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Complete List of Authors:	Tashiro, Ai; Tohoku University, Graduate School of Tohoku University Sakisaka, Kayako; National Center of Neurology and Psychiatry, National Institute of Mental Health, Japan Support Center for Suicide Countermeasures; Teikyo University Graduate School of Public Health Okamoto, Etsuji; The University of Fukuchiyama Yoshida, Honami; Kanagawa Prefectural Government, Healthcare New Frontier Promotion Headquarters Office; Kanagawa University of Human Services
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Research article

Differences in infant and child mortality before and after the Great East Japan Earthquake and Tsunami: A large population-based ecological study

Ai Tashiro[1*], Kayako Sakisaka[2,3], Etsuji Okamoto[4] and Honami Yoshida[5,6]

Author affiliations

[1]Graduate school of Environmental Studies, Tohoku University, Miyagi, Japan.
[2]National Center of Neurology and Psychiatry, National Institute of Mental Health, Japan Support Center for Suicide Countermeasures, Tokyo, Japan,
[3]Teikyo University Graduate School of Public Health, Tokyo, Japan.
[4]Department of Health and Welfare Management, the University of Fukuchiyama, Kyoto, Japan.
[5]Healthcare New Frontier Promotion Headquarters Office, Kanagawa Prefectural Government, Kanagawa, Japan.
[6]Kanagawa University of Human Services, Kanagawa, Japan

Correspondence to:
Ai Tashiro; ai.tashiro.d4@tohoku.ac.jp. Tel:+81-22-752-2266.
Graduate School Environmental Studies, Tohoku University, Japan.
Aramaki 468-1 Aoba, Aoba-ku, Sendai, Miyagi, 9800845, Japan.

[*]Correspondence: atashiro11@gmail.com
[1]Graduate school of Environmental Studies, Tohoku University, Japan.
Full list of author information is available at the end of the article.

Abstract

Objectives: To examine the associations between the different characteristics of medical care with geological information and the influence of changes in normal and emergency situations on infant and child mortality in northeastern Japan, where the Great East Japan Earthquake and Tsunami (GEJET) struck in 2011.

Design: Large population-based ecological study using online data

Setting: A total of 20 Secondary Medical Area (SMA) in the disaster-affected zones in the northeastern prefectures (Iwate, Fukushima, and Miyagi).

Participants: A total of 1 748 children under 10 years died in the 20 SMA in the disaster-affected zone from 2008 to 2014. Meanwhile, 771 children died in 2011.

Primary and secondary outcome measures: Multiple regression analysis for infant and child mortality rate was employed. The mean values were applied for infant and child mortality rates and other factors before GEJET (2008–2010) and after GEJET (2012–2014).

Results: Mortality rate per 100 000 persons was 39.1±41.2 before 2011, 226.7±43.4 in 2011, and 31.4±39.1 after 2011. The most common cause of death among children under 10 years old was accidents during 2008-2014. Regarding mortality rate, the results of regression analysis showed that the mortality rate was positively associated with low age in each period, while coastal zone was negatively associated with disaster base hospitals (DBH) in 2011. By contrast, the Ob-Gyn (β=−189.9, p=0.02) and public health nurses (β=−1.7, p=0.01) were negatively associated with mortality rate in 2011.

Conclusions: The mortality rate of children under 10 years old in 2011 was 6.4 times higher than before and after 2011. In particular, child mortality rates were significantly influenced by residence in coastal zones where local medical resources for child healthcare are limited. The mortality rate was 12-fold higher in these coastal zones than in inland zones.

Keywords: *Great East Japan Earthquake and Tsunami, population-based ecological study, vulnerability, child healthcare disparities, infant and child mortality, GIS*

Strengths and limitations of this study

- This study is among the few studies on the long-term impact of infant and child mortality in the disaster-affected zone in Japan with integrated way using GIS (Geographic Information System). We clarified the damages of natural disasters on the patterns of potential influences of poor child healthcare in the disaster-affected zone.
- We employed longitudinal study on statistical as well as geological distribution using online data on child mortality differences before and after 2011 and in 2011 by sex, age group, and secondary medical area in the disaster-affected zone (Integrated approach).
- This study is an ecological study using online data, we were not able to assess and identify individual social and economic factors that influence child mortality during the study period.

Article Focus

- GEJET significantly affected the mortality rate of the target age. A total of 771 children under 10 years old died in 2011. This mortality rate was 6.4 times higher than before and after 2011.
- In particular, the disaster influence of GEJET on child mortality rates was significantly higher in coastal zones with poor local medical resources for child healthcare; the mortality rate was 12-fold higher in coastal zones than in inland zones.

Key Messages

- In Japan, a disaster epidemiology system is urgently needed to establish a disaster pediatrics and perinatal liaison system for the development of an emergency plan specific and unique to its community.
- The results of our study would be helpful to reestablish and improve child health disaster preparedness in Japan.

INTRODUCTION

Natural disasters cause significant socioeconomic damages and large-scale death. Particularly, infants and children face unique vulnerabilities during and after a natural disaster. On March 11, 2011, the Great East Japan Earthquake and Tsunami (GEJET) stuck northeastern Japan, and the tsunami that followed thereafter caused massive damage and a high death rate, particularly children in coastal zones due to several reasons, including drowning. In this year, the death rate of children under 10 years old in these affected areas increased by 0.4-fold[1]. Given this demographic profile, the influence of natural disasters on mortality, particularly on infants and children, is not well understood.

These affected areas had poorer medical resources compared to other areas in Japan. The emergency medical response capacity was also low. The disaster significantly crippled the medical resources and healthcare services for infants and children. Hurricane Katrina and the Southern California wildfires reinforced the need to provide pediatric-specific guidelines to medical personnel responding to disasters in both hospital and pre-hospital settings[2,3,4]. As of 2011, the lack of regional disaster medical management plan in Japan resulted in the difficulty in responding to the healthcare needs of children at risk. Disaster medical assistance teams (DMAT), which was launched in 2005 were not able to respond to expectant or nursing mothers and children due to the lack of an information sharing system and network with local hospitals, clinics, and emergency-response organizations[5,6,7]. Based on the lessons learned from the absence of liaison between DMAT and local medical care organizations, setting a liaison system for pediatric and perinatal medical care during disasters was demanded in 2016. In establishing the liaison system, however, only few prior studies determined the influence of disaster on child mortality and examined the association of between areas with poor medical resources and how to manage preventable child death[8,9].

In this paper, we investigated the dynamics of infant and child mortality (age, 0–9 years.) in northeastern Japan before and after 2011. Our study aimed to examine associations between the different characteristics of medical care, including the preparedness of ob-gyn, pediatricians and public health nurses (PHN), and the geological distribution of hospitals/clinics. In addition, we also determined the influence of changes in normal and emergency conditions on infant and child mortality. Empirical evidence on these different aspects of large population-based ecological time series regarding infant and child mortality can contribute to the establishment of a local liaison system for pediatric and perinatal medical care during disasters.

METHODS

Study population

Due to the influence of geographic and social traits on patterns of inundation and casualties, we compared data from Iwate, Miyagi, and Fukushima. These regions share a common trait, namely, a deeply indented coastline with narrow flatlands bordered by sea and mountains, which increases their vulnerability to tsunami damage. The total number of clustered SMA was 20 (Figure 1). From 2008 to 2014, according to the DWH database, the total number of deaths of children aged 0–9 years in Iwate, Fukushima, and Miyagi was 1 748 (0–4 years: 1 345; 5–9 years: 403). In 2011, the total number of deaths for children aged 0–9 years was 717 in three prefectures (Iwate: 168; Miyagi, 452; and Fukushima: 97).

__Figure 1.__ Map of the study area

Study site

Regarding medical resources, we mapped the location of DBH in Figure 2, including CDMH and LDMC and added data from other medical facilities, such as PMC, pediatric clinics, and Ob-Gyn clinics in Figure 2-a. We also gave 10 km margin from each DBH and observed the covering range of those medical facilities in Figure 2-b. Most SMA had DBH except Iwate-chubu and Soso area. Meanwhile, the coastal zones in Iwate, Kuji, Miyako, Kamaishi, and Kesen also had DBH. Most of these DBH combined PMC function but had few pediatrics. Most pediatrics were distributed out of the 10 km margin in Iwate. As for Miyagi, most DBH are centralized in inland zone and Sendai, which is the prefectural capital in Miyagi.

As of 2014, the numbers of full time doctors and clinic were as follows: pediatric clinics, 824 (Iwate: 290, Miyagi: 404, Fukushima: 497); pediatricians, 1191 (Iwate: 290, Miyagi: 404, Fukushima: 497); Ob-Gyn clinics, 216 (Iwate: 81, Miyagi: 49, Fukushima: 88), Ob-Gyn doctors, 332 (Iwate: 124, Miyagi: 62, Fukushima: 146). Regarding PMC, Iwate and Miyagi had 10 each, and Fukushima had 5. Meanwhile, in terms of disaster medical facilities, Iwate had 11 DBH (2 CDMH and 9 LDMC); Miyagi had 13 DBH (1 CDMH and 12 LDMC), and Fukushima had 8 DBH (1 CDMH and 7 LDMC). As for Fukushima, Soso did not have a DBH, as shown in Figure 2. While each DBH was located in inland areas in each SMA except Iwaki, in coastal zone, pediatrics was located along the coast and was not covered in the 10-km margin of the DBH. Iwaki had a DBH and centralized PMCs for neighboring coastal zones.

***Figure 2.** Location of DBH, including CDMH and LDMC.*

Study design and setting

We performed a large population-based ecological study using data from the Statistical Bureau of Japan (*e-stat*)[10] of the Data Warehouse for Healthcare and Welfare Plan (DWH)[11]. The *e-stat* is an official site for

Japanese government statistics. Each database is produced by all ministries in the government. *e-stat* records ecological data set of several categories, such as prefectures, age group, and sex, to analyze the mortality rate of a specific area and age group. However, we could not complete the analysis by only using data from *e-stat*; thus, we used the DWH database, which categorizes more specific factors, such as medical administration, health center area, and municipal data, such as the number of PHN; death by age, sex, and year; and categorized medical areas. In Japan, medical administration areas are broadly divided into 3 units: each municipality is designated as primary medical area, a combination of two municipalities is designated as secondary medical area (SMA), and a prefecture is designated as tertiary medical area. Under the Medical Care Act, SMA is defined as the essential unit for health care planning, within which all necessary care shall be proved. In view of this principle, we used SMA as unit of analysis in our ecological study design to identify the inequality of medical resources and to determine the influence of available medical resources on infants and child mortality.

Regarding medical resources, our study used the database of Japan Medical Analysis Platform (JMAP)[12], Japan Association of Obstetricians and Gynecologists (JAOG)[13], and Medicare Information Laboratory (MIL)[14]. JMAP collects medical information and institutional data nationwide. We obtained the number of medical doctor by detailed categories. JAOG records information from comprehensive/local perinatal maternal child medical center and perinatal medical centers (PMC). Meanwhile, the MIL of the Ministry of Health, Labor and Welfare records a list of disaster base hospitals (DBHs), including core disaster medical hospital (CDMH) and local disaster medical center (LDMC). DBH is a disaster-ready hospital, which has a function to support local medical institution and accepts the seriously ill serious disabled. DBH is placed as hospital to carry central role on in medical care relief activities at the time of disaster. In principle, each prefecture should have more than one CDMH, and each SMA should have more than one LDMC.

We analyzed data from *e-stat*, DWH, JMAP, JAOG, and MIL in three prefectures, namely, Iwate, Fukushima, and Miyagi, from 2008 to 2014. We investigated damages and impacts of disasters during a 7-year period, i.e., before GEJET (2008–2010), 2011, and after GEJET (2012–2014). We chose these three prefectures because they were the most severely affected prefectures in 2011, and more than 99% of all deaths were in these areas[15]. Integrating data from *e-stat*, DWH, JMAP, JAOG, and MIL enables us to identify mortality rates by sex, age group, and region.

Measurements

We analyzed infant and child mortality rates by sex, age group (0–4 years and 5–9 years), and SMA in Iwate, Miyagi, and Fukushima. The leading causes of mortality by sex, study span, and SMA were examined for each age group. To calculate death rates per 100 000 inhabitant children under 10 years of age, official resident registration data for inhabitants were used. We calculated the age-specific death rate using the administrative reports of resident registry of municipalities in *e-stat* and DWH as denominators. The specific causes of death for ages 0–4 years and 5–9 years were ranked up to 5th from 2008 to 2014 in Japan. Demographic and ecological characteristics were also analyzed to examine the relationship with death caused by natural disasters. To determine the potential effect of disasters on the different SMA mortality rate, we analyzed ecological characteristics through the Geographic Information Systems[16]. We mapped the bar graph of infant and child death. We also mapped the location of medical facilities, such as pediatrics, Ob-Gyn clinics, DBH, and PMC using ArcGIS 10.4[17]. In addition, to determine the DBH coverage of neighboring medical facilities and clinics, we gave a 10 km margin from each DBH location.

Patient and Public involvement

In this study, patients and public were not involved.

Statistical analysis

Quantitative variables are presented as means±standard deviation (SD). We conducted multiple regression analysis for infant and child mortality rate according to each of the classified period (before 2011, during 2011, and after 2011). Regression model analyses was applied for infant and child mortality rates and other data before GEJET (2008–2010) and after GEJET (2012–2014). To examine the associations between mortality rate and ecological characteristics, we included 12 variables in the regression models. Dummy variables were used for sex, age group (0–4 years vs. 5–9 years), location of SMA, location of DBH, and prefecture. Meanwhile, the continuous variables were the number of DBH, pediatrics, pediatricians per 100 000 population, Ob-Gyn clinics, Ob-Gyn per 100 000 population, and PHN. Statistical significance was tested at a two-sided significance level of 0.05, and all confidence intervals were reported as two-sided values with a confidence level of 95%. Statistical analyses were performed with Stata 14.0[18].

Results

Table 1 summarizes the baseline characteristics of medical resources in Iwate, Miyagi, and Fukushima. Data were expressed as mean ± SD. As shown in Table 1, medical resources in Iwate were significantly fewer than in other prefectures. In particular, the mean number of pediatrics in Iwate was lower than that in other prefectures (Iwate: 12.8, Miyagi: 80.3, and Fukushima: 99.0). As for the number of pediatrics and Ob-Gyn, the national average of pediatricians per 100 000 population was 17.9 and that of Ob-Gyn was 3.94 in 2015. Compared with this data, those of the study areas were lower than the national average.

Table 1 Baseline characteristics of medical resources in affected areas in the three prefectures

Medical Resources	**Iwate**	**Miyagi**	**Fukushima**
Pediatric clinic	12.8 (14.3)	80.3 (97.6)	99.0 (144.6)
Pediatricians per 100 000 population	8.0 (2.5)	12.5 (1.6)	23.8 (8.9)
Pediatrician	32 (60.4)	101 (123.9)	70 (57.5)
PMC	1.1 (0.9)	2.5 (1.7)	0.7 (0.8)
Ob-Gyn per 100 000 population	2.9 (1.9)	2.7 (0.5)	3.6 (1.1)
Ob-Gyn clinic	4.9 (5.9)	22.0 (32.1)	19.8 (30.1)
Ob-Gyn Dr.	7 (8.6)	37 (56.4)	17 (18.4)
PHN			
PHN before 2011	N/A	N/A	N/A
PHN 2011	128 (55.8)	365 (92.3)	204 (119.3)
PHN after 2011	132 (54.6)	371 (86.1)	213 (99.9)

Note: The value of each medical resource was expressed as mean ± SD before 2011 (2008–2010), during 2011, and after 2011 (2012–2014).

The mortality rate per 100 000 population as classified according to the medical care area: SMA is shown in Figure 3. From this figure, mortality late before and after 2011 was only minimally different among the SMA, and the rates were under 100 per 100 000 population. By contrast, the rates were significantly higher in 2011 than in other periods. The mortality rates were higher in coastal zones, such as Ishinomaki-Tome-Kesennuma (ITK), Kamaishi, Kesen, and Miyako, than those of other SMA in Iwate. In particular, the mortality rate for children aged 0–4 years in Kamaishi was 1469.5 per 100 000 population, which was the highest among all 20 MSA.

* **Figure 3.** Mortality rate per 100 000 population as classified according to Medical Care area*

Figure 4 shows the influence of SMA location on infant and child mortality by age group, sex, and periods. From this mortality boxplot, we can see that the mortality rate of children under 10 years was significantly higher than before and after 2011 in coastal zones. Moreover, the mortality rate of children aged 0–4 years was higher than that of aged 5–9 years. Furthermore, the mortality rates of males were higher than those of females in coastal zone. Meanwhile, regardless of age, sex, and periods, mortality rates followed similar pattern in inland zone, in which each mean of mortality rate was not statistically different.

***Figure 4.** Influence of SMA location on infant and child death by age group, sex, and period*

A total of 1 748 deaths of children aged 0–9 years were confirmed in the 20 MSA from 2008 to 2014 in the affected area. Table 2 summarizes the mortality rate of children under 10, medical resources in target areas before and after 2011, and in 2011. A total of 1062 infant and child deaths were identified: the mean death rate before 2011 was 191, the number of death in 2011 was 717, and the mean death rate after 2011 was 152.7. As shown in Table 2, the values present the number or means of mortality rate by individual attributes (sex, age group, mortality rate per 100 000 population, region, and location of DBH) for infants and children by period. The results show no significant difference in the proportion of death proportion as analyzed according to sex from 2008 to 2014. However, the number of male deaths in 2011 was 3.5 times higher than before 2011 and 4.2 times higher than after 2011. The rate of female deaths was 4.1 times higher than before 2011 and 5.3 times higher than after 2011. As for age group, in each period, the number of death of children aged 0–4 years was higher than that of children aged 5–9 years. Proportion gaps of death were noted between those aged 0–4 years and 5–9 years before and after 2011 (72.8%–74.6%). However, the gaps decreased to 25.2% in 2011. In 2011, the mortality rate in the coastal zone was 11.7 times higher than in the inland zone. Meanwhile, the mortality rate in DBH along coast was 10 times higher than in that not along coast zone.

Table 2 Population mortality of children under 10 and medical resources in target areas before, after, and in 2011

	Before 2011 2008–2010	2011	After 2011 2012–2014
Sex			
Male (N=550)	104 (54.3)	361 (50.3)	85 (55.9)
Female (N=511)	88 (45.7)	356 (49.7)	67 (44.1)
Age group			
0–4 years (N=748)	167 (87.3)	449 (62.6)	132 (86.4)
5–9 years (N=313)	24 (12.7)	268 (37.4)	21 (13.6)
Mortality rate per 100 000 (N=1067)[b]	39.1±41.2	226.7±43.4	31.4±39.1
Secondary medical area[b]			
Coastal (N=795.8)	41.8±42.3	456.5±489.4	33.9±34.0
Inland (N=265.9)	36.8±40.5	38.7±44.7	29.4±36.5
Location of DBH[b]			
Not along the coast (N=175.2)	37.0±41.5	54.9±70.6	27.0±34.0
Along the coast (N=886.5)	42.9±40.7	545.7±519.6	39.5±35.2

Note: Values are shown as n (%) or mean±SD. b Each mean of values presents factors potentially affecting the mortality rate, and variables were analyzed using student t test with significance at the 5%. All values were statistically significant at 5%.

***Figure 5.** Death distribution of children aged 0–9 years in affected areas in 2011 by SMA.*

Figure 5 presents the death distribution of children aged 0–9 in affected areas before, after, and in 2011 by SMA. In Figure 5-a, the number of death in Sendai was the highest, and 49 infants were dead in 2011 (males: 21, females: 28). ITK had 25 deaths in 2011. As the tangency, the number of male deaths was higher than females, and the mortality rate is remarkably high along the coastal zones, particularly in 2011. In Figure 5-b, as for children age of 1–4 years, the number of deaths before and after 2011 was lower than that in 2011. Among children aged 1–4 years, the number of death in ITK was the highest at 123 (42.8%) out of the total 237 deaths in 2011. In particular, 45 (36.6%) out of the 123 children who died were 3-years old. In Figure 5-c, as for children aged 5–9 years, 268 died 2011. Similar to the death rate of those aged 1–4 years, child mortality for those aged 5–9 years was also the highest in ITK at 145 (54.1%) in 2011.

The top 5 caused of child mortality for those aged 0–9 years from 2008 to 2014 are shown in Table 3. Before and after 2011, congenital deformities were the primary cause of death for those aged 0 years in Japan (mortality rate = 81.3). the accidental death was ranked 5th before 2011, but it ranked 3rd in 2011 (mortality rate = 18.7). For children aged 1–4 years, congenital deformities were also the primary cause of death except in 2008 and 2011 (mean mortality rate = 3.8). The mean value of accidental death was 3.8 in 2008 and 9.1 in 2011. Meanwhile, the accidental death was the primary cause of death for children aged 5–9 years from 2008 to 2013. The mortality rate from natural disasters in 2011 was 3 times higher than that in other periods.

Sex, age group, location of SMA, prefecture, DBH, and the number of pediatrics per 100 000 population, pediatricians, Ob-Gyn, Ob-Gyn per 100 000 population, Ob-gyn Dr., and PHN were tested for their association with infant and child mortality in the 20 MSA (Table 4). In this analysis, no significant differences (p>0.05) in the mortality rate in terms of sex were noted before and after 2011. By contrast, significant differences were noted in childhood mortality as assessed according to age group. The mortality rate of children aged 0–4 years was higher than those aged 5–9 years before, after, and in 2011 ($p<0.01$). In 2011, mortality rate was positively associated with location of DBH, the number of DBH, and the number of PHN in the 20 SMA, indicating that in 2011, the occurrence of natural disaster and medical resources were associated with increased infant and child mortality rate. By contrast, mortality rate was negatively associated with the number of Ob-Gyn in 2011, indicating that the number of Ob-Gyn was associated with decreased infant mortality rate ($\beta=-189.9$, $p=0.02$).

Table 3 Causes of death and the mortality rate per 100 000 population for children aged under 10 years

Age		Before 2011						2011		After2011					
		2008		2009		2010				2012		2013		2014	
	Rank	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR
0year	1	Congenital deformities	91.5	Congenital deformities	83.8	Congenital deformities	85.4	Congenital deformities	81.9	Congenital deformities	77.8	Congenital deformities	78.4	Congenital deformities	70.4
	2	Respiration Disorders	34.6	Respiration Disorders	33.7	Respiration Disorders	34.1	Respiration Disorders	30.5	Respiration Disorders	30.2	Respiration Disorders	29.9	Respiration Disorders	24.6
	3	SIDS	14.1	SIDS	13.5	SIDS	13.1	accidental death	18.7	SIDS	13.6	SIDS	11.8	SIDS	0.2
	4	**Accidental death**	13.0	**Accidental death**	11.4	**Accidental death**	10.5	SIDS	12.3	**Accidental death**	9.0	**Accidental death**	8.6	Haemorrhagic Diseases	0.3
	5	Haemorrhagic Diseases	11.7	Haemorrhagic Diseases	9.3	Haemorrhagic Diseases	7.9	Haemorrhagic Diseases	8.1	Haemorrhagic Diseases	7.8	Haemorrhagic Diseases	7.4	**Accidental death**	7.9
1-4year	1	**Accidental death**	3.8	Congenital deformities	3.8	Congenital deformities	3.8	**Accidental death**	9.1	Congenital deformities	4.2	Congenital deformities	3.4	Congenital deformities	3.8
	2	Congenital deformities	3.8	**Accidental death**	3.5	**Accidental death**	3.5	Congenital deformities	3.9	**Accidental death**	2.9	**Accidental death**	2.6	**Accidental death**	2.6
	3	Cancer	2.2	Cancer	2.0	Cancer	2.0	Cancer	1.9	Cancer	2.4	Cancer	2.0	Cancer	1.6
	4	Pneumonia	1.3	Heart Diseases	1.5	Pneumonia	1.7	Pneumonia	1.8	Heart Diseases	1.4	Heart Diseases	1.3	Heart Diseases	1.2
	5	Heart Diseases	1.2		1.0	Heart Diseases	1.3	Heart Diseases	1.4	Pneumonia	1.1	Pneumonia	1.3	Pneumonia	1.2
5-9year	1	**Accidental death**	2.2	**Accidental death**	2.2	**Accidental death**	2.3	**Accidental death**	6.5	**Accidental death**	1.9	**Accidental death**	2.0	Cancer	1.9
	2	Cancer	1.8	Cancer	1.8	Congenital deformities	1.9	Cancer	1.8	Cancer	1.6	Cancer	2.0	**Accidental death**	1.7
	3	Other Cancers	0.7	Heart Diseases	0.7	Cancer	0.5	Other Cancers	0.7	Congenital deformities	0.7	Other Cancers	0.7	Congenital deformities	0.6
	4	Heart Diseases	0.6	Other Cancers	0.6	Pneumonia	0.5	Congenital deformities	0.6	Other Cancers	0.6	Heart Diseases	0.4	Heart Diseases	0.5
	5	Congenital deformities	0.6	Congenital deformities	0.6	Heart Diseases	0.4	Heart Diseases	0.5	Pneumonia	0.5	Pneumonia/ Congenital deformities	0.4	Pneumonia	0.5

Note: COD, cause of death; MR, mortality rate per 100 000 population.

Table 4 Factors affecting infant and child mortality during the study period

Factors	2008–2010			2011			2012–2014		
	β	*s.e.*	*p*	*β*	*s.e.*	*p*	*β*	*s.e.*	*p*
Intercept	22.2 (−25.0, 69.4)	23.6	(0.35)	−196.8 (−651.9, 258.3)	227.7	(0.90)	−18.9 (−62.8, 25.1)	22	(0.39)
Sex									
Male	−0.4 (−12.7, 11.9)	6.2	(0.95)	−42.6 (−161.2, 76.0)	59.3	(0.48)	7.7 (−3.7, 19.2)	5.7	(0.18)
Female	Ref. group			Ref. group			Ref. group		
Age group									
0–4 years	74.8* (62.4, 87.2)	6.2	<0. 00 1	164.2 *(45.1, 283.4)	59.6	(0.01)	49.7 *(38.2, 61.3)	5.8	<0.001
5–9 years	Ref. group			Ref. group			Ref. group		
Location of DBH									
Inland	Ref. group			Ref. group			Ref. group		
Coastal	15 (−7.2, 37.3)	11.1	(0.18)	91.1 (−123.3, 305.4)	107.2	(0.39)	−15.1 (−35.8, 5.6)	10.4	(0.15)
Location of DBH									
Not along the coast	Ref. group			Ref. group			Ref. group		
Along the coast	−11.4 (−44.6,21.9)	16.6	(0.49)	370.8* (50.4, 691.1)	160.2	(0.02)	19.2 (−11.7, 50.2)	15.5	(0.22)
Prefecture									
Iwate	−16.9 (−56.5, 22.6)	19.8	(0.39)	245.7 (−135.2, 626.6)	190.6	(0.20)	13.3 (−23.5, 50.1)	18.4	(0.47)
Miyagi	−31.9* (−63.4, −0.6)	15.8	(0.05)	−195.4 (−497.8, 107.1)	151.3	(0.20)	−12.7 (−41.9, 16.5)	14.7	(0.39)
Fukushima	Ref. group			Ref. group			Ref. group		
Pediatrics per 100 000 population	−0.6 (−2.1, 1.0)	4.5	(0.79)	−64.2 (−150.3, 21.9)	7.7	(0.60)	1.2 (−0.2, 2.7)	0.7	(0.10)
Pediatrician	0.0 (−0.2, 0.2)	0.1	(0.09)	−0.3 (−2.0, 1.5)	0.9	(0.76)	0.0 (−0.2, 0.2)	0.01	(0.84)
Ob-Gyn	12.3 (−4.6, 29.2)	8.5	(0.15)	−189.9* (−352.9, -26.8)	81.6	(0.02)	0.9 (−16.7, 14.8)	0.06	(0.49)
Ob-Gyn per 100 000 population	0.4 (−8.5, 9.4)	4.5	(0.92)	−64.2 (−150.3, 21.9)	43.1	(0.14)	5.0 (−13.3, 3.3)	4.20	(0.23)
Ob-Gyn Dr.	−0.5 (−1.2, 0.2)	0.4	(0.17)	−2.1 (−9.1, 5.0)	3.5	(0.56)	−0.1 (−0.8, 0.5(	0.30	(0.69)
PHN	-	-	-	−1.7* (0.4, 2.9)	0.6	(0.01)	0.0 (−0.1, 0.2)	−0.10	(0.49)

Note: DBH; disaster base hospital. PHN; public health. nurse; s.e., standard error. *p<0.05.

DISCUSSIONS

This study revealed mortality differences before, after, and in 2011 by sex, age group, and SMA. Several studies reported that the medical resources in a prefecture impact the rate of childhood mortality, particularly in Iwate that has poor medical service system; as such, amending the evaluation standards of existing medical centers is needed [19,20]. Iwate needs to support the recovery of children and their caregivers during and after the March 2011 GEJET. Another previous study reported that medical facilities are forced to integrate or discontinue due to a declining population. The policy to control the medical expense due to the worsening of fiscal conditions, the loss of medical liaison between medical education institutions and regional/rural hospitals were also associated with imbalanced medical resource allocation[19]. The results of this analysis indicate the needs for improving accessibility of local medical facilities, simulating a transportation scenario during emergency situations, and pre-assigning residents to local hospitals during emergencies[21]. However, the previous studies did not focus on the ecological spatial influence on infant and child death. Access to medical care for infant and child can be improved by establishing a liaison system with local child care system to compensate for the potential lack of healthcare resources. Our study considered spatial or geographic characteristics by scattering DBH, PMC, pediatrics, and Ob-Gyn location. We found uneven distribution of doctors and healthcare facilities for infants and children in affected areas. Most DBH in Miyagi were concentrated in the metropolitan city, while several DBH in Iwate were located along the coast. Some local pediatrics were not covered by DBH. In Fukushima, Soso has no DBH and Ob-Gyn centered in Iwaki, where the incidence of radiation-related cancer in children has increased due to the meltdowns at the Fukushima Daiichi Nuclear Power Plant. A Child Care Emergency Preparedness Toolbox by GSA[22] details how to deal with child care and support liaison system. However, Japan has not established an official Child Care Emergency Disaster Plan yet, although an information service for Infants and Perinatal Disaster Liaison is currently studied. Few studies focused on the effect of employing PHNs to mitigate child health risk. However, we found that an adequate number of PHNs would reduce infant and child mortality rates ($\beta=-1.7$, p=0.01 in 2011), and the number of Ob-Gyn was negatively associated with mortality rate ($\beta=-189.9$, p=0.02) in 2011. To address the uneven distribution of medical resource, the core disaster medical facilities and local healthcare centers should be strengthened for infant and child care and an adequate number of PHNs should be provided in and out of the medical care area. To establish the liaison system, the numerous issues faced by disaster-affected individuals should be comprehensively addressed, and management should include enhancing the support structure, schemes to form communities, reconstruction of the disaster-affected areas, support for children, and a system for sharing of information among healthcare infrastructures.

Water-related disasters often increase the risk of infant and child death. According to the World Health Organization, prematurity is the primary cause of death for neonates (16%), while pneumonia is the primary cause of death for children aged 1–59 months (13%)[23, 24]. By contrast, the primary cause of death in these age groups differs worldwide. We found that the primary cause of death for children under 5 years old was congenital deformities. Accidental death is ranked among the top 4 causes of mortality for children below 5 years, while it ranked as the 1st cause of mortality for children aged 5–9 years from 2008 to 2013 in Japan. In 2011, the rank of accidental death as a cause of mortality moved up or remained for children aged 0–9 years, which might be attributed to the impact of drowning, hypothermia, and decondition as a cause of mortality during GEJET. In general, these results show that children under 10 years of age were exposed to accidents in Japan, and the risk of death is increased during disasters.

Previous studies have indicated evidence on the relationship of mortality from tsunami and other factors in local areas. For instance, the study on the 2004 tsunami in Indonesia indicated the effects of mortality on subsequent fertility among residents and caused widespread shock among residents[25,26,27]. Meanwhile, 1.7 million children are among the 4.4 million people displaced due to typhoon Haiyan in the Philippines, and the death toll stands at more than 4 000[28]. Age-specific mortality tended to increase with age. A previous study showed that the mortality rate among children aged 0 to 4 years was higher than those aged 5 to 14 years in specific parts of Iwate, northern Miyagi, and south Fukushima from March to November 2011[9]. Our study showed the same tangency, and the age difference significantly influenced mortality rate. However, our study focused on lower-aged children and investigated all medical care areas in the three prefectures and compared the influence of DBH located in inland and coastal zones on childhood mortality before, after, and in 2011. We found that the mortality rate of children aged 0–9 years was lower in coastal zones than that in ocean zone in 2011. Collectively, the results of our study and those of previous studies suggest that the GEJET significantly affected the rate of childhood mortality before and after its occurrence.

Principal findings

We observed significant healthcare disparities by region remained significant associated with infant death. A total of 7 out of the 32 DBH located in the coastal zones were related to the risk of infant and child death in 2011: In coastal zones, the rate of child death was higher than that in inland zone. From 2008 to 2012, the accidental death belonged to the top 5 causes of death for children aged 0–9 years. This result indicated that infants and children are exposed to accidents regardless of disaster outbreaks. In 2011, we found that mortality rate in the coastal zone was 10 times higher.in the inland zone. The mortality rate in 2011 increased 11-fold compared to before and after 2011 when no tsunami occurred. Furthermore, the mortality rate of children under 5 years old was 164.2 times higher than that of children under 10 years old in 2011.

Accuracy of case, exposure, and outcome identification

Our study analyzed ecological data collected from the databases of *e-stat*, DWH, JMAP, and MIL which are widely used databases in Japan. However, misclassification of the data is possible, and the definition of the point where and how to count the number of migrants and immigrants is uncertain. Regarding general practitioners, pediatricians, and Ob-Gyn, we applied data only registered in JMAP. Data for mortality rate was calculated via the Residential Basic Book in SMA. As such, some infant and child data may be missing. However, these data are official reports from the Japanese government. Thus, the validity of our calculated data is garanteed.

Study limitations

Our study has several limitations. First, for 2008–2010 and 2012–2014, the mean data of each three year was applied for analysis. As such, some inconsistencies may be present from the real data of each year. Nevertheless, the period analyzed in the current study appears to be long enough to identify causes of death and determine the ecological characteristics related to the mortality of children under 10 years old. The changing trends in human casualties caused by northeastern disasters indicated that ecological factors are associated with childhood mortality. Second, the study failed to include individual social and economic factors related to deaths by natural disasters. Vulnerability, such as the effects of natural disasters on health, depends on personal characteristics, including location of residence, age, income, education, and disability, and economic factors, including socio-economic status of parents and the budget of the healthcare facilities in each SMA) in danger [29,30]. Our study did not consider these factors during analysis due to the limitations of population-based ecological data. The limitation, however, applies to most previous studies that assessed the effects of for children under 10 years old using ecological data.

Abbreviations

GEJET: Great East Japan Earthquake and Tsunami; SMA: Secondary Medical Area; DMAT: Disaster Medical Assistance Teams; DWH: Data Warehouse for Healthcare and Welfare Plan; JMAP: Japan Medical

Analysis Platform; JAOG: Japan Association of Obstetricians and Gynecologists; MIL: Medicare Information Laboratory; DBH: Disaster Base Hospital; CDMH: Core Disaster Medical Hospital; LDMC: Local Disaster Medical Center; PMC: Perinatal medical center; Ob-Gyn: Obstetricians and Gynecologists; PHN: Public Health Nurse; ITK: Ishinomaki-Tome- Kesennuma; SD: Standard deviation; *s.e.*: Standard error; COD: Cases of death; MR: Mortality rate; N/A: Not applicable.

DECLARATIONS

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

AT designed the study and methodology, conducted the analysis, and drafted the manuscript. KS, HY assisted in manuscript preparation, and revised the draft. EO provided data sources, study materials, and revised the manuscript. All authors read and approved the final manuscript.

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Data sharing statement

No additional data available.

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Figure 1

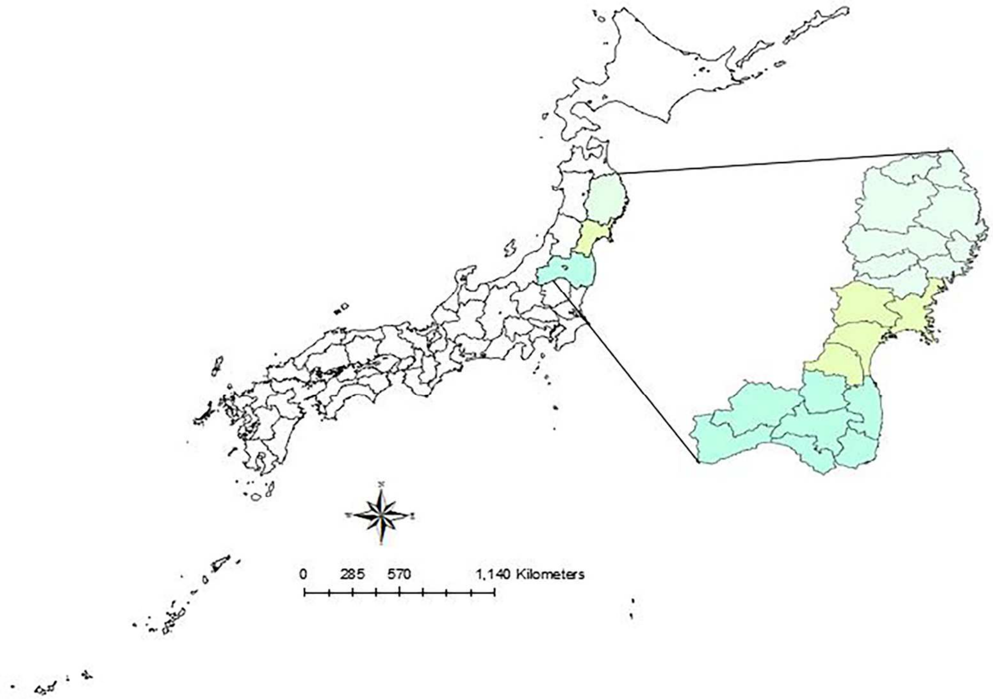
Note: Municipalities severely damaged by the tsunami were included in the analysis and were classified into 3 areas according to their geographic characteristics. The boundary indicates secondary medical area (SMA) in each prefecture. *

Figure 2

Figure 2-a. Location of DBH including CDMH and LDMC. Figure 2-b. Medical facilities. DBH: Disaster Base hospital PMC: Perinatal Medical Center (Central and Local).

Figure 5

Figure 5-a. Number of infant death (aged 0 years). Figure 5-b. Number of infant death (aged 0 years). Figure 5-c. Number of infant death (aged 0 years)



Municipalities severely damaged by the tsunami were included in the analysis and were classified into 3 areas according to their geographic characteristics. The boundary indicates secondary medical area (SMA) in each prefecture.

180x128mm (300 x 300 DPI)

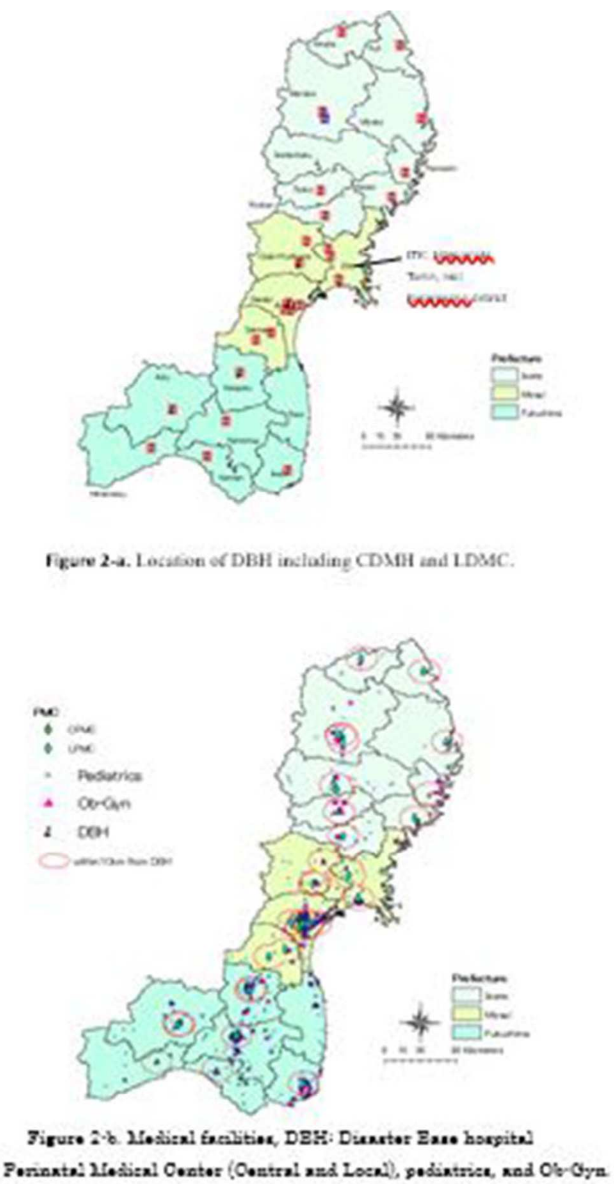
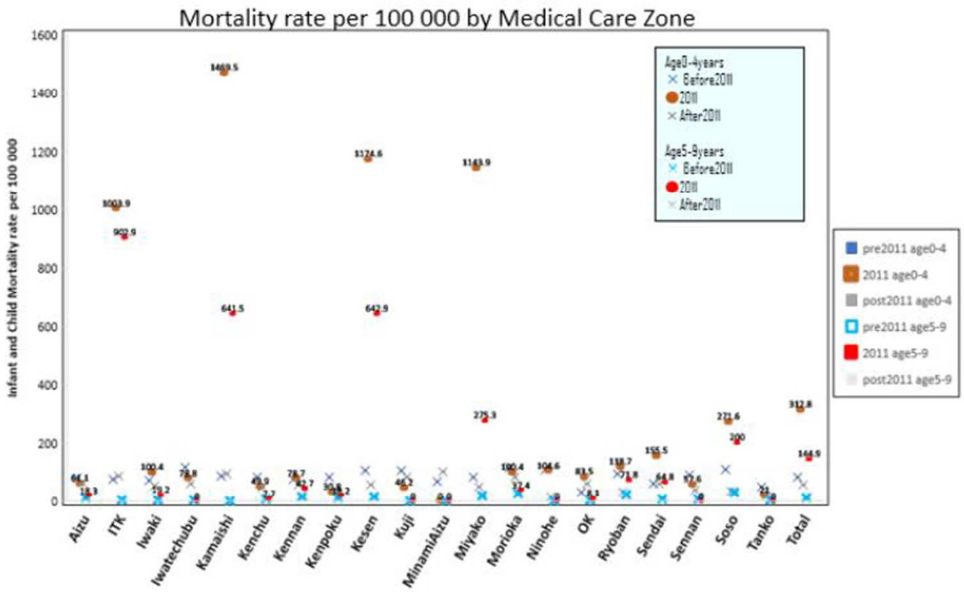


Figure 2-a. Location of DBH including CDMH and LDMC. Figure 2-b. Medical facilities. DBH: Disaster Base hospital PMC: Perinatal Medical Center (Central and Local).

90x127mm (300 x 300 DPI)



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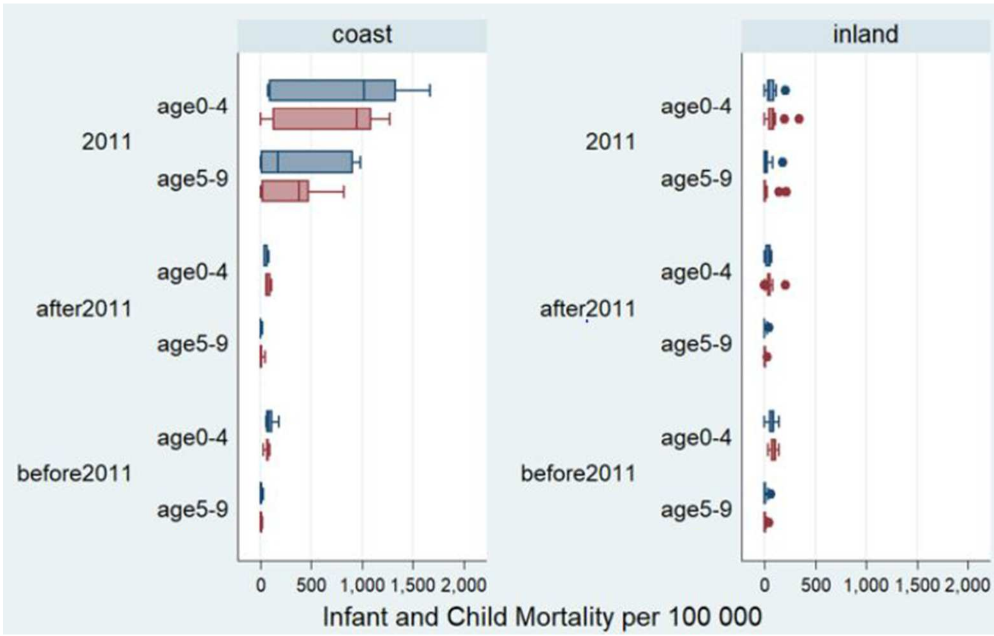

200x126mm (300 x 300 DPI)

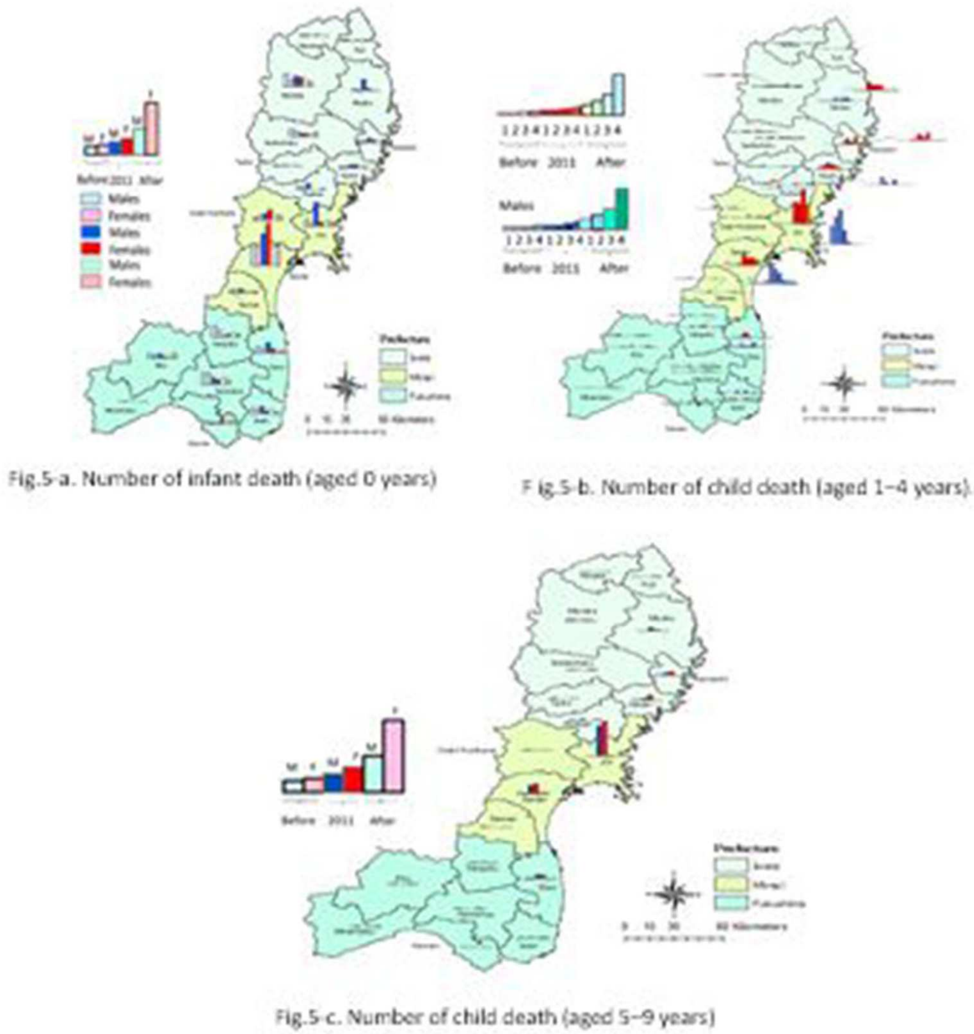

Figure 5-a. Number of infant death (aged 0 years). Figure 5-b. Number of infant death (aged 0 years). Figure 5-c. Number of infant death (aged 0 years)

99x107mm (300 x 300 DPI)

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Differences in infant and child mortality before and after the Great East Japan Earthquake and Tsunami: A large population-based ecological study

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Research article

Differences in infant and child mortality before and after the Great East Japan Earthquake and Tsunami: A large population-based ecological study

Ai Tashiro[1*], Kayako Sakisaka[2], Etsuji Okamoto[3], and Honami Yoshida[4,5]

Author affiliations

[1]Graduate School of Environmental Studies, Tohoku University, Miyagi, Japan

[2]Teikyo University Graduate School of Public Health, Tokyo, Japan

[3]Department of Health and Welfare Management, the University of Fukuchiyama, Kyoto, Japan

[4]Healthcare New Frontier Promotion Headquarters Office, Kanagawa Prefectural Government, Kanagawa, Japan

[5]Kanagawa University of Human Services, Kanagawa, Japan

[*]Corresponding author: Ai Tashiro (e-mail: atashiro11@gmail.com).

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ABSTRACT

Objectives: To examine associations between access to medical care, geological data, and infant and child mortality in the area of Northeastern Japan that was impacted by the Great East Japan Earthquake and Tsunami (GEJET) in 2011.

Design: A population-based ecological study using publicly available data.

Setting: Twenty secondary medical areas in the disaster-affected zones in the northeastern prefectures of Japan (Iwate, Fukushima, and Miyagi).

Participants: Children younger than ten years who died in the twenty secondary medical areas between 2008 and 2014 (N= 1 748).

Primary and secondary outcome measures: Multiple regression analysis for infant and child mortality rate. The mean values were applied for infant and child mortality rates and other factors before the GEJET (2008–2010) and after the GEJET (2012–2014).

Results: Between 2008 and 2014, the most common cause of death among children younger than ten years was accidents. The mortality rate per 100 000 persons was 39.1±41.2 before 2011, 226.7±43.4 in 2011, and 31.4±39.1 after 2011. Regression analysis revealed that the mortality rate was positively associated with low age in each period, while the coastal zone was negatively associated with fewer disaster base hospitals in 2011. By contrast, the number of obstetrics and gynecology centers (β = -189.9, p=0.02) and public health nurses (β = -1.7, p=0.01) were negatively associated with mortality rate per person in 2011.

Conclusions: In 2011, the mortality rate among children younger than ten years was 6.4 times higher than that before and after 2011. Residence in a coastal zone was significantly associated with higher child mortality rates.

Keywords: Great East Japan Earthquake and Tsunami, population-based ecological study, vulnerability, child healthcare disparities, infant and child mortality, GIS

Strengths and limitations of this study

- This study integrates infant and child mortality data with GIS information to assess the influence of damages caused by a natural disaster on child healthcare.
- A longitudinal study of statistical as well as geological distribution was used to evaluate differences in child mortality before, during, and after 2011 by sex, age group, and the secondary medical area in the disaster-affected zone.
- Since this ecological study used publicly available data, we were not able to assess and identify individual social and economic factors influencing child mortality during the study period.

INTRODUCTION

Natural disasters cause significant socioeconomic damages and large-scale deaths. Compared with adults, infants and children are more vulnerable during and after natural disasters[1]. On March 11 2011, the Great East Japan Earthquake and Tsunami (GEJET) stuck Northeastern Japan, and the tsunami that followed caused massive damage and a high death rate, particularly of children in coastal zones due to several reasons, including drowning. Particularly among children in coastal zones, in 2011, the death rate of children younger than 10 years in areas affected by the earthquake and tsunami increased by 40%[2]. Given this demographic profile, the influence of natural disasters on mortality, particularly of infants and children, is not well understood.

Areas affected by the earthquake and tsunami were generally poorer. The disaster significantly crippled the medical resources and healthcare services for infants and children. Although Hurricane Katrina in 2005 and the Southern California wildfires in 2017 reinforced the need to provide pediatric unitspecific guidelines to medical personnel responding to disasters in both hospital and pre-hospital settings in the U.S.[3, 4, 5], as of 2011, the lack of a regional disaster medical management plan in Japan resulted in difficulty in responding to the healthcare needs of children at risk. Disaster medical assistance teams (DMATs), which were launched in 2005 were unable to respond to expectant or nursing mothers and children due to the lack of an information sharing system and network with local hospitals, clinics, and emergency-response organizations[6, 7, 8]. Regarding the establishment of a liaison system between DMATs and local medical care organizations, only a few prior studies determined the influence of disaster on child mortality and examined the association between areas with poor medical resources and how to manage preventable child deaths[9, 10].

In this paper, we investigated the dynamics of infant and child mortality (age, 0–9 years) in Northeastern Japan before and after 2011. This study aimed to examine the associations between the different characteristics of medical care, including the preparedness of obstetrics and gynecology (Ob-gyn) centers, pediatricians and public health nurses (PHNs), and the geological distribution of hospitals/clinics. We also determined the influence of changes in normal and emergency conditions on infant and child mortality. Empirical evidence on these different aspects of large population-based ecological time series regarding infant and child mortality can contribute to the establishment of a local liaison system for pediatric and perinatal medical care during disasters.

METHODS

Study population

Due to the influence of geographic and social characteristics on patterns of inundation and casualties, we compared data from Iwate, Miyagi, and Fukushima. These regions share common topographical features, namely, a deeply indented coastline with narrow flatlands bordered by sea and mountains, which increases their vulnerability to damage caused by tsunami. The total number of clustered secondary medical areas (SMAs) was 20 (Figure 1). From 2008 to 2014, according to the Data Warehouse for Healthcare and Welfare Plan (DWH) database, a total of 1 748 deaths occurred among children aged 0–9 years in Iwate, Fukushima, and Miyagi (0–4 years: 1 345; 5–9 years: 403). In 2011, a total of 717 deaths occurred among children aged 0–9 years in the three prefectures (Iwate: 168; Miyagi: 452; and Fukushima: 97).

***Figure 1.** Map of the study area*

Study site

Regarding medical resources, we mapped the location of disaster base hospitals (DBHs) in Figure 2, including core disaster medical hospitals (CDMHs) and local disaster medical centers (LDMCs) and added data from other medical facilities, such as perinatal medical centers (PMCs), pediatric clinics, and Ob-Gyn clinics in Figure 2-a. We also gave a 10 km margin from each DBH and observed the range of coverage of those medical facilities in Figure 2-b. Most SMAs had DBHs except the Iwate-chubu and Soso areas. Meanwhile, the coastal zones in Iwate, Kuji, Miyako, Kamaishi, and Kesen also had DBHs. Most of these DBHs combined PMC function but had few pediatric units. Most pediatric units were distributed out of the 10 km margin in Iwate. In Miyagi, most DBHs were centralized in the inland zone and Sendai, which is the prefectural capital of Miyagi.

As of 2014, the numbers of full time doctors and clinics were as follows: pediatric clinics, 824 (Iwate: 290, Miyagi: 404, Fukushima: 497); pediatricians, 1 191 (Iwate: 290, Miyagi: 404, Fukushima: 497); Ob-Gyn clinics, 216 (Iwate: 81, Miyagi: 49, Fukushima: 88), Ob-Gyn doctors, 332 (Iwate: 124, Miyagi: 62, Fukushima: 146). Regarding PMC, Iwate and Miyagi had ten each, and Fukushima had five. Meanwhile, regarding disaster medical facilities, Iwate had 11 DBHs (2 CDMHs and 9 LDMCs); Miyagi had 13 DBHs (1 CDMH and 12 LDMCs), and Fukushima had 8 DBHs (1 CDMH and 7 LDMCs). In Fukushima, Soso did not have a DBH, as shown in Figure 2. While each DBH was located in inland areas in each SMA except Iwaki, in the coastal zone, pediatric units were located along the coast and did not cover the 10-km margin of the DBH. Iwaki had a DBH and centralized PMCs for neighboring coastal zones.

Figure 2. Location of DBHs, including CDMHs and LDMCs.

Study design and setting

We performed a population-based ecological study using data from the Statistical Bureau of Japan (*e-Stat*)[11] and from the Data Warehouse for Healthcare and Welfare Plan (DWH)[12]. *e-Stat* is the official portal for Japanese government statistics. Each database is produced by all ministries in the government. *e-Stat* records ecological data of several categories, such as prefectures, age groups, and sex, to analyze the mortality rates of specific areas and age groups. However, we could not complete the analysis by only using data from *e-Stat*. Thus, we also used data from the DWH database, which categorizes more specific factors, such as medical administration, health center area, and municipal data, such as the number of PHNs; death by age, sex, and year; and categorized medical areas. In Japan, medical administration areas are broadly divided into three units: each municipality is designated as a primary medical area, a combination of two municipalities is designated as an SMA, and a prefecture is designated as a tertiary medical area. Under the Medical Care Act, the SMA is defined as the essential unit for health care planning, within which all necessary care shall be provided. Based on this principle, we used the SMA as the unit of analysis in our ecological study design to identify the inequality of medical resources and to determine the influence of available medical resources on infant and child mortality.

Regarding medical resources, our study used the database of the Japan Medical Analysis Platform (JMAP)[13], Japan Association of Obstetricians and Gynecologists (JAOG)[14], and Medicare Information Laboratory (MIL)[15]. JMAP collects medical information and institutional data nationwide. We obtained the number of medical doctors by detailed categories. JAOG records information from comprehensive/local perinatal maternal child medical centers and PMCs. Meanwhile, the MIL of the Ministry of Health, Labour and Welfare records a list of DBHs, including CDMHs and LDMCs. A DBH is a disaster-ready hospital, which has a function of supporting local medical institutions and accepts the seriously ill and seriously disabled. DBHs are placed as hospitals to play a central role in medical care relief activities during disasters. In principle, each prefecture should have more than one CDMH, and each SMA should have more than one LDMC.

We analyzed data from *e-Stat*, DWH, JMAP, JAOG, and MIL in three prefectures (Iwate, Fukushima, and Miyagi) from 2008 to 2014. We investigated damages and impacts of disasters during a 7-year period, i.e., before the GEJET (2008–2010), 2011, and after the GEJET (2012–2014). We chose these three prefectures because they were the most severely affected prefectures in 2011, and more than 99% of all deaths were recorded in these areas[16]. Integrating data from *e-Stat*, DWH, JMAP, JAOG, and MIL enabled us to identify mortality rates by sex, age group, and region.

Measurements

We analyzed infant and child mortality rates by sex, age group (0–4 years and 5–9 years), and SMA in Iwate, Miyagi, and Fukushima. The leading causes of mortality by sex, study span, and SMA were examined for each age group. To calculate death rates per 100 000 inhabitant children younger than ten years, official resident registration data for inhabitants were used. We calculated the age-specific death rate using the administrative reports of resident registries of municipalities in *e-Stat* and DWH as denominators. The specific causes of death for ages 0–4 years and 5–9 years were ranked up to 5th from 2008 to 2014 in Japan. Demographic and ecological characteristics were also analyzed to examine deaths caused by natural disasters. To determine the potential effect of disasters on the different SMA mortality rates, we analyzed ecological characteristics using Geographic Information Systems[17]. We mapped the bar graph of infant and child deaths. We also mapped the location of medical facilities, such as pediatric units, Ob-Gyn clinics, DBHs, and PMCs using ArcGIS version 10.4 (Esri, Redlands, CA)[18]. Also, to determine the DBH coverage of neighboring medical facilities and clinics, we gave a 10 km margin from each DBH location.

Patient and public involvement

In this study, patients and the public were not involved.

Statistical analysis

Quantitative variables are presented as means±standard deviation (SD). We conducted multiple regression analysis of infant and child mortality rates according to each of the classified periods (before 2011, during 2011, and after 2011). Regression model analyses were applied for infant and child mortality rates before the GEJET (2008–2010) and after the GEJET (2012–2014). To examine the associations between mortality rate and ecological characteristics, we included 12 variables in the regression models. Dummy variables were used for sex, age group (0–4 years vs. 5–9 years), locations of SMAs, locations of DBHs, and prefecture. Meanwhile, the continuous variables were the number of DBHs, pediatric units, pediatricians per 100 000 population, Ob-Gyn clinics, Ob-Gyn doctors per 100 000 population, and PHNs. Statistical significance was tested at a two-sided significance level of 0.05, and all confidence intervals were reported as two-sided values with a confidence level of 95%. Statistical analyses were performed using Stata 14.0 (Stata Corp., College Station, TX)[19].

RESULTS

Table 1 summarizes the baseline characteristics of medical resources in Iwate, Miyagi, and Fukushima. Data were expressed as mean ± SD. As shown in Table 1, medical resources in Iwate were significantly fewer than those in other prefectures. In particular, the mean number of pediatric clinics in Iwate was lower than those in other prefectures (Iwate: 12.8, Miyagi: 80.3, and Fukushima: 99.0). The national average of pediatricians per 100 000 population was 17.9 and that of Ob-Gyn doctors was 3.94 in 2015. Compared with this data, those of the study areas were lower.

Table 1 Baseline characteristics of medical resources in affected areas of the three prefectures

Medical Resources	Iwate	Miyagi	Fukushima
Pediatric clinic	12.8 (14.3)	80.3 (97.6)	99.0 (144.6)
Pediatricians per 100 000 population	8.0 (2.5)	12.5 (1.6)	23.8 (8.9)
Pediatrician	32 (60.4)	101 (123.9)	70 (57.5)
PMC	1.1 (0.9)	2.5 (1.7)	0.7 (0.8)
Ob-Gyn per 100 000 population	2.9 (1.9)	2.7 (0.5)	3.6 (1.1)
Ob-Gyn clinic	4.9 (5.9)	22.0 (32.1)	19.8 (30.1)
Ob-Gyn Dr.	7 (8.6)	37 (56.4)	17 (18.4)
PHN			
PHN before 2011	N/A	N/A	N/A
PHN 2011	128 (55.8)	365 (92.3)	204 (119.3)
PHN after 2011	132 (54.6)	371 (86.1)	213 (99.9)

Note: The value of each medical resource was expressed as mean (SD) before 2011 (2008–2010), during 2011, and after 2011 (2012–2014).

The mortality rate per 100 000 population as classified according to the medical care area (SMA) is shown in Figure 3. From this figure, the mortality rates before and after 2011 were only minimally different among the SMAs, and were lower than 100 per 100 000 population. By contrast, the rates were significantly higher in 2011 than in the other periods. The mortality rates were higher in coastal zones, such as Ishinomaki-Tome- Kesennuma (ITK), Kamaishi, Kesen, and Miyako, than those of other SMAs in Iwate. In particular, the mortality rate for children aged 0–4 years in Kamaishi was 1 469.5 per 100 000 population, which was the highest among all 20 SMAs.

* **Figure 3.** Mortality rate per 100 000 population as classified according to medical care area*

Figure 4 shows the influence of SMA location on infant and child mortality by age group, sex, and period. From this mortality boxplot, we can see that the mortality rate of children younger than 10 years was significantly higher than those before and after 2011 in coastal zones. Moreover, the mortality rate of children aged 0–4 years was higher than that of children aged 5–9 years. Furthermore, the mortality rates of males were higher than those of females in the coastal zone. Meanwhile, regardless of age, sex, and period, mortality rates followed a similar pattern in the inland zone, in which each mean mortality rate was not statistically different.

***Figure 4.** Influence of SMA location on infant and child death by age group, sex, and period*

A total of 1 748 deaths of children aged 0–9 years were confirmed in the 20 SMAs from 2008 to 2014 in the affected area. Table 2 summarizes the mortality rate of children younger than 10 years according to the availability of medical resources in target areas before, during, and after 2011. A total of 1 062 infant and child deaths were identified; the mean death rate before 2011 was 191, the number of death in 2011 was 717, and the mean death rate after 2011 was 152.7. As shown in Table 2, the values are presented as numbers or means of mortality rate by individual attributes (sex, age group, mortality rate per 100 000 population, region, and location of DBH) for infants and children by periods. The results show no significant difference in the proportion of death rate as analyzed according to sex from 2008 to 2014. However, the number of male deaths in 2011 was 3.5 times higher than before 2011 and 4.2 times higher than after 2011. The rate of female deaths was 4.1 times higher than before 2011 and 5.3 times higher than after 2011. Regarding age group, in each period, the number of deaths of children aged 0–4 years was higher than that of children aged 5–9 years. Proportionate gaps of death were noted between those aged 0–4 years and 5–9 years before and after 2011 (72.8–74.6%). However, the gaps decreased to 25.2% in 2011. In 2011, the mortality rate in the coastal zone was 11.7 times higher than in the inland zone. Meanwhile, the mortality rate in DBHs along the coast was 10 times higher than in those not along the coastal zone.

Table 2 Population mortality of children younger than 10 years and medical resources in the target areas before, during, and after 2011

	Before 2011	**2011**	**After 2011**
	2008–2010		**2012–2014**
Sex			
Male (N=550)	104 (54.3)	361 (50.3)	85 (55.9)
Female (N=511)	88 (45.7)	356 (49.7)	67 (44.1)
Age group			

0–4 years (N=748)	167 (87.3)	449 (62.6)	132 (86.4)
5–9 years (N=313)	24 (12.7)	268 (37.4)	21 (13.6)
Mortality rate per 100 000 (N=1067)[b]	39.1±41.2	226.7±43.4	31.4±39.1
Secondary medical area[b]			
Coastal (N=795.8)	41.8±42.3	456.5±489.4	33.9±34.0
Inland (N=265.9)	36.8±40.5	38.7±44.7	29.4±36.5
Location of DBH[b]			
Not along the coast (N=175.2)	37.0±41.5	54.9±70.6	27.0±34.0
Along the coast (N=886.5)	42.9±40.7	545.7±519.6	39.5±35.2

Note: Values are shown as n (%) or mean±SD. Each mean of values presents factors potentially affecting the mortality rate, and variables were analyzed using the student *t*-test at the 5% level of significance. All values were statistically significant at $\alpha = 0.05$.

***Figure 5.** Mortality distribution among children aged 0–9 years in affected areas in 2011 by SMA*

Figure 5 presents the mortality distribution of children aged 0–9 years in the affected areas before, during, and after 2011 by SMA. As shown in Figure 5-a, the number of deaths in Sendai was the highest, with 49 infant deaths in 2011 (males: 21, females: 28). ITK recorded 25 deaths in 2011. Tangentially, the number of male deaths was higher than female deaths, and the mortality rate was remarkably high along the coastal zones, particularly in 2011. As shown in Figure 5-b, among children aged 1–4 years, the number of deaths before and after 2011 was lower than that in 2011. Among children aged 1–4 years, the number of deaths in ITK was the highest at 123 (42.8%) out of the total 237 deaths in 2011. In particular, 45 (36.6%) out of the 123 children who died were 3-year olds. Among children aged 5–9 years, 268 died in 2011 (Figure 5-c). Similar to the mortality rate of those aged 1–4 years, the child mortality rate among those aged 5–9 years was also the highest in ITK at 145 (54.1%) in 2011.

The top five causes of child mortality among children aged 0–9 years from 2008 to 2014 are shown in Table 3. Before and after 2011, congenital deformities were the primary cause of death among those aged 0 years in Japan (mortality rate = 81.3%). Accidental death was ranked fifth before 2011, but ranked third in 2011 (mortality rate = 18.7%). Among children aged 1–4 years, congenital deformities were also the primary cause of death except in 2008 and 2011 (mean mortality rate = 3.8%). The mean rate of accidental death was 3.8% in 2008 and 9.1% in 2011. Meanwhile, accident was the primary cause of death among children aged 5–9 years from 2008 to 2013. The mortality rate due to natural disasters in 2011 was three times higher than that in other periods.

Sex, age group, the location of SMA, prefecture, DBH, and the number of pediatric clinics per 100 000 population, pediatricians, Ob-Gyn clinics, Ob-Gyn clinics per 100 000 population, Ob-gyn doctors, and PHNs were tested for their association with infant and child mortality in the 20 SMAs (Table 4). In this analysis, no significant differences ($p>0.05$) in the mortality rate regarding sex were noted before and after 2011. By contrast, significant differences were noted in child mortality as assessed according to age group. The mortality rate of children aged 0–4 years was higher than those aged 5–9 years before, during, and after 2011 ($p<0.01$). In 2011, the mortality rate was positively associated with the location of DBH, the number of DBHs, and the number of PHNs in the 20 SMAs, indicating that in 2011, the occurrence of the natural disaster and existence of fewer medical resources were associated with increased infant and child mortality rates. By contrast, the mortality rate was negatively associated with the number of Ob-Gyn centers in 2011, indicating that a higher number of Ob-Gyn centers was associated with decreased infant mortality rate (β = -189.9, $p=0.02$).

Table 3 Causes of death and the mortality rate per 100 000 population for children aged under ten years

Age		Before 2011								2011		After2011				
		2008		2009		2010						2012		2013		2014
	Rank	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	
0year	1	Congenital deformities	91.5	Congenital deformities	83.8	Congenital deformities	85.4	Congenital deformities	81.9	Congenital deformities	77.8	Congenital deformities	78.4	Congenital deformities	70.4	
	2	Respiration Disorders	34.6	Respiration Disorders	33.7	Respiration Disorders	34.1	Respiration Disorders	30.5	Respiration Disorders	30.2	Respiration Disorders	29.9	Respiration Disorders	24.6	
	3	SIDS	14.1	SIDS	13.5	SIDS	13.1	accidental death	18.7	SIDS	13.6	SIDS	11.8	SIDS	0.2	
	4	**Accidental death**	13.0	**Accidental death**	11.4	**Accidental death**	10.5	SIDS	**12.3**	**Accidental death**	9.0	Accidental death	8.6	Haemorrhagic Diseases	0.3	
	5	Haemorrhagic Diseases	11.7	Haemorrhagic Diseases	9.3	Haemorrhagic Diseases	7.9	Haemorrhagic Diseases	8.1	Haemorrhagic Diseases	7.8	Haemorrhagic Diseases	7.4	**Accidental death**	7.9	
1-4year	1	**Accidental death**	3.8	Congenital deformities	3.8	Congenital deformities	3.8	Accidental death	9.1	Congenital deformities	4.2	Congenital deformities	3.4	Congenital deformities	3.8	
	2	Congenital deformities	3.8	**Accidental death**	3.5	**Accidental death**	3.5	Congenital deformities	**3.9**	**Accidental death**	2.9	**Accidental death**	2.6	**Accidental death**	2.6	

	3	Cancer	2.2	Cancer	2.0	Cancer	2.0	Cancer	1.9	Cancer	2.4	Cancer	2.0	Cancer	1.6
	4	Pneumonia	1.3	Heart Diseases	1.5	Pneumonia	1.7	Pneumonia	1.8	Heart Diseases	1.4	Heart Diseases	1.3	Heart Diseases	1.2
	5	Heart Diseases	1.2		1.0	Heart Diseases	1.3	Heart Diseases	1.4	Pneumonia	1.1	Pneumonia	1.3	Pneumonia	1.2
5-9year	1	**Accidental death**	2.2	**Accidental death**	2.2	**Accidental death**	2.3	Accidental death	**6.5**	**Accidental death**	1.9	**Accidental death**	2.0	Cancer	1.9
	2	Cancer	1.8	Cancer	1.8	Congenital deformities	1.9	Cancer	1.8	Cancer	1.6	**Cancer**	2.0	**Accidental death**	1.7
	3	Other Cancers	0.7	Heart Diseases	0.7	Cancer	0.5	Other Cancers	0.7	Congenital deformities	0.7	Other Cancers	0.7	Congenital deformities	0.6
	4	Heart Diseases	0.6	Other Cancers	0.6	Pneumonia	0.5	Congenital deformities	0.6	Other Cancers	0.6	Heart Diseases	0.4	Heart Diseases	0.5
	5	Congenital deformities	0.6	Congenital deformities	0.6	Heart Diseases	0.4	Heart Diseases	0.5	Pneumonia	0.5	Pneumonia / Congenital deformities	0.4	Pneumonia	0.5

Note: COD, cause of death; MR, mortality rate per 100 000 population.

Age		Before 2011						2011		After2011					
		2008		2009		2010				2012		2013		2014	
	Rank	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR
0year	1	Congenital deformities	91.5	Congenital deformities	83.8	Congenital deformities	85.4	Congenital deformities	81.9	Congenital deformities	77.8	Congenital deformities	78.4	Congenital deformities	70.4

	2	Respiration Disorders	34.6	Respiration Disorders	33.7	Respiration Disorders	34.1	Respiration Disorders	30.5	Respiration Disorders	30.2	Respiration Disorders	29.9	Respiration Disorders	24.6
	3	SIDS	14.1	SIDS	13.5	SIDS	13.1	accidental death	18.7	SIDS	13.6	SIDS	11.8	SIDS	0.2
	4	**Accidental death**	13.0	**Accidental death**	11.4	**Accidental death**	10.5	SIDS	12.3	**Accidental death**	9.0	**Accidental death**	8.6	Haemorrhagic Diseases	0.3
	5	Haemorrhagic Diseases	11.7	Haemorrhagic Diseases	9.3	Haemorrhagic Diseases	7.9	Haemorrhagic Diseases	8.1	Haemorrhagic Diseases	7.8	Haemorrhagic Diseases	7.4	**Accidental death**	7.9
1-4year	1	**Accidental death**	3.8	Congenital deformities	3.8	Congenital deformities	3.8	**Accidental death**	9.1	Congenital deformities	4.2	Congenital deformities	3.4	Congenital deformities	3.8
	2	Congenital deformities	3.8	**Accidental death**	3.5	**Accidental death**	3.5	Congenital deformities	3.9	**Accidental death**	2.9	**Accidental death**	2.6	**Accidental death**	2.6
	3	Cancer	2.2	Cancer	2.0	Cancer	2.0	Cancer	1.9	Cancer	2.4	Cancer	2.0	Cancer	1.6
	4	Pneumonia	1.3	Heart Diseases	1.5	Pneumonia	1.7	Pneumonia	1.8	Heart Diseases	1.4	Heart Diseases	1.3	Heart Diseases	1.2
	5	Heart Diseases	1.2		1.0	Heart Diseases	1.3	Heart Diseases	1.4	Pneumonia	1.1	Pneumonia	1.3	Pneumonia	1.2
5-9year	1	**Accidental death**	2.2	**Accidental death**	2.2	**Accidental death**	2.3	**Accidental death**	6.5	**Accidental death**	1.9	**Accidental death**	2.0	Cancer	1.9
	2	Cancer	1.8	Cancer	1.8	Congenital deformities	1.9	Cancer	1.8	Cancer	1.6	Cancer	2.0	**Accidental death**	1.7
	3	Other Cancers	0.7	Heart Diseases	0.7	Cancer	0.5	Other Cancers	0.7	Congenital deformities	0.7	Other Cancers	0.7	Congenital deformities	0.6
	4	Heart Diseases	0.6	Other Cancers	0.6	Pneumonia	0.5	Congenital deformities	0.6	Other Cancers	0.6	Heart Diseases	0.4	Heart Diseases	0.5

5	Congenital deformities	0.6	Congenital deformities	0.6	Heart Diseases	0.4	Heart Diseases	0.5	Pneumonia	0.5	Pneumonia/ Congenital deformities	0.4	Pneumonia	0.5

Age		**Before 2011**						**2011**		**After2011**					
		2008		**2009**		**2010**				**2012**		**2013**		**2014**	
	Rank	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR	COD	MR
0year	1	Congenital deformities	91.5	Congenital deformities	83.8	Congenital deformities	85.4	Congenital deformities	81.9	Congenital deformities	77.8	Congenital deformities	78.4	Congenital deformities	70.4
	2	Respiration Disorders	34.6	Respiration Disorders	33.7	Respiration Disorders	34.1	Respiration Disorders	30.5	Respiration Disorders	30.2	Respiration Disorders	29.9	Respiration Disorders	24.6
	3	SIDS	14.1	SIDS	13.5	SIDS	13.1	accidental death	18.7	SIDS	13.6	SIDS	11.8	SIDS	0.2
	4	**Accidental death**	13.0	**Accidental death**	11.4	**Accidental death**	10.5	SIDS	12.3	**Accidental death**	9.0	**Accidental death**	8.6	Haemorrhagic Diseases	0.3
	5	Haemorrhagic Diseases	11.7	Haemorrhagic Diseases	9.3	Haemorrhagic Diseases	7.9	Haemorrhagic Diseases	8.1	Haemorrhagic Diseases	7.8	Haemorrhagic Diseases	7.4	**Accidental death**	7.9
1-4year	1	**Accidental death**	3.8	Congenital deformities	3.8	Congenital deformities	3.8	**Accidental death**	9.1	Congenital deformities	4.2	Congenital deformities	3.4	Congenital deformities	3.8
	2	Congenital deformities	3.8	**Accidental death**	3.5	**Accidental death**	3.5	Congenital deformities	3.9	**Accidental death**	2.9	**Accidental death**	2.6	**Accidental death**	2.6
	3	Cancer	2.2	Cancer	2.0	Cancer	2.0	Cancer	1.9	Cancer	2.4	Cancer	2.0	Cancer	1.6
	4	Pneumonia	1.3	Heart Diseases	1.5	Pneumonia	1.7	Pneumonia	1.8	Heart Diseases	1.4	Heart Diseases	1.3	Heart Diseases	1.2
	5	Heart	1.2		1.0	Heart	1.3	Heart	1.4	Pneumonia	1.1	Pneumonia	1.3	Pneumonia	1.2

		Diseases				Diseases		Diseases							
5-9year	1	**Accidental death**	2.2	**Accidental death**	2.2	**Accidental death**	2.3	**Accidental death**	6.5	**Accidental death**	1.9	**Accidental death**	2.0	Cancer	1.9
	2	Cancer	1.8	Cancer	1.8	Congenital deformities	1.9	Cancer	1.8	Cancer	1.6	Cancer	2.0	**Accidental death**	1.7
	3	Other Cancers	0.7	Heart Diseases	0.7	Cancer	0.5	Other Cancers	0.7	Congenital deformities	0.7	Other Cancers	0.7	Congenital deformities	0.6
	4	Heart Diseases	0.6	Other Cancers	0.6	Pneumonia	0.5	Congenital deformities	0.6	Other Cancers	0.6	Heart Diseases	0.4	Heart Diseases	0.5
	5	Congenital deformities	0.6	Congenital deformities	0.6	Heart Diseases	0.4	Heart Diseases	0.5	Pneumonia	0.5	Pneumonia/ Congenital deformities	0.4	Pneumonia	0.5

Table 4 Factors affecting infant and child mortality during the study period

Factors	2008–2010			2011			2012–2014
	β	*s.e.*	*p*	*β*	*s.e.*	*p*	*β*
Intercept	22.2 (−25.0, 69.4)	23.6	-0.35	−196.8 (−651.9, 258.3)	227.7	(−0.9)	−18.9 (−62.8, 25.1)
Sex							
Male	−0.4 (−12.7, 11.9)	6.2	-0.95	−42.6 (−161.2, 76.0)	59.3	-0.48	7.7 (−3.7, 19.2)
Female	Ref. group			Ref. group			Ref. group
Age group							
0–4 years	74.8* (62.4, 87.2)	6.2	< 0.001	164.2 *(45.1, 283.4)	59.6	-0.01	49.7 *(38.2, 61.3)
5–9 years	Ref. group			Ref. group			Ref. group
Location of DBH							
Inland	Ref. group			Ref. group			Ref. group
Coastal	15 (−7.2, 37.3)	11.1	-0.18	91.1 (−123.3, 305.4)	107.2	-0.39	−15.1 (−35.8, 5.6)
Location of DBH							
Not along the coast	Ref. group			Ref. group			Ref. group
Along the coast	−11.4(−44.6,21.9)	16.6	-0.49	370.8* (50.4, 691.1)	160.2	-0.02	19.2 (−11.7, 50.2)
Prefecture							
Iwate	−16.9 (−56.5, 22.6)	19.8	-0.39	245.7 (−135.2, 626.6)	190.6	-0.2	13.3 (−23.5, 50.1)
Miyagi	−31.9* (−63.4, −0.6)	15.8	-0.05	−195.4 (−497.8, 107.1)	151.3	-0.2	−12.7 (−41.9, 16.5)
Fukushima	Ref. group			Ref. group			Ref. group
Pediatrics per 100 000 population	−0.6 (−2.1, 1.0)	4.5	-0.79	−64.2 (−150.3, 21.9)	7.7	-0.6	1.2 (−0.2, 2.7)
Pediatrician	0.0 (−0.2, 0.2)	0.1	-0.09	−0.3 (−2.0, 1.5)	0.9	-0.76	0.0 (−0.2, 0.2)
Ob-Gyn	12.3 (−4.6, 29.2)	8.5	-0.15	−189.9* (−352.9, -26.8)	81.6	-0.02	0.9 (−16.7, 14.8)

Ob-Gyn per 100 000 population	0.4 (−8.5, 9.4)	4.5	-0.92	−64.2 (−150.3, 21.9)	43.1	-0.14	5.0 (−13.3, 3.3)
Ob-Gyn Dr.	−0.5 (−1.2, 0.2)	0.4	-0.17	−2.1 (−9.1, 5.0)	3.5	-0.56	−0.1 (−0.8, 0.5)
PHN	-	-	-	−1.7* (0.4, 2.9)	0.6	-0.01	0.0 (−0.1, 0.2)

Note: DBH, disaster base hospital; PHN; public health nurse; s.e., standard error. *p<0.05.

DISCUSSION

The results of this analysis indicate the need to improve the accessibility of local medical facilities, simulate a transportation scenario during emergency situations, and pre-assign residents to local hospitals during emergencies[20]. However, previous studies did not focus on the influence of the spatial ecology on infant and child mortality. Access to medical care for infants and children can be improved by establishing a liaison system with the local child care system to compensate for the potential lack of healthcare resources.

This study revealed mortality differences between normal and abnormal periods, i.e., before, during and after the 2011 earthquake and tsunami by sex, age group, and SMA. Disaster impact on child mortality was associated with abnormalities. Several studies have reported that the availability of medical resources in a prefecture affects the rate of child mortality, particularly in Iwate that has a poor medical service system; as such, there is the need to amend the evaluation standards of existing medical centers[21, 22]. Iwate needs to support the recovery of children and their caregivers during and after the March 2011 GEJET. Another previous study reported that medical facilities are forced to integrate or discontinue due to the declining population. The policy to control the medical expense due to worsening fiscal conditions, loss of medical liaison between medical education institutions and regional/rural hospitals were also associated with imbalanced medical resource allocation[21]. Developing obstetrics and disaster preparedness is an urgent issue for proper child care accessibility (e.g., information on evacuation, available hospitals, preparation in and for a disaster, and geographical materials) in disaster-affected rural areas. Based on the lessons learned from the absence of liaison between DMATs and local medical care organizations, there was a demand to set a liaison system for pediatric and perinatal medical care during disasters in 2016.

The Child Care, Emergency Preparedness Toolbox, developed by the General Services Administration[23] details how to deal with child care and support liaison systems. However, Japan has not established an official child care emergency disaster plan yet, although an information service for infants and perinatal disaster liaison is currently being studied. Few studies have focused on the effect of employing PHNs to mitigate child health risk. However, this result suggests that lack of obstetric units following a disaster made proper infant and child care difficult. This study showed that grasping geographical medical resource distribution allows the enhancement of information liaison between health systems and medical units. To establish the liaison system, the numerous issues faced by disaster-affected individuals should be comprehensively addressed, and management should include enhancing the support structure, schemes to form communities, reconstruction of the disaster-affected areas, support for children, and a system for sharing of information among healthcare infrastructures.

Principal findings

We observed that healthcare disparities by region remained statistically significantly associated with infant death. A total of 7 out of the 32 DBHs located in the coastal zones were related to the risk of infant and child death in 2011; the child mortality rate was higher in coastal zones than that in the inland zones. From 2008 to 2012, accidents was in the top five causes of death among children aged 0–9 years. This result indicated that infants and children are exposed to accidents regardless of disaster outbreaks. In 2011, we found that the mortality rate in the coastal zone was ten times higher than that in the inland zone. The mortality rate in 2011 increased 11-fold compared to that before and after 2011 when no tsunami had occurred. Furthermore, the mortality rate of children younger than 5 years was 164.2 times higher than that of children younger than 10 years in 2011.

The accuracy of the case, exposure, and outcome identification

Our study analyzed ecological data collected from the databases of *e-Stat*, DWH, JMAP, and MIL which are widely used databases in Japan. However, misclassification of the data is possible, and the definition of the point where and how to count the number of migrants and immigrants is uncertain. Regarding general practitioners, pediatricians, and Ob-Gyn doctors, we applied data only registered in JMAP. Data for mortality rate was calculated via the Residential Basic Book in the SMAs. As such, data of some infants and children may be missing. However, these data are official reports from the Japanese government. Thus, the validity of our calculated data is guaranteed.

Study limitations

Our study has several limitations. First, for 2008–2010 and 2012–2014, the mean data of three years were used in the analysis. As such, some inconsistencies may be present from the real data for each year. Nevertheless, the period analyzed in the current study appears to be long enough to identify the causes of death and determine the ecological characteristics related to the mortality of children younger than 10 years. The changing trends in human casualties caused by northeastern disasters indicated that ecological factors are associated with childhood mortality. Second, the study failed to include individual social and economic factors related to deaths due to natural disasters. Vulnerability, such as the effects of natural disasters on health, depends on personal characteristics, including the location of residence, age, income, education, and disability, as well as economic factors, including socio-economic status of parents and the budget of the healthcare facilities in each SMA during disasters[24, 25]. Our study did not consider these factors during the analysis due to the limitations of population-based ecological data. Furthermore, many people were killed by the tsunami on March 11 2011, but we could not estimate the biased results on the date because we obtained only annual data. There might exist location bias of DBH in coastal areas. We should also have focused on normal days of accidents. However, we used annual data and could only compare normal accident spans before and after 2011 and abnormal accidents in 2011. The limitation, however, applies to most previous studies that assessed the impacts on mortality of children younger than 10 years using ecological data.

Abbreviations

GEJET: Great East Japan Earthquake and Tsunami; SMA: Secondary Medical Area; DMAT: Disaster Medical Assistance Team; DWH: Data Warehouse for Healthcare and Welfare Plan; JMAP: Japan Medical Analysis Platform; JAOG: Japan Association of Obstetricians and Gynecologists; MIL: Medicare Information Laboratory; DBH: Disaster Base Hospital; CDMH: Core Disaster Medical Hospital; LDMC: Local Disaster Medical Center; PMC: Perinatal Medical Center; Ob-Gyn: Obstetrician and Gynecologist center; PHN: Public Health Nurse; ITK: Ishinomaki-Tome- Kesennuma; SD: Standard deviation; *s.e.*: Standard error; COD: Causes of death; MR: Mortality rate; N/A: Not applicable.

DECLARATIONS

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

AT designed the study and methodology, conducted the analysis, and drafted the manuscript. KS and HY assisted in manuscript preparation, and revised the draft. EO provided data sources, study materials, and revised the manuscript. All authors read and approved the final manuscript.

Provenance and peer review

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Data sharing statement

No additional data available.

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Figure 1

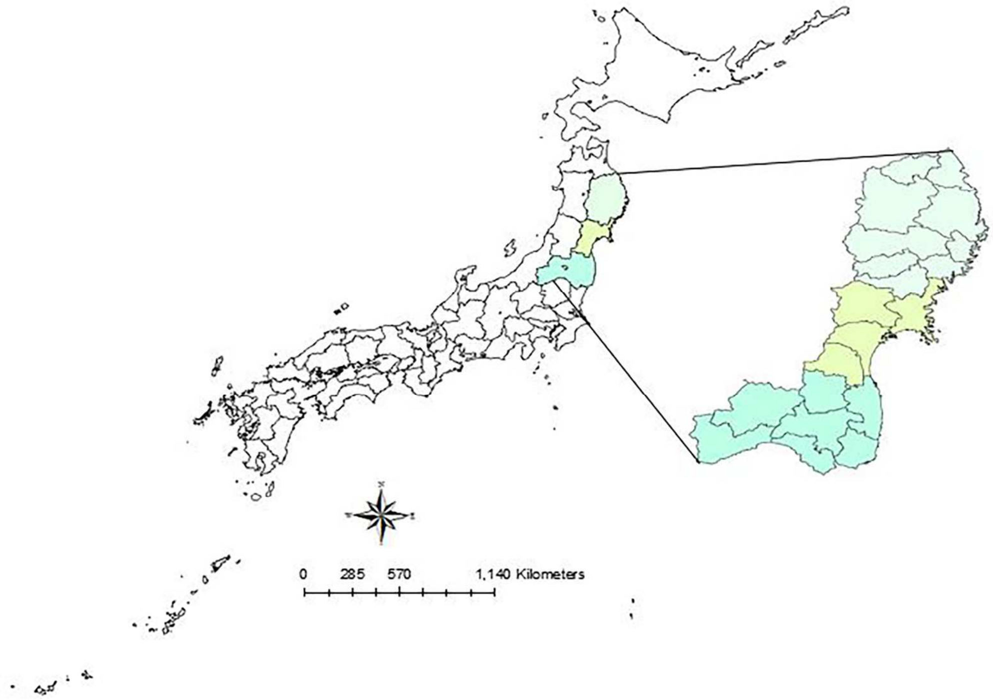
Note: Municipalities severely damaged by the tsunami were included in the analysis and classified into three areas according to their geographic characteristics. The boundary indicates secondary medical areas (SMAs) in each prefecture. *

Figure 2

Figure 2-a. Location of DBHs including CDMHs and LDMCs. Figure 2-b. Medical facilities. DBH: disaster base hospital; PMC: perinatal medical center (central and local).

Figure 5

Figure 5-a. Number of infant deaths (aged 0 years). Figure 5-b. Number of infant deaths (aged 0 years). Figure 5-c. Number of infant deaths (aged 0 years)



Municipalities severely damaged by the tsunami were included in the analysis and were classified into 3 areas according to their geographic characteristics. The boundary indicates secondary medical area (SMA) in each prefecture.

180x128mm (300 x 300 DPI)

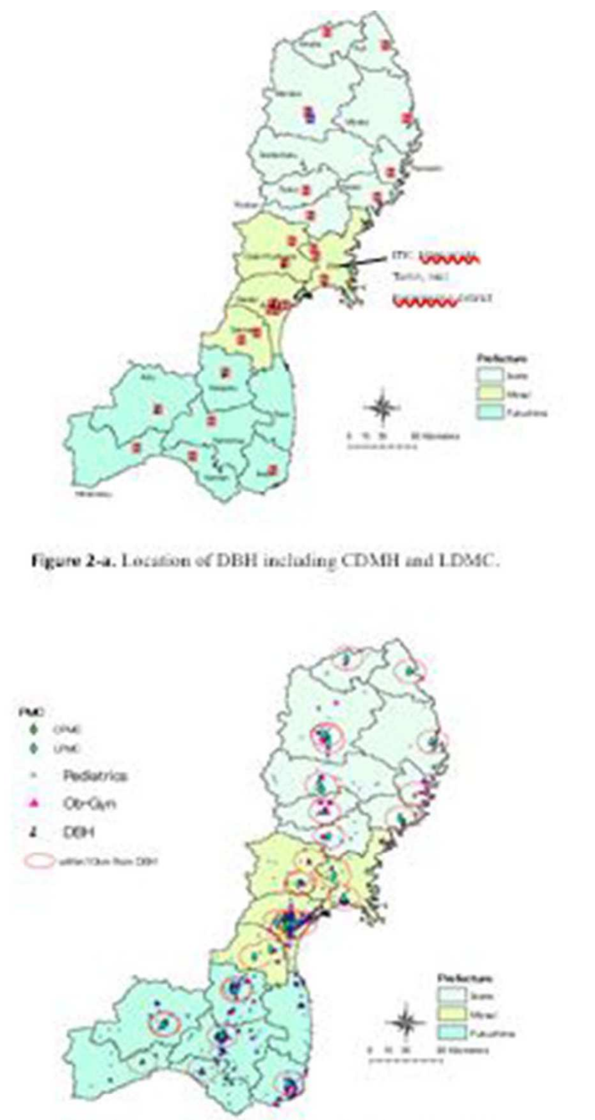
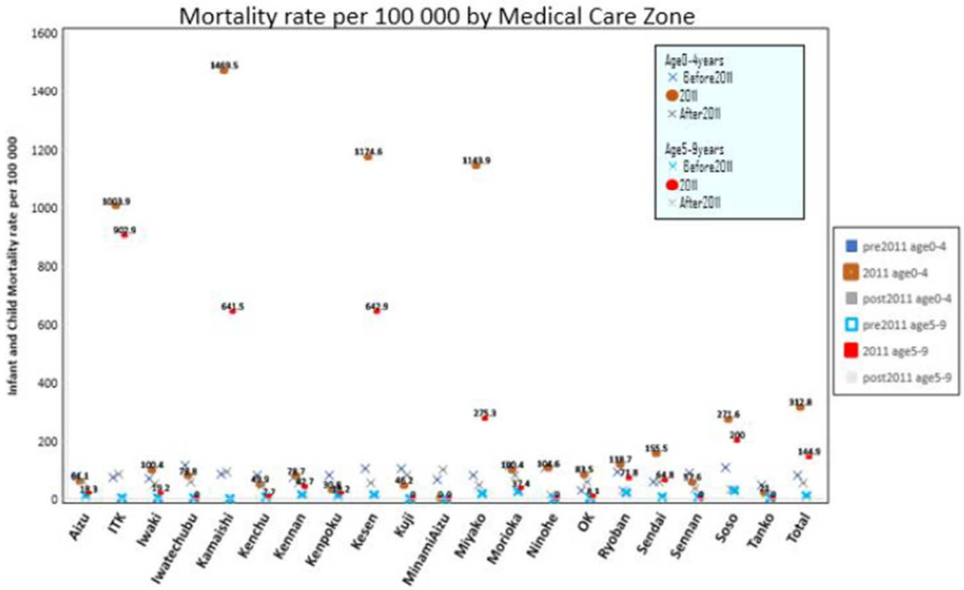


Figure 2-a. Location of DBH including CDMH and LDMC.

Figure 2-b. Medical facilities, DBH: Disaster Base hospital
PMC: Perinatal Medical Center (Central and Local), pediatrics, and Ob-Gyn.

Figure 2-a. Location of DBH including CDMH and LDMC. Figure 2-b. Medical facilities. DBH: Disaster Base hospital PMC: Perinatal Medical Center (Central and Local).

90x127mm (300 x 300 DPI)



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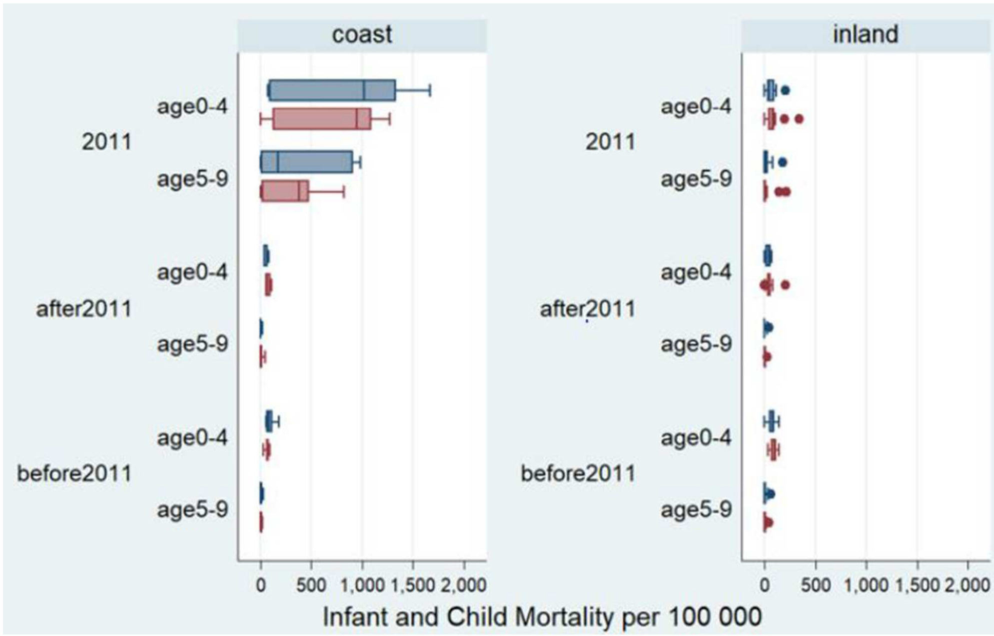

200x126mm (300 x 300 DPI)

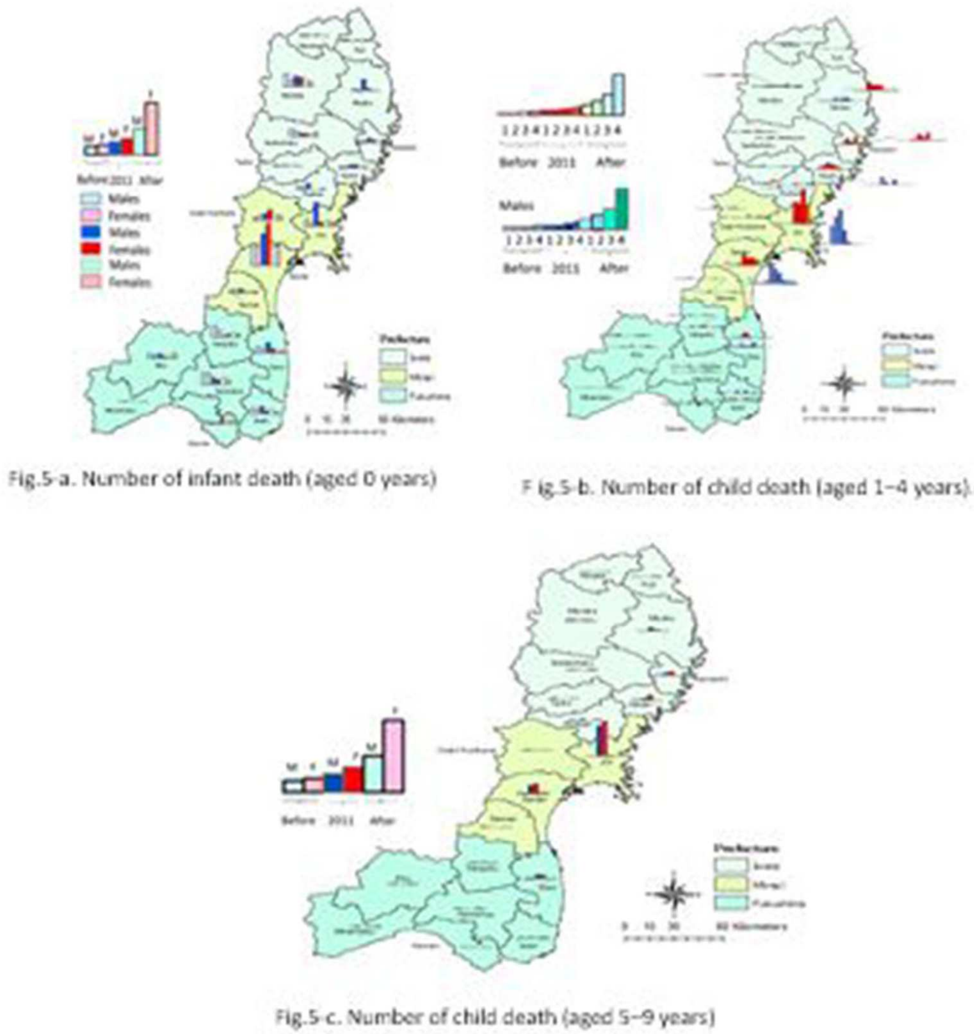

Figure 5-a. Number of infant death (aged 0 years). Figure 5-b. Number of infant death (aged 0 years). Figure 5-c. Number of infant death (aged 0 years)

99x107mm (300 x 300 DPI)