

AN EARTHQUAKE VULNERABILITY ASSESSMENT OF ASAN TO INDRACHOWK SETTLEMENTS OF THE CITY CORE OF KATHMANDU

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Abstract

Nepal, a South Asian Himalayan country, is particularly vulnerable to earthquake disasters due to its young geology, hilly terrain, and widespread non-engineered infrastructures. The country exhibits significant physical and cultural diversity in terms of geology, altitude, and location. Social and cultural activities were virtually prohibited for many years following the earthquake; the physical damage from past earthquakes was less severe than anticipated in comparison to the social and cultural consequences. Based on the study, this research proposes a tripartite mitigation framework for physical, social and cultural vulnerability of the Asan to Indrachowk settlements in Kathmandu's city core, an area critical for its socio-cultural and economic significance, employing mixed-methods analysis and Analytic Hierarchy Process (AHP). The pragmatism/mixed method has been employed to find composite vulnerability. Physical vulnerabilities arise from non-engineered, high-rise buildings, social vulnerabilities from limited community resources, and cultural vulnerabilities from the erosion of traditional practices. The research outcome revealed physical (63.25%, extreme), social (41.3%, highly) and cultural (44.15%, highly) vulnerable. The composite vulnerability score of 57.23% indicates extreme vulnerability, necessitating urgent retrofitting and cultural preservation measures.

Keywords: Cultural Vulnerability; Earthquake Vulnerability; Kathmandu City Core; Physical Vulnerability; Social Vulnerability

Introduction

Vibrations of the earth's surface caused by waves originating from a source of disturbance in the earth's mass are called earthquakes. In an earthquake, the ground vibrates and trembles, which results in shaking and vibrating everything in its path and causes inadequately and improperly reinforced structures to crumble and break. Nothing is spared. Both intangible assets, such as cultural

behaviors, rituals, conventions, etc., and tangible assets, such as buildings, roads, etc., may be impacted by an earthquake. Earthquakes, as low-probability, high-impact events, cause extensive damage primarily through the failure of human-made structures like buildings and lifelines (bridges, dams, and transportation systems etc.), which were supposedly designed and constructed for the

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comfort of human beings and built up over time. Earthquakes may be caused by volcanic eruptions or strain-building processes inside the Earth's mass (Bozorgnia & Bertero, 2004; Caputo & Pavlides, 2008; Chandradhara, 2018).

Nepal is a Himalayan country with a lot of physical and cultural heterogeneity in terms of geology, altitude, and location, as well as widespread poverty. Its young geology, mountainous terrain, and extensive non-engineered infrastructure make it more vulnerable to earthquakes. Ranked among the top 20 multi-hazard-prone countries, Nepal is 4th, 11th, and 30th in terms of climate change, earthquake, and flood risk, respectively. Other major disasters in Nepal are landslides, fires, droughts, epidemics, storms, hailstorms, avalanches, and Glacial Lake Outburst Flood/GLOF. These disasters often result in extensive damage to human resources, animals, agricultural land, crops and infrastructure. Thus, Nepali people are living with natural hazards as a matter of fate and have come to accept the various disasters created by geographical disasters as a part of life. Historical data suggest a major earthquake occurs approximately every 75 years (Gautam *et al.*, 2021; JICA, 2002; WHO, 2016).

Brief introduction to the earthquake history of Nepal and the effects

Nepal has experienced many earthquakes since its existence. The oldest records of earthquakes in Kathmandu are only available from 1223 A.D. The records of past earthquakes up to the year 1934 are either very brief or nonexistent. However, the records of earthquakes after 1934 A.D. are found in different kinds of literature from Nepal and abroad (Marahatta, 2012). The details of major earthquakes and their effect are described here.

The Great Bihar-Nepal Earthquake 1934 A.D

The Great Bihar-Nepal Earthquake, also known as the *Magh* Earthquake of 16th January 1934 A.D., struck around 2 p.m. local time. The Kingdom of Nepal and its neighbouring areas were struck. The earthquake had a value of 8 on the Richter scale. The death toll was the largest of any recorded earthquake in Nepal's history. In Nepal, a total of 8519 people were killed. There were 12397 buildings that had fallen totally, 25658 buildings with significant damage and 17684 with moderate damage. The earthquake caused serious damage to cultural heritage, as well as human casualties, and for months, cultural festivals were either closed or only partially held in the Kathmandu Valley (KVTDC, 2002; Rana, 2013).

Udayapur Earthquake 1988 A.D.

On August 21, 1988 A.D., the earthquake of magnitude 6.8 on the Richter scale struck the Udayapur district of eastern Nepal. The earthquake killed 721 people, demolished an estimated 60,000 houses, and wreaked havoc on infrastructures. The worst-affected places were Dharan, Dhankuta, Terathum, Panchthar, Ilam, Morang, and Bhaktapur in the eastern section. For months, cultural festivals in the earthquake-affected areas were either cancelled or only partially held due to the earthquake's severe effects on human casualties and cultural legacy (Bothara *et al.*, 2018).

Gorkha Earthquake 2015

The powerful earthquake that occurred on April 25, 2015 A.D., with a moment magnitude of 7.8 on the Richter scale, started at Barpak in the Gorkha District, approximately 80 km Northwest of Kathmandu and struck at 11:56 a.m. local time. Similarly, on May 12 at 12:50 p.m. local time, the largest of hundreds of aftershocks, measuring 7.3 on the Richter scale, with an epicentre at the border between Sindhupalchowk and Dolakha Districts, about 35 km east of Kathmandu, occurred. These earthquakes are thought to have affected the lives of eight million people. Of the 75 districts in the nation, 31 have been impacted. Residential and public structures, historical sites, schools, health facilities, rural roads, bridges, water supply systems, agricultural land, hiking trails, hydropower plants, and sports facilities were all severely damaged. A total of 8,580 persons perished in Nepal, including 3,851 males and 4,729 females. There were 14,734 persons injured in total, with 9,400 men and 5,334 women. A total of 1,578 government houses were damaged, with 692 entirely ruined and 886 partially damaged. A total of 635,843 privately owned houses were damaged, with 458,454 of them destroyed and 177,389 partially destroyed. Because of the devastating impacts of the earthquake on human victims and cultural heritage, cultural festivals in the districts affected by the earthquake were either cancelled or only partially held for months (CBS, 2012; MoHA, 2015; Manandhar *et al.*, 2016; ICA, 2016; NPC, 2016a, 2016b).

Brief introduction to Earthquake Vulnerability Assessment

Since the beginning of the study on earthquake vulnerability assessment, many ways of analysis of the vulnerabilities have been developed. All methods are sufficient to assess vulnerability. The method for measuring and conceptualising vulnerability will vary depending on the aim of the

assessment, and there is a range of tools and frameworks to guide the process. The particularities of a place and community, and advance a human-centred approach to development are most effective and likely to yield sustainable, inclusive, and equitable outcomes. The seismic/earthquake vulnerability of a structure is a quantity linked with its weakness in the event of an earthquake of a certain magnitude. The seismic risk of historical and monumental buildings is their inability to withstand the effects of an earthquake, while the inability or cessation of traditional custom and ritual is a cultural loss that can be caused by an earthquake. Mixed/pragmatism method research is the process by which a researcher uses both qualitative and quantitative approaches or methods to collect and examine data, combine the results, and draw conclusions (Caputo & Pavlides, 2008; Moret, 2014; ISCRP, 2015; Regnault *et al.*, 2018).

Composite vulnerability assessment is a tool to calculate different types of vulnerabilities of any behaviour and determine how vulnerable a system is to damage or loss because of multiple factors. The assessment is carried out by integrating several frequently related signs into a single numerical score. This approach helps to establish a thorough knowledge of vulnerability by integrating multiple dimensions like physical, social, and environmental issues (Vicent *et al.*, 2008; Wehbe & Baroud, 2024).

Brief introduction of Kathmandu Valley

Among the various theories about when the settlement in Kathmandu began, the Swayambhu Puran states that the Kathmandu Valley was formerly a lake. There were lotus plants with lovely lotus flowers blooming on the hill where the Swayambhu Stupa is located. To create a livable

land, the god Manjushree used a sword known as Chandhrashtra to cut a gorge at a location known as Kashapaal, later called Chobhar, and drained away the waters; after that, the settlement development started gradually (Thapa *et al.*, 2008; Shrestha & Shrestha, 2009).

The Kathmandu Valley, often referred to as the Nepal Valley, is the capital of Nepal and forms the core of the nation's most populous urban region. The Kathmandu Valley is known for its exceptional traditional settlements, distinctive urban society, and home to one of the most advanced brick, stone, timber, and bronze crafts in the world. The functions of public and private open spaces, religious squares and courtyards, not only define the valley's identity but also contribute to essential cultural and commercial role and maintenance of everyday life. The seven collections of monuments and structures serve as examples of the Kathmandu Valley's cultural legacy, and historical accomplishments. The multi-ethnic group known as the Newars, who have inhabited this isolated Himalayan valley for the past two millennia, still strive to proudly maintain the remnants of their tangible and intangible assets, despite the countless earthquakes that have struck Kathmandu throughout its history (Nepali, 1965; Gellner, 1986; Tiwari, 1989; Shrestha, 1998; Thapa *et al.*, 2008; Thapa & Murayama, 2010; MoUD, 2015).

Brief introduction of Asan to Indrachowk corridor/ Study area

The Asan Indrachowk corridor was established between the third and the twelfth centuries and developed in the thirteenth to the sixteenth centuries (Nepali, 1965). Two of Kathmandu's primary market hubs are Asan and Indrachowk. A broad road

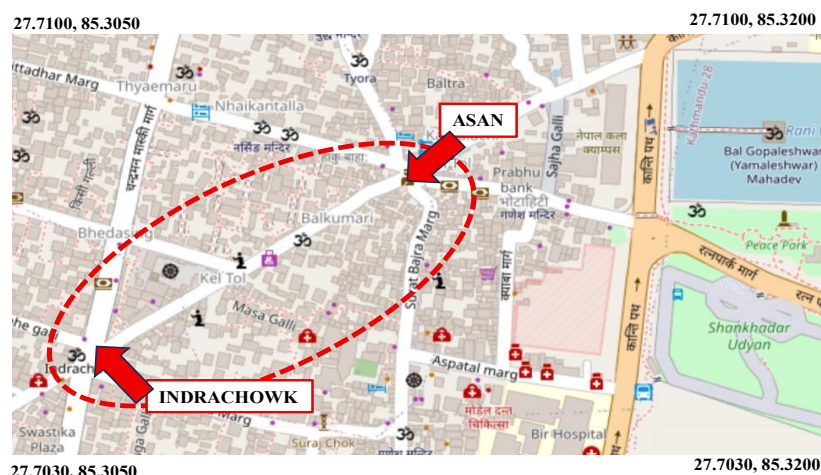


Figure 1. The Study Area
(Source: Google Map)

runs alongside these two market centres, which are crucial for improving the social, economic, cultural, and political well-being of Kathmandu's citizens (Figure 1).

The Asan to Indrachowk area is a bustling, historic marketplace and a significant intersection. It is well-known for its vibrant market, temples, and functions as a centre of commerce and culture. Offering a window into traditional Nepali life and commerce, the area is a well-liked tourist and local destination. The neighbourhoods surrounding the corridor are extremely crowded, with many stores, parks, open spaces, and temples. The ancient market areas of Asan and Indrachowk are renowned for their unique Newari architecture and lively ambience (Pokharel, 1994) (Figure 2).

Asan

Asan Tole has a total of six paved streets with numerous Hindu shrines and sacred Buddhist courtyards as shown in Figure 2. In addition to a temple devoted to Lord Ganesh and to Lord Narayan, the street is home to the shrine of their patron deity/goddess Annapurna Ajima. The goddess is represented by a filled grain measure. There is a stone figure of a fish (known as Nyalon) at the centre of the square that is believed to have fallen from the sky. Asan, also known as Ason Tol or Ason, is a ceremonial, market, and residential plaza in the heart of Kathmandu. Asan has been recognised as one of the best instances of a traditional market among the Newari people. According to some Buddhists in Asan, the area was originally named Ashok Mandap after India's King Ashoka and was later altered to Asan. Sacred dances and musical performances take place on a stone platform called Asan Dabu, during festivals. Shrines and sacred courtyards can be seen on the streets and

alleyways extending out from the square. The Buddhist courtyards of Takse Baha, Kwathu Baha, Haku Baha, Dhlsikwa Baha, Dagu Baha, Asan Baha, and Hwakha Baha are located around the square's perimeter. Each one has a well-decorated shrine house with a Buddha picture and various stupas (Lewis, 1995; Shrestha, 2011).

Indrachowk

Indrachowk, also known as Purnavati in ancient times, is a ceremonial and market area on the artery that runs through Kathmandu's historic district. The Hindu deity of the sky, Indra, is honoured by the square's name. This location was known as Yambi/Yapung/Yam during Kirat's reign. An iconic feature of Indrachowk is the massive Akash Bhairav/Aaju Dyo or "God of the Sky" temple located on the western edge of the square. The Akash Bhairav, Bakha Bhairav, Shiva temple, Ganesh Temple, Mahalaxmi Temple and stone jars (Wangha) are other important monuments of the Indrachowk. It is a hexagonal intersection that marks the old India-Tibet trade route, which is today a busy market street. At Indrachowk, six streets come together to connect the square to Kathmandu's major neighbourhoods as shown in Figure 2. The square in Indrachowk serves as a ceremonial centre, with major festival pageants and chariot processions of the Jana Baha Dyo Jatra and Indra Jatra passing through (Nepali, 1965; Lewis, 1993; Shrestha & Shrestha, 2009; Singh & Keitsch, 2014).

This study examines the scenarios of the key characteristics of settlement development and the transformation process of people's behaviours towards their customs, rituals and practices related to earthquake vulnerabilities, including cultural understanding.

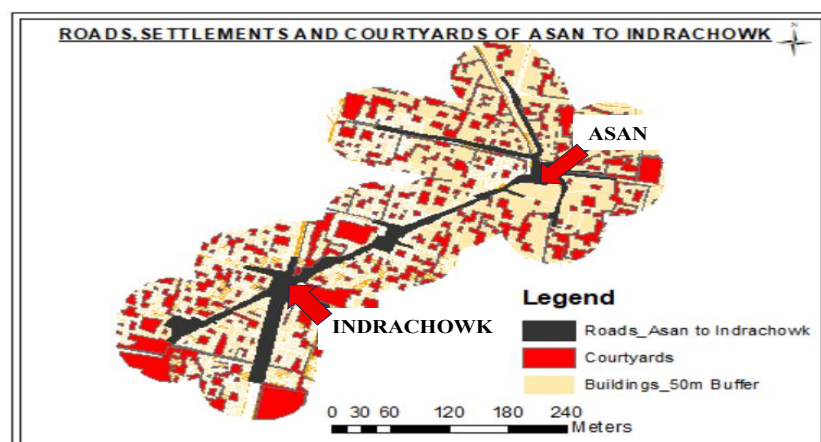


Figure 2. Settlements & Road Networks of the Study Area

Materials and Methods

Methodology

So far, no one has studied how much the earthquake is affecting the cultural sector of the study area. Therefore, the main objective of this study is to find out how much the earthquake is affecting the cultural sector of this area/region by assessing the composite vulnerability of the region. As the research is exploratory, the mixed-method approach has been applied to calculate quantitative and qualitative components of earthquake vulnerabilities.

This study aims to address (1) parameters of vulnerabilities, emphasising cultural aspects; (2) existing vulnerability assessment practices; and (3) methods to calculate composite vulnerability. The research questions for the study are: (a) What are the parameters of physical, social, and cultural vulnerabilities? (b) What methods assess these vulnerabilities? (c) What techniques quantify composite vulnerability? (d) What measures can reduce vulnerability?.

There are different tools for scoring earthquake vulnerability, and for this study, the Giupponi *et al* (2015) method has been adopted, which is discussed below.

Table 1. Giupponi method of Normalised value

S.N.	Normalised Value	Vulnerability Level
1	0	Not Vulnerable
2	0.25	Slightly Vulnerable
3	0.5	Highly Vulnerable
4	0.75	Extremely Vulnerable
5	1	Fully Vulnerable

Table 1 says that the normalised values for different vulnerability levels can be categorised as 0 to 1 or 0% to 100%. In which 0 represents not vulnerable, 0.25 slightly vulnerable, 0.5 highly vulnerable, 0.75 extremely vulnerable and 1 fully vulnerable,

Data collection

For this study, primary and secondary sources of data served as the foundation. Key informant interviews, household surveys, and building surveys were used to gather the study's primary data. Additionally, focus group discussions, wealth rankings, modelling, GIS mapping, and excel/SPSS models were used as additional sources of primary data. Secondary data were gathered from articles, research papers, theses, and books that were either published or unpublished.

The procedure of gathering data was divided into two phases. A phenomenology study was

carried out in the first phase, and a perception questionnaire survey was used to get user input in the second phase. Users at the study area were asked survey questions, and forms were distributed to local people and scholars. A detailed Field Study Performa was developed, incorporating physical and socio-economic parameters of the study. Based on a defined study approach, methods, and tools, the necessary information was collected from the field study of almost one year, i.e. from July 2017 to August 2018. The population, buildings, household size, and physical infrastructure were measured using site surveyors, enumerators, including engineers and sociologists. A sampling frame has been created by counting the total no of buildings within the study area. Sample size was calculated using Cochran's formula for a finite population (at 95% confidence level). A total of 150 respondents were included, representing all 610 households in the study area (50-meter buffer from the corridor).

Formulae;

$$n = \frac{z^2 p q N}{e^2 (n-1) + z^2 p q}$$

Where;

- n = Sample size
- z = The value of the standard variate at a given confidence level
- p = Sample proportion
- q = 1-p
- e = Given precision rate or acceptable error
- N = Population

Calculated n = 42 < 150.

The collected data and information were edited, coded and presented in an appropriate format. As the research has adopted mixed methods, the qualitative and quantitative analysis were carried out. The interviews, observation and phenomenological analysis were used for qualitative data analysis, mean, bar charts, descriptive statistics for quantitative analysis, Analytical Hierarchy Process (AHP) for determining weightage of different types of vulnerabilities, and Chi-square test for categorical data validation were used.

Data Analysis

Data analysis is a critical stage of research, which turns unprocessed data into insights that may be put to use. Proper analysis guarantees that study findings are accurate, dependable, and significant, regardless of whether they are qualitative or quantitative. Hence, for this study, the special features of the study area were inspected minutely, and the data analysed to discover meaningful patterns, trends, and insights.

Behaviours of settlement changes

The settlement development pattern of the Malla period/reign was the radial roads in a grid layout, worship places/temples along with row houses, deities at sacred places, and tangible and intangible assets at every node. In addition, construction of the Nani's/courtyards, sufficient underpasses, and water supply sources, wells at every courtyard were the special features of settlement development of Kathmandu valley. The study area was renovated massively after the 1934 earthquake, as many courtyards, buildings and temples were reconstructed. It is assumed that the haphazard usage of modern materials triggered the vulnerability of the area rather than using traditional ones (Nepali, 1965; Shrestha & Vaidya, 1978; Tiwari, 1989; Rana, 2013; and Shrestha, 2021; KMC, 2010). To find the effect of earthquakes, several analyses were done in this study. Details of the data analysis of some variables of the vulnerabilities are discussed here.

Data analysis of the physical vulnerability assessment of the study area

To calculate physical vulnerability, nine different types of variables used in the study of Pakistan, Gujarat, and cities of India (Kr & Chourasia, 2007; Mustafa *et al.*, 2011; and Ainuddin & Routray, 2012): high rise, quality of construction, vertical irregularity, soft story, plan irregularity, pounding, cladding, soil condition, ground condition and slope ambience were used. Two new variables were added as per the special characteristics of the study area: resilient factor and age of building by the author.

Table 2. Physical vulnerabilities and capacity index

S.N.	Variables	Vul. Type
1	High Rise	A
2	Quality of Construction	I
3	Vertical Irregularity	I
4	Soft Storey	I
5	Plan Irregularity	A
6	Pounding	I
7	Cladding	M
8	Soil Condition	M
9	Ground Condition & Slope Ambience	M
10	Resilient factor*	I
11	Age of Building*	I

In Table 2, S. N. stands for Serial Number, Vul. Type stands for Vulnerability type, 'A' stands for Attitudinal behavior or variables related with psychological factors, subjective preferences and intangible factors affecting decision makers, 'I' stands for Institutional behavior or variables related

with variables refers to rules and regulations affecting decision maker and 'M' stands for Materialistic behavior or variables related with resource based, economic and tangible factors affecting decision maker. Analyses of some data on the physical vulnerability are discussed as follows:

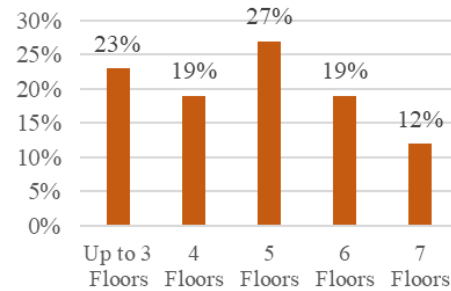


Figure 3. Floor composition of buildings

There are five types of buildings regarding floor composition in the study area. 12% of buildings are of seven, 19% of buildings are of six, 27% of buildings are of five, 19% of buildings are of four, and 23% are with up to three floors. This data shows that, 77% buildings are of four or more floors. Similarly, the region is urbanised and experiencing vertical growth, with the majority of buildings being four stories or above. The prevalence of five-story/storey buildings (27%) points to a practical approach to housing that strikes a balance between cost and size. As taller structures become more prevalent, policymakers should concentrate on safety rules and infrastructure resilience. Thus, in the region, 77% of buildings are highly vulnerable to earthquakes, as shown in Figure 3.

The study area uses four different kinds of building materials to construct buildings. 61% of buildings are made of pillars, beams and properly designed, 22% of buildings are made of pillars and beams but not properly designed, 13% of buildings are made of stone/brick cement masonry, and 4% buildings are made of stone/brick in mud mortar.

The structural data of these buildings provides important information about construction methods, safety regulations, and socio-economic conditions that can be obtained in the area. While masonry/mud (17%) represents remaining rural/traditional techniques, pillar-beam (83%) is the predominant material, reflecting the region's urban, vertical rise. Not properly designed (22%) and non-engineered (17%) structures pose the greatest safety dangers, necessitating legislative actions. Thus, regarding the possible collapse of buildings due to earthquakes, 39% of buildings are highly vulnerable, as illustrated in Figure 4.

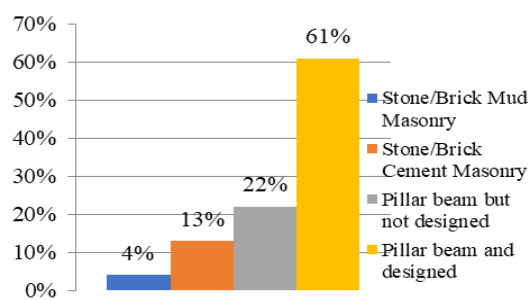


Figure 4. Construction materials of buildings

Finally, evaluating all the variables, including the aforementioned variables, the overall physical vulnerability score was found to be 63.25%, which proves that the study area is extremely vulnerable physically.

Data analysis of social vulnerability assessment of the study area

To calculate social vulnerability, nine different types of variables used in the study of Pakistan, Gujarat, and cities of India (Kr & Chourasia, 2007; Mustafa *et al.*, 2011; and Ainuddin & Routray, 2012), as education level, age, health coverage, special needs for old/pregnant women, children and disable population, social capital, housing capital, employment, income, and facade. Two new variables were added, as per the special characteristics of the study area: awareness and community trust by the author, as shown in Table 3.

Table 3. Social vulnerabilities and capacity index

S.N.	Variables	Vul. Type
1	Educational level	M
2	Age	M
3	Health coverage	I
4	Special needs for old/pregnant women, children and disable population	I
5	Social capital	I
6	Housing capital	A
7	Employment	M
8	Income	M
9	Facade	I
10	Awareness*	A
11	Community Trust*	I

Analyses of some data on social vulnerability are discussed here.

Regarding the education status of the study area, 18% of people are above bachelor level, 56% of people are higher secondary to bachelor level, 13% of people are secondary level, and 13% are primary level. Important information about labour preparedness, socioeconomic conditions, and

human capital development can be gleaned from the research area's educational levels.

Although 74% of people in the study area have at least a secondary education, 26% do not, putting them at risk of continuing to live in poverty. While uplifting the underprivileged, strategic investments in education, vocational training, and digital access can unlock the potential of the majority, who are 56% mid-educated. As 13% of people have a primary level, the study area is less vulnerable, as shown in Figure 5.

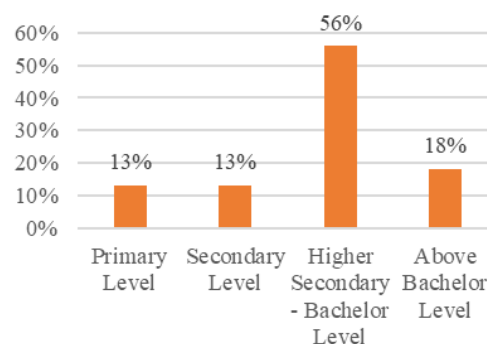


Figure 5. Education status of the study area

Earthquakes

Figure 6 shows that 92% of the public is aware that human deaths occur due to the collapse of buildings and not earthquakes, while only 8% do not know. Although 92% awareness is admirable, there remains a chance to save lives due to the 8% gap. Stricter building enforcement combined with targeted actions can guarantee that no one is left behind. Thus, regarding general knowledge of the earthquake, the study area is less vulnerable.

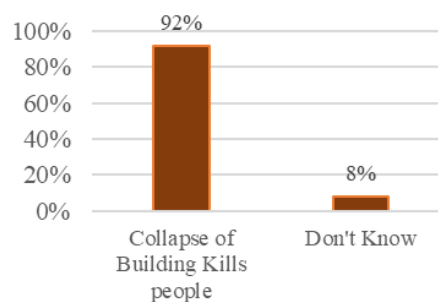


Figure 6. General knowledge about earthquakes

The study shows that 64% of people have jobs, 28% have their own businesses, and 8% have other income opportunities. This result shows that, as salaried work makes up the majority of jobs, the job market exhibits stability, and business owners of

28% can be boosted by introducing new business opportunities, including upliftment of the 8% of persons who work irregularly. Therefore, the study area is slightly vulnerable in terms of income, as illustrated in Figure 7.

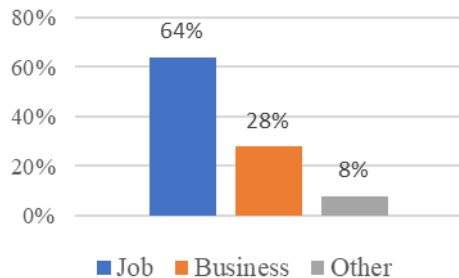


Figure 7. Income status of the study area

The study reveals that only 32% of people are involved in the Guthi/community trust organisations, and 68% are not. The Guthi system is found to be very much alive in Newari society, and it is a matter of concern that 64% of the people are not involved in Guthi, even though the study area is a Newari majority area. Thus, the 68% gap indicates unrealised potential for safer neighbourhoods, economic empowerment, and social cohesion, even though 32% membership represents a strong foundation. Hence, Guthi is extremely vulnerable, as shown in Figure 8.

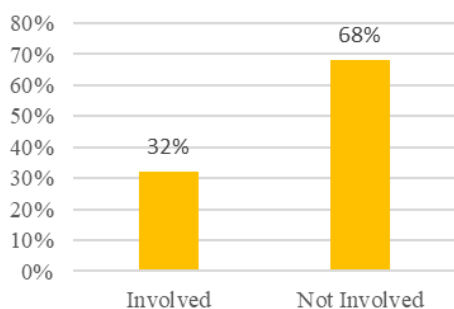


Figure 8. Involvement in the Guthi organisation

Finally, when evaluating all other social variables, the overall social vulnerability score was found to be 41.3%, which proves that the study area is highly vulnerable socially.

Data analysis of the cultural vulnerability assessment of the study area

While studying earthquake vulnerability, most researchers seem to focus on physical and social

issues only. The extent to which earthquakes have affected cultural conditions is not yet known, as cultural aspects have not been studied. In particular, no one has studied the Asan to Indrachowk area of Kathmandu. To study cultural vulnerability, a total of eleven variables were developed. Of these, four are 'A'/attitudinal, four are 'M'/materials, and three are 'I'/institutional, as personal (serious disease related), language/communication, dress (women), food habits, religion and religious beliefs (festivals), marriage and religious customs, social relations, building permits, education system, work habits and products, and common festivals as listed in Table 4.

Table 4. Cultural vulnerabilities and capacity index

S.N.	Variables	Vul. Type
1	Personality (serious disease related)	A
2	Language / communication	I
3	Dress Female	M
4	Food habits	M
5	Religion & religious faiths (Celebrations)	A
6	Customs of marriages and religions	A
7	Social relationship	I
8	Building Permit	I
9	System of education	M
10	Work habits and products	M
11	Common Festivals	A

Few databases collected for the cultural vulnerability calculation are as follows:

In the study area, 65% people are Hindus, 20% are Buddhists, and 15% are Muslims. For centuries, Hindus and Buddhists of this area have celebrated all their festivals together, demonstrating the mutual social harmony and tolerance of the people of this place. This mix affects every aspect of daily life, including festivals, food, social interactions, fashion choices, the design of inclusive policies, accurate assessment of social trends, and understanding of demographics.

Hence, the area is slightly vulnerable regarding religion, as shown in Figure 9.

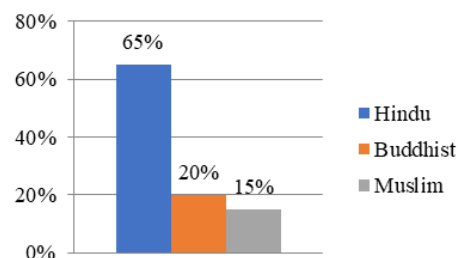


Figure 9. Religion of the people of the study area

Regarding the clothing of the women of the study area, 70% use Salwar and Kameez and 30% use Sari and Blouse. This depicts that the majority of women in the research area choose the Salwar Kameez due to its convenience and safety benefits, even if the sari still has cultural significance. It shows how design changes can improve safety in both groups without sacrificing cultural values, which could be a topic for future study.

As the score of the Saree user is 30%, the area is highly vulnerable regarding the outfits of the women, as shown in Figure 10.

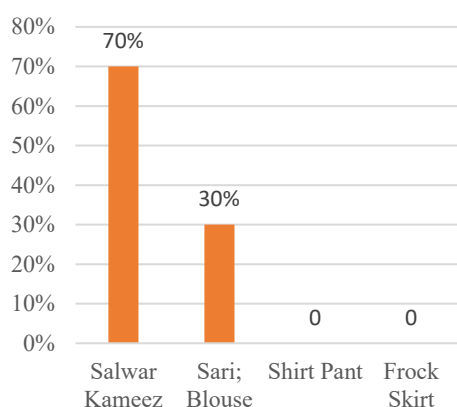


Figure 10. Clothing of the women of the study area

Finally, when evaluating all other variables of culture, the overall cultural vulnerability score was found to be 44.15%, which proves that the study area is highly vulnerable culturally.

Results and Discussion

Results

This section presents the results obtained from the study. This study has assessed the nature of physical, social, and cultural vulnerability, its interrelationships, proximity, and how it has affected society and culture as well. The results of the study are discussed below.

Physical vulnerability of the study area

The study concludes that, in the Asan to Indrachowk area, the physical parameters, such as old-aged buildings and courtyards of the old settlements, are being used for shopping, storage, and restaurant purposes, so they are being maintained and seem in good condition. The soil and ground condition may be deteriorated, as many

buildings are using deep boring for water and pounding, and the quality of construction and claddings is medium. But as there are many non-engineered high-rise buildings with vertical irregularities, the plan irregularities and resilient factors are poor.

In addition, the study area has unsafe building practices due to 22% undesigned pillar-beam structures, along with 17% masonry structures. High-density urban development has 77% buildings with more than four floors and low community participation, or 68% uninvolved. The individual composite physical vulnerability scored 63.25%, or extremely vulnerable. It indicates the serious and vital work as engineering interventions, social empowerment and economic incentives necessary for restructuring, retrofitting, or any appropriate physical upliftment to be carried out to protect physical vulnerability along the road networks of the Asan to Indrachowk area.

The results of the study closely match those of the Multi-Hazard Risk Assessment of the Kathmandu Valley (Khatakho, *et al*, 2021), as the results highlight that the densely populated settlements, old settlements, and the central valley are the most hazard/risk-prone areas in Kathmandu Valley. Despite variations in methodology, this association remains, indicating strong support for the notion. Future studies, however, might recommend next approaches.

Social vulnerability of the study area

The study concludes that, in the Asan to Indrachowk area, social parameters such as education level, social capital, age composition, employment, income, awareness, and community trust (Guthies) are at satisfactory levels. Health facilities, housing capital, and the facade are in the middle. But resting places/platform like Falcha and Dabali, community buildings like Dyo Chhen, old songs, instruments, care of old/pregnant women, children, and disabled people are poor.

The detailed table used to calculate Composite Social Vulnerability is given below.

Table 5 is the modified table of the composite vulnerabilities and capacity index of the household level study of Pakistan (Mustafa *et al*, 2011). It shows that the variables of the social vulnerability have been divided into three major elements as Material (35%), Institutional (50%) and Attitudinal (15%). The key drivers of social vulnerability such as education, employment and community participation, are diverse.

Table 5. Social composite vulnerability calculation at the community level

	Social Vulnerability	Vulnerability	Capacity
A	Material vulnerabilities	35	
1	Education Level: start value	8	
	Start value represents 100% illiterate people		
	Add 2 for every 25% literates		-8
B	Institutional vulnerability	50	
5	Health Coverage: start value	15	
	Start value represents no health insurance		
	Lower score by 2 for every 20% health insurance		-3
	Lower score by 1 for every 20% people who spent less than Rs. 30000 every year		-2.75
C	Attitudinal vulnerability	15	
10	Awareness: Start value*		
	Start value represent buildings more than three storey	5	
	Lower score by 1 for every 20% aware people		-5
	Total vulnerability score	100	
	Total capacity score		-58.7
	Combined vulnerability and capacity score	41.3	

As 26% of the population has attained primary/secondary education, 64% are paid workers, and 68% are not involved in community organisations, this indicates that there are socio-economic inequalities and an institutional gap in the study area. Therefore, due to all the factors of social vulnerability mentioned above and others, the study area is socially highly vulnerable. It indicates the serious and vital work of investing in education and skill development, strengthening community partnerships, economic support for target groups, strengthening social capital, such as old traditions and a cohesive synthesis of people, and places need to be preserved to protect the social vulnerability of the study area.

The results of the study closely match those of the Assessment of social vulnerability to natural hazards in Nepal (Gautam, 2017), which reveals that eastern and central regions depicted low to moderate social vulnerability to natural disasters in general. Despite variations in methodology, this association remains, indicating strong support for the notion.

Future studies, however, might recommend next approaches.

Cultural vulnerability of the study area

The study on cultural vulnerability assessment is a new dimension in this regard, as the earthquake cultural vulnerability assessment has not been carried out for the traditional settlements of the city cores of Kathmandu, particularly for the Asan to Indrachowk area of Kathmandu. The study area has strong social bonding and a mixture of effects that affect every aspect of daily life, including festivals, cuisine and social interactions, because 65% are Hindu, and 20% are Buddhist, which shows the area is less vulnerable regarding social harmony. Regarding the clothing of the women, 70% use Salwar and Kameez, 30%, Sari, and Blouse. Thus, the clothing of the women in the study area is highly vulnerable.

The study reveals that, in the courtyards and road junctions of the Asan to Indrachowk area (as Janabahal, Asan Chowk, and Indrachowk), undivided personality, religion, religious faith, social relationships, and common festivals are in a good position. Whereas language/communication, clothing patterns of women, food habits, education, and work habits are in the medium position. But indigenous games, local species/cuisine like Yomari, and the continuation of ancestors' professions and knowledge sharing with younger generations are either in the worst condition or have vanished.

It indicates the serious and vital work necessary for food habits, continuation of ancestors' professions and knowledge sharing with younger generations to be carried out to protect cultural vulnerability by all stakeholders.

Composite vulnerability

The analysis using the Analytical Hierarchy Process (AHP) has assigned physical (71.34%), social (18.66%), and cultural (10%) weights. Similarly, the individual physical, social, and cultural vulnerability scores are found to be 63.25%, 41.3%, and 44.15%, respectively. Therefore, the composite vulnerability score of the study area is found to be 57.23%, indicating that the Asan to Indrachowk settlement in the centre of Kathmandu city is extremely vulnerable.

Discussion

In vulnerability assessment research, cultural vulnerability is a new task. Culture is the collection of methods that arises when a group employs the fundamental resources that are present in its members to solve issues. Culture is the expression of art, literature, music, and a host of other subjects

of a society at a certain time. In cultural studies, practices and events are examined to indicate the place these studies occupy in historical formations. These meanings are given to settings by human societies, and the same environment might have multiple meanings depending on the culture. However, the extent to which cultural disparities in settings exist is unknown. The case study approach allows, amongst other things, critical events, interventions, policy developments, and program-based service reforms to be studied in detail in a real-life context (Hall, 1997; Pokharel, 2003; Matsumoto, 2007; Coningham *et al.*, 2011; Crowe *et al.*, 2011).

The objective of the assessments is to identify places that are vulnerable, comprehend the causes of that vulnerability, and provide information for the creation of successful mitigation and adaptation plans. For this, different variables of physical, social, and cultural vulnerabilities were considered to evaluate the composite vulnerability of earthquakes. The different indicators were given weights before being combined to create a single vulnerability score. The weightage of the physical, social, and cultural vulnerability was calculated using the Analytical Hierarchy Process (Saaty, 2008) and based on this, the composite vulnerability was calculated. Additionally, to achieve the designed objectives, explore the answers to the research questions, accomplish the intended goals, and investigate the responses to the research questions, the case study methodology was employed.

To find composite vulnerability, mixed method was used considering physical, social and cultural vulnerabilities. In-depth interviews, questionnaire surveys, and library research were used to gather data about the subject and the study is limited to assessing the composite vulnerability of the study area only. To provide a spatial quantification of vulnerability to be used for the calculation, the dimensions of adaptive capacity, coping capacity, and vulnerability need to be assessed and aggregated.

Thus, for normalising selected indicators, a generalised approach of value function, i.e., establishing upper and lower thresholds as well as a range of values that indicate various significant

performance levels in relation to predetermined goals, is used to mathematically express human judgments. The AHP method was used to calculate the weightage of the three different vulnerabilities. The importance factors, assumed as per the specific nature of the site, are as follows:

- a) Physical to physical is of equal importance.
- b) Physical has a much greater importance than social.
- c) Physical is of greater importance than culture
- d) Social is of equal or moderate importance to culture.

Based on the assumed importance, the weightage calculation is carried out here.

Table 6 depicts that physical vulnerability is 7 times more important than social vulnerability and 5 times more important than cultural vulnerability. It indicates that physical structures play a vital role in social and cultural variables in the study area.

Table 6. Pairwise comparison matrix

Particulars	Physical	Social	Cultural
Physical	1	7	5
Social	0.1429	1.0000	3.0000
Cultural	0.2000	0.3333	1.0000
Sum	1.3429	8.3333	9.0000

Table 7 for normalised pairwise comparison shows that each column adds up to exactly 1.000 meaning the raw data has been scaled so that the factors can be compared proportionally. The table quantifies the relative importance of these three categories against one another.

Table 7. Normalised pairwise comparison matrix

Particulars	Physical	Social	Cultural
Physical	0.7447	0.8400	0.5556
Social	0.1064	0.1200	0.3333
Cultural	0.1489	0.0400	0.1111
Sum	1.0000	1.0000	1.0000

Table 8 reveals that as per the scores obtained by Criteria Weights (CW), top priority should be given to physical vulnerability (71.34%), secondary focus to social vulnerability (18.66%) and minimal resource allocation needed for cultural vulnerability (10%).

Table 8. Criteria Weightage

Particulars	Physical	Social	Cultural	Weighted Sum Value (WSV)	Criteria weights (CW)	Ratio (WSV/CW)
Physical	0.7134	1.3060	0.5001	2.5195	0.7134	3.5316
Social	0.1019	0.1866	0.3000	0.5885	0.1866	3.1545
Cultural	0.1427	0.0622	0.1000	0.3049	0.1000	3.0484
Sum						9.7345

Table 9 shows that the calculated value of $\lambda_{\max}$ is 3.244 and C.I. is 0.1224.

Table 9. Consistency check

$\lambda_{\max} = \text{Ration} / n = 9.7345 / 3 = 3.2448$
Consistency Index (C.I.) = $(\lambda_{\max} - n) / (n - 1) = 0.1224$
where n is the number of compared elements.

Table 10 shows that the calculated Consistency Index (0.1224) is less than the table value for 3 variables (0.58). Hence, the check ensures the weights reflect expert intent.

Table 10. Standard Table of Random Consistency Index (RI)

n	1	2	3	4	5
RI	0	0	0.58	0.9	1.1
n	6	7	8	9	10
RI	1.24	1.32	1.41	1.45	1.49

Consistency Ratio = $0.1224 < 0.58$; OK

Table 11 shows that, after completion of all AHP steps to quantify priority scores, it concludes that the weightages for the physical, social and cultural vulnerabilities are 71.34%, 18.66% and 10% respectively. To examine the relationship between the variables used for the study, the Chi-Square test has been used.

Table 11. Final Weightage

Vulnerability Type	Weight	Percentage (%)
Physical	0.7134	71.34%
Social	0.1866	18.66%
Cultural/Cul.	0.1000	10.00%

Hypothesis setting;

H_0 = The variables are independent.

H_1 = The variables are dependent.

Table 12 defines that two sets of values as calculated and assumed have been used to compare vulnerability factors across three categories: physical, social and cultural. A weighted percentage is given to each category, adding up to 100% for each set.

Table 12. Assumption Table

Vulnerability parameters/weightage	Physical	Social	Cultural
Calculated	71.34	18.66	10.00
Assumed	33.33	33.33	33.33

Table 13 compares two different ways of weighing vulnerability factors-Physical, Social, and Cultural to reach a total score. The row calculated shows the actual weight of each category. In the study Physical vulnerability is the dominant factor at 71.34%, while Social and Cultural factors play smaller roles.

Table 13. Calculation of Observed Value

Vulnerability /Calculation	Physical	Social	Culture	Total
Calculated	71.34	18.66	10.00	100.00
Assumed	33.33	33.33	33.33	99.99
Total	104.67	51.99	43.33	199.99

Table 14 defines the mathematical formulas used to calculate values in a vulnerability assessment matrix. It uses a Row/Column or (R/C) notation system to determine the weight or distribution of Physical, Social, and Cultural factors. Where Sum R is equal to the total sum of a specific row: Sum C is equal to the total sum of a specific column and Total/Grand Total is equal to the overall sum of all values in the data set (Kothari, 2010).

Table 14. Calculation of Expected Value

Vulnerability/Calculation	Physical	Social	Cultural
Calculated	$\frac{(\sum R1 \times \sum C1)}{\text{Total}}$	$\frac{(\sum R1 \times \sum C2)}{\text{Total}}$	$\frac{(\sum R1 \times \sum C3)}{\text{Total}}$
Assumed	$\frac{(\sum R2 \times \sum C1)}{\text{Total}}$	$\frac{(\sum R2 \times \sum C2)}{\text{Total}}$	$\frac{(\sum R3 \times \sum C3)}{\text{Grand Total}}$

Table 15 is a Chi-Square Goodness of Fit test calculation. Where Observed value or O is the actual data points recorded in the study. Expected value or E is the values expected to see if the data followed a specific theory or if all factors were equal. The residual or (O-E) is the difference between the actual data and expectation. A positive number means the observation was higher than expected; a negative number means it was lower. The square difference or $(O-E)^2$, removes negative signs so that all deviations are treated as positive magnitudes. Weight by Expectation or $(O-E)^2 / E$ means divide the squared value by the expected value to find the contribution of the particular row. Sum of Chi-Square or Total Calculated Chi-Square is the addition of all the values in the final column. The table defines a Chi-Square test calculation, resulting in a final statistic of 30.50.

Table 15. Calculation of Chi-Square

S.N.	Observed value (O)	Expected value (E)	(O-E)	(O-E) ²	$\frac{(O-E)^2}{E}$
1	71.34	52.34	19.00	361.1	6.90
2	18.66	26.00	-7.34	53.8	2.07
3	10.00	21.67	-11.67	136.1	6.28
4	33.33	52.33	-19.00	361.1	6.90
5	33.33	25.99	7.34	53.8	2.07
6	33.33	21.66	11.67	136.1	6.28
Calculated Chi-sq.=					30.50

Calculation of Degree of Freedom:

$$df = (Column - 1) \times (Row - 1)$$

$$df = (3 - 1) \times (2 - 1) = 2$$

Tabular value for 2 degrees of freedom in 5% significance level = 5.99

The calculated value of Chi -Sq.(30.50) > Tabular value (5.99), we reject the Null Hypothesis.

Since the null hypothesis is rejected, the chi-square test confirmed that all the variables are dependent or confirmed the results of AHP.

The research found that, regarding the physical vulnerability of the study area, high-rise buildings, vertical irregularity, and plan irregularity are highly vulnerable. Quality of construction, soft story, pounding, cladding, soil condition and ground condition are at medium and resilient factors, and building age is poor or extremely vulnerable as shown in Table 16.

Table 16. The relation between variables and the physical vulnerability level

S. N.	Variables	Vulnerability level
1	High rise	High
2	Quality of construction	Medium
3	Vertical irregularity	High
4	Soft story	Medium
5	Plan irregularity	High
6	Pounding	Medium
7	Cladding	Medium
8	Soil condition	Medium
9	Ground condition	Medium
10	Resilient factor	Poor
11	Building age	Poor

This study found that, the traditional knowledge of indigenous people to be incredibly valuable and effective, although it has been ignored so far. The residents of the area, both indigenous people and immigrants, believe that this old city is changing its social, and cultural identity as it attempts to modernise and become a smart city and raise education level, social capital, age

composition, employment, income, awareness, and community trust (*Guthies*).

Thus, to reduce such risks, a detailed physical, social, and cultural vulnerability assessment is necessary. Due to the absence of such data, it is very hard to quantify the risk of the study area. Further, cultural vulnerability due to the earthquake in the study area has not been assessed yet. An integrated assessment of physical, social, and cultural vulnerabilities resulting from earthquakes will facilitate the assessment of seismic vulnerability. Considering this, the present study is undertaken and is confined to determining the combined vulnerability of Asan to the Indrachowk area of Kathmandu Metropolitan City.

Conclusion

The Asan to Indrachowk area/corridor in Kathmandu's city core is extremely vulnerable to earthquakes (composite score: 57.23%), driven by non-engineered high-rise buildings, weak community trust, and eroding cultural practices. Ancient structures, impacted by historical disasters, and underutilised traditional knowledge highlight the urgent need for retrofitting, enhanced health facilities, and cultural preservation to mitigate risks as the area modernises.

- **Physical Vulnerability:** Extreme vulnerability (score: 63.25%) due to non-engineered high-rise buildings with poor resilience, despite maintained courtyards and medium-rated soil, ground, and construction quality.

- **Social Vulnerability:** High vulnerability (score: 41.3%) with satisfactory education, employment, and awareness but inadequate health facilities, community assets (e.g., Falcha, Dyo Chhen), and care for vulnerable groups.

- **Cultural Vulnerability:** High vulnerability (score: 44.15%) with strong religious faith and festivals but declining language, dress, food habits (e.g., Yomari), and ancestral professions.

• Composite Vulnerability: Extreme vulnerability (score: 57.23%), calculated using AHP weights (71.34% physical, 18.66% social, 10% cultural), imposing immediate interventions.

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