The Great East Japan Earthquake Disaster: distribution of hospital damage in Miyagi prefecture

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List of Abbreviation

GEJED: Great East Japan Earthquake Disaster

CI: Confidence interval

OR: Odds Ratio

UNISDR: United Nations International Strategy for Disaster Reduction

WHO: World Health Organization

Abstract

Introduction: In catastrophic events, maintaining function of local health facilities is a key to reducing disaster risks for health. However, little research has been conducted on what types and levels of care are the most likely to be affected. **Problem:** The Great East Japan Earthquake (GEJED) was one of a few mega-disasters that occurred in an industrialised society. This research aims 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 non-profit organisations, 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 of hospitals, coast line, local boundaries, and the inundated area, as well as population size and seismic intensity were collected from public databases. Logistic regression were conducted to identify the risk factors for hospitals ceasing inpatient and outpatient services. The impact was visually displayed on maps to show the geographical distribution of damage. **Results:** Data from 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, whilst 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 coast line. **Conclusions:** Implementation of building regulation 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 would be essential for disaster preparedness.

Introduction

In catastrophic disasters, the health impacts can be significant and a successful response to the aftermath requires functioning health facility availability. 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 hospital functional capacities during and in the aftermath of disasters. The 2009 Global Platform for Disaster Risk Reduction confirmed the importance of protecting hospital infrastructure through its statement that "One prime way of [protecting people's health] is making hospitals safer by enforcing and implementing building codes to ensure quality construction." [2]

Even so, critical damage to health facilities as a result of disasters is being regularly reported 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 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 which took up to three weeks as serious challenges were experienced in evacuating patients when transportation routes were disconnected.[5] In the 2010 Pakistan flood, the damage to more than 400 out of 3,000 health facilities disrupted rapid disaster response.[6] A detailed understanding of disaster damage to hospitals is a cornerstone for effective health contingency planning and response.

The Great East Japan Earthquake Disaster (GEJED) on 11th March, 2011, was one of a small number of mega-disasters that 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 more than 200,000 houses,[8] disrupted electricity to 8,910,000 homes and water supply to 2,200,000. [7] With regard to health facilities, at least 11 out of 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 of the characteristics in this disaster was that it occurred at an urban area with a rapidly ageing population. Due to the high prevalence of pre-existing chronic conditions among the elderly, the disaster medicine was predominated by

primary care, such as control of hypertension and diabetes. [11] In addition, transportation was severely disrupted at 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 away from the community. In this term, assessment of geographical distribution of damaged hospitals and types of care they provided is essential to assess health impact of the disaster. However, to date, little research was conducted to give an overview of hospital damage at a community level [12] [13] [14] and no research, on types of care.

This study aims at building a holistic understanding of the impact of hospital damage on the community, by evaluating records collected in specific local areas affected by the GEJED and identifies determinants for the degree of structural and functional damage of healthcare facilities, with respect to their pre-existing resources.

Methods

Study design

A cross-sectional survey of hospital damage after the GEJED was conducted on the period of March 2012 to July 2013. The target area was Miyagi Prefecture, the closest prefecture to the epicentre of the earthquake. Before the GEJED, the population size of the Miyagi Prefecture was 2.3 million, of which at least 9,544 were killed by the earthquake and the associated tsunamis.[8] There had been 147 hospitals in total. , 2011 #12}

Data Collection

1) Data on hospital damage

At first information was collected by a questionnaire sent to those in charge of the liaison section of each hospital by mail and e-mail (AN and SO). To reduce the burden on the hospitals, publicly available resources were also searched and data were collected between March 2011 and 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 surveillance: [15] (i) physical building damage; (ii) damage affecting electricity; (iii) damage affecting water supply; (iv) and operational status of inpatient and outpatient wards. Each damage category was stratified by levels of severity. Definition of terms and content of data collected are listed in Table 1.

The resources from which information of hospital status were collected included publications by the national government, the Miyagi Prefectural Government, the medical associations, news resources, literature, and home webpages of hospitals. Supplement 1 shows the list of data source.

2) Geographical data

The locations of the hospitals were searched using Google Map, [16] and the longitude and the latitude of the centre of each hospital were obtained. Data on seismic intensity were obtained from the Japan Meteorological Agency.[17] Data on coastal line, boundaries, and population size at each local area were obtained from Digital Japan, [18] and data of inundated area were from Sawada and Takeuchi Laboratory.[19]

Geographical measures

All mapping and geographical analyses were performed using ArcGIS software (v9c, California, USA). Distance from the coast line to each hospital was calculated and reported in kilometres (km). To estimate seismic intensity at each the 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.

Statistical analysis

All analyses were undertaken using STATA10 (v10, StataCorp LP, Texas, USA). Prevalence of damage to hospital structure and functionality, and their combination, were estimated. To characterise 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 coefficiencies and p-values were reported

where applicable.

Ethical considerations

The hospital questionnaire was received approval from the Tohoku University ethical committee, and respondents were required to return consent form with questionnaire.

Results

Hospital damage data were obtained from 143 of the 147 hospitals (97%) in Miyagi prefecture, although only 11 (7.7%) responses to the questionnaire were received. This low response rate was explained by a complaint of the respondent that hospital staff had been already 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 area, are shown in Figure 1A and 1B.

Hospital damage is shown in Table 2. Thirty-nine hospitals (27%) suffered with critical building damage, including four (2.8%) that completely collapsed and seven (4.9%) that experienced flooding of the ground floor or higher. With regard to infrastructure damage, 131 out of 136 hospitals (96%) experienced electrical power outages and 123 out of 133 (92%) lost their water supply completely. As a result of these damage, 26 out of 118 (22%) stopped accepting inpatients at an acute phase, and 24 out of 122 (20%) stopped accepting outpatients, with other 10 (8.5%) and 25 (20.5%) restricted their operations, respectively.

Hospital damage by operational status of impatient wards is summarised in Figure 2. Seventy-seven per cent of the hospitals that ceased impatient care had suffered from critical building damage (Severely damaged, Inundated, and Totally collapsed, Figure 2A). However, 11 out of 28 of the hospitals (39%) enhanced their capacities of inpatients care even though they had received critical structural damage. Moreover, most of the hospitals were 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 (Figure 2B and C).

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 be protective against 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 in/outpatient operations.

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

In Japan, hospital beds can be categorised 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, number of psychiatric care beds were significantly associated with the likelihood of ceasing operations (9% increased risk for every 10 psychiatric care beds), even after controlling for distance from coast line and seismic intensity. When looking 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 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 3A). Eight out of 59 hospitals providing secondary care (14%) were damaged, of which 5 (63%) were located within 3km from the coast line (Figure 3B). By contrast, among 18 primary care hospitals that ceased operation, only 7 (39%) were located at the coastal area (Figure 3C). Hospitals at southwest area appear more likely to cease their operation. As a result, some towns with population size smaller than 50,000 lost all hospital function they had.

Discussion

This is the first research to provide a holistic view of hospital damage by the GEJED, the first urban mega-disaster this decade. The significant association between the distance from coast line and the risk of ceasing inpatient operations suggests that the impact of the tsunami, which affected more 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 pre-existing conditions is becoming a major burden in disaster response. According to a governmental report, among 1,950 deaths determined as disaster-related deaths by 2012, 283 (15%) died from the deterioration of pre-existing conditions due to closure of community hospitals.[20] Taken together with the uneven distribution of hospital damage, there might have been a gap between health needs and the provision of healthcare at the time of the GEJED.

Currently the Japanese government gives subsidies for implementing anti-seismic building code only to core hospitals and emergency department buildings, leaving other hospital 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 that might have been anticipated given this damage. On the other hand, 12 hospitals that suffered no or

small building damage limited their operations (Figure 2A). 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 function of elevators disrupted patients' transfer, which indirectly affected the functions 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 line was associated with the less likelihood of ceasing operations, there is an on-going discussion whether or not to build health facilities at the 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.[21] Therefore, with advanced technology, building hospitals at the coastal area 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 their upper floors without climbing hills.[22] Nevertheless, to achieve this, further innovation is required to secure vital services after massive inundation.

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

Since the establishment of the UNISDR in 2001, [23] considerable efforts have been made towards global disaster risk reduction including the *Hyogo Framework for Action 2005-2015*, [24] a framework of the works required to reduce disaster loss. However, little has been mentioned about the provision of healthcare, and even less, hospitals. This research will be helpful to raise awareness in the importance of health facilities, which has not been fully addressed especially in the developed countries.

To achieve full hospital preparedness in the complex modern society 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 healthcare needs in each community, further assessment should include multi-disciplinary assessment of health system with regard to crisis preparedness,[25] damage assessment of small health facilities, miscellaneous factors that affected their operations, and health needs assessment.

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Tables & Figures

Table 1. Definition of terms and contents of the data collected.

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 it was before the disaster
		Restricted		Hospitals restricted their operation to some extent
		Closed		Hospitals needed to evacuate the patients or stopped accepting patients
	Building	**Totally collapsed**		Building was obviously collapsed, or 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 the tsunami.
		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, and there was not sufficient stock.
			No data on stock	Supply was ceased, details on stock not available
			Sufficient Stock	Supply was ceased, but stock was sufficient
			No lost water supply	Supply was not ceased

Table 2. Overall damage to hospitals and hospital beds.

Category		Status		Number of hospitals (%)	Number of beds (%)
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 (27.0)
		Partially damaged		12 (8.4)	2,263 (8.7)
		No / small damage		92 (64.3)	14,793 (57.1)
		Total		**143**	**25,928**
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 (19.5)	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 3. Risk of ceasing operations of inpatient care by hospital damage.

Categories	Subcategories	OR	(95% C.I.)
Building damage	**Totally collapsed**	n.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.[¶¶]	
	No outage	Reference	
Water supply	**Shortage**	7.0*	(1.55, 31.18)
	Sufficient stock	0.7	(0.12, 4.22)
	No water-cut	Reference	

OR: odds ratio, C.I. : confidence interval

*p<0.05

¶ All hospitals lost function. ¶¶All hospitals maintained function

Table 4. Risk of ceasing operations of inpatient care by locations and function types of hospitals.

Factors	β	(95% C.I.)
Seismic intensity (Richter scale)	-0.28	(-1.96, 1.40)
Distance from coastal line (per km)	-0.0894*	(-0.150, -0.029)
Total number of beds (per 10 beds)	-0.006	(-0.035, 0.022)
Number of psychiatric care beds (per 10 beds)	0.09*	(0.036, 0.14)
Number of nursing care beds (per 10 beds)	0.09	(-0.070, 0.24)
Number of rehabilitation beds (per 10 beds)	0.14	(-0.13, 0.41)
Function of hospitals	**OR**	
Primary	1.43*	(1.06, 1.22)*
Secondary	1.24*	(1.01, 1.54)*
Tertiary	Reference	

β: coefficiency, OR: odds ratio, C.I. : confidence interval

*p<0.05

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

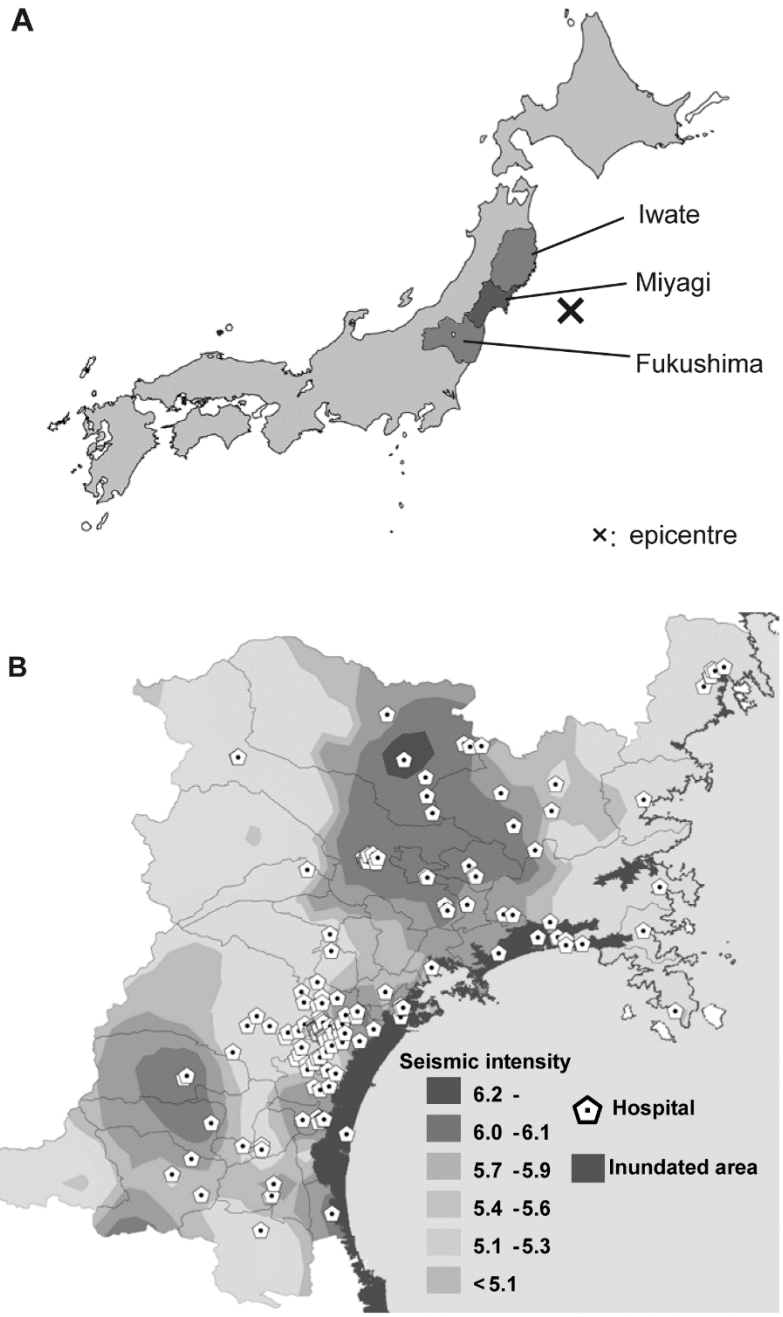


Figure 2. Operational status of inpatient wards by hospital damage. (A) Building Damage and operation (B) Electricity and operation (C) Water supply and operation.

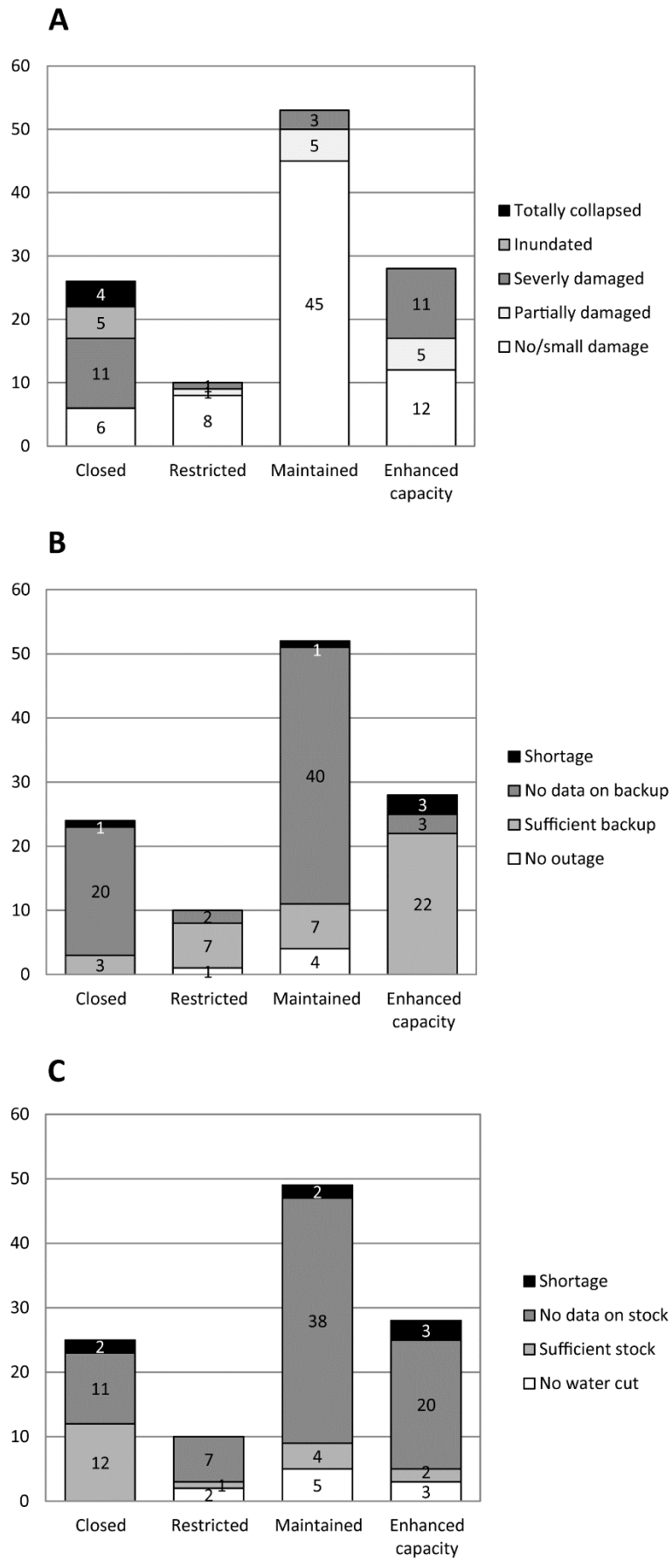
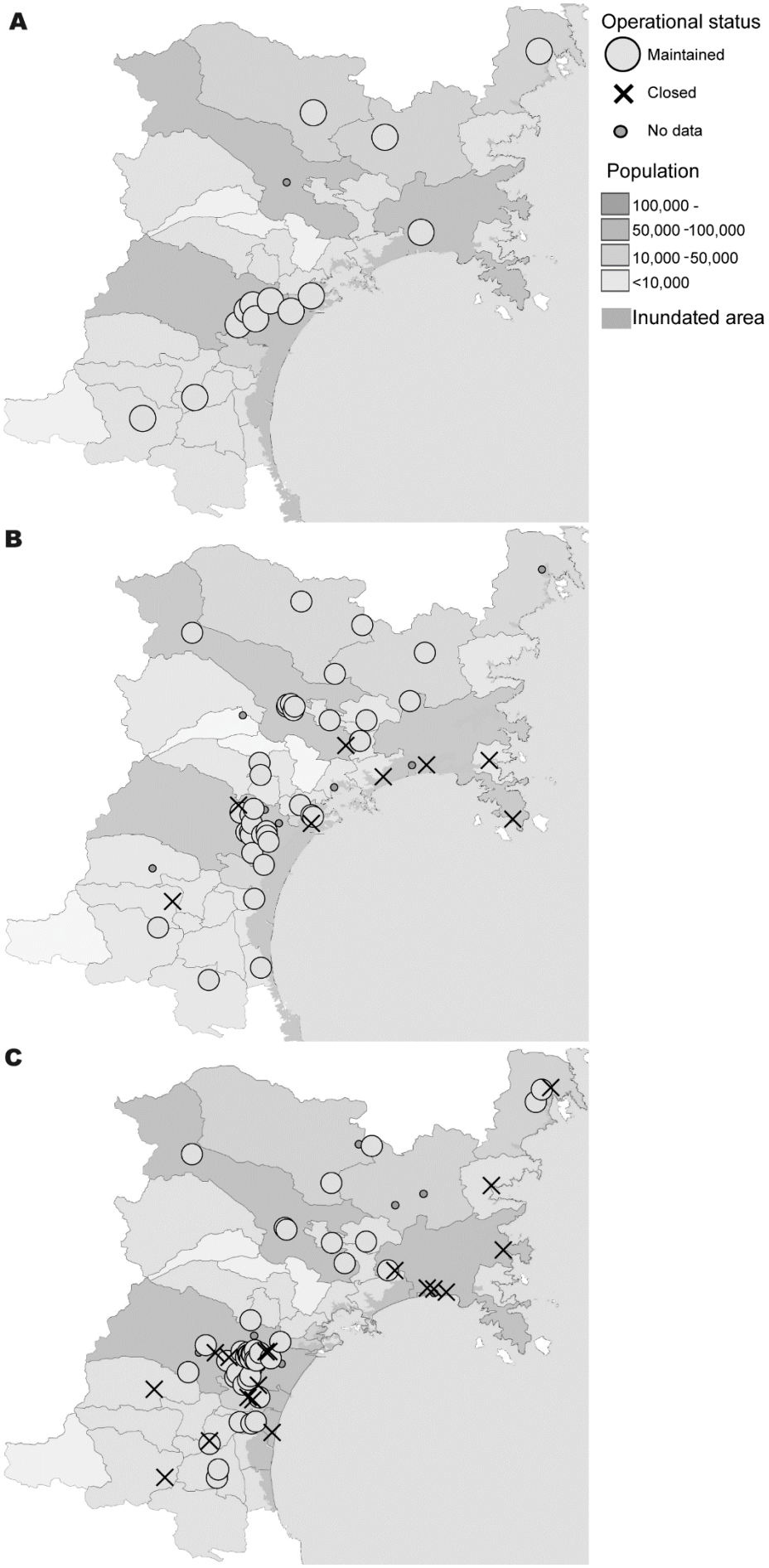


Figure 3. Operational status of the hospitals by hospital type. (A) Tertiary care hospitals (B) Secondary care hospitals (C) Primary care hospitals.



Supplement 1. Documents and websites accessed for data collection.

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