The Great East Japan Earthquake Disaster: Distribution of Hospital Damage in Miyagi Prefecture

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Abbreviations:
GEJED: Great East Japan Earthquake Disaster
UNISDR: United Nations International Strategy for Disaster Reduction
WHO: World Health Organization

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Abstract

Introduction: In catastrophic events, a key to reducing health risks is to maintain functioning of local health facilities. However, little research has been conducted on what types and levels of care are the most likely to be affected by catastrophic events.

Problem: The Great East Japan Earthquake Disaster (GEJED) was one of a few "megadisasters" that have occurred in an industrialized society. This research aimed to develop an analytical framework for the holistic understanding of hospital damage due to the disaster.

Methods: Hospital damage data in Miyagi Prefecture at the time of the GEJED were collected retrospectively. Due to the low response rate of questionnaire-based surveillance (7.7%), publications of the national and local governments, medical associations, other nonprofit organizations, and home web pages of hospitals were used, as well as literature and news sources. The data included information on building damage, electricity and water supply, and functional status after the earthquake. Geographical data for hospitals, coastline, local boundaries, and the inundated areas, as well as population size and seismic intensity were collected from public databases. Logistic regression was conducted to identify the risk factors for hospitals ceasing inpatient and outpatient services. The impact was displayed on maps to show the geographical distribution of damage.

Results: Data for 143 out of 147 hospitals in Miyagi Prefecture (97%) were obtained. Building damage was significantly associated with closure of both inpatient and outpatient wards. Hospitals offering tertiary care were more resistant to damage than those offering primary care, while those with a higher proportion of psychiatric care beds were more likely to cease functioning, even after controlling for hospital size, seismic intensity, and distance from the coastline.

Conclusions: Implementation of building regulations is vital for all health care facilities, irrespective of function. Additionally, securing electricity and water supplies is vital for hospitals at risk for similar events in the future. Improved data sharing on hospital viability in a future event is essential for disaster preparedness.

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Introduction

In catastrophic disasters, the health impacts can be significant. A successful response to the aftermath requires that functioning health facilities be available. In 2008, the United Nations International Strategy for Disaster Reduction (UNISDR) and the World Health Organization (WHO) set up a global campaign called Hospitals Safe from Disasters[1] to raise awareness and to increase efforts to ensure hospitals' functional capacities during and in the aftermath of disasters. The 2009 Global Platform for Disaster Risk Reduction confirmed the importance of protecting hospital infrastructure by stating that "one prime way of [protecting people's health] is making hospitals safer by enforcing and implementing building codes to ensure quality construction."[2]

Despite these efforts, critical damage to health facilities as a result of disasters is reported regularly all over the world. For instance, in the Hanshin-Awaji Earthquake in Japan in 1995, four hospitals were completely burned and eight partially burned by

Category	Subcategory	Definition	
Background	**General**	Hospital name, address	
	Hospital function	Primary care hospitals: those without emergency department Secondary care hospitals: those providing acute care other than tertiary care Tertiary care hospitals: those providing tertiary acute care	
	Number of beds	Total number of beds Psychiatric care beds Long-term care beds: geriatric care beds and convalescence care beds	
Damage to hospitals	**Operational**	**Enhanced capacity**	Hospitals surged their capacities and accepted patients from more damaged hospitals
		Maintained	Hospitals continued care at the same level as before the disaster
		Restricted	Hospitals restricted their operations to some extent
		Closed	Hospitals needed to evacuate patients or stopped accepting patients
	Building	**Totally collapsed**	Building was obviously collapsed, 1/20 of the walls or beams were leaning severely, or 75% of the foundation was damaged.
		Inundated	Ground floor or higher was submerged by tsunami waters.
		Severely damaged	Building was damaged to the extent that it affected the major hospital function
		Partially damaged	Building was damaged, but it did not affect the major function of the hospital
		No/small damage	No serious damage in the building was reported
	Infrastructural	**Electricity** Shortage	Supply was disconnected, and there was not sufficient backup
		No data on backup	Supply was disconnected, details of backup not available
		Power generator	Supply was disconnected, but the backup or stock was sufficient
		No outage	Supply was not disconnected
		Water Shortage	Supply was ceased: insufficient stock.
		No data on stock	Supply was ceased; details on stock not available
		Sufficient Stock	Supply was ceased: stock was sufficient
		No lost water supply	Supply was not ceased

Table 1. Definition of Terms and Content of the Data Collected

secondary fires.[3] In the 2003 Bam earthquake in Iran, the lack of a structured disaster management plan was reported to have hampered the triage of 12,000 injured patients.[4] In 2005, Hurricane Katrina in the United States led to the evacuation of nine hospitals, and because of disrupted transport routes, the evacuation faced serious challenges and took up to three weeks.[5] In the 2010 Pakistan flood, the damage to more than 400 of the 3,000 health facilities disrupted rapid disaster response.[6] A detailed understanding of disaster damage to hospitals is a cornerstone of effective health contingency planning and response.

The Great East Japan Earthquake Disaster (GEJED) on March 11, 2011, was one of a small number of "megadisasters" that have caused diverse and interrelated damage to a wide range of geographical areas. The initial earthquake, of magnitude 9.0 on the Richter scale, and the resultant five to six tsunamis that rose up to 41 m above sea level[7] structurally damaged 128,894 houses, flooded

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more than 200,000 houses,[8] and disrupted electricity to 8,910,000 homes and water supply to 2,200,000.[7] With regard to health facilities, at least 11 of the 380 hospitals in the disaster area failed completely, 84 stopped accepting new inpatients, and 45 closed outpatient wards.[9] Furthermore, unprepared evacuation of hospitals caused increased mortality of patients, especially among the elderly.[10]

One characteristic of this disaster was that it occurred in an urban area with a rapidly aging population. Due to the high prevalence of preexisting chronic conditions among the elderly, disaster medicine provided was predominately primary care, such as control of hypertension and diabetes.[11] In addition, transportation was severely disrupted in the disaster area due to destruction of roads and interruption of fuel supply. Therefore, for the residents, maintaining access to nearby hospitals was a much more critical issue than maintaining function of tertiary hospitals some distance away from the community. In this instance, essential to assessing the health impact of disaster was the assessment of geographical distribution of damaged hospitals and types of care they provided. However, to date, little research has been conducted to give an overview of hospital damage at a community level[12-14] and no research on associated disruption of the various types of care.

This study aimed to build a holistic understanding of the impact of hospital damage on the community by evaluating records collected in specific, local areas affected by the GEJED. This study also aimed to identify the determinants for the degree of structural and functional damage of health care facilities, with respect to their preexisting resources.

Methods

Study Design

A cross-sectional survey of hospital damage after the GEJED was conducted from March 2012 through July 2013. The target area was Miyagi Prefecture, the closest prefecture to the epicenter of the earthquake. Before the GEJED, the population of the Miyagi Prefecture was 2.3 million, of which at least 9,544 were killed by the earthquake and the associated tsunamis.[8] Prior to the earthquake, there had been 147 hospitals.[15]

Data Collection

Data on Hospital Damage—At first, information was collected by a questionnaire sent by mail and e-mail to those in charge of the liaison section of each hospital. To reduce the burden on the hospitals, publicly available resources also were searched and data were collected for March 2011 through June 2013.

Besides collecting information on hospital characteristics such as number of beds, clinical divisions, and types of patient care (primary, secondary, and tertiary), four main domains of hospital damage were identified according to previous research: (1) physical building damage; (2) damage affecting electricity; (3) damage affecting water supply; and (4) operational status of inpatient and outpatient wards.[16] Each damage category was stratified by levels of severity. Definitions of terms and content of data collected are listed in Table 1.

The resources from which information on hospital status were collected included publications by the national government, the Miyagi Prefectural Government, the medical associations, news resources, literature, and home pages of hospitals' websites. Appendix 1 (online only) shows the list of data sources.

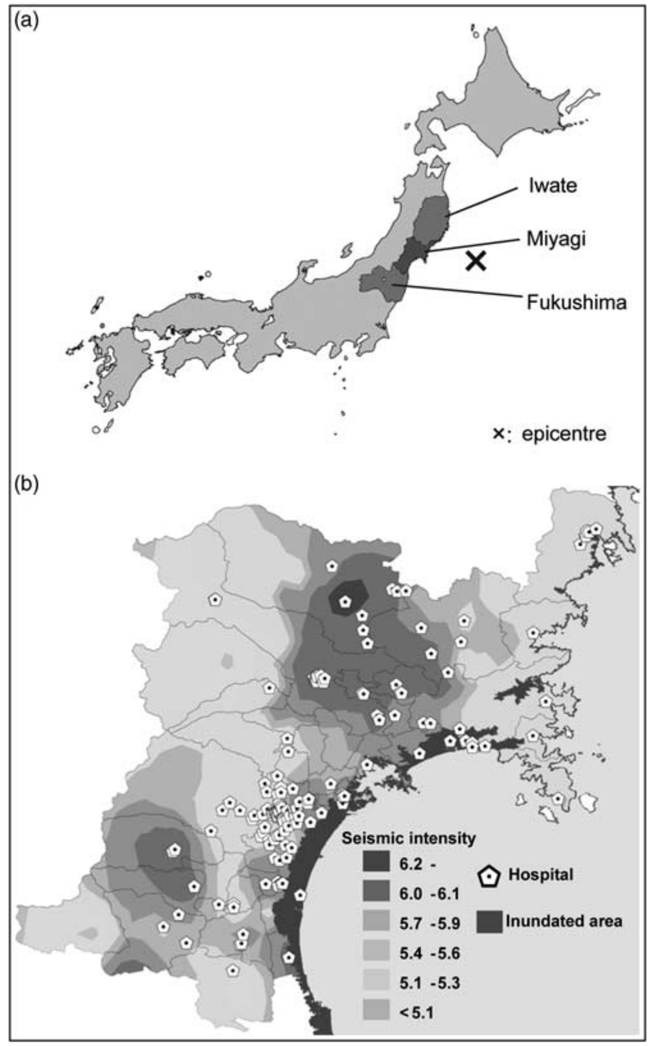

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Figure 1. Map of Japan: (A) Epicenter and the three most affected prefectures (B) The Miyagi prefecture showing hospital and estimated seismic intensity and tsunami inundated areas.

Geographical Data—The locations of the hospitals were searched using Google Maps,[17] and the longitude and the latitude of the center of each hospital were obtained. Data on seismic intensity were obtained from the Japan Meteorological Agency.[18] Data on the coastline, boundaries, and population size for each local area were obtained from Digital Japan,[19] and data of inundated areas were from Sawada and Takeuchi Laboratory.[20]

Geographical Measures

All mapping and geographical analyses were performed using ArcGIS software (v9c, Redlands, California USA). Distance from the coast to each hospital was calculated and reported in kilometers (km). To estimate seismic intensity at each hospital, the data on seismic intensities at 320 separate points in the Tohoku area of six prefectures including Miyagi[17] were spatially interpolated by inverse distance weighting. The population size of each local area was used to estimate the impact of functional loss of hospitals by area.

Category	Status		Hospitals n (%)	Beds n (%)
Building	Critical damage	Totally collapsed	4 (2.8)	601 (2.3)
		Inundated	7 (4.9)	1,010 (3.9)
		Severely damaged	28 (19.6)	6,991 (27.2)
	Partially damaged		12 (8.4)	2,263 (8.8)
	No/small damage		92 (64.3)	14,793 (57.7)
	Total		**143**	**25,658**
Electricity	Power outage, shortage of electricity		5 (3.7)	905 (5.6)
	Power outage, no data on backup		85 (62.5)	11,660 (72.3)
	Power outage, sufficient backup		41 (30.1)	2,908 (18.0)
	No power outage		5 (3.7)	665 (4.1)
	Total		**136**	**16,138**
Water	Lost water supply, shortage		7 (5.3)	2,286 (9.1)
	Lost water supply, no data on stock		88 (66.2)	12,982 (51.7)
	Lost water supply, sufficient stock		28 (21.1)	7,816 (31.1)
	No lost water supply		10 (7.5)	2,015 (8.0)
	Total		**133**	**25,099**
Operational Status	**Inpatient ward**	Enhanced capacity	28 (23.7)	7,868 (34.0)
		Maintained	54 (45.8)	8,031 (34.7)
		Restricted	10 (8.5)	2,155 (9.3)
		Closed or evacuated	26 (22.0)	5,090 (22.0)
		Total	**118**	**23,144**
	Outpatient ward	Enhanced capacity	20 (16.4)	
		Maintained	53 (43.4)	
		Restricted	25 (20.5)	
		Closed	24 (19.7)	
		Total	**122**	

Table 2. Overall Damage to Hospitals and Hospital Beds

Statistical Analysis

All analyses were undertaken using STATA10 (v10, StataCorp LP, College Station, Texas, USA). Prevalence of damage to hospital structure and functionality, and their combination, were estimated. To characterize the cross-sectional association between different types of damage and hospital operation, unadjusted and adjusted logistic regression was conducted. Odds ratios (ORs) and corresponding 95% confidence intervals (CIs), or coefficients and *P* values were reported where applicable.

Ethical Considerations

The hospital questionnaire received approval from the Tohoku University Ethical Committee, and respondents were required to return consent forms with questionnaires.

Results

Hospital damage data were obtained for 143 of the 147 hospitals (97%) in Miyagi prefecture, although only 11 (7.7%) responses to the questionnaire were received. Data on electricity supply, water supply, and status of inpatient and outpatient wards were available for 136, 133, 118, and 122 hospitals, respectively. This low response rate was explained by a complaint of the respondents that hospital staff had been "fed up" with responding to the same kinds of questions repeatedly. The locations of the Miyagi prefecture and Miyagi prefecture hospital location data, mapped against seismic intensity and the tsunami inundation areas, are shown in Figures 1A and 1B.

Hospital damage is shown in Table 2. Thirty-nine hospitals (27%) suffered critical building damage, including four (2.8%)

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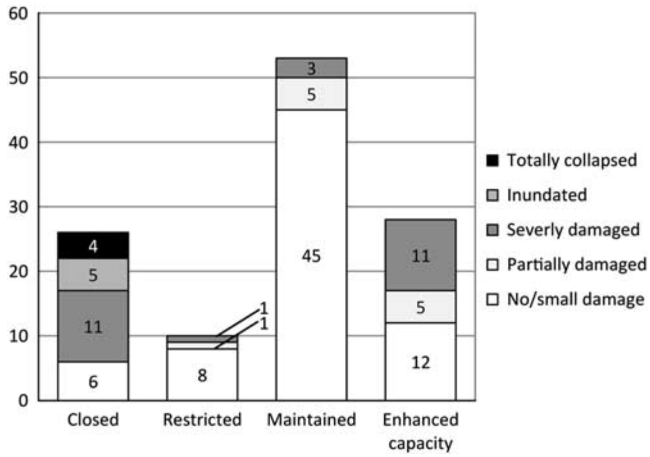

Figure 2. Operational Status of Inpatient Wards and Building Damage

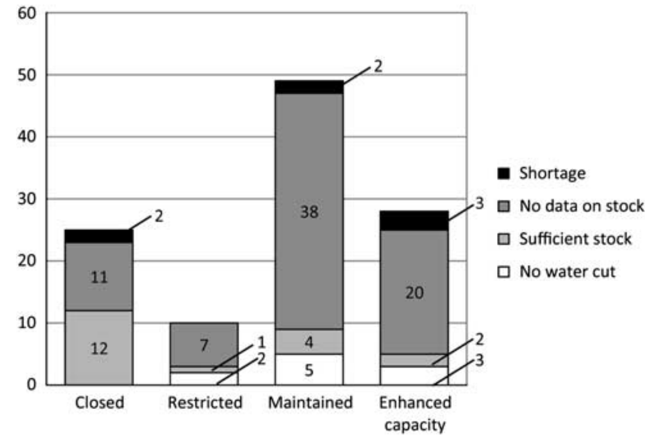

Figure 4. Operational Status of Inpatient Wards and Water Supply

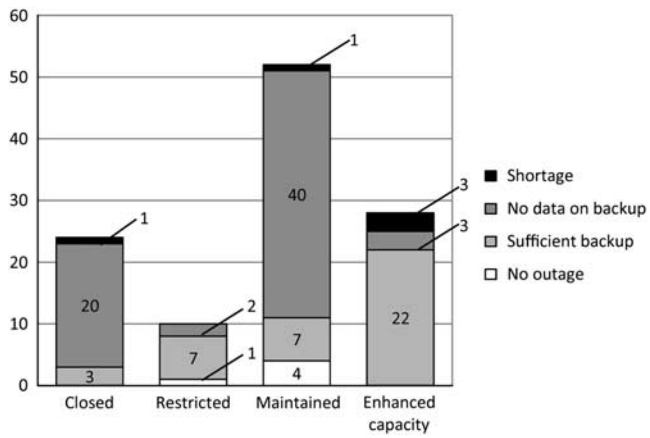

Figure 3. Operational Status of Inpatient Wards and Electricity Supply

that completely collapsed and seven (4.9%) that experienced flooding on the ground floor or higher. With regard to infrastructure damage, 131 out of 136 hospitals (96%) reporting on power supply experienced electrical power outages and 123 out of 133 (92%) reporting on water supply lost their water supply completely. As a result of these damages, 26 of the 118 (22%) hospitals with functional damage stopped and 10 (8.5%) restricted accepting inpatients at an acute phase. In addition, 24 out of the 122 (20%) stopped and 25 (20.5%) restricted accepting outpatients.

Hospital damage by operational status of impatient wards is summarized in Figure 2, 3, and 4. Seventy-seven percent of the hospitals that ceased inpatient care had suffered from critical building damage (Severely damaged, Inundated, and Totally collapsed, Figure 2). However, 11 of the 28 hospitals that had received critical structural damage (39%) enhanced their capacities of inpatients. Moreover, most of the hospitals suffered from interrupted electricity/water supply (100% and 89%, respectively), or both, of which three hospitals each enhanced their capacities even when they ran short of electricity or water (Figures 3 and 4).

When the association between damage type and likelihood of stopping accepting patients in inpatient and outpatient wards was evaluated, building damage was the most strongly associated with the loss of patient care (Table 3, OR = 37.0 when hospitals were inundated, OR = 10.8 when severely damaged). Availability of electricity generators appeared to protect against the ceasing operation of inpatient wards, as all the hospitals with power generators maintained their functions. Although shortage in water supply significantly increased the risk of ceasing operation (OR = 7.0), sufficient water stock was not significantly protective against ceasing inpatient or outpatient operations.

The association between characteristics of hospitals and likelihood of ceasing operations in inpatient wards were also evaluated (Table 4). Distance from coast significantly decreased the risk of ceasing inpatient operations (9% by 1 km) while seismic intensity did not show a significant association.

In Japan, hospital beds can be categorized by care types, such as general and intensive care beds, nursing care beds, rehabilitation beds, beds for infectious diseases, and psychiatric care beds. When the risk of ceasing inpatient operation by bed functions were calculated, the number of psychiatric care beds was significantly associated with the likelihood of ceasing operations (9% increased risk for every 10 psychiatric care beds), even after controlling for distance from coast and seismic intensity. When evaluating by hospital type, primary care and secondary care hospitals were significantly more likely to cease their operations than tertiary care hospitals (OR = 1.43 and OR = 1.24, respectively).

The hospitals providing tertiary care were comparatively unaffected by the disaster, even if they were located in areas with high seismic intensity or close to the inundated area (Figure 5). Eight out of 59 hospitals providing secondary care (14%) were damaged, of which five (63%) were located within 3 km from the coast line (Figure 6). By contrast, among 18 primary care hospitals that ceased operation, only seven (39%) were located at the coastal area (Figure 7). Hospitals in the southwest area appear more likely to cease operations. As a result, some towns with a population size less than 50,000 lost all functioning hospitals.

Discussion

This is the first research to provide a holistic view of hospital damage by the GEJED, the first urban megadisaster of this

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Categories	Subcategories	OR	95% CI
Building damage	Totally collapsed	n.a.[a]	
	Inundated	37.0	6.1-226.3
	Severely damaged	10.8	3.4-34.9
	No apparent damage	Reference	
Electricity	Shortage	1.07	0.165-7.00
	Power generator	n.a.[b]	
	No outage	Reference	
Water supply	Shortage	7.0[c]	1.55-31.18
	Sufficient stock	0.7	0.12-4.22
	No water cut	Reference	

Table 3. Risk of Ceasing Inpatient Care by Hospital Damage
Abbreviations: CI, confidence interval; OR, odds ratio.
[a]All hospitals lost function.
[b]All hospitals maintained function.
[c]$P < .05$.

Factors	β	95% CI
Seismic intensity (Richter scale)	-0.28	-1.96 to 1.40
Distance from coastline (per km)	-0.0894[a]	-0.150 to -0.029
Total number of beds (per 10 beds)	-0.006	-0.035 to 0.022
Number of psychiatric care beds (per 10 beds)	0.09 [a]	0.036 to 0.14
Number of nursing care beds (per 10 beds)	0.09	-0.070 to 0.24
Number of rehabilitation beds (per 10 beds)	0.14	-0.13 to 0.41
Function of hospitals	OR	
Primary	1.43 [a]	1.06 to1.22 [a]
Secondary	1.24 [a]	1.01 to 1.54 [a]
Tertiary	Reference	

Table 4. Risk of Ceasing Inpatient Care by Location, Function and Types of Hospital
Abbreviations: CI, confidence interval; OR, odds ratio.
[a]$P < .05$.

decade. The significant association between the distance from the coast and the risk of ceasing inpatient operations suggests that the impact of the tsunami, which affected more of the coastal area, would have been larger than that of the earthquake.

The most notable finding in this research was the uneven damage to hospitals. Statistical analyses revealed that care for chronic conditions, such as primary care and psychiatric care, were the most affected even when the hospitals were 'safe' from the tsunamis.

Due to the rapidly changing demography in modern cities, disaster medicine is no longer acute care only. Instead, chronic and preexisting conditions are becoming a major burden in disaster response. According to a governmental report, by 2012, among the 1,950 deaths determined to be disaster related, 283 (15%) died from the deterioration of preexisting conditions due to closure of community hospitals.[21] Taken together with the uneven distribution of hospital damage, there might have been a gap between health needs and the provision of health care at the time of the GEJED.

Currently the Japanese government gives subsidies for implementing antiseismic building codes only to core hospitals and emergency department buildings, leaving other hospital

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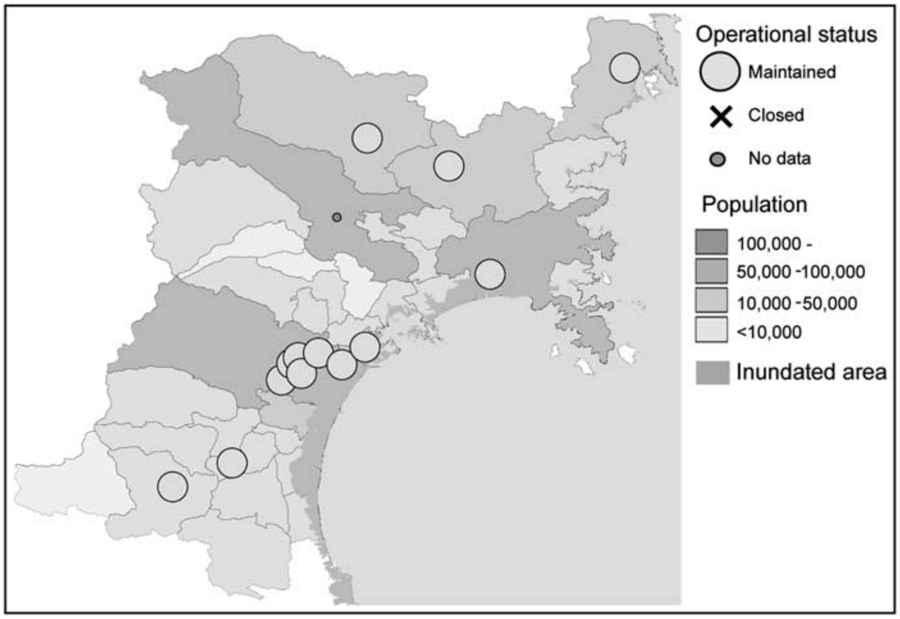

Figure 5. Operational Status of Tertiary Care Hospitals

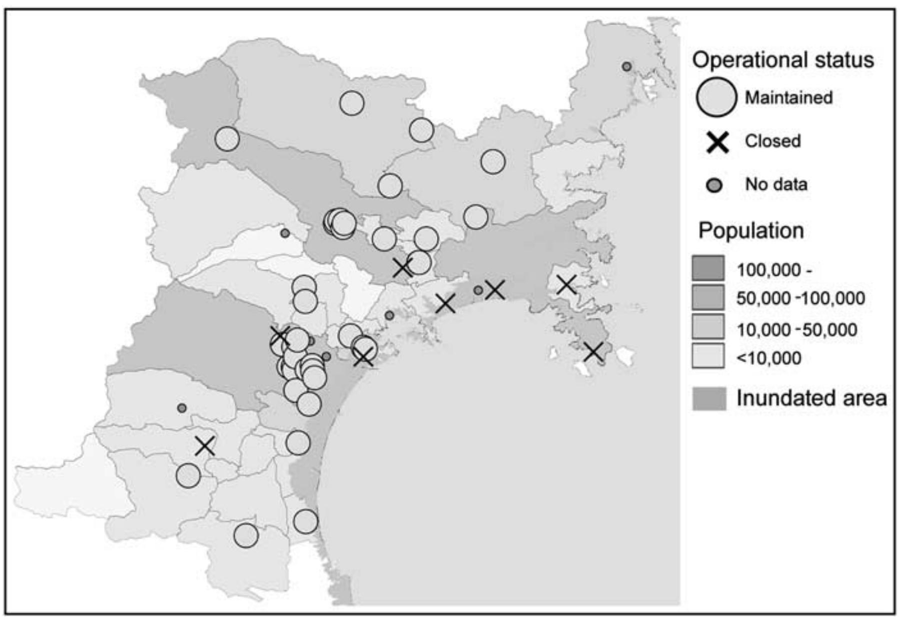

Figure 6. Operational Status of Secondary Care Hospitals

buildings unprotected. This research suggests that enhancing the capacity of non emergency hospitals that provide vital community services should be seriously considered when plans are made to prepare hospitals for future major disasters. Distribution of subsidies should be reconsidered so that action plans against extreme events are developed and implemented in all the hospitals in disaster prone areas without exception.

Another finding in this research was the limited impact of each, single component of hospital function. Although more than 90% of the hospitals were damaged to some extent, the number of hospitals that closed or evacuated patients was smaller than what might have been anticipated given this damage. On the other hand, 12 hospitals that suffered no or small building damage limited their operations (Figure 2). These findings suggest that there are miscellaneous factors influencing hospital ability to function following a disaster, which were not revealed by simple surveillance. For example, even for hospitals with power generators, many outpatients and staff could not go home due to the loss of transportation, so the consumption of electricity and water was much greater than estimated. In other cases, loss of

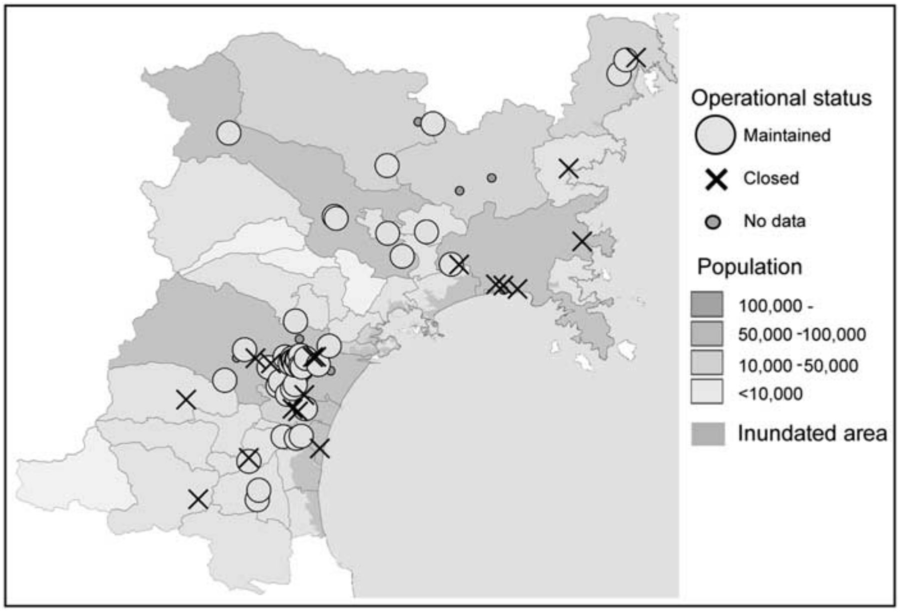

Figure 7. Operational Status of Primary Care Hospitals

elevator function disrupted patients' transfer, which indirectly affected the functioning of operating theatres and intensive care units. With increasing dependency on electricity, the risks associated with power shortage grow in intensity and complexity. Future research should include regular assessment of such side effects of electricity shortage. Additionally, in a complicated modern society, hospitals cannot be independent from local community networks. Therefore, the planning of hospital preparedness against disasters should also be considered as a part of the reinforcement of community resilience.

Of note, although the longer distance from the coast was associated with the less likelihood of ceasing operations, there is ongoing discussion whether or not to build health facilities in coastal areas. It should be noted that in most of the buildings that 'totally collapsed', the load-bearing elements often remained intact even after the buildings were submerged by the tsunamis. As a result, many people were saved by evacuating to the higher floors of the buildings located at the coastal area.[22] Therefore, with advanced technology, building hospitals in coastal areas could be beneficial. Some experts even advocate the construction of tall health facility buildings on the seashore flood plain, so that vulnerable people can find safety in the upper floors without climbing hills.[23] Nevertheless, to achieve this, further innovation is required to secure vital services after massive inundation.

Since the establishment of the UNISDR in 2001,[24] considerable efforts have been made towards global disaster risk reduction including the *Hyogo Framework for Action 2005-2015*,[25] a requirements framework to reduce disaster loss. However, little has been mentioned about the provision of health care, and even less, hospitals. This research will be helpful to raise awareness about the importance of health facilities, which has not been fully addressed, especially in the developed countries.

To achieve full hospital preparedness in a complex, modern society such as Japan, hospital damage should be assessed in line with health needs analyses. This surveillance revealed that hospital damage was not equal among the types of care the hospital provided. For the local government to establish an investment policy that fits the health care needs in each community, further assessment should include multidisciplinary assessment of a health system with regard to crisis preparedness,[26] damage assessment of small health facilities, miscellaneous factors that affected operations, and health needs assessment.

Limitations

As most of the data used in this analysis was collected from open sources, data quality cannot be verified. In particular, it is not clear whether missing data means that there was no damage or that damage was so severe that data was unobtainable. Another limitation is the lack of data on communication failure. In many areas, widespread disconnection of communication tools severely disrupted timely rescue activity, for which prompt information on needs was essential. Academic-based surveillance was reported to have been carried out, but has not been disseminated.

Conclusion

This analysis of hospital damage showed that hospitals seeing patients with chronic conditions were the most vulnerable after the GEJED. The strong association between building damage and ceasing care suggested that strengthening building regulation is the first priority for health care facilities, irrespective of function. Although securing electricity and water supplies is also vital for hospitals at risk for similar events, the discrepancy between the infrastructural damage and functional damage suggested there were more complicated factors affecting hospital functions, such as human factors, nonstructural factors, and infrastructure outside the hospitals.

As global population is rapidly aging, hospital viability in emergencies should be evaluated in terms of hospital accessibility and provision of chronic care. For effective preparedness, development of improved data sharing system such as mapping and global assessment tools is required for all disaster-prone countries.

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