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Original Research

Tsunami inundation after the Great East Japan Earthquake and mortality of affected communities

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ABSTRACT

Objective: To examine the relationship between mortality rate and tsunami inundation after the Great East Japan Earthquake (GEJE) in 2011.
Study design: Cross-sectional study.
Methods: One hundred and fifty-five town or village sections in Ishinomaki, Myagi Prefecture, were included in this study. Three areas in the city were classified by characteristic landforms: plains area ($n = 114$), ria coastal area ($n = 27$) and Kitakami riverside ($n = 14$). The correlation coefficient between tsunami inundation depth and mortality rate was calculated for each area, and the differences between the areas were examined. Furthermore, multivariate analyses adjusted for the characteristics of the sections were conducted using census data taken before the GEJE.
Results: An association was found between inundation depth and mortality rate for Ishinomaki as a whole ($r = 0.65$, $P < 0.001$), Kitakami riverside ($r = 0.85$, $P < 0.001$) and the plains area ($r = 0.75$, $P < 0.001$) in separate analyses. However, no association was detected between inundation depth and mortality rate for the ria coastal area ($r = 0.14$, $P = 0.47$).
Conclusion: The ria coastal area has good accessibility to the hills and tight bonding between members of the community. These factors seemed to play crucial roles in the lower mortality rate in this area despite the deep inundation.
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Introduction

There are numerous vacant lots along the coast of north-eastern Japan that formerly contained communities comprised of houses, ports and workplaces. On 11 March 2011, a huge tsunami caused by the Great East Japan Earthquake (GEJE, magnitude 9.0) wreaked havoc on the area.[1,2] Nearly 400,000 houses and 20,000 public buildings were completely or partially destroyed, and 400,000 people were forced to evacuate.[2–4] The catastrophic power of the GEJE took nearly 20,000 lives.[2,5] Among the municipalities, Ishinomaki in Miyagi Prefecture suffered the greatest number of deaths ($n = 3471$).

There is a need to investigate factors that mitigated the human mortality rate, regardless of the physical damage, in order to prepare for the next disaster. Of nearly 20,000 casualties, more than three-quarters of deaths were due to

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drowning in the tsunami rather than collapsed buildings.[6] Some perished while attempting to rescue their families, while others had no knowledge of the impending tsunami and were unable to escape in time.

The mortality rate increased with the inundation depth,[7] and a relationship has been reported between the mortality rate and the proportion of the population that lived in the area of inundation.[8] In contrast, some communities in the ria coastal area of Ishinomaki reported no fatalities, despite the fact that almost all houses were destroyed by the tsunami. The Japanese Government reported that the average mortality rate in the ria coastal area was lower than that of the plains area at the same inundation depth.[7]

Mortality rate trends in inundated areas of past disasters have been reported, but to the authors' knowledge, this is the first study to investigate the relationship between inundation depth and mortality rate.[9–13] It was hypothesized that the mortality rate experienced by a community is not determined solely by the inundation depth of a tsunami. This study investigated the relationship between the inundation depth of the GEJE tsunami and mortality rate, and explored the factors, including landforms, that affected the degree of mortality.

Methods

Setting

A cross-sectional study was performed to examine the study hypothesis using data from Ishinomaki, Miyagi Prefecture. Ishinomaki is one of the major port cities in Tohoku District, and its main industries include fishing, marine product processing and paper manufacturing. The population of Ishinomaki used to be 160,000, but it decreased by >5% following the GEJE due to the large number of deaths ($n = 3471$).[14]

Ishinomaki can be divided into three geographical areas based on characteristic landforms: plain, ria coast and Kitakami riverside (see Fig. 1). The plains area, which contains the largest population among the three areas, is located in the southern part of the city and includes the main administrative functions, a residential area, a major port, and a fishing and paper industrial region. The ria coastal area, which is comprised of a number of rural fishing villages, is on the north-eastern coast. Each village was divided by a steep landscape with coves and valleys, and the population density was low. The Kitakami riverside, along the Kitakami River, is located at the northern border of the city and is comprised of mixed agricultural and residential areas.

Sample population

Ishinomaki is comprised of seven areas, each of which used to consist of old towns. However, the area now contains 177 town or village sections (hereafter 'sections'), and is further divided into 354 blocks. The populations in the sections classified by the 2010 Census were included in this study.[15]

Five sections from the plains area were excluded as their population data were missing from the 2010 Census: Shiomi-cho, Mikawa-cho, Shigeyoshi-cho, Nishihama-cho and Aza-Yokotsutsumi. The 15 sections in Ogatsu-cho were consolidated into a single section (Total-Ogatsu) as the exact addresses of 103 residents killed in the GEJE (out of 158 deaths) were unknown. Four sections in Kitakami-cho were consolidated into a single section (Total-Kitakami) as the exact addresses of 154 residents killed in the GEJE (out of 194 deaths) were unknown. Therefore, 155 sections were included in the final analysis: 114, 27 and 14 for the plains area, ria coastal area and Kitakami riverside, respectively.

Inundation depth of the tsunami

Using data from the Ministry of Land, Infrastructure and Transport,[16] the tsunami inundation level for each block was evaluated and classified into the following seven levels: 0, not flooded; 1, ~0.5 m; 2, 0.5–1 m; 3, 1–2 m; 4, 2–4 m; 5, 4–8 m; and 6, ~8 m. The mean inundation depth of each section was calculated based on the values of the block members of each section.

Mortality rate

The mortality rate of each section was calculated by dividing the number of deaths caused directly by the GEJE by the population before the GEJE, obtained from the 2010 Census.[15] Data from the census were used because it was impossible to know the exact locations of the deaths. Nearly 80% of the deaths in Miyagi Prefecture were caused by drowning,[6] and it is speculated that most were washed away by the huge tsunami. Thus, it may be assumed that the locations where the bodies were found were not the same as where they were at the time of the tsunami. Some deaths were witnessed, or the location was reported, but many cases only included information on where the body was found or no report existed. Thus, the location of the deaths was estimated based on residential addresses.

Miyagi Prefectural Government formally recognised 3471 GEJE-related deaths from 11 March 2011 to 30 September 2012, of which 3251 fatalities were caused directly by the tsunami or collapsed buildings.[14] Miyagi Prefectural Police Department reported 3158 deaths with detailed information (age, sex and address) after obtaining permission from the families.[17]

From these data, 30 deaths that could not be classified into sections based on the 2010 Census, and 49 deaths that lacked an exact address were excluded. Ultimately, 3079 deaths were included in the mortality rate estimate.

Other features of the sections

Using the 2010 Census data,[15] 16 representative variables that were relevant in the analysis of factors affecting mortality in the communities were selected. In Japan, a census is conducted every 5 years and is a count of all residents and households. This provides initial insight into local populations. In addition to sex and age distributions, the proportions of people or households in the following categories were calculated: marital status (widowed or divorced), number of people who lived in the same section continuously (born or lived in the section for >20 years, or lived in the section for <five years), the industry in which individuals were engaged (agriculture/forestry/fisheries, manufacturing), education

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