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Assessing the vulnerability of different age groups regarding flood fatalities: case study in the Philippines

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Abstract

This study aimed to identify age groups vulnerable to flood fatalities and quantify their vulnerability by means of statistical methods. First, the study obtained data of 122 victims directly resulting from five flood disasters in the Philippines over the period 2010–2013 which was used to compare the number of flood fatalities in each age group with the population numbers. The chi-square goodness-of-fit test shows that only one age group, people aged ≥70, was vulnerable to flood fatalities. Vulnerabilities of people aged ≥70 and <70, respectively, were quantified in terms of mortality, i.e., the ratio of flood fatalities and affected people. This study obtained two lognormal distribution curves moderately describing histograms built with samples on the mortality of the two age groups. Based on probabilistic parameters of the selected lognormal distribution curves, the study concludes that people aged ≥70 have more than three times the vulnerability to the risk of flood fatality than people aged <70. It is also suggested that the age dependency ratio, which is widely used to consider demographic vulnerability in flood vulnerability studies, should not be applied to the Philippines.

Keywords: Children; Flood fatalities; Flood risk; Older adults; Social vulnerability; The Philippines

1. Introduction

In this study, the focus is on flood fatalities. Generally speaking, floods cause 40–50% of the total number of fatalities from natural hazards (Diaz, 2004; FitzGerald *et al.*, 2010). Jonkman (2005) mentions more specifically that Asian river floods accounted for 40% of the total number of flood fatalities for the period 1975–2001. For the last two decades, UN systems, inter-governmental development banks, governments and international research institutes have collaborated to reduce flood fatalities. They have paid increasing attention to mobilizing official development aid and national budgets in constructing flood control infrastructure and early warning systems, and have advanced non-structural measures such as risk awareness, disaster education, and community-based risk reduction

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programs. Nevertheless, it is too early to say if flood fatalities are following a downward trend. Figure 1 shows the global records on human losses due to flood disasters for the last 20 years, according to data from EM-DAT. The number of flood fatalities is mainly composed of a small number of extreme disasters such as the 1998 China flood and the 1999 Venezuela flood. Moreover, the average flood fatalities over 20 years, i.e., 7,807 persons per year, is not inconsiderable when compared with the annual records observed recently (the annual numbers of fatalities in 2010, 2011 and 2013 were 8,446, 6,154 and 8,058 persons, respectively). Indeed, some experts (Penning-Rowsell *et al.*, 2005; Ashley & Ashley, 2008) have argued that it is not easy to find a decreasing trend of flood fatalities even in highly developed countries such as in Europe or the USA.

As with other types of natural hazards, flood risks arise multi-dimensionally from the occurrence or severity of flood events, the biophysical proximity to the hazard, and pre-existing social conditions interacting with the hazard (Kron, 2005; Lowe *et al.*, 2013; Solín & Skubinčan, 2013; Lee *et al.*, 2015a): i.e., risk is a function of hazard, exposure and vulnerability. Among those components, recently the greatest attention has been given to pre-existing social conditions, i.e., vulnerability. This trend has occurred not only because up to now vulnerability has been less addressed than other components, but also because vulnerability is a 'lens' necessary to see risks. In other words, the understanding of social conditions intersected by flood events is essential to an understanding of the real shape of the risk, provided that flood risks are embodied by human systems.

Vulnerability to flood fatalities cannot be explained by just one or two social conditions. Lee *et al.* (2015b) state that flood fatalities correlate with comprehensive factors in social conditions: (i) people's marginality relevant to demographics, disability, and other socio-economic weaknesses; (ii) urbanization relevant to deforestation, illegal settlement, urban sprawl, and other environmental deterioration; (iii) political corruption relevant to accountability, effectiveness, and regulatory quality; and (iv) coping capacity relevant to multi-leveled efforts to overcome flood disasters, including early

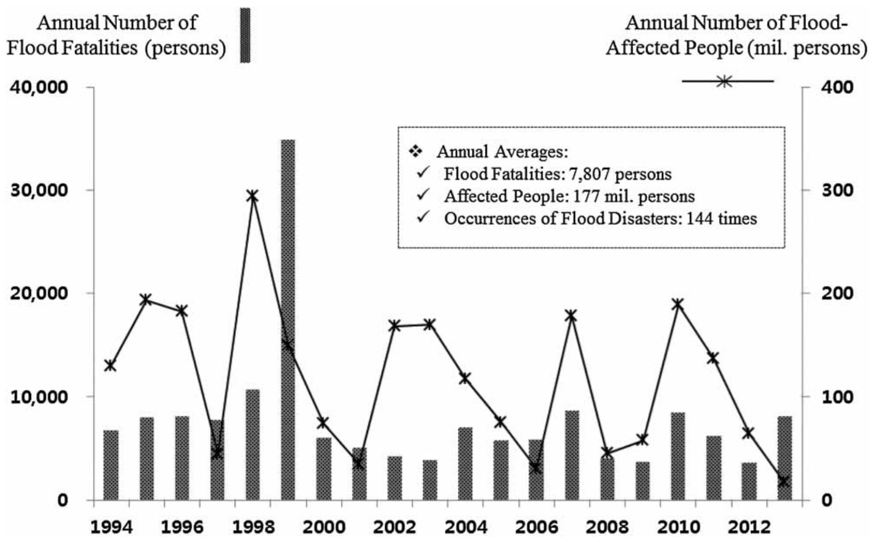

Fig. 1. Global statistics of flood effects on humans over the last two decades. Data: EM-DAT ver.12.07 (created on 10 March 2014).

warning systems, information and communication technologies, disaster education, and community-based programs. A significant problem exists in understanding the vulnerability factors. Social scientists have been building conceptual models for the vulnerability structure, proposed various factors, and selected proxies since the 1970s in order to measure these factors. However, little evidence is available for confidence in the direct relation between the proposed factors and proxies to flood fatalities (Roberts *et al.*, 2009; Cornell *et al.*, 2012). This problem might well explain why vulnerability studies are deficient in theories (Hilhorst & Bankoff, 2004; Birkmann, 2007), and why vulnerability studies cannot be fully convincing to other stakeholders who are responsible for disaster risk reduction (ICHARM, 2013; Lee *et al.*, 2015a).

With a focus on the demographic factor of vulnerability, this study aims to identify age groups vulnerable to flood fatalities and quantify their vulnerability by means of appropriate methods. It should first be noted that age in itself does not equate to vulnerability. Even when a certain age group is identified as being vulnerable to flood fatalities, an individual belonging to the group should not be considered as having a disadvantage. Instead, it is accepted that the group has an overall tendency toward certain physical, psychological, social and economical conditions which limit their ability to overcome flood disasters (Vink *et al.*, 2014).

Table 1 presents how vulnerable age groups are viewed in current flood vulnerability studies. Most studies take note of two extremes of the age spectrum, i.e., children and older adults. However, these two age groups are not determined by evidence related to flood fatalities. Instead, it is usually assumed

Table 1. Examples of vulnerable age groups assumed in previous studies.

Previous studies	Type of natural hazard	Categories selected for vulnerable age groups	Applied area
Cutter *et al.* (2000)	• Not specific	• % of population aged $\leq$17 • % of population aged >65	• Georgetown, USA
Tapsell *et al.* (2002)	• Flood	• % of population aged $\geq$75	• Salford, Manchester, and Maidenhead, UK
Cutter *et al.* (2003)	• Not specific	• % of population aged <5 • % of population aged $\geq$65	• US counties
Dao & Peduzzi (2003)	• Flood, cyclones, and earthquake	• % of population aged <15 or $\geq$65 (age dependency ratio)	• (suggested indicator for global usage)
Flanagan *et al.* (2011)	• Hurricane Katrina	• % of population aged $\leq$17 • % of population aged $\geq$65	• Orleans Parish, USA
Islam *et al.* (2013)	• 11 natural hazards	• % of population aged <15 or $\geq$65 (age dependency ratio)	• Assasuni Upazila, Bangladesh
Ferraris *et al.* (2013)	• Flood and landslide	• % of population aged <15 or $\geq$65 (age dependency ratio)	• Semarang Metropolitan Area, Indonesia
UNISDR (2013)	• Not specific	• % of population aged <15 or $\geq$65 (age dependency ratio)	• (suggested indicator for global usage)
Ahsan & Warner (2014)	• Not specific	• % of population aged <15 or $\geq$65 (age dependency ratio)	• Koyra Upazila, Bangladesh
Lee *et al.* (2015b)	• Flood	• % of population aged <15 or $\geq$65 (age dependency ratio)	• 14 countries in Asia

by using the dependency ratio that Shryock & Siegel (1975) originally developed for the purpose of measuring the labor force in a country. To provide evidence, this study set up two objectives:

- Objective 1 was to identify vulnerable age groups on the basis of disaster records of flood fatalities; age groups vulnerable to flood fatalities were examined in the limited number of studies of American, Australian, and European cases. However, the authors could not find any studies analyzing vulnerable age groups in less developed countries, despite a large number of flood fatalities.
- Objective 2 was to quantify the vulnerability of the identified age groups to flood fatalities; quantification was considered essential in order to compare the levels of vulnerability among age groups and also understand the effects of the population distribution of the age groups on flood fatalities. However, the authors could not find any previous studies providing evidence about the differences in vulnerability between a certain age group and other groups.

To achieve the two objectives, the Philippines was selected for a case study, because it is located in Southeast Asia where floods pose large threats to human lives, and the number of flood fatalities is announced every year by the government. The Philippines is located in the North-West Pacific Ocean where annually many typhoons originate. Moreover, this country is situated just below the Inter-tropical Convergence Zone with northeast and southwest monsoons. As a result, the whole territory is exposed to floods and storm surges. Based on the United Nations International Strategy for Disaster Reduction estimation of the 1980–2010 data, flood disasters occur three times a year on average. Each flood disaster kills more than 23 people.

2. Previous studies

2.1. Basic concept of demographic vulnerability to flood fatalities

Previous studies in the public health discipline have usually considered that children are unable to properly adapt to urgent situations when a flood occurs. Flanagan *et al.* (2011) point out that children lack knowledge and experience, and thus they are very limited in terms of perceiving risks from warning signals and media information, and deciding on evacuation. Although parents can play a great role in reducing the vulnerability of children, they are not always looking after their children. For example, children spend a great deal of time in infant care facilities and schools, and playing with their friends on the streets. In some countries, it is common to see homeless or street youths who do not receive a family's care. Depending on their parents' socio-economic class, certain children, e.g., those with poor and working-class mothers, may stay alone at home even in highly developed countries. Limited ability of parents to protect their children from flood disaster is more often observed in less developed countries. There is thus a view that children are not vulnerable to flood fatality in developed countries (Peek, 2010).

While children's vulnerability is interpreted in the household context, older adults' vulnerability is mostly understood in the context of their health conditions and social networks. This is because older adults have a tendency to suffer from impaired physical mobility, diminished sensory awareness and chronic diseases, which, together with reduced income, can create disadvantages in taking proper action during the whole flood disaster management cycle. First, older adults often have difficulty receiving disaster information and warning signals (Friedsam, 1962; Perry, 1979), which becomes more serious when they live without sufficient social networks in isolated places, or when they are uninterested in information-seeking behavior. Second, older adults are known to be less likely to comply with suggestions or orders that local governments issue for evacuation (Fernandez *et al*., 2002; Rosenkoetter *et al*., 2007). It means that they often do not leave their houses due to psychological, medical or economic conditions (Perry, 1990; Gladwin & Peacock, 1997; Fange & Ivanoff, 2009). However, their compliance with evacuation orders has not yet been generalized. For example, Perry & Lindell (1997) showed that older adults aged over 65 comply as often as younger people. Third, a high proportion of older adults have physical difficulty in evacuation (Fernandez *et al*., 2002; Gibson & Hyunga, 2006; McGuire *et al*., 2007; Cornell *et al*., 2012). Based on a US survey by Cornell *et al*. (2012), 20.4% of people aged over 65 and 32% of people aged over 70 have difficulties in walking. Hobbs & Damon (1996) also point out that if older adults suffer from diminished sensory awareness, poor night and peripheral vision generate another difficulty in unfamiliar environments or during a rapid evacuation. Fourth, the health condition of older adults can be significantly weakened by flood disasters (Peek, 2010). When older adults come into direct contact with flood water, it often leads to fatal consequences because they have lower levels of thermoregulatory capacity and injury thresholds compared with younger people. When power outages occur in their villages, older adults with frailties cannot sustain home nursing systems. Even when they are evacuated to emergency centers, shelters or refuges, their health conditions can rapidly worsen if physical and psychological traumas are combined with pre-existing diseases, or if medical services are not adequately available in the emergency situation.

2.2. Identification of vulnerable age groups based on flood disaster records

A small number of frontier studies were conducted in the natural hazard disciplines in order to verify whether flood disaster records explain children's and older adults' vulnerability. Using Australian newspapers, historical accounts, and government and scientific reports, Coates (1999) obtained a data set of 2,213 flood victims for the period from 1788 to 1996. The author analyzed the number of fatalities for each age group as well as spatio-temporal trends of flood fatalities. People aged over 59 and under 25 were found to show a higher number of fatalities compared with the general population. The author then concluded that the results reflected 'the inability of the elderly and the very young to flee, and the greater propensity for risk-taking amongst the youthful'. Jonkman & Kelman (2005) compiled media reports, communication with the authorities, scientific literature, and disaster reports on the data of 247 flood victims for 13 flood events, which occurred in Europe and the USA. They analyzed the specific causes of death, and the victims' gender and age. Concerning vulnerable age groups, there was no clear evidence observed for the three categories, i.e., people aged 0–19, 20–60, and 60+. Thacker *et al.* (2008) analyzed a data set in the National Center for Health Statistics. For storms and floods during 1979–2004, they were able to derive data of 2,741 victims. After comparing these data with the population census data, they argued that people aged over 55 years showed a higher number of fatalities compared with the general population, and that this difference was highest in the group aged between 75 and 84 years old. Ashley & Ashley (2008) studied 1959–2005 flood victims from a database at the US National Climatic Data Center, which was used to analyze spatio-temporal trends, and the age and gender of victims. Regarding vulnerable age groups, they identified two groups, i.e., those aged between 10 and 29, and those aged over 60, as being vulnerable to flood fatalities. FitzGerald *et al.* (2010) used similar data sources to Coates (1999), but focused on recent flood victims in Australia. Based on the number of flood fatalities for the period 1997–2008, the authors drew the conclusion that young adults aged between 10 and 29 and those aged over 70 were overrepresented among those who drowned.

2.3. Findings from the literature review

From the studies summarized above, we were able to arrive at the following three points:

- Previous studies have not accumulated sufficient evidence on demographic vulnerability. Moreover, the studies looked merely into a few OECD countries. It was very surprising that no studies investigated vulnerable age groups in developing countries in Asia, despite the fact that flood-affected people are concentrated in these countries. For example, the UNISDR (2009, p. 36) ranked countries according to the number of flood-affected people per year. The top 10 countries with the highest number were all developing countries in Asia. We thus strongly argue that priority should be given to this region.
- It is a crude assertion that certain age groups are commonly vulnerable to flood fatalities. Overall, the public health and natural hazards fields took note of children's and older adults' vulnerability. However, the vulnerability of children and older adults is specific to household contexts, health conditions and social network conditions. Vulnerable age groups are very likely to differ in each country.
- Some doubt still remains regarding the validity of age groups identified in previous studies. First, when drawing their conclusions, the authors analyzed flood fatalities over several decades, apart from FitzGerald *et al.* (2010). A problem arises due to the fact that vulnerability is not static. Therefore, if the authors had excluded older records on flood victims, their studies may have resulted in more profound insights about present-day vulnerability.

3. Data collection and treatment

To perform this study, we required specific records about recent flood events, such as age, cause of death, and location for each victim. Hence, we determined to use epidemiological data of disaster situation reports issued by the National Disaster Risk Reduction and Management Council, from the Philippines. With a focus on recent flood events, we applied two criteria in choosing disaster situation reports: floods (i) occurring for the period 2010 to the present and (ii) with a minimum of 25 fatalities. The justification for the first criterion was to include recent flood events only, while that of the second was the threshold suggested by Glickman *et al.* (1992) for natural hazards. The most widely used threshold is a minimum of 10 fatalities, which was suggested by Smith (1996) and is currently applied to the EM-DAT. However, Paul (2011, p. 10) notes that this threshold is not adequate to identify natural hazards in developing countries, arguing that '(t)he deaths of 10 people would constitute a relatively significant figure for more developed nations such as the United States, but in lesser developed societies many more people tend to be killed by disasters'. We looked for another widely used but more strict threshold, and therefore decided to apply the threshold of Glickman *et al.* (1992). Figure 2 shows five flood events satisfying the criteria, showing that the total number of flood fatalities amounts to 325 people.

Each disaster situation report contains extensive records related to socio-economic impacts of the flood, including: (i) chronology of flood events; (ii) effects on each municipality such as incidents monitored, affected people, victims, depth of flooded villages, cost of assistance, cost of damage, damaged houses; and (iii) emergency management and relief activities. In particular, we used records on affected people and victims as important data. Affected people are measured in terms of the number of people living in flooded areas within each municipality. The reports calculate the number of victims at each municipality, and additionally record each victim's information including name, age, sex, location of

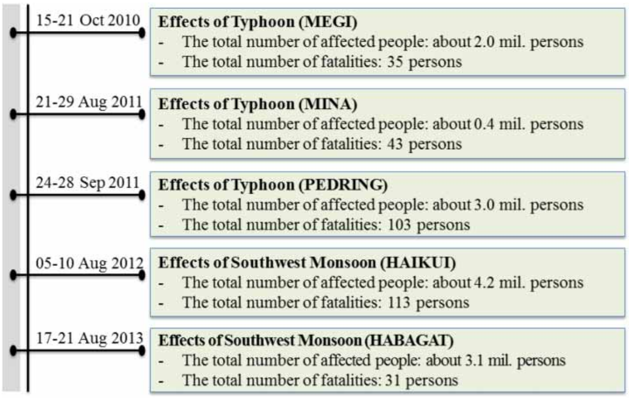

Fig. 2. Selection of flood events from the Philippines. Data: NDRRMC (2010, 2011a, b, 2012, 2013).

the incident, and cause of death. Since flood events generally occur during tropical typhoons and cyclones, some were victims due to causes unrelated to the floods, for example, being crushed by trees, falling from roofs, being blown off the road, or receiving electric shocks. After checking if each victim's death was actually caused by the flood, we found that 38% of the data relating to the 325 victims was suitable for this study. In other words, only 122 victims had causes of death such as drowning (hypothermia or asphyxiation), and heart attacks or physical trauma during evacuation. Figure 3 shows descriptive statistics on the victims' ages.

This study also required population data according to the age groups in the entire country and from the municipalities where flood fatalities occurred. Although the National Statistics Office of the Philippine Statistics Authority took a 2010 Population Census, data at the municipality level were not available for this study. We therefore decided to use the reports of the 2007 Population Census (National Statistics Office, 2007), which were declared for each province under the heading 'Household Population by Age Group, Sex, and City/Municipality'.

4. Methods

4.1. Identification of vulnerable age groups

4.1.1. Step 1: Compare flood fatalities and population by age group. To answer the question of which age groups are vulnerable to flood fatalities, we first compared the percentage of flood fatalities and the percentage of the population for each age group. The percentage of flood fatalities for each age group was calculated by dividing the sum of the victims belonging to the age group by the total number of victims, i.e., 122

$$A_i = \sum_{j=1}^{b}\sum_{k=1}^{c} V_{ij}^{k} \Big/ \sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} V_{ij}^{k} \times 100\,(\%) \tag{1}$$

where A_i is the percentage of flood fatalities in the i-th age group (%), V_{ij}^{k} is the number of victims, belonging to the i-th age group, that resulted from the j-th flood events in the k-th municipality

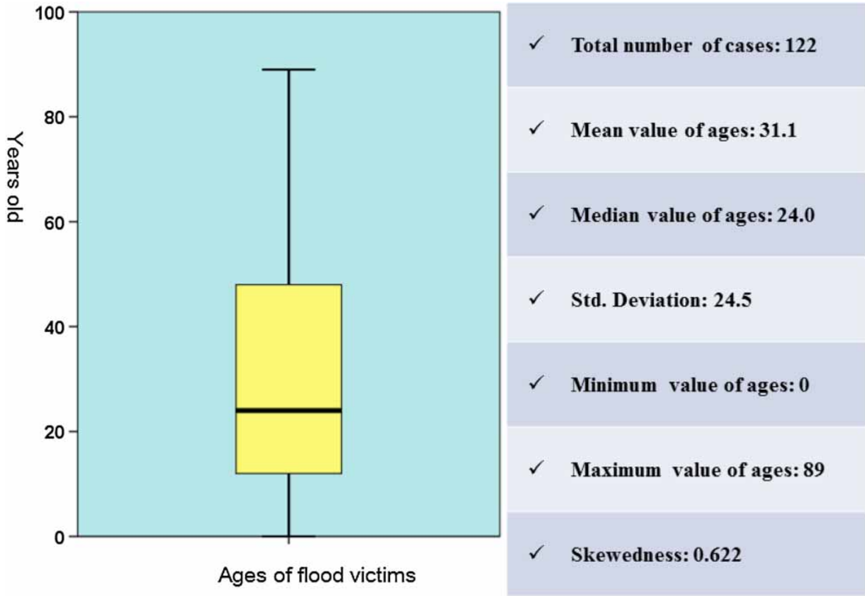

Fig. 3. Descriptive statistics on victims' ages.

(persons), i is the ID number of the age group, i.e., 1 for age <10, 2 for $10\leq$ age <20, …, 7 for $60\leq$ age <70, and 8 for age ≥ 70 ($a = 8$), j is the ID number for a flood event, i.e., 1 for the 2010 October flood, 2 for the 2011 August flood, …, and 5 for the 2013 August flood ($b = 5$), and k is the ID number for the municipality where the five floods resulted in victims, i.e., 1 for Arayat, 2 for Aritao, …, and 75 for Valenzuela city ($c = 75$). Likewise, the percentage of population for each age group was estimated by dividing the sum of the population of the age group by the total number of the population at all municipalities where the five flood events generated human losses

$$B_i = \sum_{k=1}^{c} P_i^k / \sum_{i=1}^{a} \sum_{k=1}^{c} P_i^k \times 100\,(\%) \tag{2}$$

where B_i is the percentage of population in the i-th age group (%), and P_i^k is the number in the population for the i-th age group who live in the k-th municipality. After calculating A_i and B_i over all age intervals (i) from flood victim records and population census data, we considered people at the age intervals where A_i was noticeably higher than B_i to be those in vulnerable age groups.

4.1.2. Step 2: Conduct the chi-square goodness-of-fit test. The above method in Step 1 for identifying vulnerable age groups can take into account real data from past flood events. Nevertheless, this way relies on subjective judgements made about the data, and is not rigorously supported by statistics inherent in the data. Therefore, we decided to conduct the chi-square goodness-of-fit test in order to confirm vulnerable age groups based on statistical significance. First, we established the null hypothesis (a statement to be rigorously tested) that the number of flood fatalities is proportional to population across all age groups, i.e., H0: $\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}=\sum_{k=1}^{c}P_{i}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$ for all age groups. The chi-square goodness-of-fit test was then applied to demonstrate that the null hypothesis was rejected by the conditions, as shown in Table 2, from the five disaster situation reports and the 2007 population census reports. This result would naturally lead to the recognition that there are age groups where the number of flood fatalities was disproportionate to their populations. We then eliminated the age groups which were tentatively identified as being vulnerable to flood fatalities from our hypothesis test (e.g., the row where $i=8$ is eliminated from Table 2, if older adults aged $\geq$70 were previously selected as a vulnerable age group). The test revealed that the null hypothesis could not be rejected for conditions which did not include vulnerable age groups, suggesting that the number of flood fatalities is proportional to population across all remaining age groups. With all these results, we arrived at the statistical statement that the number of flood fatalities is disproportionate to the population only for the age groups selected at Step 1.

4.2. *Quantification of age groups' vulnerability to flood fatalities*

Some experts (Hajat *et al*., 2003; Jonkman 2005; Penning-Rowsell *et al*., 2005) in the natural hazard disciplines have recommended that vulnerability should be quantified in terms of mortality, which is generally defined as the ratio of the number of flood fatalities to the number of affected people. Jonkman & Kelman (2005) note that mortality can be interpreted as 'a first indication of vulnerability factors'. This study applies the mortality concept to measure vulnerability by age group.

Table 2. Conditions for the chi-square goodness-of-fit test.

Age interval (years) i	Observed victims (from disaster situation reports)	Expected victims (from population census reports)
1 (Age <10)	$\sum_{j=1}^{b}\sum_{k=1}^{c}V_{1j}^{k}$	$\sum_{k=1}^{c}P_{1}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$
2 (10≤ Age <20)	$\sum_{j=1}^{b}\sum_{k=1}^{c}V_{2j}^{k}$	$\sum_{k=1}^{c}P_{2}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$
3 (20≤ Age <30)	$\sum_{j=1}^{b}\sum_{k=1}^{c}V_{3j}^{k}$	$\sum_{k=1}^{c}P_{3}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$
4 (30≤ Age <40)	$\sum_{j=1}^{b}\sum_{k=1}^{c}V_{4j}^{k}$	$\sum_{k=1}^{c}P_{4}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$
5 (40≤ Age <50)	$\sum_{j=1}^{b}\sum_{k=1}^{c}V_{5j}^{k}$	$\sum_{k=1}^{c}P_{5}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$
6 (50≤ Age <60)	$\sum_{j=1}^{b}\sum_{k=1}^{c}V_{6j}^{k}$	$\sum_{k=1}^{c}P_{6}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$
7 (60≤ Age <70)	$\sum_{j=1}^{b}\sum_{k=1}^{c}V_{7j}^{k}$	$\sum_{k=1}^{c}P_{7}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$
8 (Age ≥70)	$\sum_{j=1}^{b}\sum_{k=1}^{c}V_{8j}^{k}$	$\sum_{k=1}^{c}P_{8}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}/100$
Total	$\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}=122$	$\sum_{i=1}^{a}\sum_{k=1}^{c}P_{i}^{k}\times\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c}V_{ij}^{k}=122$

It is certainly reasonable to expect that the age group which was identified to be vulnerable to flood fatalities would have higher mortality than the other groups. However, there is a problem with measuring an age group's vulnerability by its mortality. It is the fact that the number of flood fatalities is highly variable across flood events (Jonkman, 2005), even with identical conditions of affected people. This variability might arise, on the one hand, because the number of flood fatalities is determined by various vulnerability factors among which the demographics constitute a very small part, but also because death cannot be explained without considering randomness, for example, reasons why someone slipped and fell into the floodwater in the course of evacuation. It is well known that observed data with high variability cannot be represented by average values aggregated temporally and spatially. When observed data have such variability, as in the case of the number of flood fatalities, it is important to understand the 'variability in nature' behind the observed data, and find out characteristic values in order to consider the natural variability in the mortality of the age groups. In this regard, we followed two steps in analyzing age groups' mortality.

4.2.1. Step 1: Formulate sample data on the age groups' mortality due to a flood event in a municipality. Let us assume that only older adults aged ≥70 were identified as a vulnerable age group by the chi-square goodness-of-fit test. Then, all age groups can be divided into two groups, i.e., people aged ≥70 and people aged <70. Based on the definition of mortality, we formulated sample data about the two age groups' mortality at each flood event and in each municipality using Equation (3).

$$\begin{aligned} x_e^{jk} &= V_{i=8}^{jk}/E_{i=8}^{jk} \approx V_{i=8}^{jk}/\left(E^{jk} \times \frac{P_{i=8}^{k}}{100}\right) \\ x_o^{jk} &= \sum_{i=1}^{7} V_i^{jk} \Big/ \sum_{i=1}^{7} E_i^{jk} \approx \sum_{i=1}^{7} V_i^{jk} \Big/ \sum_{i=1}^{7} \left(E^{jk} \times \frac{P_i^{k}}{100}\right) \end{aligned} \tag{3}$$

where x_e^{jk} and x_o^{jk} are, respectively, samples concerning mortality for people aged ≥70 and <70 (unitless) and are estimated using records of flood victims of the j-th flood event in the k-th municipality, E_i^{jk} is the number of affected people in the i-th age group of the j-th flood event in the k-th municipality (persons), and E^{jk} is the number of affected people over all the age groups (persons), being estimated using records of affected people of the j-th flood event in the k-th municipality.

4.2.2. Step 2: Draw characteristic values of age group mortality from histograms built using sample data. We built two histograms using two sets of sample data, i.e., x_o^{jk} and x_e^{jk}. The histograms were fitted to probabilistic density functions (PDFs) of various probabilistic distribution curves by using a statistical software package, the IBM SPSS ver. 19. According to statistical performance such as the Kolmogorov-Smirnov statistics (Kolmogorov, 1933) and their significance levels, well-fitted PDFs are regarded as those describing the mortality of the two age groups, X_e, and X_o. Finally, we compared the mortality of people aged ≥70 and <70 in terms of characteristic values including mean, variance and mode, thus revealing the difference in vulnerability between the two groups.

5. Results and discussion

5.1. Identification of age groups vulnerable to flood fatalities

Figure 4 shows the percentages of flood fatalities (A_i) and population (B_i) over all the defined age groups. It is notable that people aged ≥70 make up only 2.1% of all populations, but account for 12.3% of flood fatalities. For people aged <70, the number of flood fatalities was not significantly higher compared with the population. We therefore concluded that only older adults aged ≥70 years old were likely to be vulnerable to flood fatalities. For children aged <10, we were unable to find out their vulnerability as in Figure 4.

To statistically ascertain if the null hypothesis, that the number of flood fatalities is proportional to population across all age groups, should be rejected, we defined conditions for the chi-square goodness-of-fit test (as shown in Table 3) after applying the number of flood fatalities and population by age group to Table 1. As a result, the chi-square value was 62.5, and thus the p-value was close to zero at the degree of freedom = 7 (i.e., the number of all age groups, 8 − 1). Because the null hypothesis was rejected even at the significance level of 0.1%, we have strong confidence that there are age groups with the number of flood fatalities disproportional to their populations. We then repeated estimating the chi-square statistics after excluding people aged ≥70 (in Table 3, the row where $i = 8$). As a result, the chi-square value was 1.98. At the degree of freedom = 6 (i.e., the number of all remaining age groups, 7–1), the p-value was around 0.92, which is the degree to which the null hypothesis cannot be rejected at any available significance level. Hence, we found out that the number of flood fatalities is proportional to the population across all age groups except for people aged ≥70. Putting all the results together, we concluded that only older adults with ages ≥70 years were vulnerable to flood fatalities during the five flood events, and thus people could be divided into two age groups, i.e., people aged ≥70 and those aged <70, from the viewpoint of demographic vulnerability.

As mentioned, many flood disaster risk studies use the age dependency ratio, without evidence, in order to take demographic vulnerability into consideration. Considering the definition of the ratio,

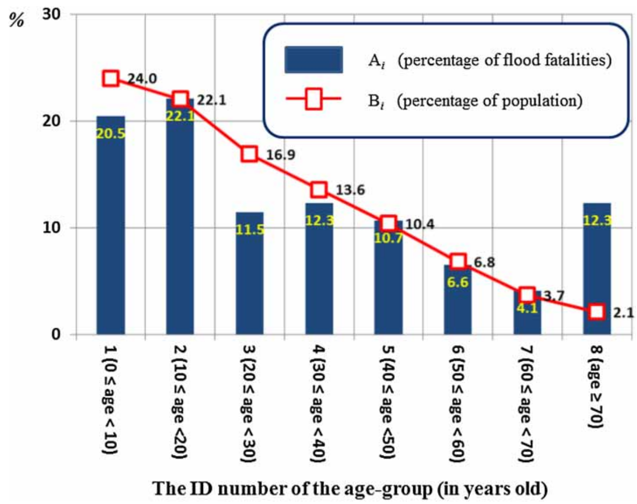

Fig. 4. Comparison of flood fatalities and population by age group.

Table 3. Conditions established for the chi-square goodness-of-fit test.

Age interval i	Observed victims (from disaster situation reports)	Expected victims (from population census reports)
1 (age <10)	25	29
2 ($10\leq$ age <20)	27	27
3 ($20\leq$ age <30)	14	21
4 ($30\leq$ age <40)	15	17
5 ($40\leq$ age <50)	13	13
6 ($50\leq$ age <60)	8	8
7 ($60\leq$ age <70)	5	4
8 (age ≥ 70)	15	3
Total	122	122

their viewpoint is naturally that children <15 years old and older adults ≥ 65 years old are vulnerable to floods, however, this is largely contradicted by the findings of this study. Based on victim records in the Philippines, children aged <15 did not seem to be vulnerable to flood fatalities. Moreover, a narrower age interval was suggested for older adults, i.e., people ≥ 70 years old.

5.2. Quantification of vulnerability of age groups to flood fatalities

Using Equation (3), two sets of sample data on age group mortality were formulated for each flood event and in each municipality. As a result, 13 samples for x_e^{jk} (the mortality of people aged ≥ 70) and 75 samples for x_o^{jk} (the mortality of people aged <70) were obtained from a total of 122 flood victims. Figure 5 presents the histograms built with the two sets for x_e^{jk} and x_o^{jk}. For both age group samples, we found mortality generally to have a low value. However, a very high value for mortality could be observed in a significant number of samples. For both age groups, mortality was thus

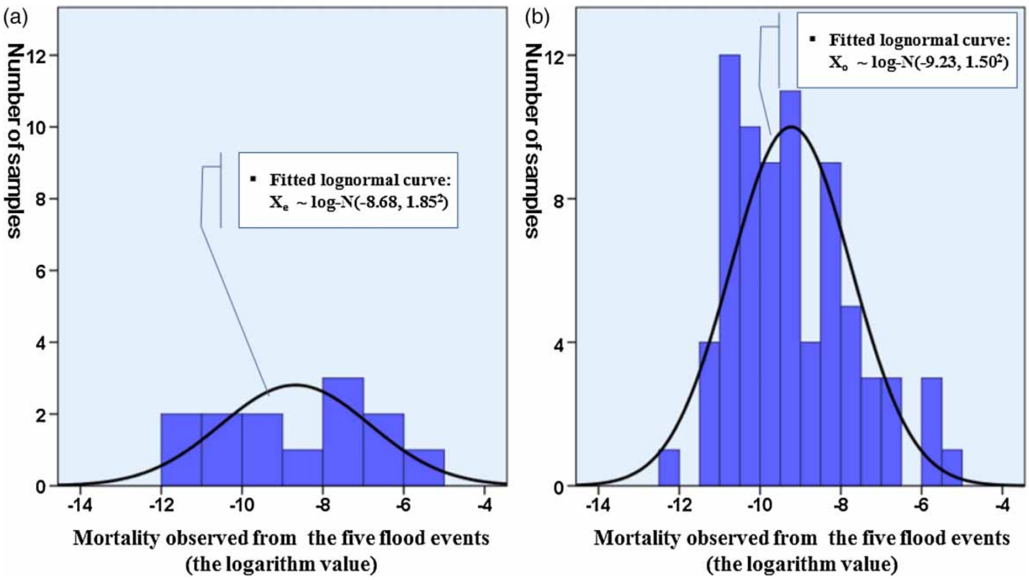

Fig. 5. Histograms of samples on mortality. (a) Older adults group; (b) other age group.

expected to follow the extreme distribution curve with positive skewedness and a heavy-tail. In this regard, the two histograms were fitted to PDFs of lognormal distribution curves. In Figure 6, Q-Q plots depict that the variability in the two age groups' mortality is moderately described by selected lognormal distribution curves, based on two viewpoints. First, observed values in mortality are similar to the values estimated from quantiles of selected lognormal distribution curves. As a result, many points are placed closely around the trend lines of Q-Q boxes. In addition, the Kolmogorov–Sminov Z values between observed and estimated values correspond to high p-values, 0.812 and 0.315, respectively. These p-values mean that the hypothesis that observed values in mortality follow the selected lognormal distribution curves cannot be rejected at any available significance level.

Figure 5 shows the lognormal distribution curves obtained by fitting the samples on mortality. Based on the selected lognormal distribution curves, the mean value of mortality for each age group was estimated as in Equation (4). This shows that for 10,000 affected people, 9.3 and 3.0 victims are observed for people aged $\geq$70 and $<$70, respectively. It can also be interpreted that the vulnerability of older adults (aged $\geq$70) is three times higher than that of people in the other group. It is important to note that (i) probabilistic characteristics of mortality were defined with extreme distribution curves, (ii) the mortality of people aged $\geq$70 has even larger variance than those of people in the other group, i.e., 2.6×10^{-5} vs. 7.7×10^{-7} in Equation (5), and (iii) based on the mode values appearing most often in the lognormal distribution curves, the two age groups do not show a large difference in mortality, i.e., 3.2×10^{-5} vs. 3.1×10^{-5} in Equation (6). Putting these together, we were able to infer that older adults' high vulnerability will not always be observed in records on flood victims.

$$X_e{}'\text{s mean} = e^{-8.68+1.85^2/2} = 9.3 \times 10^{-4}$$
$$X_o{}'\text{s mean} = e^{-9.23+1.50^2/2} = 3.0 \times 10^{-4} \quad (4)$$

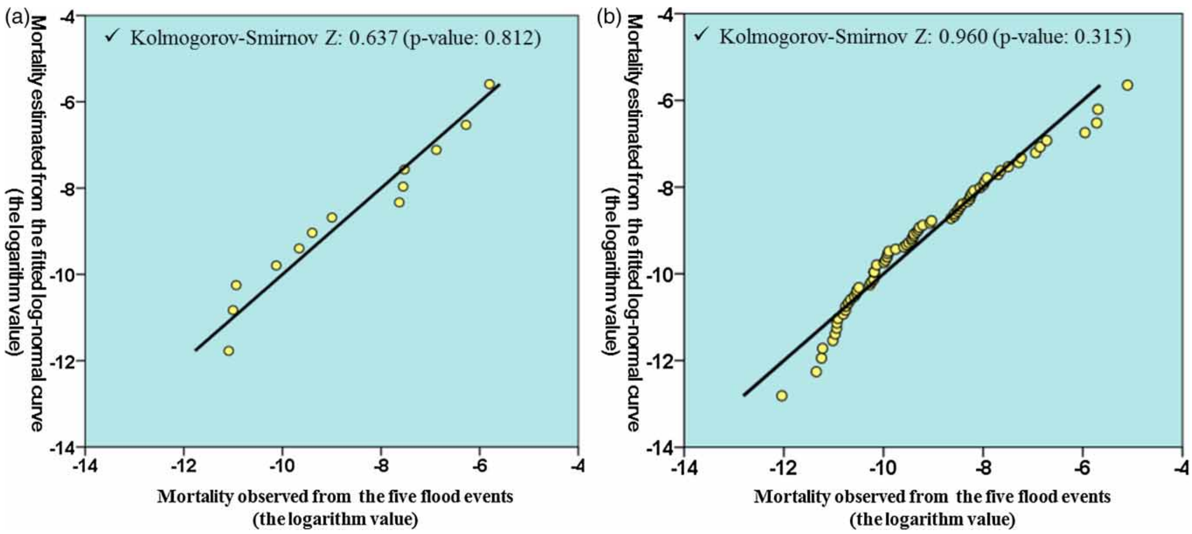

Fig. 6. Q-Q boxes: mortality from observations vs. mortality estimated from lognormal curves. (a) Older adults group; (b) other age group.

$$X_e\text{'s variance} = (e^{1.85^2} - 1)e^{2\times(-8.68)+1.85^2} = 2.6 \times 10^{-5}$$
$$X_o\text{'s variance} = (e^{1.50^2} - 1)e^{2\times(-9.23)+1.50^2} = 7.7 \times 10^{-7} \quad (5)$$

$$X_e\text{'s mode} = e^{-8.68-1.85^2/2} = 3.2 \times 10^{-5}$$
$$X_o\text{'s mode} = e^{-9.23-1.50^2/2} = 3.1 \times 10^{-5} \quad (6)$$

6. Conclusion

This study started from the perspective that strong evidence is necessary to assess vulnerability to risks of flood fatalities. Focusing on demographic factors among various aspects of vulnerability, we attempted to illustrate that the number of flood fatalities would vary according to the age groups' population distribution even when the number of affected people was constant. Based on five flood events recently occurring in the Philippines, we obtained the following findings:

- (For Objective 1) People aged ≥70 showed a remarkably high number of flood fatalities compared with their proportional population size. However, we were unable to discover any evidence underscoring children's vulnerability.
- (For Objective 2) For people aged ≥70 and <70, the magnitude of vulnerability was measured in terms of mortality. We concluded that people aged ≥70 have more than three times the vulnerability to risk of flood fatalities than other people, although older adults' vulnerability does not always appear to be higher than that of others.
- In addition, many experts currently use the age dependency ratio to consider demographic factors in their flood vulnerability studies. However, we proved that this ratio is not adequate for the Philippines, with regard to mortality. Based on the five flood events, children did not seem to be especially vulnerable to flood fatalities, and a high number of flood fatalities was observed only for people aged ≥70.

The view that older adults are especially vulnerable is not a novel idea. In the public health and natural hazards fields, many social scientists have emphasized the importance of protecting older adults from disasters, especially since the late 1990s. However, the major contribution of this study is that evidence was drawn from statistical methods in a quantitative way, and the vulnerability of older adults was revealed in a developing country in Asia where flood disasters pose greater human impact. To continue our research, further studies will be conducted by applying these methods to various other countries. Children's and older adults' vulnerability is specific to household contexts, health conditions, and social network conditions. Hence, vulnerable age groups are very likely to differ in each country, or even locality. The implications of these results should be applied to the Philippines only, until the same results are obtained in other countries.

What this study shows is that it is possible to identify with confidence certain age groups that can be more vulnerable to flood disasters. We recommend that these conclusions are translated into flood disaster risk reduction policies in two ways: (1) more details of disaster victims should be recorded, including ages, as has been done by the Philippine government, in order to (2) use this disaster victim information to identify and provide appropriate measures on the local scale for those people who are likely to have a higher mortality rate. This recommendation is also found and supported in research by Vink *et al.* (2014) and Vink (2014).

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