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Host characteristics as factors associated with the 2015 earthquake-induced injuries in Nepal: A cross-sectional study

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ABSTRACT

This study examines individual- and household-level factors associated with human injuries caused by two powerful earthquakes that hit Nepal on April 25 and May 12, 2015. A cross-sectional post-earthquake survey design was adopted to accomplish the objective of this study. Using random sampling, two of the 31 affected districts (Sindhupalchok and Lalitpur) were selected. Five study sites from each of the two districts were selected to administer questionnaire surveys. Focus group meetings and semi-structured formal and informal interviews with key informants were also used to collect relevant data. Building on previous studies, we considered nine risk factors for earthquake injuries in this study: five individual-level factors and four household-level factors. Using a goodness-of-fit chi-square test, we identified statistically significant risk factors of earthquake injuries in Nepal. Our results show that out of the nine factors, one individual-level factor – age – and two household-level factors – monthly income and type of main dwelling – were statistically significant. While long-term efforts to improve the economic conditions of those affected will reduce earthquake injuries, in the short-term, requiring seismic-resilient features in new construction and repairing damaged houses will substantially reduce earthquake injuries. Fortunately, the Nepalese Government has been ensuring that all houses are rebuilt and repaired to earthquake-resistant standards.

1. Introduction

Natural disasters produce a wide range of direct and indirect health impacts [1]. The direct health impacts of disasters include death and injury. Among other factors, the extent and nature of these impacts depend on disaster types. Because earthquakes are unpredictable, sudden-onset, cover relatively large geographic areas, these events, particularly ones with relatively high magnitude, tend to cause more death and injury than other natural disasters. Another factor associated with the high rate of earthquake-induced casualties is the number of vulnerable people exposed to such an event [2]. In general, earthquakes inflict more injury than mortality [3], with the average ratio around 3:1, three injuries to every fatality [4].

The primary objective of this study is to analyze the factors associated with human injuries caused by two powerful earthquakes that struck Nepal on April 25 and May 12, 2015. Although a considerable number of studies [e.g., [5–18]] have examined various aspects of injuries caused by earthquakes, the overwhelming majority of these studies used an epidemiological approach, and are thus based on retrospective review of operative data from hospital log books and medical records or discharge reports of patients admitted and treated mostly at a single hospital for a specific time period. A notable exception to these hospital-based earthquake injuries studies is one by Johnston et al. [19] who investigated causes of injury during the 2010/2011 Canterbury, New Zealand, earthquakes. However, they used the secondary data obtained from the New Zealand Accident Compensation Corporation (ACC).

Moreover, most of the available studies on earthquake injuries considered only one type of injury (e.g., scald, crush, acute traumatic, or musculoskeletal injuries), selected to examine only moderate, serious, or multiple injuries, and only one segment of the injured population, such as the pediatric population [17,20,21]. Less-severe injuries are generally treated outside the hospital setting [22,23]. Therefore, these studies were not representative of the spectrum of injuries sustained in the earthquake. Without information on the population at risk, identification of factors associated with seismic injuries is not feasible [20]. The present study is undertaken to fill this research gap. Findings of this study will be useful for policy makers, emergency managers, and public health professionals to prevent and reduce injuries caused by earthquakes in Nepal as well as other earthquake-

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prone countries. A comprehensive understanding of the risks for earthquake-related injuries is also needed to design programs to prepare for earthquakes and mitigate their effects.

The remainder of this paper is arranged as follows. The next section presents a review of studies dealing with risk factors associated with earthquake-induced injuries. This review was used to help select the appropriate determinants of injuries for this study. Section 3 introduces this study's methodology and includes a brief description of the study area, data collection procedure, sampling process, and analytical tools used for this study. Section 4 presents the study results, and the last section offers concluding remarks.

2. Literature review

Many factors contribute to earthquake injuries. The majority of injuries sustained from an earthquake happen because of damage to buildings or other structures from the energy of the earthquake [24]. Therefore, one's location during the event could play an important role in the resulting injuries and fatalities. Also, building height and construction materials, as well as the building codes that engineers must follow can affect the extent of injury following an event [11]. Analyzing the deaths and injuries caused by the Armenian earthquake in 1988, Armenian et al. [6] reported a higher risk of injuries for anyone who was indoor, in taller buildings, and on the upper floors of concrete panel buildings during the earthquake. They claim that being inside increased the risk of injury by 2.3.

Generally, residents of high-raised, multiple-unit residential and commercial structures faced an increased injury risk compared with those in single-unit residential structures. Within taller buildings, there was a maximum 60% increase in risk for injuries [9]. Those in precast concrete frame buildings faced additional risk, as rigid concrete structures and masonry buildings could not attenuate ground motion and were thus prone to collapse. Lightweight wooden structures that bend and deform without breaking may fare better than much stronger, but brittle, concrete structures that lose their rigidity. The majority of single-family homes in developed countries, particularly in the United States, are wooden structures that are relatively stable in earthquakes [9].

In contrast to Armenian et al.'s [6] findings regarding the risk of multiple-unit structures versus single-family units, data collected by Peek-Asa et al. [9] after the 1994 Northridge, California, earthquake, found no significant risk of injury difference between multi-unit residential structures and single-family homes [also see [11]]. This is because the building stock in southern California is subject to building codes and retrofitting that makes buildings less vulnerable to collapse. Instead, they reported association between severe injury and the age of the building. Risk was moderately greater in newer buildings—those constructed after 1975—and in residential multiple-unit and commercial structures when compared with single-family homes [20]. Still, irrespective of structure type, building or structural damage was a strong predictor of earthquake injury. Location in close proximity of buildings and other structures during earthquakes was also considered a risk factor for injuries. In contrast, the risk of injury in open areas such as fields or in the countryside was found to be very low [25].

Other built environments, such as bridges, roadways, or freeways, are also vulnerable to earthquake damage. Collapse of these structures often causes both deaths and injuries [7]. Motor vehicle crash fatalities and injuries were also tied to damage to transportation infrastructures, such as nonfunctional traffic signals and road lighting [7,9]. During the Northridge earthquake, 15% of fatal injuries were motor vehicle related and were primarily due to disruptions in traffic control devices [7].

Risk of injury during an earthquake is inversely related to the distance from the earthquake epicenter or the rupture plane [26]. In examining how individual characteristics, building characteristics, and seismic features of the 1994 Northridge, California, earthquake contributed to physical injury, Peek-Asa et al. [9] reported that every kilometer increase in distance from the rupture plane led to a 10% reduction in the risk of injury. For example, a town could be affected by shaking from a magnitude 9.0 earthquake but because it is located 1000 miles (1500 km) away, the shaking is very small. Towns built near the epicenter of the 9.0 magnitude earthquake will likely experience severe shaking. Severe shaking, or "intensity" can be measured either physically by looking at the spectral accelerations or peak ground acceleration or velocity (PGA or PGV), or through quantitative damaged measures such as Modified Mercalli Intensity (MMI).

The intensity of an earthquake at a site where people/buildings are located by far the most important measure when assessing impacts from such event. Earthquakes are more likely to cause greater damage, injuries, and deaths, if the epicenter locates in an urban area as opposed to a rural location [9].

However, Ramirez and Peek-Asa [20] claim that distance from the epicenter may misrepresent localized strength or severity of shaking. This is because other factors also influence wave transmission during a seismic event, including ground composition, liquefaction, and landslide susceptibility [also see [27,28]]. For example, an area with alluvial soil, which has high water content and thus is very effective in transmitting energy waves, may exhibit greater damage, injuries, and deaths even if far removed from the epicenter [29,30].

Shoaf et al. [22], Peek-Asa et al. [8,9], and Mahue-Giangreco et al. [11] also found that peak ground acceleration in the 1994 Northridge, California, earthquake was highly predictive of both fatal and nonfatal injury. This acceleration quantifies seismic energy based on the speed of acceleration of the ground at localized points. Acceleration for specific latitude and longitude coordinates is interpolated from underground sensors. Because these sensors are not in place in most earthquake-prone developing countries, the use of peak ground acceleration as a worldwide measure is limited. Earthquakes can occur anywhere from at the surface to 467 miles (700 km) below. In general, deeper earthquakes are less damaging because their energy dissipates before it reaches the surface.

Other seismic risk factors associated with injuries include the magnitude and severity of the event, occurrence of aftershocks, landslides, tsunamis, fires, and surface rupture [20]. Magnitude, a measure of the amount of energy released by the geophysical process, is generally perceived as directly associated with deaths and injuries. However, after review of 13 earthquakes that occurred between 2001 and 2011, Shapira et al. [31] found no strong association between magnitude and the number of casualties in each event. In addition, for studies of a single earthquake, magnitude has limited value, providing one exposure measure for the entire earthquake but not for individuals [19]. Strong aftershocks could possibly cause additional injuries and threaten the safety of local rescue teams. In mountainous regions, ground shaking may trigger landslides, rock and debris falls, rock and debris slides, slumps, and debris avalanches – and all of these tend to increase the number of earthquake-induced injuries [32].

The nature of the ground at the surface of an earthquake can also have a profound influence on the level of damage and extent of injuries and deaths. Loose, sandy, and soggy soil can liquefy if the shaking is strong and long enough [9]. Earthquake-induced tsunami is another factor that causes death and injuries as was the case with the 2011 Tohoku earthquake in Japan [33]. Time of the event is also important in determining the amount of injuries that may result. If an earthquake occurs during nighttime, early morning, or rush hours, there is a greater incidence of injuries. This is because most afflicted people are either at home asleep or on their way to their homes at the time of the disaster. If the earthquake occurs during the daytime, the extent of injuries seems to be lower than at night-time because a considerable number of people will be outdoors [22]. However, analyses of the timing of earthquakes and potential exposures can be conducted only in the context of multiearthquake studies.

The number of injuries and death also differs depending on whether the earthquake occurs in a developed or developing country. Because of the greater concentration of people, widespread poverty, and poor housing conditions, risk of injuries is higher in developing countries compared to developed countries [20]. In both types of countries, the risk is higher in urban areas than the rural areas. However, the risk is greater in urban areas of developing countries than developed countries. A relatively high proportion of people in urban areas of developing countries may be forced to live in unsafe structures or sub-standard facilities that are more likely to collapse during an earthquake. The destruction in any urban setting is so great because there are more people crowded into a relatively smaller area.

Several studies [e.g., [10,11,19,26,31]] further claim that the number of earthquake injuries is associated with two demographic variables: age and gender. Peek-Asa et al. [9] and Johnston et al. [19] reported that the elderly and females have an independent risk [also see [26]]. This could be due to decreased resiliency to injury or perhaps in the elderly to a decreased ability to take protective action. For females, increased injury risk may be introduced when mothers attempt to protect children. Individuals over age 65 had 2.9 times the risk of injury as younger people and women had 2.4 times greater risk than men [26]. The literature, however, shows an inconsistent association between injury and these two demographic characteristics [20]. People with physical disabilities have also been identified as having an increased risk of injuries [34].

Individual behavior is also associated with extent of injuries. Turning off oil stoves or electricity to prevent fire, protecting property from falling, and running outside all were related to decreased injuries and casualty rates during earthquakes in southern Italy and Armenia [35,36]. However, currently there is no unified recommendation on how to properly act during an earthquake. For example, the Department of Conservation in California, USA, recommends that people who are indoors during an earthquake not run outside and instead stay inside and get under – and hold onto a desk or table, or stand against an interior wall. The Department further discourages taking refuge in the kitchen, close to heavy furniture, fireplaces, and appliances. Contrary to this, Armenian et al. [36] reported that during 1988 Armenian earthquake, death and injury was substantially elevated among those who remained indoors compared with those who exited buildings.

Following Parrish et al. [37] and Logue et al. [38], the aforementioned factors associated with earthquake-induced injuries are grouped as host, agent, and environment characteristics (Fig. 1). Individuals and household characteristics are together considered host characteristics because they are inseparable. For example, age and gender are known risk factors for earthquake injuries and these are individual characteristics. As noted, injury probabilities of individuals depend on the type of housing in which they live, which, in turn, generally depends on household income, particularly in developing countries. Type of housing and income are both household characteristics. Similar to host, environment can be dichotomous as built (e.g., housing type, bridges, and roadways) and natural (e.g., geology and soil types) environment. Because housing type is an important component of both host and build environment, there is some overlap between host and environment characteristics (Fig. 1). A similar overlap is also found between host and agent characteristics. For example, distance from the epicenter is both a host and an agent characteristic.

Although host, agent, and environmental characteristics have independent associations with earthquake-induced death and injury, these factors also interact in many situations to increase risk [20]. For example, seismically stable structures constructed on loose soil may collapse in an earthquake, while less stable structures located on solid rock may remain standing in an earthquake of the same magnitude. The former may cause injury and death, but not the latter. As noted, the objective of this study is to examine host characteristics as factors associated with the 2015 earthquake-induced injuries in Nepal.

Fig. 1. Group of factors associated with earthquake-induced injuries.

3. Research methods

3.1. Study design

Cross-sectional studies are common in social science disciplines and such studies typically use a post-event survey to assess various exposures and outcomes [e.g., [39,40]]. This type of survey is an efficient way to track mortality and morbidity caused by natural disasters. A cross-sectional post-earthquake survey design was therefore adopted to accomplish this study's objectives. As noted, Nepal experienced two major earthquakes in 2015 – one on 25 April and the other on 12 May. The magnitude of the first earthquake was 7.8 and the second one was 7.3 on the Richter scale. The epicenter of the April 25, 2015, event was Barpak village of Gorkha District, about 50 miles (80 km) northwest of Kathmandu, the capital city of Nepal. The epicenter of the May 12, 2015, earthquake was near Kodari, close to the border of Dolakha and Sindhupalchok districts (Fig. 2). Kodari is about 50 miles (80 km) northeast of Kathmandu. These two epicenters are located in two different topographic regions – Barpak is in the central hill region and Kodari in the mountain region. Similarly, they are located in two different development regions – one is in the western and the other one is in the central development region.[1]

These two major earthquakes affected 31 of the 75 districts of Nepal. For the purpose of rescue operations, the government of the country declared 14 of the 31 affected districts as "crisis-hit" and the remaining 17 neighboring districts as partially affected [41,42].[2] Using random sampling, two of the 31 affected districts (Sindhupalchok and Lalitpur) were selected for this study. Sindhupalchok district belonged in the crisis-hit category, while Lalitpur is in the partially affected category. The former district is located in a mountain region, while the latter district is in a hill region.

With 1573 injuries, Sindhupalchok district ranked third in the number of injuries after Kathmandu and Lalitpur districts. The latter two districts experienced 7949 and 3052 injuries, respectively [41]. When transformed into injury rate per 1000 people, the rate does not differ much between the two study districts. The calculated injury rate for Sindhupalchock district was 5.47 per 1000 people and the corresponding rate was 6.52 per 1000 for Lalitpur district. The latter district is more urbanized and hence has a higher density of population than the former (1216 versus 113 persons per sq. mile) and for this reason more people sustained injuries in Lalitpur district. However, with 2071 deaths, Sindhupalchok district recorded the highest death toll as well as the highest per capita death rate with more than seven deaths per 1000 residents [43]. Selected demographic and other relevant statistics of the two selected districts are presented in Table 1.

From each selected district, five study sites (Bahrabise VDC, Irkhu VDC, Selang VDC, Chautara MP, and Melamchi MP from Sindhupalcok district, and Bhattedanda VDC, Ghusel VDC, Karysvinayak MP, Mahalaxmi MP, and Lalitpur SMC from Lalitpur district) were selected (Fig. 2).[3] This selection occurred after consulting with Nepalese government officials, officials of nongovernmental organizations (NGOs), and academicians and researchers from the Tribhuvan University, Kiritpur, Kathmandu, Nepal. From each study site, respondents were selected randomly and the number of respondents was almost similar in the size in two selected districts – 152 in Sindhupalchock district and 150 in Lalitpur district.

The main data source for this study was field surveys conducted among individual households living in 10 selected study sites. Two

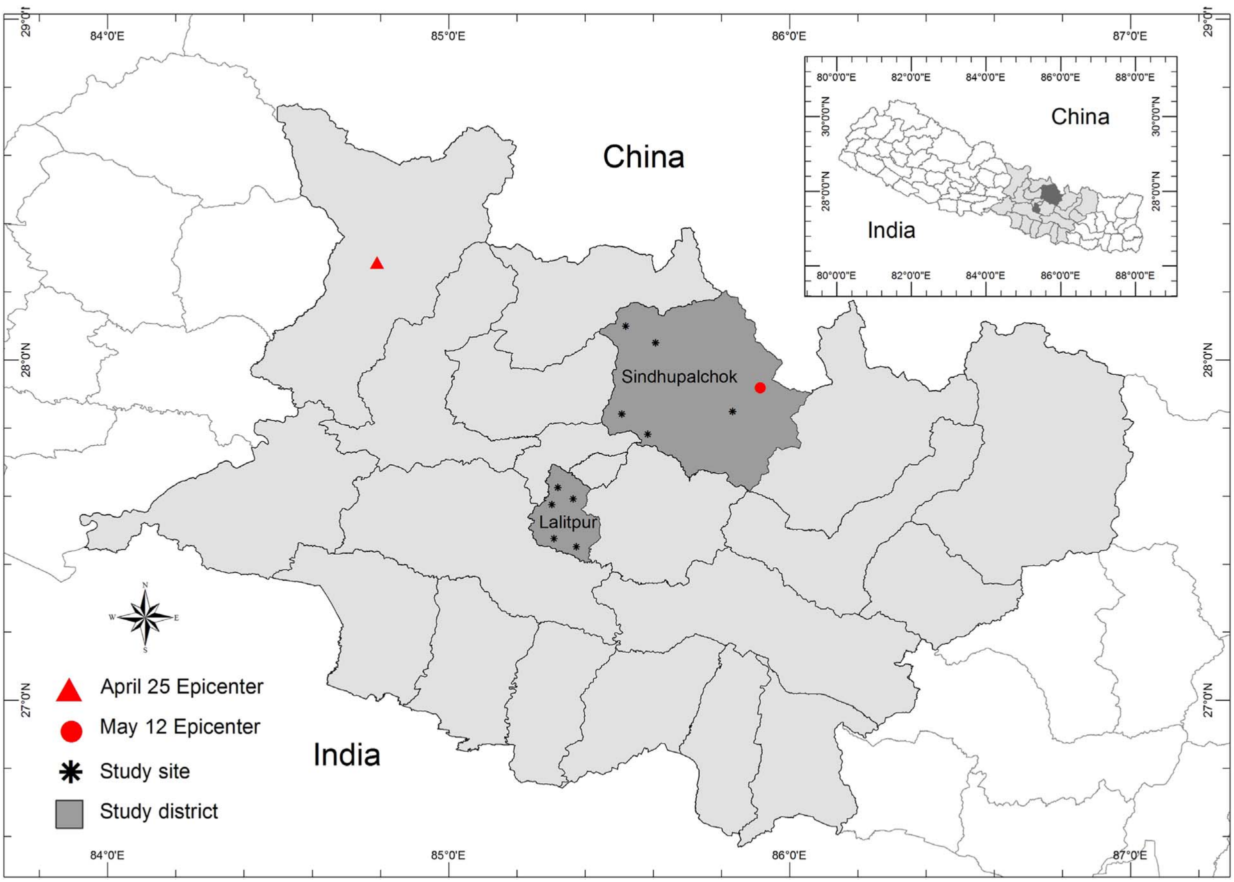

Fig. 2. Study area.

Table 1
Selected characteristics of the sampled districts.
Source: [41].

Characteristic	District		Nepal
	Lalitpur	Sindhupalchok	
Population Density (persons/sq. km)	1216	113	180
Literacy Rate (%)	73	62	
Urban Population (%)	48	9	
Ecological Belt	Hill	Mountain	–
Development Region	Central	Central	–
Per capital Disaster Effects (NPR/person)	52,765	233,370	130,000
Pre-Disaster Human Development Index (HDI)	0.601	0.455	0.491

months prior to the field survey, a structured questionnaire was developed by two members of the US research team. One of these two members is originally from Nepal. The questionnaire was sent to the Nepalese research team and the team made several changes. The questionnaire contained 27 questions, including several questions on the type, nature, and circumstances of injuries. Respondents' socio-economic and demographic characteristics, along with other relevant information, were also collected using the questionnaire, which was pre-tested to assess adequacy and relevance, as well as to address any deficiencies. The questionnaire met the research ethics standards recommended by the Institutional Review Board (IRB) of the University Research Compliance Office at Kansas State University (KSU) and hence the IRB approved the administration of the questionnaire.

The questionnaire survey was conducted during October 2015 by seven Nepalese field investigators. All the investigators were either teaching or studying at local colleges/schools at the time of the survey. Three of the seven field investigators were female. All investigators received one week of training in Kathmandu by a research and training organization, Social and Academic Innovations Place (SAIPL). The training was conducted by its director, and he also led the field survey. This project, which is funded by the National Science Foundation (NSF), requires conducting the field surveys rather quickly in order to collect original, accurate, and time-sensitive data that has the propensity to remain uncollected or collected in a less rigorous manner.

Respondents for this study were selected using random sampling. Before commencing interviews, participants were briefed regarding the purpose, consequences, and benefits of this research. They were also informed that they would not receive cash or other types of rewards for participation, their participation was strictly voluntary, and that they had the right to withdraw from the study at any time without any compensation. Furthermore, they were told they could refuse answering any questions that made them uncomfortable. Although the respondents were not briefed on how the collected data would be stored, they were informed that the data would be used strictly for this study, all information provided by the respondents was kept confidential, and their names would not be in the data collection process.

Although core information was collected through questionnaire surveys, four focus group meetings (FGMs) were conducted to gain a holistic understanding of public response to the extreme event as well as to injured persons. These FGMs were held in only three of the five study sites of Sindhupalcok district: two in Chautara, the district headquarters, and one each in Melamchi and Shikharakhpur. Each FGM was attended by eight to 12 persons and held on school premises. Two FGMs were attended by both males and females; however, because of a request by some female participants, a separate focus group meeting for males and females was conducted in Chautara (Table 2). FGP participants were selected by local field investigators. They selected

Table 2
Details of Focus Group Meetings (FGMs).

Attributes of FGMs	Site		
	Chautara	Melamchi	Shikharakhpur
Number of FGMs	2	1	1
Number of Participants	20	8	10
Gender Composition	All Males (8)[a]	Males (2)	Males (6)
	All Females (12)	Female (4)	Female (4)
Ethnic Composition	Mixed	Mixed	Mixed
Socio-economic Classes	Mixed	Mixed	Mixed

[a] Numbers are provided within parentheses.

participants in such a way that all socioeconomic classes, caste, age groups, and occupational categories were represented in the FGMs. Prior to each FGM, prospective participants from the respective study sites were asked whether they were willing to take part in the meetings.

The majority of the participants were literate and their level of education ranging from third grade to 12th grade. One-third of the participants experienced earthquake-induced injuries in their households. Their ages ranged from 21 to 63 years with an average age of 39 years. The first author, who was the Principal Investigator (PI) for the project, and the Director of the SAIPL moderated the FGMs; each lasted for about two hours. FGMs and interviews were conducted during the first week of January 2016.

Qualitative methods, such as semi-structured interviews with important stakeholders, and informal and formal discussions with village leaders, NGO and GO officials, and workers involved in responding to earthquake emergency aid were also used to collect relevant information for this study. In addition, two former members of the Nepalese parliament were formally interviewed about the event in Sindhupalchock district. Pertinent information was also collected from secondary sources, such as government offices and relevant reports published on Web sites and in Nepalese newspapers. Peer-reviewed academic literature was also searched for information on injuries caused by the 2015 Nepalese earthquake.

3.2. Selection of factors and analytic approach

Based on information presented in the Literature Review, nine host characteristics are considered as factors for earthquake injuries in this study. Of these nine factors, five (gender, age, level of education, place of residence by study district, and place of residence by rural/urban areas) are individual-level factors, and the remaining four (monthly household income, type of main dwelling, household size, and ethnicity) are household-level factors. Potential agent and environmental risk factors were not considered because inclusion of these factors is relevant only for studies dealing with multiple earthquakes in more than one country with significant environmental variations [20].

The statistically significant risk factors of human injuries caused by earthquakes were identified using the goodness-of-fit chi-square test [44]. This test compares the observed frequency counts of a single categorical variable with an expected distribution of frequency counts allocated over the same categories. It applies to a single categorical variable to examine if the distribution among categories matches a theoretical expectation. The test statistic (X^2) is defined by the following equation:

$$X^2 = \Sigma\ [(O_i - E_i)^2/E_i]$$

where O_i is the observed frequency count for the *i*th level of the categorical variable, and E_i is the expected frequency count for the *i*th level of the categorical variable. If the difference between observed and expected frequency is very high, the variable is likely to be statistically significant; if the difference is low then the variable is not statistically significant. The expected frequency for each of the selected risk factors was computed using the total number of individuals considered in this study for individual-level variables (n = 1520) and total number of households for household level variables (n = 302). Both the individual total and household total were used as the at-risk population, and the expected frequency of injuries was calculated using the respective proportion of the at-risk population. The null hypothesis assumes that there is no significant difference between the observed and the expected value.

4. Results

A total of 302 respondents were interviewed from two study districts. Of these respondents, 104 (34.44%) were heads of sample households, and the remaining respondents were senior members of households. These members represented households either because household heads were not at home at the time of the questionnaire survey or heads of the households asked them to participate in the survey. However, the total number of individuals in the 302 households was counted as 1520. This means, on average, the households consisted of 5.03 people, which is similar to the national median household size [45]. The other selected characteristics of the respondents can be found in Paul et al.'s study published in 2017 [43].

4.1. Number, types, and causes of injuries

The questionnaire survey data reveals that 107 persons from 89 households sustained various types of injuries in the study districts. These included both single and multiple injuries, but no attempt was made to differentiate between these two types of injuries. The number of persons injured in sampled households ranged from one to three. Seventy-two of the 89 households (81%) had only one member that sustained injury. Because Sindhupalchok district is closer to the epicenter of the May 2015 earthquake, we expected more injuries from this district than from Lalitpur district. The total number of injuries caused by both earthquakes was higher among the sampled households in the former district compared to the latter district (64 versus 43). It is worthwhile to mention that no one beyond household members, such as tourists or outside rescue workers, were considered subjects of interest in this study.

Earthquake injuries could occur during the earthquake event itself, during subsequent events, during search and rescue operations, or during cleanup efforts. In this study, all the 107 people sustained injuries during the event. After serious injuries, five people died and they were not included in this study. No injury occurred due to aftershocks and landslides that occurred after the two main events. The delayed collapse of unsound structures was also not reported and hence no one was injured from delayed collapse of structures. Similarly, respondents reported no falling of trees as a result of shaking, so no one sustained injury caused by falling trees. It also seems that no one was injured during search and rescue operations, or during cleanup efforts. The survey team members suspected that several people sustained minor cuts during cleanup efforts, but respondents did not report such injuries to the team members.

Due to the abrupt and violent nature of earthquakes, 47 (44%) of the 107 injuries were caused by falling objects. This is somewhat consistent with the study by Johnston et al. [19]. Thirty-two or 30% respondents sustained injuries while they were running way from the house; and 24 or 22% of the sustained injuries because of entrapment as well as collapse of an outer wall at the time of the earthquake. All of these people were inside the main dwelling or in the kitchen at the time of the earthquake. Only 4 (4%) sustained injuries while saving others who were inside the dwelling. Because the main earthquake occurred on Sunday, the weekly holiday, the overwhelming majority of the people who were injured were inside residential structures.

Relatively few cases of entrapment were reported in the study districts primarily because of absence of concrete structures. The injuries

Table 3
Selected host characteristics as risk factors of earthquake injuries in Nepal.

Variable	Study population number (%)	Observed injuries number (%)	Expected injuries (number)
Gender			
Male	782 (51.45)	54 (50.47)	55
Female	738 (48.55)	53 (49.53)	52
Chi-square = 0.037 (d.f. = 1; p = 0.084)			
Age group			
0–14	330 (21.71)	25 (23.36)	23
15–39	706 (46.45)	21 (19.63)	50
40–64	377 (24.80)	51 (47.66)	27
65 and above	107 (7.04)	10 (9.35)	7
Chi-square = 39.613 (d.f. = 3; p = 0.000)			
Level of education (number of years in school)			
Illiterate	438 (28.81)	33 (30.84)	31
1–5	659 (43.38)	48 (44.86)	46
> 5	423 (27.82)	26 (24.30)	30
Chi-square = 0.754 (d.f. = 2; p = 0.687)			
Place of residence (by study district)			
Sindhupalchok	777 (51.12)	64 (59.81)	55
Lalitpur	743 (48.88)	43 (40.19)	52
Chi-square = 3.030 (d.f. = 1; p = 0.082)			
Place of residence (by rural-urban areas)			
Rural	771 (50.72)	63 (57.94)	54
Urban	749 (49.25)	44 (42.06)	53
Chi-square = 2.700 (d.f. = 1; p = 0.1000)			
Monthly household income (in Nepalese Rupees – NPR)			
Up to 9999	122 (40.00)	26 (24.30)	43
10,000–19,999	144 (47.68)	35 (32.71)	51
> 19,999	36 (11.92)	46 (42.99)	13
Chi-square = 95.510 (d.f. = 2; p < 0.000)			
Type of main dwelling			
Pucka	49 (16.23)	8 (7.48)	17
Kutcha	253 (83.77)	99 (92.52)	90
Chi-square = 5.051 (d.f. = 1; p = 0.025)			
Household size			
1–3	50 (16.56)	12 (11.21)	18
4–7	223 (73.84)	84 (78.51)	79
> 7	29 (9.60)	11 (10.28)	10
Chi-square = 2.420 (d.f. = 2; p = 0.298)			
Ethnicity			
Hill Brahman	122 (40.40)	46 (42.99)	43
Hill Janajati	144 (47.68)	46 (42.99)	51
Hill Dalits	36 (11.92)	15 (14.02)	13
Chi-square = 1.012 (d.f. = 2; p = 0.604)			

that were encountered most frequently in the study districts included cuts, bruises, broken bones, crush injuries, asphyxia, and head trauma. Most of the injuries affected the extremities, which was similar to the Gujarat earthquake [12]. No burn injuries were reported. Information about the disability status on injured persons or treatment of injuries was not collected. No one reported loss of limbs or other body parts.

4.2. Individual-level factors associated with injuries

Two demographic characteristics of hosts, gender and age, are widely considered risk factors for earthquake-induced injuries [e.g., [9,46]]. Information presented in Table 3 shows that almost an equal number of males and females were injured as a result of the 2015 Nepal earthquakes. Since the sex ratio is slightly favorable for males in the sampled survey, relatively more males sustained injuries. The observed difference in the number of injuries between males and females is only one, but the expected difference is three (Table 3). The goodness-of-fit chi-square test confirms that the gender difference is not statistically significant.

Several reasons could account for this insignificance. One reason might relate to the timing of the earthquake. During the 2015 April and May earthquakes in Nepal, most males and females of the affected areas were outdoors in open spaces because both events occurred at noon. The timing could also have impacted the number of injuries of women in Nepal. Women are thought to be more vulnerable to earthquake injuries in part because they are more likely than men to be assigned the role of looking after and protecting children in the family [9,46,47]. However, this did not seem to factor into injuries in this study, most likely because the April earthquake occurred on a weekly holiday resulting in more children being outside during the event. The May earthquake occurred on a weekday, so many children were at school. Thus, not many women had to go inside the house to bring their children outside. Regardless of why, the insignificance of gender difference is not a surprising finding because the literature shows an inconsistent association between gender and injuries caused by earthquakes [1,9,20,46].

Regarding age as a factor of earthquake-induced injuries, as indicated, the elderly have an elevated risk of injury from earthquake events. Survey data shows that the average age of injured survivors was 41 years. Data presented in Table 3 reveals that among four age groups considered in this study, three (0–14, 40–64, and 65 and above) sustained a higher percentage of injuries compared to their share of the total study population. For example, the 40–64 age group accounted for about 25% of the study population, but this group accounted for nearly 48% of all injuries caused by the 2015 Nepal earthquakes. The chi-square value presented in Table 3 clearly suggests that age is a statistically significant factor of earthquake injuries. This finding is consistent with previous studies [e.g., [10,15,47,48]]. In this study, this risk factor became significant because of the two age groups: 15–39 and 40–64 age groups. The difference between observed and expected number of injuries was much higher than the corresponding difference between other age groups.

The 15–39 age group had the least risk of injuries from the earthquakes in Nepal because this group accounted for 46.45% of the total population, but only 19.63% of them were injured (Table 3). This is consistent with most available studies [e.g., [31]], but contradicts the finding of Johnston et al. [19] who reported that middle-aged people have a higher relative risk of injury from earthquake. However, in contrast to the 15–39 age group, the 40–60 age group had the highest risk of injuries followed by those aged 65 and above, and then those aged 0–14. It is likely that more members of the 40–64 age group stayed inside homes than members of other age groups. Also, mobility of members of this group, particularly those 50 years old and over, was restricted. These two factors might be associated with their risk level.

Available literature is silent about the relationship between individuals' level of education and earthquake injuries. To explore this relationship, Table 3 provides information on education for all respondents considered in this study. Level of education is expressed in terms of number of years of schooling and categorized into three groups. Contrary to the expectation, no relationship exists between these two variables because the calculated chi-square value is low and not statistically significant. This relationship might be caused because of use of only three levels of education. An additional level, say 10 and above, could provide a different relationship between level of education and number of injuries. However, no such attempt was made because the number of people with more than 10 years of schooling was much less compared to other categories used for this factor.

The remaining two individual characteristics of the respondents selected are place of residence in terms of district and type of residence in terms of rural or urban. The first characteristic, to some extent, also reflects respondents' distance from the epicenter, which represents one of the agent characteristics. As noted, the epicenter of the April earthquake was Barpak village of Gorkha district, and the epicenter of the May earthquake was near Kodari. The first epicenter was closer to Lalitpur district and the second one to Sindhupalchoc district. Therefore, we did not expect much injury differences between these two districts. However, the former district ranks second after

Kathmandu district in terms of number of injuries, while Sindhupalchok district ranks third. Lalitpur residents experienced many more injuries from the first earthquake than those in Sindhupalchok district (3052 versus 1573). The reverse is true for the second major earthquake.

Table 3 presents information on district residential status of the respondents. Respondents of Sindhupalchok district accounted for slightly over 51% of the study population, but nearly 60% of them sustained injuries. In contrast, respondents of Lalitpur district accounted for nearly 49% of the respondents, but they sustained injuries less than their share of the total respondents (Table 3). However, this difference was not statistically significant. The same is also true for type of resident by rural and urban areas. This is primarily explained in terms of quality of housing, which is not much different between Sindhupalchoc and Lalitpur district as well as rural and urban areas in Nepal.

4.3. Household-level factors associated with injuries

In addition to the five individual-level characteristics of the person sustaining injuries during the 2015 Nepal earthquakes, four household-level characteristics were also considered. Income is one of these household-level characteristics. Table 3 shows that monthly household income in Nepalese rupees (NPRs) is categorized into three groups: up to NPRs 9999; NPRs 10,000–19,999; and NPRs > 19,999. The table further shows that the expected frequency of the injuries was higher than the observed frequency for the first and third income groups. This implies an inverted "U"-shaped relationship between monthly household income and earthquake injuries. Thus the risk of earthquake injuries was lowest for the highest income group followed by the lowest income group. The risk was highest for the respondents of the middle income group.

The above variation of risk was probably associated with the quality of the main dwelling. The main dwellings of the lowest income group were made of the least costly materials, such as straw, bamboo, mud, locally available stone, and sun-dried brick. The 2001 Population Census of Nepal considered these as *Kachchi* or temporary houses [49]. These types of houses are generally smaller in size compared to their counterparts, *Pakki* and *Ardha-pakki* (semi-pakki) houses.[4] A collapse of a Kachchi type of structure would cause relatively few injuries. Additionally, these structures suffered less damage from earthquake due to their light weight [50,51]. Another reason for lower than expected numbers of injuries for households earning less than NRPs. 10,000 was that relatively more of these people were outside the home during the earthquake than their wealthy counterparts. The former were harvesting the crops or engaged in other outdoor manual works.

In contrast, houses of respondents of the highest income group were structurally strong as these houses were generally built with concrete. The collapse rate was lowest for this type of house. Damage and destruction of houses of the second income group was relatively more likely to result in deaths and injuries because these houses were built partially or entirely by tin either as roof and/or wall materials.

In addition to the main dwelling, most rural households also own kitchens. Households with livestock often have cattle sheds, locally called *goths*. Both of these are independent structures, and much smaller in size and weaker structurally than the main dwellings. As is evident from Table 3, main dwellings are dichotomized into two types: the masonry and reinforced concrete buildings (i.e., Pakki and Ardha-pakki buildings) and other buildings (kachchi buildings). Most of the pakki and ardha-pakki buildings had tin roofs, while the straw was used as roof material for a considerable proportion of kachchi dwellings. As noted, collapse of kachchi dwellings generally caused fewer injuries compared to houses with tin or concrete roof, particularly in Nepal, where there is little or no implementation of building code.

As expected, slightly over 16% of the study households had pakki dwellings and the overwhelming majority of these and other dwellings were single story. The number of observed injures was higher than the expected injuries in the case of kutcha houses, while the reverse is true for the pakki housing. The survey data reveals that 82% of all main dwellings totally collapsed. Kachchi dwellings accounted for about 93% of all destroyed buildings. This explains why a higher than expected number of people were injured in the case of households with kachchi housing. It must be noted that many households with monthly income NPRs > 10,000 also owned kachchi dwellings.[5] The survey data also suggest that almost all injuries were caused by either collapsing of main dwellings or falling of debris.

Based on the literature review, we assumed a positive association between household size and the number of injuries. But no such association was found. In fact, the expected number of injuries was higher than the observed number of injuries only among households with members ranging from one through three (first household size category in Table 3). We also expected ethnicity would appear as an important factor for earthquake injuries. Like the household size, ethnicity is grouped into three categories (Table 3). In the case of ethnicity, we hypothesized that *dalits* would experience the highest number of injuries compared to the other two ethnic groups considered in this study. This was hypothesized because illiteracy and poverty rates seemed to be highest among this ethnic group compared to other two [50].

As shown in Table 3, the percentage of injuries was higher among Dalits compared to their share among all selected households (14 versus 12). But this difference was not statistically significant. As the poorest segment of the population, many of them had temporary houses with mud walls and a straw roof. Probably for this reason, their observed injury was not significantly different than the expected number of injuries. A goodness-of-chi-square test also confirmed that household size is not a statistically significant factor of earthquake injuries. This association is consistent with the type of main dwellings of respondent households.

5. Conclusion

Among nine factors reflecting host characteristics, only three (age group, household monthly income, and type of main dwelling) were statistically significant with injuries caused by the 2015 earthquake in Nepal. Two of the three statistically significant factors of earthquake injuries are household characteristics. Monthly household income had a strong association with earthquake injuries in Nepal. Data presented in Table 1 clearly show that the risk of earthquake injuries was lowest for the highest income group followed by the lowest income group. The risk was highest for the respondents of the middle income group.

As expected, the second household characteristic that appeared as a significant factor for earthquake injuries in Nepal is the type of main dwelling. This is an important finding because substantial reduction of earthquake injuries can be achieved in the country by only one measure, improving the quality of the housing. Households whose houses were fully or partially damaged need to be rebuilt or repaired with seismic-resilient features. With financial assistance from several foreign agencies and countries, such as the World Bank and USAID, the Nepalese government has started to provide a housing grant to earthquake survivors for reconstruction of damaged and destroyed houses. The government has already outlined a housing reconstruction policy and ensured that all houses are rebuilt and repaired to earthquake-resistant standards [52]. The amount of this housing grant is NPRs 300,000, including NPRs 100,000 for retrofitting [52]. If the government becomes successful in enforcing building standards, the number of injuries will reduce from future earthquake events in Nepal. The new standards will ensure that housing is structurally sound in the event of significant tremors.

This paper is a byproduct of a study initially designed to assess earthquake survivors' opinions of the effectiveness of emergency aid delivered by both public and private sources in Nepal after the country was devastated by two major earthquakes in 2015. This is a major limitation of this paper. The sample size used to collect field data was not sufficient, which restricts application of sophisticated quantitative techniques to identify determinants of earthquake injuries in Nepal. Further, one cautionary note needs to be stressed. Although this study looked at two earthquake events, because they occurred in the same general area and within a gap of less than 20 days, this study's analysis treats them as a single event. It is important to remember that factors specific to one earthquake cannot easily be generalized to all earthquakes. Each earthquake is unique and offers individual complexities and challenges.

Despite limitations, this empirical study adds a new dimension and valuable insights to existing literature on factors associated with earthquake-induced injuries. Understanding these factors is essential for disaster managers, policy makers, and government officials in Nepal and other earthquake-prone countries to reduce number of injuries from future earthquake events. Given the limited number of empirical studies on injuries caused by seismic events, future research should be directed exclusively to examining the factors associated with earthquake-induced injuries.

Notes

1. Nepal has three distinct topographic regions – all run in an east/west direction. The southern part of the country has a low elevation and is called Terai or plain. It is a northern extension of the Ganges Plains of India. Immediate north of Terai is the hill region. The northern most region is the mountain region, which occurs at elevations above 6500 ft. (2000 m). Also, administratively, Nepal is divided into five development regions (far-western, mid-western, western, central, and eastern).
2. Both epicenters are located in crisis-hit districts. A district is an administrative unit in Nepal and each has several municipalities (MPs) and Village Development Committees (VDCs).
3. SMC refers to Sub-Metropolitan City. VDC represents rural area, MP is basically small town, while SMC is medium-sized city.
4. The Pakki houses are generally made of permanent materials, such as cement, brick, and tins, while the Ardha pakki houses are made of both permanent and temporary materials. Both of these types of houses are owned by households with monthly household incomes of more than NRPs 10,000.
5. Use of more than two categories of dwelling types would provide additional insight about the association between this risk factor and earthquake injuries. However, such an attempt was not made because of the complexity of materials used for such a purpose.

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