**ARTICLE**

# Impact of Socioeconomic Status and Demographic Composition on Disaster Mortality: Community-Level Analysis for the 2011 Tohoku Tsunami

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**Abstract**  On 11 March 2011, the Tohoku tsunami hit the northeastern region of Japan, causing massive damage to people and property. The tsunami was bigger than any other in Japan's recorded history, but the damage varied by community. This research addressed the effects of socioeconomic status and demographic composition on mortality in the 2011 Tohoku tsunami using community-level data. These effects were estimated using regression analysis, taking into account a variety of potential contributing aspects at the community level, including strength of the tsunami, population characteristics, gender, age, education, household composition, evacuation methods, and occupation. It was found that the height of the tsunami and the shares of three-generation households and employees in the manufacturing industry are all positively correlated with tsunami mortality. The impacts of these factors on mortality are particularly large for the older adults.

**Keywords**  2011 Tohoku tsunami · Community-level analysis · Demographic composition · Disaster risk reduction · Mortality · Socioeconomic status

## 1 Introduction

Natural hazards and disasters cause tremendous damage to both human life and physical property. An enormous earthquake with a magnitude of M 9.0—the Great East Japan Earthquake (GEJE)—hit northeastern Japan at 2:46 p.m. on 11 March 2011, and the tsunami caused by the GEJE—the 2011 Tohoku tsunami—wiped out many lives and buildings. The massive tsunamis recorded a maximum height of 9.3 m at Soma and a run-up height of 40.5 m in Iwate, which is the highest ever observed in Japan. Approximately 20,000 people were killed or declared missing, with more than 90% of the deaths being caused by drowning.

Previous studies have addressed the physical, socioeconomic, and demographic determinants of tsunami mortality using municipality-, community-, or household-level data. It has been found in this literature that the strength of tsunami is a main determinant of tsunami deaths (Frankenberg et al. 2011; Suppasri et al. 2012; Aldrich and Sawada 2015; Latcharote et al. 2018). Several demographic characteristics are considered to be underlying factors that increase the risk of natural hazards and prevent mitigation of human and physical damage from disasters (Donner and Rodríguez 2008). Increasing population, especially in urban areas, could increase exposure to hazards, partly due to immigration of minority groups (Donner and Rodríguez 2008). Population composition is another key aspect of risk, because older adults, infants, and women are less likely to survive tsunamis than prime-age men (Yeh 2010; Frankenberg et al. 2011; Suppasri et al. 2012; Aldrich and Sawada 2015; Ear 2017). Household composition could also influence disaster damage because households with vulnerable members such as older adults and infants are probably more susceptible to disasters (Frankenberg et al. 2011). Other potential elements of disaster impacts are education, social capital, and occupation, which are known to generate different results in building a long-standing and effective culture of disaster risk reduction and mitigation at the community level (King 2000; Martin 2010; Frankenberg et al. 2011; Frankenberg et al. 2013; KC 2013). It follows that the social science disaster research literature has attempted to shed light on the

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influence of various demographic, social, and economic attributes on disaster mortality at the municipality, community, and household levels.

This research aimed to address the effects of socioeconomic status and demographic composition on mortality in the 2011 Tohoku tsunami using community-level data. In regression analysis, death counts are regressed on various demographic, socioeconomic, and institutional variables. In the case of the 2011 tsunami, several existing studies have attempted to clarify the physical and social determinants of mortality, mainly using municipality-level data. Aldrich and Sawada (2015) explored sociodemographic and political factors related to mortality during the 2011 tsunami, and found that the height of the tsunami, crime rate (a proxy for social capital), and political support for the Liberal Democratic Party of Japan (LDP) influenced mortality rates. Latcharote et al. (2018) showed that for towns in the Sendai plain, fatality ratios for older people were higher than for all the other age groups, and female fatality ratios were higher than male fatality ratios.

The main contribution and importance of this study is that it analyzed tsunami mortality using community-level data. Community-level variables better capture population and household characteristics, socioeconomic status, and geographical conditions of the local community. This is advantageous in addressing determinants of disaster deaths because many disaster preparedness measures require community-based disaster risk management to build a long-term culture of safety involving as many community residents as possible (Shaw, Takeuchi, et al. 2012). In this study, a census district is considered as a community. In Japan, census districts are much smaller in population and geographical size than municipalities, and are contained within single municipalities. The literature has highlighted the importance of community-level attributes in the formation of disaster risk reduction measures. Ishiwatari and Arakida (2012, p. 3) stated that "community evacuation measures should be the centerpiece of disaster risk management systems. Because the Sanriku region has suffered from frequent tsunamis, its local communities have passed their knowledge from generation to generation, mainly by constructing commemorative monuments and by conducting education and drills." Shaw, Ishiwatari, et al. (2012, p. 3) also stated that "local communities play a key role in preparing for disastrous events such as the Great East Japan Earthquake (GEJE), and are normally the first responders to take action." Other previous studies also highlighted the importance of communities in establishing disaster-resilient societies (King 2000; Martin 2010; KC 2013).

Another contribution of this study is that it examined determinants of tsunami mortality from a variety of aspects—strength of the tsunami, population characteristics, gender, age, education, household composition, evacuation, community, and occupation—at the community level. Previous research, using panel individual microdata for the 2004 Indian Ocean tsunami, found that older people and women are likely to die relative to other groups when a tsunami occurs, pre-tsunami household compositions are predictive of survival, prime-age fishermen may help their families survive, and educated men are more likely to survive the tsunami than other groups (Frankenberg et al. 2011; Frankenberg et al. 2013). Various aspects of community characteristics are important underlying factors for tsunami survival.

## 2 Community-Level Determinants of Tsunami Mortality

Among the underlying determinants for tsunami deaths, strength of tsunami is the most notable and has the greatest potential to affect tsunami mortality in affected regions (Frankenberg et al. 2011; Suppasri et al. 2012; Aldrich and Sawada 2015; Latcharote et al. 2018). The strength of the tsunami is measured by quantitative variables such as the height of the tsunami, tsunami arrival time, and distance from the coast. Tsunami height is a major determinant of mortality in all tsunamis, not just the 2011 event: a doubling of the height of the tsunami leads to more than twice the strength of the tsunami in terms of power to pull and push physical structures (Aldrich and Sawada 2015; Latcharote et al. 2018). To explain the strength of the tsunami, this study employed "log of tsunami height" as a control variable in regression equation.

Population, one of the demographic attributes, is also a primary determinant of disaster mortality. The higher the number of residents who are exposed to disasters, the higher the number of fatalities (Kahn 2005). Larger populations not only lead to a larger number of victims but also generate the conditions for more frequent exposures. Unlike mortality, mortality rates—calculated by dividing mortality by the total population in a region—are not affected by population size. Population is therefore not usually incorporated as a control for mortality rate in the regression analysis (Frankenberg et al. 2011; Aldrich and Sawada 2015; Latcharote et al. 2018). This study then used "log of population" as a control in regressions with "log of mortality" being employed as the dependent variable, while for the regression where "mortality rate" was employed as the dependent variable, population was not included.

Gender has received much attention because of the higher fatality rates of women than men in tsunamis (Yeh 2010; Frankenberg et al. 2011; Ear 2017). One explanation for this mortality difference is physical strength, particularly swimming ability and height (Frankenberg et al. 2011). Additionally, the traditional role of women in the household often indicates that they are the ones saving their

parents and children, which may contribute to the disparity between women's and men's mortality rates (MacDonald 2005). Yet, women tend to take warnings or threat notifications more seriously than men do (Slovic 2000). During the 2011 Tohoku tsunami, prime-age women were likely to die picking up their children from school (Latcharote et al. 2018). Evidence from previous studies then suggests the higher mortality rate of women. Because the fatality data used in this research identify gender of deaths, death tolls categorized by gender are also employed as the dependent variables in regression analyses.

In addition to gender, age plays a crucial role in determining mortality from a tsunami. The mortality profile by age is U-shaped—higher mortality for children and older adults and lower for prime-age adults, particularly males—because physical strength and swimming ability are critical for tsunami survival (Rofi et al. 2006; Frankenberg et al. 2011). In particular, older adults are vulnerable to hazard events. A study on human damages in Japanese earthquakes found that more than half of casualties are older people (over 60 years old) (Wisner 1998); in the case of Hurricane Katrina, the majority of fatalities were among people 65 years old or older (Whitman et al. 1997). Apart from physical strength, psychological attributes may be a contributing factor to older fatalities (Donner and Rodríguez 2008). Because older people are more likely to have experienced false alarms and misguided warnings in the past, they are less responsive to warnings than younger people. Ages of deaths are available from the data, and then deaths classified by ages were employed as the dependent variables in extended regressions of this study. "Share of population aged 14 years old or under" and "share of population aged 65 years old or over" were added as the controls to reflect generational differences in mortality.

The demographic composition of the household has the potential to influence vulnerability to extreme disasters. Mortality from the Indian Ocean tsunami was lower for the households with more prime-age men, and this protective effect of prime-age men was greatest for their children and prime-age women (Frankenberg et al. 2011, p. F174). Also, a married man whose wife died in the tsunami was more likely to die than an unmarried man or a man living separately from his spouse, since husbands frequently died trying to save their family (Frankenberg et al. 2011). Even in the case of the 2011 Tohoku tsunami, people living together with others were more likely to die on the day of the tsunami (Aida et al. 2017). Households headed by single mothers tend to be less educated and poorer than women in two-parent households and thus are at greater risk during the course of disasters (Rodriguez and Russell 2006; Donner and Rodríguez 2008). Furthermore, for vulnerable people, such as elderly and poor individuals, social ties played a crucial role in escaping from the Tohoku tsunami (Ye and Aldrich

2019). Differences in mortality among households are taken into account by the control variables "share of single-person households," "share of three-generation households," and "share of households composed of people aged 65 or over." From the above discussion, single-person households are expected to evacuate more easily and be more likely to survive the tsunami, while three-generation households seem to face more difficulty because they need more time to evacuate with their families. Regardless of the number of household members, however, households composed exclusively of people 65 years old or over seem vulnerable to the tsunami.

Education is also a key to mitigating disaster risks. Highly educated individuals and societies have better preparedness and responses to disasters and suffer less disaster damages (Frankenberg et al. 2013; Muttarak and Lutz 2014). From a disaster risk reduction point of view, the existing literature supports the benefits of investing in formal and informal education on disaster risk reduction to build a culture of safety (Martin 2010). As in preceding relevant studies, this study adopted "average years of schooling" as a control variable in regression analyses.

Successful disaster risk management requires a shift in focus from preparedness and humanitarian assistance to the building of community resilience (Seek 2007). Past tsunami experiences, and transmission of these experiences from generation to generation, are key to future successful evacuation because devastating tsunamis occur rarely but periodically over a long-time span. Additionally, vulnerabilities are likely to arise from persistent conflicts in the communities. Social and organizational factors in the community, such as ways of decision making, leadership, divisions within the community, and social coping systems, affect how the community manages disaster preparedness and mitigation, and hence its vulnerability to disasters (Wachtendorf et al. 2008; Martin 2010). It should be noted that disaster preparedness measures need collective action and long-term effort to support communities in applying their knowledge and skills (Martin 2010).

Even in the case of the Tohoku tsunami, community-based disaster management played a key role in protecting residents from the tsunami. Traditional knowledge—in concrete tsunami experience—was transmitted from ancestors to descendants in small villages over a period of up to 1000 years (Aldrich and Sawada 2015). There are hundreds of tsunami stones, some of which are more than 600 years old, along the coastal area of Japan (Fackler 2011). These help to raise residents' awareness of tsunamis, but tsunami stones and other traditional teachings do not always ensure the survival of residents during tsunamis (Plümper et al. 2017). In consideration of past tsunami experience and its effects on fatalities in the 2011 tsunami, "log of death in the Meiji Sanriku tsunami" was employed as one of the controls in regressions of this study. The Meiji Sanriku tsunami is a

massive tsunami that hit the northern Tohoku coastal area in 1896, which killed about 22,000 people.

As community-based disaster risk management is incorporated in the daily lives of the residents, their motivation to participate in local disaster management activities is a key to achieving actual disaster mitigation. Participation rates in disaster drills vary by neighborhood, with more residents participating in smaller, more cohesive communities (Shaw, Ishiwatari, et al. 2012). As variables for capturing community-level resilience, this study employed "share of homeowner households." Homeowner households are more devoted to the current community and have a stronger motivation to improve the community than those living in rental houses, so the more homeowners, the stronger the solidarity within the community. Also, houses that are not rental properties are generally better constructed and provide better protection from the wave of a tsunami.

Evacuation measures are at the center of disaster risk management systems. Evacuation on foot is standard in Japan as evacuation by vehicle could cause traffic jams and thus prevent emergency vehicles from reaching disaster sites immediately. In the case of the 2011 tsunami, unfortunately, many victims chose evacuation by vehicle for their families, in some cases returning to their homes to take their children and/or parents, and were stuck in traffic jams and swept away in a car (Ishiwatari and Arakida 2012). In this study, "share of those who commute within the home municipality" and "share of those who commute by car" serve as proxies for tsunami evacuation. Residents commuting within the home municipality are regarded as having more local knowledge of tsunami evacuation routes, hazard maps, location of evacuation shelters, and the history of tsunamis. However, they may be vulnerable because of overconfidence in both the sea wall and their local knowledge of tsunami evacuation and past tsunamis, which could lessen their chance of survival in the tsunami. The mortality consequences of commuting within the hometown and by car are therefore expected to be ambiguous.

Another socioeconomic factor of tsunami survival is occupation. The 2011 tsunami hit around 3 p.m. on Friday, 11 March, a time when many people were out of the home attending work or school and not together with their families. Occupations with high tsunami survival rates include fishermen, who are likely to be good swimmers and have more knowledge of tsunamis (Frankenberg et al. 2011), and farmers, who work closer to their houses than other workers and are therefore more likely to be familiar with their tsunami escape routes. To control for occupational influence on mortality, "share of employees working in the manufacturing industry" and "share of employees working in the service industry" were incorporated into regression equations. Note that the reference occupation comprises the primary sector (the extraction and production of raw materials, such as

agricultural and fishery industries) and hence the two variables are expected to have a positive relationship with tsunami death toll because those who work for these industries are more vulnerable.

## 3 Methodology

The socioeconomic and demographic effects of the 2011 Tohoku tsunami on communal mortality are estimated using ordinary least squares (OLS) and zero-inflated negative binomial (ZINB) regressions. The ZINB regression is used because many districts, specifically 55 districts in the sample, have zero tsunami deaths (see, for example, Kahn 2005; Aldrich and Sawada 2015).

In the baseline regression, the empirical equation is specified as follows:

$$Y_{ij} = \alpha + X_{ij}\beta + Z_j\gamma + \in_{ij},$$

where $Y_{ij}$ is log of the death toll from the 2011 Tohoku tsunami in district $i$ of municipality $j$. $X_{ij}$ is a vector of district-level explanatory variables and $\beta$ denotes its coefficient vector, while $Z_j$ is a vector of municipality-level variables and $\gamma$ denotes its coefficient vector. $\in_{ij}$ stands for the heteroskedastic error. $X_{ij}$ consists of socioeconomic and demographic variables, as detailed in Sect. 2.

$Z_j$ consists of a set of variables representing municipal geographic, socioeconomic, demographic, and political characteristics as well as the strength of the tsunami: log of geographical area; log of flooded area; log of the elevation of government building; log of income per taxpayer; unemployment rate; evacuation facilities per capita; investment expenses per capita in 2008–2010; crime per 1000 people in 2009; share of LDP (Liberal Democratic Party of Japan) support in the 2009 HR (House of Representatives) election; and a merged municipality dummy variable. Flooded area relates to the strength of the tsunami. Geographical area and the elevation of government building explain geographical characteristics. Municipal economic conditions are captured by income per taxpayer and unemployment rate. Physical measures towards tsunami preparedness are measured using the number of evacuation facilities per capita and investment expenses per capita in 2008–2010 as proxy variables. Crime rate can be a proxy for social ties in the regressions, since social ties would influence the sharing of the threat notification, mutual help, and community-based disaster risk management (Aldrich and Sawada 2015).

Following Aldrich and Sawada (2015), this study adopted the share of those who supported the LDP in the 2009 HR election as a control, because the LDP has long been the ruling party in the Diet (the House of Representatives) and hence might have discretional power to allocate grants for

investment. Another underlying factor influencing mortality is a municipal merger (Murosaki and Koda 2013). The residents then are likely to lack community solidarity and a sense of identification with the new municipality, which adversely affects disaster risk reduction measures (Murosaki and Koda 2013). In contrast, municipal mergers are expected to enhance municipalities' capacity for disaster risk management and preparedness through the expansion of its scale and higher levels of specialized knowledge. A dummy for merged municipalities was used to explain the influence of municipal mergers. The definitions and sources of the variables are presented in Table 1.

In addition to the baseline specification, some extended models were used to check validity of regression results from the baseline. To begin with, the sample was restricted to districts with a population under 1000, to include only smaller communities. As explained above, the ZINB model was run where the inflated equation models whether the tsunami killed as a function of the height of the tsunami and the number of deaths in the Meiji Sanriku tsunami, while the death toll counts were regressed on the same covariates as in the OLS. Because several previous studies, including those focusing on the 2011 Tohoku tsunami, adopted mortality rate as the dependent variable in their regression analyses, this study also ran a regression using mortality rate as the dependent variable. From the viewpoint of sex differential in tsunami mortality, male and female fatalities were regressed on the explanatory variables. For detailed examination of the influence of age on death tolls, this study also performed the regressions using fatalities by age in 10-year increments as the dependent variable.

## 4 Data

The main dataset used in this research is from the census district level—the district used for creating the Census. More specifically, among three categories of census district—municipality, upper tier, and lower tier—the upper tier (299) and lower tier (50) districts were used in the present research. The upper tier was used as the main sampling unit because data on the death count from the tsunami are not available for many lower-level districts. The lower tier was used for municipalities where the upper tiers have a very large population and there are small numbers of upper tiers. Municipalities for which the lower tier was used as a sampling unit include part of Kesennuma City, Yamamoto Town, and part of Minamisoma. The sample was restricted to districts where the heights of the tsunami were recorded in the database of the 2011 Tohoku tsunami (TTJS Group 2011). The TTJS Group (2011) recorded data at more than 12,637 sites along the coastal region of Tohoku, including the date of the recording, the reliability of the record—ranked from

A (most reliable) to E (least reliable)—the names of the team members who recorded the data, as well as the tsunami's height and coordinates. By using only the records with a reliability rating of B or higher, the average tsunami height for each district was calculated. Thus, only districts with data on tsunami height were sampled, meaning that the districts sampled are similar in terms of exposure to the tsunami disaster. The sampled years are 2010 for data from the Census, public finance data, and data collected annually, and the most recent year before 2010 for which data are available, for data collected every two years or more. The data on death toll are as of 9 December 2011. Descriptive statistics are provided in Table 2.

## 5 Empirical Results

This section provides estimates of mortality from the 2011 Tohoku tsunami with regard to socioeconomic, demographic, geographical, and disaster risk management-related characteristics at the community and municipal levels.

### 5.1 Baseline Results

As found in the baseline regression in column (1) of Table 3, tsunami height and population have positive effects on tsunami fatalities, specifically showing that a one percentage increase in tsunami height increases tsunami deaths by 1.03%. The shares of three-generation households and of employees working in the manufacturing industry are also positively correlated with the number of deaths from the tsunami. As shown in columns (2) and (3) in Table 3, regardless of sample and specification, tsunami height and population have significantly positive impacts on tsunami mortality. Also, larger shares of three-generation households and those who work in the manufacturing industry give rise to significant increases in mortality. Column (4) shows that the estimates obtained from the regression where fatality rate is the dependent variable are consistent with the results of other regressions. In columns (5) and (6), the dependent variables are male and female deaths. There are few differences between the estimates from the two regressions, and the estimates significant in the baseline model are still significant in both regressions, with almost the same magnitudes of the coefficients. To check the possibility of multicollinearity, the variance inflation factor (VIF) was calculated and no multicollinearity was found in the regressions.

To disentangle the relationship between tsunami mortality and sociodemographic factors, this study also ran regressions with districts with a population under 1500 being sampled, with the municipality-fixed effects model, with the multilevel model, with a variable on the 2010 Chili tsunami being included to control the experience of overestimation

**Table 1** Variable definition, sources, and value units

| Variable and Value Unit | Definition | Sources |
|---|---|---|
| A. Death toll | | |
| Deaths (count) | Death toll from the 2011 Tohoku tsunami | 1 |
| Mortality rate (%) | Percentage of deaths from the 2011 Tohoku tsunami to total population | 1 |
| Deaths, male (count) | Male deaths from the 2011 Tohoku tsunami | 1 |
| Deaths, female (count) | Female deaths from the 2011 Tohoku tsunami | 1 |
| Deaths aged 14 or under or aged 65 or over (count) | Death aged under 14 or over 65 from the 2011 Tohoku tsunami | 1 |
| Deaths aged 15–64 (count) | Deaths aged 15–64 from the 2011 Tohoku tsunami | 1 |
| B. District-level variables | | |
| Tsunami height (m) | Height of the tsunami, averaged at the district level by the values measured at several points | 2 |
| Deaths in the Meiji Sanriku tsunami (count) | Death toll in the Meiji Sanriku tsunami, which hit the Tohoku coastal regions in 1896 | 3 |
| Population (count) | Population, 2010 | 4 |
| Share of population aged 14 or under (%) | Share of population aged 14 or under to total population, 2010 | 4 |
| Share of population aged 65 or over (%) | Share of population aged 65 or over to total population, 2010 | 4 |
| Average years of schooling (years) | Average years of final schooling, which is calculated from the numbers of those who graduated finally from each category of schooling, 2010 | 4 |
| Share of single-person households (%) | Share of single-person households to total households, 2010 | 4 |
| Share of three-generation households (%) | Share of three-generation households to total households, 2010 | 4 |
| Share of households composed of people aged 65 or over (%) | Share of the households in which all the members are 65 years old or over to total households, 2010 | 4 |
| Share of those who commute by car (%) | Share of the workers and students who commute by car to total, 2010 | 4 |
| Share of those who commute within the home municipality (%) | Share of the over 15 years old people who commute within a home municipality to work to over 15 years old workers, 2010 | 4 |
| Share of homeowner households (%) | Share of homeowner households to total households, 2010 | 4 |
| Share of employees working in the manufacturing industry (%) | Share of employees working in the secondary industry to labor force, 2010 | 4 |
| Share of employees working in the service industry (%) | Share of employees working in the tertiary industry to labor force, 2010 | 4 |
| C. Municipality-level variables | | |
| Geographical area (km$^2$) | Geographical area, 2010 | 4 |
| Flooded area (km$^2$) | Flooded area in the 2011 Tohoku tsunami | 5 |
| Elevation of the government building (m) | Elevation of the government building, 2010; the author measured the elevation of government buildings by the Google Map | - |
| Income per taxpayer (thousand JPY) | Taxable income of local income tax per taxpayer, 2010 | 6 |
| Unemployment rate (%) | Percentage of unemployed people to labor force, 2010 | 4 |
| Evacuation facilities per capita (count) | Number of elementary school, junior high school, high school in 2010, and community center in 2008, per capita | 4, 7, 8 |
| Investment expenses per capita (thousand JPY) | Spending on ordinary construction works, disaster recovery works, and disaster mitigation measures per capita, 2008–2010 | 4, 9 |
| Crime per 1000 persons (count) | Criminal cases known to the police per 1,000 persons, 2009 | 4, 10 |
| Share of LDP support in the 2009 HR election (%) | Share of Liberal Democratic Party (LDP) supporters in the 2009 House of Representatives (HR) election to total voters | 11 |
| Merged municipality dummy | Dummy that takes one for merged municipalities during the Heisei great merger by 2010 | 12 |
| Log of difference in estimated and observed height in the 2010 Chili tsunami (m) | Log of the difference between the estimated and observed values in the tsunami height in the 2010 Chili tsunami | 13 |

1 = National Police Agency (2011) List of Fatalities in the GEJE (Iwate: http://www.pref.iwate.jp/~hp0802/oshirase/kouhou/saigaijyouhou/oshirase/oshirase.html; Miyagi: http://www.police.pref.miyagi.jp/hp/jishin/itai/kakunin/itai_kakunin.html; Fukushima: http://www.police.pref.fukushima.jp/shinsai/index.html; The Web data were retrieved on 9 December 2011); 2 = The 2011 Tohoku Earthquake Tsunami Joint Survey (TTJS) Group (TTJS Group 2011) (https://coastal.jp/tsunami2011/index.php); 3 = Ministry of Internal Affairs (1934) Report on the Recovery of Municipalities Affected by the Meiji Sanriku Tsunami; 4 = Ministry of Internal Affairs and Communications (MIC), Statistics Bureau (2010) Census (https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00200521&tstat=000001039448); 5 = Geospatial Information Authority of Japan (2011) (https://www.gsi.go.jp/common/000059939.pdf); 6 = MIC (2010) Survey on Municipal Taxation (https://www.soumu.go.jp/main_sosiki/jichi_zeisei/czaisei/czaisei_seido/ichiran09.html); 7 = Ministry of Education, Culture, Sports, Science and Technology (MEXT) (2010) Report on Basic Research on School (https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00400001&tstat=000001011528); 8 = MEXT (2008) Survey on Social Education (https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00400004&tstat=000001017254); 9 = MIC (2010) Survey on Municipal Financial Settlement (https://www.soumu.go.jp/iken/kessan_jokyo_2.html); 10 = MIC (2009) System of Social and Demographic Statistics (SSDS) (https://www.e-stat.go.jp/en/regional-statistics/ssdsview); 11 = Yuki Mori (2009) 45th JED-M Data (http://www.bokutakusha.com/databank/index.html); 12 = MIC (https://www.soumu.go.jp/gapei/gapei.html). 13 = The Japan Meteorological Agency (2010) The Tsunami Warning on the 2010 Chili Tsunami (https://www.data.jma.go.jp/svd/eqev/data/tsunamihyoka/20100227chile/index.html). All the Web data except death tolls were retrieved on 5 August 2020

**Table 2** Descriptive statistics

| Variable | Mean | Std. Dev. | Max. | Min. |
|---|---|---|---|---|
| A. Death tolls | | | | |
| Deaths (count) | 30.01 | 79.95 | 981 | 0 |
| Mortality rate (%) | 1.82 | 3.07 | 37.6 | 0 |
| Deaths, male (count) | 13.61 | 35.85 | 442 | 0 |
| Deaths, female (count) | 16.40 | 44.32 | 539 | 0 |
| Deaths aged 14 or under or aged 65 or over (count) | 18.24 | 47.27 | 557 | 0 |
| Deaths aged 15–64 (count) | 11.16 | 32.58 | 420 | 0 |
| B. Community-level variables | | | | |
| Tsunami height (m) | 6.66 | 4.21 | 20.6 | 0.2 |
| Deaths in the Meiji Sanriku tsunami (count) | 40.2 | 189.7 | 2,135 | 0 |
| Population (count) | 1,647 | 2,365 | 17,046 | 22 |
| Share of population aged 14 or under (%) | 12.78 | 2.81 | 26.77 | 0 |
| Share of population aged 65 or over (%) | 27.13 | 6.56 | 85.39 | 4.1 |
| Average years of schooling (years) | 11.73 | 0.51 | 16.32 | 9.5 |
| Share of single-person households (%) | 22.7 | 8.4 | 85.4 | 0 |
| Share of three-generation households (%) | 16.74 | 8.12 | 65.52 | 0 |
| Share of households composed of people aged 65 or over (%) | 18.46 | 5.85 | 82.98 | 2.08 |
| Share of those who commute by car (%) | 72.35 | 9.87 | 100 | 10.20 |
| Share of those who commute within the home municipality (%) | 71.72 | 21.85 | 100 | 13.68 |
| Share of homeowner households (%) | 74.27 | 16.10 | 100 | 25.00 |
| Share of employees working in the manufacturing industry (%) | 28.41 | 6.45 | 59.15 | 0 |
| Share of employees working in the service industry (%) | 62.70 | 10.61 | 95.41 | 2.56 |
| C. Municipality-level variables | | | | |
| Geographical area (km$^2$) | 445.29 | 390.34 | 1,259.89 | 13.27 |
| Flooded area (km$^2$) | 28.78 | 25.61 | 73.00 | 0.50 |
| Elevation of the government building (m) | 8.78 | 11.75 | 60.00 | 0.30 |
| Income per taxpayer (thousand JPY) | 2,677 | 188 | 3,557 | 2,302 |
| Unemployment rate (%) | 7.94 | 0.79 | 10.81 | 5.16 |
| Evacuation facilities per capita (count) | 0.0007 | 0.0003 | 0.0021 | 0.0002 |
| Investment expenses per capita (thousand JPY) | 4.84 | 0.27 | 6.11 | 4.06 |
| Crime per 1000 persons (count) | 10.72 | 2.27 | 15.02 | 3.31 |
| Share of LDP support in the 2009 HR election (%) | 27.86 | 1.74 | 37.96 | 20.79 |
| Merged municipality dummy | 0.55 | 0.50 | 1 | 0 |
| Log of difference in estimated and observed height in the 2010 Chili tsunami (m) | 1.76 | 0.28 | 1.94 | 1.25 |

The number of observations is 349; the sample is the same as for the baseline regression in Table 3. Per capita statistics are a weighted average of population, while statistics of per capita income are a weighted average for all taxpayers

*LDP* Liberal Democratic Party of Japan; *HR* House of Representatives

of tsunami height, and with fatalities classified by age cohort being used as the dependent variables. The extended regressions provide evidence supporting the findings of the baseline analysis.[1]

Turning to municipality-level variables in the baseline regression, communities with a narrower geographical area and those more widely flooded by the tsunami were likely to see more fatalities. The significant positive effect of evacuation facilities per capita is seen except for when districts

with a population of less than 1000 were sampled, possibly indicating that evacuation facilities were built more in municipalities with a higher likelihood of tsunami strike.

## 5.2 Tsunami Mortality by 10-Year Age Categories

Given much attention on age in tsunami evacuation research, tsunami fatalities were classified by age groups in 10-year increments, and then deaths by age group were regressed on the explanatory variables. Only the coefficients of the key and significant variables—log of tsunami height, share of

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[1] The author provides the regression results upon request.

**Table 3** Estimates of death toll from the 2011 Tohoku tsunami

| Models | All districts, baseline | Sample districts with population < 1000 | Zero-inflated negative binomial regression | Dependent variable: fatality rate (%) | Dependent variable: male deaths | Dependent variable: female deaths |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Log of tsunami height | 1.030*** | 0.944*** | 1.492*** | 2.475*** | 0.906*** | 0.877*** |
| | (0.180) | (0.116) | (0.264) | (0.473) | (0.138) | (0.159) |
| Log of death in the Meiji Sanriku tsunami | 0.0948** | 0.102* | 0.0565 | −0.0515 | 0.0791* | 0.102** |
| | (0.0457) | (0.0505) | (0.0520) | (0.0872) | (0.0400) | (0.0396) |
| Log of population | 0.627*** | 0.653*** | 0.824*** | | 0.554*** | 0.550*** |
| | (0.111) | (0.110) | (0.119) | | (0.0915) | (0.0982) |
| Share of population aged 14 or under | −0.0650** | −0.0426* | −0.0936** | −0.164*** | −0.0687*** | −0.0387 |
| | (0.0289) | (0.0246) | (0.0414) | (0.0525) | (0.0238) | (0.0305) |
| Share of population aged 65 or over | −0.0200 | −0.0195 | −0.00806 | −0.0527 | −0.0235 | −0.00342 |
| | (0.0192) | (0.0242) | (0.0316) | (0.0501) | (0.0175) | (0.0160) |
| Average years of schooling | −0.0294 | 0.0586 | 0.0597 | 0.117 | −0.0213 | −0.0372 |
| | (0.134) | (0.0946) | (0.120) | (0.176) | (0.130) | (0.114) |
| Share of single-person households | −0.0113 | −0.0160* | −0.0182 | −0.0506** | −0.0130 | −0.00718 |
| | (0.00960) | (0.00823) | (0.0147) | (0.0240) | (0.00984) | (0.00798) |
| Share of three-generation households | 0.0207*** | 0.0118** | 0.0375*** | 0.102*** | 0.0213*** | 0.0146** |
| | (0.00736) | (0.00443) | (0.0126) | (0.0260) | (0.00619) | (0.00653) |
| Share of households composed of people aged 65 or over | 0.0169 | 0.0187 | 0.00867 | 0.0594* | 0.0142 | 0.00849 |
| | (0.0118) | (0.0161) | (0.0223) | (0.0334) | (0.0109) | (0.00955) |
| Share of those who commute by car | −0.00893 | −0.00410 | −0.0125 | −0.0359*** | −0.0109* | −0.00428 |
| | (0.00564) | (0.00484) | (0.00832) | (0.0120) | (0.00541) | (0.00468) |
| Share of those who commute within the home municipality | 0.0144 | 0.0148* | 0.0162 | 0.0380* | 0.0126 | 0.00969 |
| | (0.00941) | (0.00780) | (0.0103) | (0.0212) | (0.00782) | (0.00802) |
| Share of homeowner households | −0.00866 | −0.00956 | −0.0232*** | −0.0466*** | −0.0104* | −0.00712 |
| | (0.00583) | (0.00586) | (0.00715) | (0.0125) | (0.00561) | (0.00451) |
| Share of employees working in the manufacturing industry | 0.0259*** | 0.0316*** | 0.0411*** | 0.114*** | 0.0190*** | 0.0251*** |
| | (0.00551) | (0.00502) | (0.00899) | (0.0199) | (0.00475) | (0.00557) |
| Share of employees working in the service industry | 0.0151* | 0.00608 | 0.0168* | 0.0369** | 0.0111 | 0.0146* |
| | (0.00784) | (0.00561) | (0.00983) | (0.0177) | (0.00698) | (0.00730) |
| Log of geographical area | −0.526*** | −0.334*** | −0.443*** | −0.714*** | −0.432*** | −0.443*** |
| | (0.124) | (0.116) | (0.147) | (0.258) | (0.103) | (0.106) |
| Log of flooded area | 0.913*** | 0.163 | 1.009*** | 1.367*** | 0.844*** | 0.797*** |
| | (0.157) | (0.152) | (0.178) | (0.224) | (0.129) | (0.138) |
| Log of the elevation of government building | −0.148 | −0.367*** | −0.126 | −0.481** | −0.0869 | −0.145 |
| | (0.117) | (0.128) | (0.120) | (0.219) | (0.100) | (0.0978) |
| Log of income per taxpayer | 0.280 | 0.0743 | 1.608 | 6.756* | −0.133 | 0.554 |
| | (2.021) | (2.351) | (2.534) | (3.718) | (1.585) | (1.804) |
| Unemployment rate | −0.196 | −0.282** | −0.0218 | −0.0701 | −0.130 | −0.168 |
| | (0.127) | (0.119) | (0.134) | (0.173) | (0.0938) | (0.118) |

**Table 3** (continued)

| Models | All districts, base-line | Sample districts with population < 1000 | Zero-inflated negative binomial regression | Dependent variable: fatality rate (%) | Dependent variable: male deaths | Dependent variable: female deaths |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Evacuation facilities per capita | 712.3*** | 98.26 | 876.5*** | 1,884*** | 643.4*** | 646.6*** |
| | (249.7) | (279.7) | (254.6) | (370.1) | (205.6) | (205.2) |
| Investment expenses per capita | −0.256 | −0.203 | −0.156 | −0.552 | −0.107 | −0.145 |
| | (0.236) | (0.225) | (0.332) | (0.332) | (0.188) | (0.216) |
| Crime per 1,000 persons | −0.0965** | 0.0291 | −0.0727 | −0.140* | −0.0827** | −0.0793* |
| | (0.0462) | (0.0507) | (0.0524) | (0.0689) | (0.0359) | (0.0401) |
| Share of LDP support in the 2009 HR election | 0.0222 | −0.0261 | 0.0274 | 0.0497 | 0.0224 | 0.0200 |
| | (0.0320) | (0.0551) | (0.0283) | (0.0516) | (0.0275) | (0.0299) |
| Merged municipality dummy | −0.119 | 0.490** | −0.540** | −0.912*** | −0.322* | −0.0884 |
| | (0.201) | (0.197) | (0.247) | (0.326) | (0.165) | (0.184) |
| Inflate equation | | | | | | |
| Log of tsunami height | | | −0.636 | | | |
| | | | (0.779) | | | |
| Log of death in the Meiji Sanriku tsunami | | | −78.09*** | | | |
| | | | (17.29) | | | |
| Log of α | | | 0.252 | | | |
| | | | (0.161) | | | |
| Adjusted $R^2$ | 0.475 | 0.377 | | 0.200 | 0.475 | 0.451 |
| Log likelihood | | | −1250 | | | |
| Observations | 349 | 207 | 349 | 349 | 349 | 349 |

The dependent variable is log of (death toll + 1) for columns (1), (2), (5), and (6), deaths for column (3), and fatality rate (%) for column (4). Standard errors cluster robust with regard to municipality are in parentheses. *Significant at 10%, **Significant at 5%, and ***Significant at 1%. Constants are abbreviated. Following the regression specification in previous studies, log of population is not included when fatality rate is employed as the dependent variable, column (4)

*LDP* Liberal Democratic Party of Japan; *HR* House of Representatives.

three-generation households, and share of employees working in the manufacturing industry—are illustrated with their 95% confidence intervals in Fig. 1.

In Fig. 1, the impacts of tsunami height on fatalities steadily increase with age, thereby suggesting that tsunami height is more critical as tsunami victims grow older. The graph of the share of three-generation households is V-shaped, with the bottom of the V occurring at ages 30–39, and the greatest impact occurring for the older adults. The coefficients of the share of employees working in the manufacturing industry are U-shaped with respect to age, with larger impacts for older adults. As a consequence, from an age profile-mortality point of view, the mortality consequences of community-level variables on sociodemographic and disaster risk-related characteristics are clearer for older adults.

# 6 Discussion

Three-generation households appear to have been more vulnerable to the tsunami. This may be because people from these households waited for some of their family members or went to find and/or pick up family members, and found it difficult to leave quickly. In the Tohoku tsunami, 21% of the respondents evacuated after doing something or urgently, because they went to find or pick up family members. Of those who evacuated in a hurry, 49% were caught in the tsunami (Cabinet Office 2011b). In total, 15.2% of people living with their grandparents could not evacuate, whereas only 7.6% of people living alone or with others apart from grandparents did not evacuate (Cabinet Office 2011c). The social and economic status of a household may be related to the formation of three-generation households, as reported in the United States and other countries. Traditionally in

**Fig. 1** Coefficients of community-level key variables by age group. *Notes* Tsunami fatalities are classified by age group in 10-year increments. Each group of deaths is regressed on the same explanatory variables as in the baseline regression. Only the coefficients of the key variables—log of tsunami height, share of three-generation households, and share of employees working in the manufacturing industry—are provided. The vertical axis shows the point estimates of each variable; the horizontal axis shows age groups. The vertical bars show the 95% confidence intervals
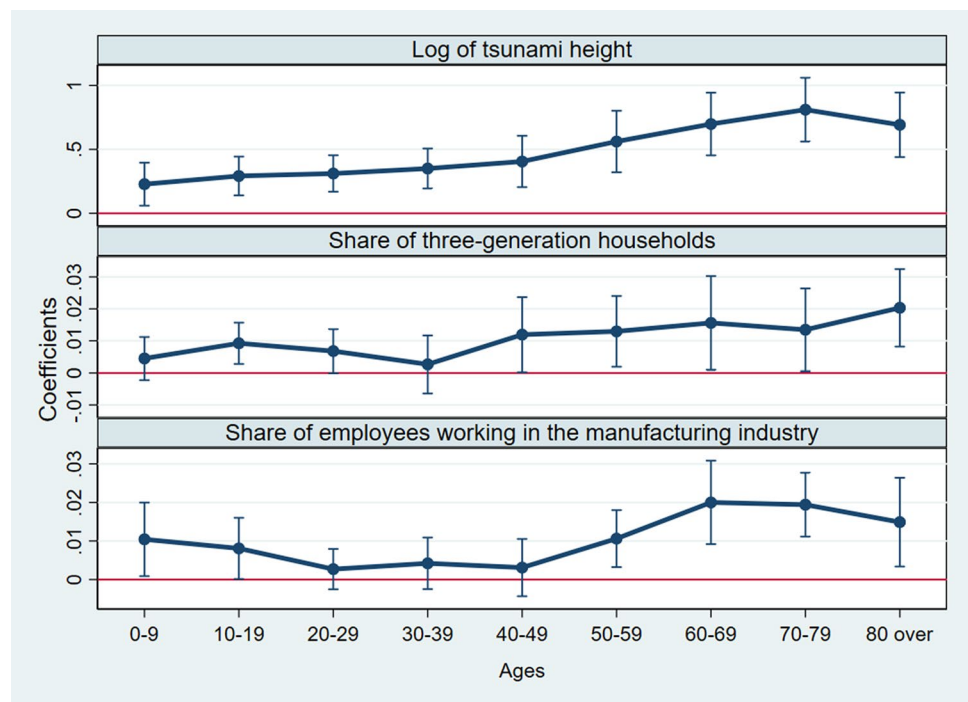


Japan, however, other elements, including the demonstration of filial piety, the need to care for older parents, and being the oldest son, are the key drivers for adult children to reside with their older parents (Hashimoto 1996; Koyano 1996; Takagi et al. 2007). Additionally, multigenerational co-residence is more prevalent in Tohoku than in other regions in Japan because of indigenous cultural practices (Ministry of Health, Labour and Welfare 2000).

The impact on mortality of share of the population working in the manufacturing industry is significant, partly because public awareness about community-based disaster risk reduction measures was unlikely to grow in communities that relied to a large extent on the manufacturing industry. This is because of the large proportion of prime-age men working in this industry. In 2010 in Japan, the proportion of prime-age men to total employees in the manufacturing industry (the secondary industry) was 69% (calculated from Census of Japan 2010). These men are generally not involved in community-based disaster risk reduction drills, especially compared with children (who attend evacuation drills at school) and older adults (who tend to be more involved in community activities). A survey by Sendai, Miyagi reported that the proportion of prime-age people (aged 20–64 years) who had often attended disaster risk reduction drills was around 6%, whereas around 18% of older adults (over 65 years) had done so (Sendai 2012). Communities with more workers in the manufacturing industry would therefore be more vulnerable to tsunami hazard. A survey on the tsunami targeted towards community members reported that factory workers who moved around a lot for their jobs did not know

about past tsunamis and had not participated in evacuation drills. As a result, they did not leave immediately (Cabinet Office 2011a). To make this worse, manufacturing facilities and warehouses are generally built on low, flat ground, often close to the sea, because of availability of large spaces, electricity, and raw materials (most of which are imported from abroad in Japan) and easier access to ports.

One potential reason for higher mortality among infants and older adults in communities with more three-generation households is that children and older people in these areas tended to return to the house before evacuating and/or wait for family members. Around 32% of those who were with their grandchildren or grandparents (or, generally, children or older adults in three-generation households) returned home and waited for family members after the earthquake, whereas only 9% of those who were with their parents and 21% of people with their children waited for family members (Cabinet Office 2011c). It therefore took them longer overall to evacuate the area (Ishiwatari and Arakida 2012), which made them more likely to die. In communities where more people work in the manufacturing industry, older adults were also more vulnerable than other age groups, possibly because generally, they relied on help from their neighbors when escaping from the tsunami. As explained above, in communities with high shares of manufacturing workers, the levels of disaster risk preparedness and awareness are likely to be low, and hence the residents did not help the older adults to escape. In communities where solidarity was fostered, residents collected neighbors and evacuated with older people living alone at the time of the tsunami (Cabinet

Office 2011a). Overall, the community-level risk factors, such as three-generation households and living in communities with a heavy manufacturing industry presence, were especially critical for older adults.

## 7 Conclusion

The findings of this research show that: First, the height of the tsunami, population, the share of three-generation households, and the share of employees working in the manufacturing industry are positively correlated with tsunami mortality. The positive link between the height of the 2011 Tohoku tsunami and its mortality is confirmed by prior empirical studies with a focus on the 2011 Tohoku tsunami (Suppasri et al. 2012; Aldrich and Sawada 2015; Latcharote et al. 2018). At the time of the tsunami, many people wanted to escape with and/or wait for their family members, and therefore, people living in three-generation households needed more time to reach a safe place with their families, and were more vulnerable to the tsunami. The vulnerability of the community with a high proportion of three-generation households is consistent with the findings in Frankenberg et al. (2011) and Aida et al. (2017). Manufacturing industry workers tended not to attend local disaster risk reduction activities in their community relative to the children and older people, resulting in weak social ties in the community and the failure of disaster risk preparedness and awareness. Thus, the occupational characteristics in the community are also a key element to determine tsunami mortality. Second, the impacts on mortality of the tsunami height and the shares of three-generation households and of people working in the manufacturing industry are large particularly for the older adults. This result suggests that these variables seem to be the critical factors for people vulnerable to tsunami disasters.

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