as a destination for better education and healthcare services, while 40% reported migration for better livelihood/economic opportunities. This indicates the increasing pressure of urbanization on resource distribution, resource use, and service and infrastructure accessibility. An earlier social vulnerability assessment study on Nepal (Aksha et al., 2019) indicated that poor infrastructure and the rental population, besides economic conditions/poverty are major determinants of urban social vulnerability.Kathmandu was identified as the most vulnerable city, which contrasts with the findings of this study. This is because selected indicators like service accessibility and housing conditions in the Kathmandu metropolitan are relatively better, which is validated by the findings of Mainali & Pricope (2017). The lack of access to quality healthcare, education, and job opportunities exacerbates socio-economic inequalities in urban areas. The pressure on resources and services additionally impacts the overall livability and quality of life, impairing the social and economic welfare of urban residents.

The current and future spatial expansion, increase in population, and selection of residence sites by migrants will significantly drive territorial dynamics in the Valley, which in turn will affect the attainment of sustainable development goals like a safer urban population and settlement. Moreover, there are overlapping and ambiguous roles and responsibilities of authorities, and a gap exists in the formulation and implementation of collaborative and joint policy and programs between local authorities. Inadequate enforcement of environmental regulations, gaps in addressing the needs of marginalized and vulnerable populations, and insufficient risk assessment regarding UV are major challenges and gaps. It is suggested that the sectors that are relevant and directly linked to multiple authorities, such as river environment (upstream-downstream linkages that are not possible or effective to control by individual municipalities) and waste management (common issues of disposal, landfill sites, and pollution), should be led by regional authorities with the active participation of local municipalities. River environment protection and improvement in slums and squatters should be designed and implemented through the co-production of a better urban environment by engaging the community and relevant sectoral stakeholders, and a community-based self-help approach for a sustainable urban environment.

Conclusion

The prevailing socio-physical contexts and systems are determinants of UV, disaster, and their intensity of damage and loss. Even though different communities share similar exposure, it may have differential consequences depending upon their divergent coping capacity, risk-bearing, and institutional preparedness.

Most studies conducted in Nepal have focused on physical or natural disaster-induced vulnerability rather than looking into socio-physical dimensions. This study applied the Social Vulnerability Index (SoVI) assessment tool based on three thematic indicators to understand the spatiality of the socio-physical vulnerability situation of the Valley, which aids in informed policy formulation and implementation, efficient resource planning and allocation, and potential disaster risk management at the local level. Spatial patterns of vulnerability are highly significant for enhancing the understanding of UV and settlement growth. The findings of this research help refine relevant policies and prioritize programs at the local and regional levels. By understanding where gaps exist, policymakers and stakeholders can develop strategies to ensure more resilient communities with equitable access to resources and services. The study findings facilitate urban risk management and enhance urban sustainability by identifying socially vulnerable communities and understanding policy priorities to minimize community vulnerability.

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Declarations

The authors declare no competing interests.

References

Adamiak, C. (2016). Cottage sprawl: Spatial development of second homes in Bory Tucholskie, Poland. *Landscape and Urban Planning, 147*(1), 96–106. https://doi.org/10.1016/j.landurbplan.2015.11.003

Adhikari, A. (2021). Why cities fail: Urban development lessons for the Kathmandu Valley. *The Record*. https://www.recordnepal.com/why-cities-fail-urban-development-lessons-for-the-kathmandu-valley

Armas, I., & Gavris, A. (2016). Census-based social vulnerability assessment for Bucharest. *Procedia Environmental Sciences, 32*, 138–146. https://doi.org/10.1016/j.proenv.2016.03.018

Arunachalam, M., Saravanavel, J., & Kochuparampil, A. J. (2023). PCA-based approach for mapping social vulnerability to hazards in the Chennai metropolitan area, east coast of India. *Annals of GIS, 29*(4), 529–552. https://doi.org/10.1080/19475683.2023.2226189

Bajracharya, A., Pradhan, P., Amatya, P., Khokhali, B. B., Shrestha, S., & Hasan, A. (2015). *Planning for affordable housing during densification in Kathmandu: Lessons from four settlements*. International Institute for Environment and Development. https://www.jstor.org/stable/resrep01315

Bennett, N. J., Blythe, J., Tyler, S., & Ban, N. C. (2016). Communities and change in the Anthropocene: Understanding social–ecological vulnerability and planning adaptations to multiple interacting exposures. *Regional Environmental Change, 16*, 907–926. https://doi.org/10.1007/s10113-015-0839-5

Central Bureau of Statistics. (2011). *Population census 2011: Preliminary report*. National Planning Commission, Government of Nepal.

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly, 84*(2), 242–261.

Cutter, S. L., Mitchell, J. T., & Scott, M. S. (2000). Revealing the vulnerability of people and places: A case study of Georgetown County, South Carolina. *Annals of the Association of American Geographers, 90*(4), 713–737.

Cutter, S. L., & Morath, D. P. (2014). The evolution of the social vulnerability index (SoVI). In J. Birkmann (Ed.), *Measuring vulnerability to natural hazards: Towards disaster-resilient societies* (pp. 304–321). United Nations University Press.

Cutter, S. L. (2024). The origin and diffusion of the Social Vulnerability Index (SoVI). *International Journal of Disaster Risk Reduction*, 104576. https://doi.org/10.1016/j.ijdrr.2024.104576

Fatemi, F., Ardalan, A., Aguirre, B., Mansouri, N., & Mohammadfam, I. (2016). Social vulnerability indicators in disasters: Findings from a systematic review. *International Journal of Disaster Risk Reduction, 22*, 219–227.

Flacke, J., Maharjan, B., Shrestha, R., & Martinez, J. (2022). Environmental inequalities in Kathmandu, Nepal: Household perceptions of changes between 2013 and 2021. *Frontiers in Sustainable Cities, 4*, 835534. https://doi.org/10.3389/frsc.2022.835534

Gautam, D. (2017). Assessment of social vulnerability to natural hazards in Nepal. *Natural Hazards and Earth System Sciences, 17*(12), 2313–2320.

Ge, Y., Dou, W., & Zhang, H. (2017). A new framework for understanding urban social vulnerability from a network perspective. *Sustainability, 9*(10), 1723. https://doi.org/10.3390/su9101723

Government of Nepal, Ministry of Home Affairs. (2010). *Nepal hazard assessment, Part I: Hazard assessment*.

Hossain, S., Spurway, K., Zwi, A. B., Huq, N. L., Mamun, R., Islam, R., & Adams, A. M. (2017). *Urbanisation and natural disaster: A systematic review*. University College London. https://eppi.ioe.ac.uk/cms/Default.aspx?tabid=3707

Jenks, G. F. (1967). The data model concept in statistical mapping. *International Yearbook of Cartography, 7*, 186–190.

Khatakho, R., Gautam, D., Aryal, K. R., Pandey, V. P., Rupakhety, R., Lamichhane, S., & Adhikari, R. (2021). Multi-hazard risk assessment of Kathmandu Valley, Nepal. *Sustainability, 13*(10), 5369. https://doi.org/10.3390/su13105369

Kathmandu Valley Development Authority. (2016). *Vision 2035 and beyond: 20-year strategic development plan*.

Mainali, J., & Pricope, N. G. (2017). High-resolution spatial assessment of population vulnerability to climate change in Nepal. *Applied Geography, 82*, 66–82.

Meerow, S., & Newell, J. P. (2016). Urban resilience for whom, what, when, where, and why? *Urban Geography, 40*(3), 309–329. https://doi.org/10.1080/02723638.2016.1206395

Mesta, C., Cremen, G., & Galasso, C. (2022). Urban growth modelling and social vulnerability assessment for a hazardous Kathmandu Valley. *Scientific Reports, 12*(1), 6152. https://doi.org/10.1038/s41598-022-09347-x

Mesta, C., Cremen, G., & Galasso, C. (2023). Quantifying the potential benefits of risk-mitigation strategies on future flood losses in Kathmandu Valley, Nepal. *Natural Hazards and Earth System Sciences, 23*, 711–731. https://doi.org/10.5194/nhess-23-711-2023

Metzger, M. J., & Schröter, D. (2006). Towards a spatially explicit and quantitative vulnerability assessment of environmental change in Europe. *Regional Environmental Change, 6*, 201–216. https://doi.org/10.1007/s10113-006-0020-2

Ministry of Urban Development. (2017). *National urban development strategy (NUDS) 2017: Part A*. Government of Nepal.

Muzzini, E., & Aparicio, G. (2013). *Urban growth and spatial transition in Nepal: An initial assessment*. World Bank. https://fid4sa-repository.ub.uni-heidelberg.de/3556/

National Planning Commission. (2020). *The fifteenth plan (FY 2019/20–2023/24)*. Government of Nepal.

National Statistical Office. (2023). *National population and housing census 2021: National report*. Government of Nepal. https://censusnepal.cbs.gov.np/results/files/result-folder/National_Report_English.pdf

Otto, I. M., Reckien, D., Reyer, C. P. O., Marcus, R., Le Masson, V., Jones, L., & Serdeczny, O. (2017). Social vulnerability to climate change: A review of concepts and evidence. *Regional Environmental Change, 17*, 1651–1662. https://doi.org/10.1007/s10113-017-1105-9

Sengupta, U. (2013). *The divided city? Squatters' struggle for urban space in Kathmandu*. Routledge. https://doi.org/10.4324/9780203085332

Siagian, T. H., Purhadi, P., Suhartono, S., & Ritonga, H. (2014). Social vulnerability to natural hazards in Indonesia: Driving factors and policy implications. *Natural Hazards, 70*, 1603–1617. https://doi.org/10.1007/s11069-013-0888-3

Singh, R. P., & Dhakal, J. (2024). Problems and prospects of urbanization in Kathmandu Valley. *International Journal of Atharva, 2*(1), 19–33. https://doi.org/10.3126/ija.v2i1.62821

Shrestha, D., Basnyat, D. B., Gyawali, J., Creed, M. J., Sinclair, H. D., Golding, B., & Haiju, R. (2023). Rainfall extremes under future climate change with implications for urban flood risk in Kathmandu, Nepal. *International Journal of Disaster Risk Reduction, 97*, 103997. https://doi.org/10.1016/j.ijdrr.2023.103997

Shrestha, S., Karna, B. K., Chapagain, P. S., Dahal, K., Timalsina, K., & Paudel, N. R. (2024). Territorial dynamics of spatial growth in Kathmandu Valley, Nepal: Understanding geographical notions of urban sustainability. *GeoJournal, 89*(1), 13. https://doi.org/10.1007/s10708-024-11019-4

Shrestha, S., & Paudel, D. P. (2022). Everyday water use in Kathmandu Valley of Nepal: Contextualizing marginality and social vulnerability. In P. K. Pradhan & W. Leimgruber (Eds.), *Nature, society, and marginality* (pp. 187–204). Springer. https://doi.org/10.1007/978-3-031-21325-0_9

Tyler, S., & Moench, M. (2012). A framework for urban climate resilience. *Climate and Development, 4*, 311–326. https://doi.org/10.1080/17565529.2012.745389

Zachariah, M., Jha, R., Mondal, A., Rauniyar, S., Vahlberg, M., Kayastha, B., Raju, E., & Regmi, A. (2024). *Rapid urbanization and climate change: Key drivers of dramatic flood impacts in Nepal*. Imperial College London. https://doi.org/10.25561/115192

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