Eight-year trends in the effect of the Great East Japan Earthquake on obstetrics outcomes using the Fukushima Health Management Survey

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Abstract

Information on longitudinal effects of natural/environmental disasters on obstetrics outcomes is limited. This study analyzed longitudinal changes, over an 8-year period, in obstetrics outcomes after the Great East Japan Earthquake and the Fukushima power plant accident. We used data from the first 8 years of the Pregnancy and Birth Survey by the Fukushima prefectural government and compared data on obstetrics outcomes by year. Longitudinal changes in the occurrence of preterm birth before 37 gestational weeks, low birth weight, and anomalies in newborns were assessed in all six districts in Fukushima. The total number of participants was 57537. In 8 years, maternal age, rate of conception after sterility treatment, and incidence of cesarean section delivery tended to increase ($p<0.001$, $p<0.001$, and $p=0.009$, respectively). Although significant differences were observed in preterm birth and low birth weight among the districts ($p=0.020$ and $p=0.025$, respectively), no significant trend was observed in the preterm birth, low birth weight, and anomalies in newborns in all six districts ($p=0.096$, $p=0.269$, and $p=0.239$, respectively). The Great East Japan Earthquake and the Fukushima power plant accident were associated with increased incidence of cesarean section delivery but had no significant adverse effects on obstetrics outcomes.

Introduction

The Great East Japan Earthquake and Tsunami and the subsequent accident at the Fukushima Daiichi Nuclear Power Station are the most tragic events in Japananse history. The Tsunami in Fukushima resulted in the death of several thousand individuals, especially those who lived in the coastal area of Soso and Iwaki district suffered damage. After the power station accident, many people (including the pregnant woman) who lived in these coastal areas were forced to seek refuge, by government order. On the contrary, Aizu district, which is a mountainous area in Fukushima prefecture and located far from Fukushima Daiichi poweplant, was less effected by this event compared to the costal areas (Fig. 1). After the earthquake disaster, Fukushima health care investigation (FHMS) started a population-based study on residents in Fukushima prefecture from 2011 to evaluate the effect of low dose radiation exposure on pregnancy outcomes [1]. Although several studies have reported the association between disaster and perinatal health [2] or the effects of the Great East Japan Earthquake on perinatal outcomes in 2011 [3–7], only a few studies have examined chronological trends in the occurrence of perinatal outcomes after the disaster. The chronological trends in pregnancy outcomes after the Great East Japan Earthquake are of worldwide interest. Currently, the FHMS maintains the data from the investigation of the effects of this disaster on pregnancy and infant care.

This study aimed to examine 8-year chronological trends in perinatal outcomes after the Great East Japan Earthquake in Fukushima Prefecture by district, using data from the FHMS.

Results

The survey questionnaire was sent via mail to 115,155 pregnant women during the study period. In total, 57,537 women (response rate 50.0%) responded to the questionnaire. Women who had given birth before March 11, 2011 (n = 459), who received maternal and child health handbooks outside Fukushima Prefecture (n = 176), for whom sufficient data were unavailable (n = 128), who were pregnant at the time of the survey (n = 165), who had had an abortion (n = 427), and those with triplets (n = 3) were excluded from the study. After applying these exclusion criteria, 57,375 women were finally included in the analyses. The number of cases from 2011 to 2018 was 9,299, 7,085, 7,152, 7,024, 6,913, 7,191, 6,332, and 6,541, respectively (Fig. 2).

Table 1 shows the chronological changes in response rates by district. The Mantel-Haenszel test showed a significant decrease trend in the response rate from 58.2% in 2011 to 51.4% in 2018 ($p < 0.001$). This decreasing trend was observed in all districts except Kennan ($p = 0.652$). The Chi-square test showed differences in response rates among districts. During the study period, Kenpoku had the highest response rate, except in 2011, when the area with the highest response rate was Soso (65.6%), a coastal area and the location of the Fukushima Daichi power plant.

Table 1
Chronological change in response rate by each district

	2011	2012	2013	2014	2015	2016	2017	2018	[a]p va
Response rate									
All Fukushima, %	58.2	49.1	47.3	46.8	47.8	51.3	47.1	51.4	< 0
(Res/Send)	(9299/15972)	(7085/14420)	(7152/15108)	(7024/15017)	(6913/14454)	(7191/14019)	(6332/13435)	(6541/12730)	
Kenpoku, %	62.8†	55.5†	53.2†	52.4†	52.3†	55.9†	50.9†	56.5†	< 0
(Res/Send)	(2289/3647)	(1857/3347)	(1936/3637)	(1841/3515)	(1806/3453)	(1875/3352)	(1634/3212)	(1702/3015)	
Kenchu, %	59.3	48.7	44.5†	44.8†	45.2†	49.8*	46.8	51.1	< 0
(Res/Send)	(2858/4819)	(2067/4243)	(1982/4453)	(1961/4376)	(1924/4261)	(2065/4150)	(1862/3980)	(2006/3923)	
Kennan, %	50.2†	48.1	48.5	46.5	47.9	51.1	45.1	50.0	0
(Res/Send)	(631/1256)	(560/1164)	(588/1213)	(553/1188)	(560/1168)	(571/1118)	(473/1048)	(504/1008)	
Soso, %	65.6†	43.7†	45.4	42.2†	44.2†	43.6†	40.5†	42.3†	< 0
(Res/Send)	(963/1468)	(500/1145)	(535/1178)	(512/1213)	(523/1183)	(511/1171)	(442/1091)	(424/1003)	
Iwaki, %	55.9†	47.8	45.1*	45.8	46.6	50.1	45.5	49.1*	< 0
(Res/Send)	(1515/2711)	(1203/2516)	(1195/2649)	(1213/2648)	(1148/2461)	(1192/2377)	(1054/2317)	(1034/2105)	
Aizu, %	50.4†	44.8†	46.3	45.5	49.4	52.8	48.5	52.0	0
(Res/Send)	(1043/2071)	(898/2005)	(916/1978)	(944/2077)	(952/1928)	(977/1851)	(867/1787)	(871/1676)	
[b]p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	

[a] p-value was calculated by the Mantel-Haenszel test for trend.

[b] p-value was calculated by Chi-square test. † indicates p < 0.01, * indicates p < 0.05

Table 2 shows the characteristics of the respondents based on the year of delivery. Although maternal age, gestational age at delivery, and the ratio of male newborns showed significant differences during the study period ($p < 0.001$, $p < 0.001$, and $p = 0.046$), there was no significant difference in the mean neonatal weight ($p = 0.912$). Additionally, there were no significant differences in the rate of single pregnancy ($p = 0.368$). The rate of conception after sterility treatment and cesarean delivery tended to increase ($p < 0.001$ and $p = 0.005$).

Table 2
Characteristics of respondents based on year of delivery

	2011	2012	2013	2014	2015	2016	2017	2018	p-value
Maternal age, mean ± SD	30.7 ± 5.0	31.0 ± 5.0	31.3 ± 5.0	31.4 ± 5.1	31.6 ± 5.0	31.4 ± 5.0	31.6 ± 5.0	31.8 ± 5.0	< 0.001[b]
n	8598	6940	7044	6940	6815	7091	6288	6463	
Twin pregnancy, %	0.9	0.9	1,1	1.0	0.9	0.8	0.8	0.9	0.368[a]
Gestational week, mean ± SD	38.9 ± 1.7	38.9 ± 1.7	38.9 ± 1.7	38.9 ± 1.8	38.8 ± 1.8	38.9 ± 1.7	38.8 ± 1.7	38.8 ± 1.8	< 0.001[b]
n	8566	6926	7015	6930	6801	7086	6286	6453	
Neonatal weight, mean ± SD	3013 ± 418	2993 ± 435	3003 ± 435	2996 ± 455	2994 ± 445	2999 ± 432	3007 ± 432	3003 ± 438	0.912 [b]
n	8603	6935	7088	6999	6859	7122	6319	6504	
Mode of pregnancy									
Sterility treatment, %	4.3	5.4	6.0	6.6	6.9	7.9	8.0	8.4	< 0.001[a]
Sex of newborn									
male, %	51.4	52.5	50.4	51.3	50.1	50.3	50.7	50.8	0.046[a]
Stillbirth, %	0.25	0.29	0.34	0.21	0.25	0.21*	0.22*	0.18*	0.690[a]
Mode of delivery									
cesarean delivery, %	20.7	21.7	20.3	21.0	22.3	21.2	21.8	22.6	0.005[a]

*excluded confirmed abortion and stillbirth cases or cases of neonates not confirmed to survive; before sending the questionnaires,

[a] p-value was calculated by the Mantel-Haenszel test for trend.

[b] p-value was calculated by Jonckheere-Terpstra trend test.

Table 3 shows the chronological change in the occurrence of preterm birth (PTB) by the district. The Chi-square test showed no significant difference in the occurrence of PTB among the districts, except in 2012 ($p = 0.020$). There was no significant trend in the occurrence of PTB between 2011 and 2018 in all areas ($p = 0.197$)

Table 3
Chronological change in the occurrence of preterm birth by each district

	2011	2012	2013	2014	2015	2016	2017	2018	[a]p-value
All area, n (%)	395 (4.6)	393 (5.6)	373 (5.3)	375 (5.4)	386 (5.6)	380 (5.3)	335 (5.3)	341 (5.2)	0.197
Kenpoku, n (%)	91 (4.3)	82 (4.5) *	94 (4.9)	96 (5.2)	105 (5.9)	91 (4.9)	72 (4.4)	89 (5.3)	0.247
Kenchu, n (%)	114 (4.3)	127 (6.2)	95 (4.8)	107 (5.5)	119 (6.2)	103 (5.0)	103 (5.6)	108 (5.4)	0.254
Kennan, n (%)	28 (4.7)	23 (4.1)	33 (5.7)	25 (4.6)	34 (6.1)	30 (5.3)	27 (5.7)	29 (5.8)	0.197
Soso, n (%)	38 (4.3)	31 (6.5)	35 (6.6)	31 (6.1)	30 (5.8)	29 (5.7)	21 (4.8)	9 (2.2)	0.207
Iwaki, n (%)	71 (5.1)	65 (5.5)	69 (5.9)	72 (5.9)	46 (4.1)	63 (5.3)	62 (5.9)	56 (5.5)	0.886
Aizu, n (%)	53 (5.4)	65 (7.3) *	47 (5.2)	44 (4.7)	52 (5.5)	64 (6.6)	50 (5.8)	50 (5.7)	0.962
[b]p-value	0.633	0.020	0.501	0.718	0.215	0.498	0.481	0.111	

[a] p-value was calculated by the Mantel-Haenszel test for trend.

[b] p-value was calculated by Chi-square test. * indicates $p < 0.05$

Table 4 shows the chronological change in the occurrence of low birth weight (LBW) by the district. There was no significant difference with regard to the occurrence of LBW during the study period. In 2011, a significant difference in the occurrence of LBW was observed between Kenpoku (7.6%) and Iwaki districts (10.3%). In 2012, there was also a significant difference with respect to the occurrence of LBW between Kenpoku (7.6%) and Aizu districts (11.3%).

Table 4
Chronological change in the occurrence of low birth weight by each district

	2011	2012	2013	2014	2015	2016	2017	2018	[a]p-value
All Fukushima, n (%)	736 (8.6)	640 (9.3)	681 (9.6)	683 (9.8)	650 (9.5)	659 (9.3)	584 (9.3)	589 (9.1)	0.500
Kenpoku, n (%)	160 (7.6) *	138 (7.6)†	171 (8.9)	168 (9.2)	155 (8.7)	151 (8.1)	155 (9.5)	145 (8.6)	0.107
Kenchu, n (%)	217 (8.3)	208 (10.3)	191 (9.7)	192 (9.8)	208 (10.9)	187 (9.2)	166 (9.0)	180 (9.0)	0.908
Kennan, n (%)	47 (8.0)	51 (9.2)	58 (9.9)	49 (9.1)	54 (9.8)	56 (9.9)	38 (8.1)	46 (9.3)	0.756
Soso, n (%)	70 (7.9)	43 (9.3)	47 (8.9)	57 (11.3)	56 (10.9)	46 (9.1)	50 (11.3)	34 (8.2)	0.254
Iwaki, n (%)	143 (10.3)†	101 (8.6)	120 (10.3)	119 (9.8)	99 (8.7)	118 (10.0)	98 (9.3)	99 (9.7)	0.759
Aizu, n (%)	99 (10.2)	99 (11.3) *	94 (10.4)	98 (10.4)	78 (8.4)	101 (10.4)	77 (8.9)	85 (9.7)	0.210
[b]p-value	0.031	0.025	0.761	0.736	0.099	0.349	0.638	0.867	

[a] p-value was calculated by the Mantel-Haenszel test for trend.

[b]p-value was calculated by the Chi-square test. † indicates $p < 0.01$, * indicates $p < 0.05$

Table 5 shows the chronological change in the occurrence of anomalies in newborns. There was no significant trend in the occurrence of anomalies in newborns between 2011 and 2018 in all areas (p = 0.069). Kenchu district tended to show a decrease in the rate of anomalies in newborns (p = 0.011)

Table 5
Chronological change in the occurrence of anomalies in newborns by district

	2011	2012	2013	2014	2015	2016	2017	2018	[a]p-value
All Fukushima, n (%)	238 (2.85)	161 (2.35)	170 (2.44)	163 (2.36)	150 (2.21)	176 (2.49)	153 (2.44)	144 (2.23)	0.069
Kenpoku, n (%)	55 (2.66)	39 (2.17)	44 (2.32)	54 (2.99)	31 (1.75)	41 (2.22)	40 (2.47)	41 (2.45)	0.684
Kenchu, n (%)	78 (3.07)	49 (2.43)	50 (2.60)	49 (2.54)	48 (2.54)	57 (2.81)	34 (1.85)	36 (1.82)	0.011
Kennan, n (%)	24 (4.20)	13 (2.39)	9 (1.56)	11 (2.04)	18 (3.26)	12 (2.14)	9 (1.92)	10 (2.01)	0.088
Soso, n (%)	18 (2.09)	13 (2.86)	9 (1.75)	9 (1.79)	7 (1.36)	13 (2.60)	8 (1.82)	12 (2.88)	0.800
Iwaki, n (%)	38 (2.81)	26 (2.23)	35 (3.04)	22 (1.83)	27 (2.41)	26 (2.24)	33 (3.15)	22 (2.15)	0.694
Aizu, n (%)	25 (2.63)	21 (2.40)	23 (2.58)	18 (1.93)	19 (2.04)	27 (2.80)	29 (3.36)	23 (2.67)	0.408
[b]p-value	0.268	0.970	0.411	0.261	0.181	0.787	0.099	0.607	

[a] p-value was calculated by the Mantel-Haenszel test for trend.

[b] p-value was calculated by Chi-square test.

Table 6 shows the chronological change in neonatal anomalies by year. There was no significant trend in the occurrence of each neonatal anomaly.

Table 6
Chronological change in the occurrence of major anomalies in newborns

	2011	2012	2013	2014	2015	2016	2017	2018	p-value*
All anomaly	238/8345	161/6858	170/6954	163/6915	150/6790	176/7064	153/6278	144/6455	0.069
%	2.85%	2.35%	2.44%	2.36%	2.21%	2.49%	2.44%	2.23%	
Cataract	1	2	1	0	0	1	1	1	0.743
%	0.01%	0.03%	0.01%	0.00%	0.00%	0.01%	0.02%	0.03%	
Cardiac malformation	77	54	70	53	53	66	38	60	0.445
%	0.92%	0.79%	1.01%	0.77%	0.78%	0.93%	0.61%	0.93%	
Kidney/urinary tract malformation	22	14	12	24	14	16	25	14	0.451
%	0.26%	0.20%	0.17%	0.35%	0.21%	0.23%	0.40%	0.22%	
Spina bifida	5	5	3	5	4	3	4	3	0.678
%	0.06%	0.07%	0.04%	0.07%	0.06%	0.04%	0.06%	0.05%	
Microcephaly	1	1	0	1	0	0	0	0	0.129
%	0.01%	0.01%	0.00%	0.01%	0.00%	0.00%	0.00%	0.00%	
Hydrocephalus	1	3	4	2	1	2	1	1	0.478
%	0.01%	0.04%	0.06%	0.03%	0.01%	0.03%	0.02%	0.02%	
Cleft lip/palate	17	14	14	14	14	11	8	7	0.079
%	0.20%	0.20%	0.20%	0.20%	0.21%	0.16%	0.13%	0.11%	
Intestinal atresia	6	7	7	9	4	10	7	5	0.710
%	0.07%	0.10%	0.10%	0.13%	0.06%	0.14%	0.11%	0.08%	
Imperforate anus	4	2	2	5	2	2	3	4	0.695
%	0.05%	0.03%	0.03%	0.07%	0.03%	0.03%	0.05%	0.06%	
Poly/syndactylism	22	15	22	14	14	18	16	13	0.554
%	0.26%	0.22%	0.32%	0.20%	0.21%	0.25%	0.25%	0.20%	
Others	104	61	55	63	58	64	59	54	0.070
%	1.25%	0.89%	0.79%	0.91%	0.85%	0.91%	0.94%	0.84%	
a p-value was calculated by the Mantel-Haenszel test for trend.									
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Discussion

This is the first population-based study that examined chronological trends for pregnancy outcomes after a major disaster. Although the response rate in 2011 was the highest, especially in the Soso district, where the most damage occurred, the response rate tended to decrease over the years, with more than 50% reported in 2018. We also found a trend increase in mean maternal age, rate of conception after sterility treatment, and rate of cesarean delivery over the years. There were no distinct changes in the trend of occurrence regarding PTB, LBW, and fetal anomaly.

The response rate in this study was approximately 50%, and this varied significantly over the years and between the districts. While Kenpoku constantly had a higher response rate than other districts, Soso had a higher rate only in 2011. This difference may be related to their concern that pregnant women in Kenpoku and Soso districts were exposed to relatively higher radiation doses. Disasters potentially influence a range of reproductive outcomes [8]. Many studies examined the effects of exposure to disasters on pregnancy outcomes, and these exposures were usually from so-called “attacks” such as the World Trade Center disaster, the bombing attack in Serbia, and the Madrid train bombing; environmental and chemical disasters such as the Bhopal gas release in India, the Three Mile Island accident, and the Chernobyl accident; and natural disasters such as earthquakes, hurricanes, floods, and ice streams [3]. The Great East Japan Earthquake and Fukushima Daiichi nuclear accident form a complex disaster. They included natural disasters such as the Great Earthquake and tsunami and environmental/technical disasters such as the nuclear power plant accident.

The association between environmental/chemical disasters with the risk of PTB and fetal growth is conflicting. Goldman et al. reported that the Love Canal disaster in the United States did not show any increased risk of PTB among 227 residents [9]. However, Levi et al. reported that the Chernobyl accident affected the shortened gestational age among 88 mothers of Swedish women who were anxious at the time of the disaster [10]. In conflict with our study, the earthquake disaster in China increased the risk of PTB. Tan et al. compared PTB incidence with 6,638 pregnant women before the disaster and 6,365 pregnant women after the disaster [11]. The incidence of PTB was 5.6% and 7.4%, respectively, and was significantly high after the disaster ($p < 0.01$) [11]. In the whole of Japan, the number of high-risk women for obstetric complications is increasing along with increasing maternal age at first pregnancy [12–14]: the incidence of PTB pregnancy week (5.7%) and LBW < 2,500 g (9.4%) is approximately stable after the disaster [15]. The risk of PTB at Fukushima prefecture after the Great East Japan Earthquake is also conflicting. Hayashi et al. have reported no significant increase in the incidence of PTB < 37 weeks in the first year of the disaster among all pregnant women in Fukushima prefecture, using the same FHMS data [16]. At the time of the disaster, many pregnant women were forced to evacuate suddenly, which caused depressive symptoms in mothers [4, 17]. In relation to these depressive symptoms, Suzuki et al. have reported that the pregnant women who changed perinatal examination facilities by medical adaptation were significantly associated with shortening (β = -10.6, P < 0.001) of the gestational period and PTB (adjustment odds ratio 8.5, 95% confidence interval 5.8–12.5) compared to women who visited only one facility at Fukushima prefecture after the disaster [18].

The association between the environment or a natural disaster and fetal growth is also conflicting [16, 19–22]. Regarding fetal growth, we have reported no evidence that the Great East Japan Earthquake and the Fukushima Daiichi nuclear accident increased the risk of fetal growth restriction in Fukushima after the first year of the disaster [5].

Using an institution-based investigation of the coastal area where the most catastrophic damage occurred [4], Leppold et al. reported no increased proportions of PTBs or low birthweight in any year after the disaster (merged post-disaster risk ratio of PTB: 0.68, 95% CI: 0.38–1.21 and low birthweight birth: 0.98, 95% confidence interval: 0.64–1.51) [23]. In Japan, pregnant women may have better access to relief programs or receive adequate support from their families, society, and government during the disaster [4].

The effect of disasters on congenital anomalies is the main public concern. Some studies have reported that disasters are related to congenital abnormalities. Examples of the disasters include a nuclear reactor accident in Chernobyl in 1986 in Ukraine and a nuclear accident at Three Mile Island in Pennsylvania in 1979. A review of the influence of the Chernobyl disaster showed an increase in microchepalous and neural tube defects [24–26]. However, the incidence of major congenital anomalies did not increase in most European countries [27–29]. It was reported that 2–3% of all newborn babies had congenital abnormalities at birth [30, 31]. In Japan, from 2011 to 2016, the incidence of congenital disabilities was 2.43–2.59%, according to a report by the International Clearing house for Birth Defects Surveillance and Research) Japan Center [32]. Using a Japanese birth cohort study that included 12,804 pregnant women in Fukushima Prefecture, Kyozuka et al. reported that the prevalence of major congenital anomalies at delivery between 2011 and 2014 in Fukushima Prefecture was 1.6–3.2%, depending on maternal age [6]. Using the same data set as the present study, Fujimori et al. reported that the occurrence of congenital anomaly in Fukushima prefecture during the first year after the disaster was 2.72% (238/8672) [3].

Environmental endocrine disrupters, a group of compounds with potentially adverse health effects, are thought to be associated with cryptorchidism [33]. Kojima et al. decried the difficulties in clarifying the prevalence of cryptorchidism because of complexities in design settings for epidemiological surveys of this disease. They rejected the hypothesis that cryptorchidism increased in Japan because of the Fukushima Daiichi Nuclear Power Plant accident [34]. Hirai et al., using the All Japanese Cardiovascular Surgery Database, reported no increase in the number of patients with congenital heart disease from 2010 to 2013 [35].

Our study has several strengths. In Japan, few epidemiological studies involve pregnant women in a community, and our study is one of them. Large-scale studies and data supported by the government are considered valuable. In addition, we obtained relatively precise data on gestational ages and birth weights of the participants from their maternal and child health handbooks.

Nevertheless, this study has potential limitations. First, because the response rate was only approximately 50–60% through the study period, the actual incidence of adverse outcomes may have been overestimated if there was an overrepresentation of women affected the most by the disasters, especially pregnant women, in 2011 and 2012. Second, as this study used a self-administered questionnaire, it is assumed that the mothers answered correctly, especially regarding fetal anomalies. Third, this survey analyzed each district and failed to investigate the relationship with individual radiation exposure doses.

In conclusion, the findings of our study and those of previous studies indicated that there was little effect on pregnant women exposed to the Great East Japan Earthquake and other kinds of disasters during the first 8 years. Improving the understanding of the adverse reproductive effects of disasters requires as much preparedness as needed for an emergency response to prevent mortality and morbidity [4]. Further studies should be conducted to examine whether the disaster causes early pregnancy loss, such as miscarriage or abortion, and psychological complications.

Methods

Study design

For this analysis, we used the maternal survey questionnaire results from the FHMS. The methods used for the FHMS and maternal survey have been previously reported [1]. Maternal survey is a population-based study conducted as part of the FHMS launched by the Fukushima Prefecture government in 2011 to assess the health condition of pregnant women and their neonates after the Great East Japan Earthquake. In this study, Fukushima Prefecture was divided into six districts [3], and women who received the maternal and child health handbook on August 1, 2010, were included. The maternal and child health handbook is a unique perinatal health care initiative in Japan. The handbook helps maintain a record of women's antenatal and postnatal checkups by physicians. The self-reported questionnaire was sent to the participants by mail on January 18, 2012. While completing the questionnaire, the mothers were asked to refer to their maternal and child health handbooks. This study was approved by the local ethics review committee of Fukushima Medical University, Japan (Approval No, 1317), and written informed consent was obtained from all the participants. All procedures in this study were performed in accordance with the ethical standards of the institutional and/or national research committee and the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

The participants were pregnant women and their newborns delivered between March 11, 2011, and December 31, 2018. Cases of delivery before March 11, 2011, women who received a maternal and child health handbook outside Fukushima Prefecture, those with insufficient data, pregnant women at the time of the survey, those who had had an abortion, and mothers with triplets were excluded from this analysis.

Maternal Data and obstetrics outcome

The self-reported questionnaire included maternal information, such as geographic districts where pregnant women received the maternal and child health handbook, year of delivery, maternal age at delivery, single or multiple gestational pregnancies, gestational weeks at delivery, mode of pregnancy, and mode of delivery, and neonatal information, such as neonatal birth weight, sex of newborn, and presence of anomalies in newborns. The six geographic districts classified were Kenpoku, Kenchu, Kennan, Soso, Iwaki, and Aizu (Fig. 1). Delivery before 37 gestational weeks was defined as PTB, and birth weight less than 2500 g was defined as the LBW. The mode of pregnancy was categorized as natural pregnancy or sterility treatment, such as ovulation induction, artificial insemination, or in vitro fertilization. Mode of delivery was categorized as vaginal delivery or cesarian section. Major anomalies reported in newborns were as follows: cataracts, cardiac malformation, kidney or urinary tract malformation, spina bifida, microcephaly, hydrocephalous, cleft lip or palate, intestinal atresia (esophagus, duodenum, and ileum), imperforate anus, and poly or syndactylism. Every anomaly reported in the questionnaire was defined as a major anomaly.

Statistical analysis

The maternal characteristics of neonates were categorized into six groups according to the year of birth. Chi-square test was used to compare the categorical variables, such as response rate and perinatal outcomes, among the areas per year. The extended Mantel-Haenszel Chi-square test for linear trends was used to analyze the trends in proportion between 2011 and 2018. The Jonckheere-Terpstra trend test was also used to analyze trends in continuous variables between 2011 and 2018. SPSS ver. 26 (IBM Japan, Tokyo) was used for data analysis, and a $p < 0.05$ was considered to indicate statistical significance.

Declarations

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Author contributions

H.K., K.F., S.Y., A.G, and K.K. initiated the concept and designed the study, and K.H., A.N., K.S., and M.O. provided additional advice. K.I, T.M, and Sh. Y collected the data. H.K., K.I., and T.O. analyzed the data and wrote the manuscript. H.O. and K.K reviewed the manuscript and gave critical advice. All authors read and approved the final manuscript.

Additional Information

Competing interests

The authors declare no competing interests

Data availability

The datasets used analysed during the current study available from the corresponding author on reasonable request.

References

1. Yasumura, S. *et al.* Study protocol for the Fukushima health management survey. J. Epidemiol. **22**, 375–383 (2012).
2. Harville, E., Xiong, X. & Buekens, P. Disasters and perinatal health: a systematic review. Obstet. Gynecol. Surv. **65**, 713–728 (2010).
3. Fujimori, K. *et al.* Pregnancy and birth survey after the great East Japan earthquake and Fukushima daiichi nuclear power plant accident in Fukushima prefecture. Fukushima J. Med. Sci. **60**, 75–81 (2014).
4. Kyozuka, H. *et al.* Impact of the Great East Japan Earthquake on feeding methods and newborn growth at 1 month postpartum: results from the Fukushima Health Management Survey. Radiat. Environ. Biophys. **55**, 139–146 (2016).
5. Yasuda, S. *et al.* Influence of the Great East Japan Earthquake and the Fukushima Daiichi nuclear disaster on the birth weight of newborns in Fukushima Prefecture: Fukushima Health Management Survey. J. Matern. Fetal Neonatal Med. **30**, 2900–2904 (2017).
6. Kyozuka, H. *et al.* The Japan Environment and Children's Study (JECS) in Fukushima Prefecture: Pregnancy Outcome after the great East Japan earthquake. Tohoku J. Exp. Med. **246**, 27–33 (2018).
7. Kyozuka, H. *et al.* The effect of the Great East Japan Earthquake on hypertensive disorders during pregnancy: a study from the Fukushima Health Management Survey. J. Matern. Fetal Neonatal Med. **33**, 4043–4048 (2020).

8. Cordero, J. F. The epidemiology of disasters and adverse reproductive outcomes: lessons learned. *Environ. Health Perspect.* **101** Supplement 2, 131–136 (1993).
9. Goldman, L. R., Paigen, B., Magnant, M. M. & Highland, J. H. Low birth weight, prematurity and birth defects in children living near the hazardous waste site, Love Canal. Hazardous Waste Hazardrous. Materials. **2**, 209–223 (1985).
10. Levi, R., Lundberg, U., Hanson, U. & Frankenhacuser, M. Anxiety during pregnancy after the Chernobyl accident as related to obstetric outcome. J. Psychosom. Obstet. Gynecol. **10**, 221–230 (1989).
11. Tan, C. E. *et al.* The impact of the Wenchuan earthquake on birth outcomes. PLOS ONE **4**, e8200 (2009).
12. Kyozuka, H. *et al.* The effect of maternal age at the first childbirth on gestational age and birth weight: the Japan Environment and Children's Study (JECS). *J. Epidemiol.* 29, 187–191 (2019), JE
13. Kyozuka, H. *et al.* Risk factors for placenta accreta spectrum: findings from the Japan environment and Children's study. BMC Pregnancy Childbirth **19**, 1–7 (2019).
14. Yamaguchi, A. *et al.* Japan envi-ronment and children's study group. Risk of preterm birth, low birthweight and small-for-gestational-age infants in pregnancies with adenomyosis: A cohort study of the Japan Environment and Children's Study. Acta Obstet. Gynecol. Scand. **98**, 359–364 (2019).
15. Mother's and children's health organization in *Maternal and Child Health Statistics of Japan. Live Births and Percentages by Period of Gestation*; Vol. 49 1980–2011 (2019).
16. Hayashi, M., Fujimori, K., Yasumura, S., Goto, A. & Nakai, A. Obstetric outcomes in women in Fukushima Prefecture during and after the Great East Japan Earthquake and Fukushima nuclear power plant accident: the Fukushima Health Management Survey. Open J. Obstet. Gynecol. **06**, 705–713 (2016).
17. Goto, A., Bromet, E. J., Fujimori, K. & Pregnancy and Birth Survey Group of Fukushima Health Management Survey. Immediate effects of the Fukushima nuclear power plant disaster on depressive symptoms among mothers with infants: a prefectural-wide cross-sectional study from the Fukushima Health Management Survey. BMC Psychiatry **15**, 59 (2015).
18. Suzuki, K., Goto, A. & Fujimori, K. Effect of medical institution change on gestational duration after the Great East Japan Earthquake: the Fukushima Health Management Survey. J. Obstet. Gynaecol. Res. **42**, 1704–1711 (2016).
19. Chang, H. L., Chang, T. C., Lin, T. Y. & Kuo, S. S. Psychiatric morbidity and pregnancy outcome in a disaster area of Taiwan 921 earthquake. Psychiatry Clin. Neurosci. **56**, 139–144 (2002).
20. Xiong, X. *et al.* Exposure to Hurricane Katrina, post-traumatic stress disorder and birth outcomes. Am. J. Med. Sci. **336**, 111–115 (2008).
21. Tong, V. T., Zotti, M. E. & Hsia, J. Impact of the Red River catastrophic flood on women giving birth in North Dakota, 1994–2000. Matern. Child Health J. **15**, 281–288 (2011).
22. Hamilton, B. E., Sutton, P. D., Mathews, T. J., Martin, J. A. & Ventura, S. J. The effect of Hurricane Katrina: births in the U.S. Gulf Coast Region, before and after the Storm. Natl Vital Stat. Rep. **58**, 1–32 (2009).
23. Leppold, C. *et al*. Birth outcomes after the Fukushima Daiichi nuclear power plant disaster: a long-term retrospective study. Int. J. Environ. Res. Public Health **14**, 542 (2017).
24. Wertelecki, W. Malformations in a Chornobyl-impacted region. Pediatrics **125**, e836–e843 (2010).
25. Wertelecki, W. *et al.* Chornobyl 30 years later: radiation, pregnancies, and developmental anomalies in Rivne, Ukraine. Eur. J. Med. Genet. **60**, 2–11 (2017).
26. Wertelecki, W. *et al.* Chornobyl, radiation, neural tube defects, and microcephaly. Eur. J. Med. Genet. **61**, 556–563 (2018).
27. Dolk, H. & Nichols, R. Evaluation of the impact of Chernobyl on the prevalence of congenital anomalies in 16 regions of Europe. EUROCAT Working Group. Int. J. Epidemiol. **28**, 941–948 (1999).
28. Hoffmann, W. Fallout from the Chernobyl nuclear disaster and congenital malformations in Europe. Arch. Environ. Health **56**, 478–484 (2001).
29. Little, J. The Chernobyl accident, congenital anomalies and other reproductive outcomes. Paediatr. Perinat. Epidemiol. **7**, 121–151 (1993).
30. Cragan, J. D. & Gilboa, S. M. Including prenatal diagnoses in birth defects monitoring: experience of the Metropolitan Atlanta Congenital Defects Program. Birth Defects Res. A Clin. Mol. Teratol. **85**, 20–29 (2009).
31. Dolk, H., Loane, M. & Garne, E. The prevalence of congenital anomalies in Europe. Adv. Exp. Med. Biol. **686**, 349–364 (2010).
32. ICBDSR. (International clearinghouse for birth defects surveillance and Research) Japan center. https://icbdsr-j.jp/data.html, in Japanese.
33. Gurney, J. K. *et al.* Risk factors for cryptorchidism. Nat. Rev. Urol. **14**, 534–548 (2017).
34. Kojima, Y. *et al.* Cryptorchidism after the Fukushima Daiichi Nuclear Power Plant accident: causation or coincidence? Fukushima J. Med. Sci. **65**, 76–98 (2019).
35. Hirata, Y. *et al.* Congenital heart disease after the Fukushima nuclear accident: the Japan cardiovascular surgery database study. J. Am. Heart Assoc. **9**, e014787 (2020).

Figures

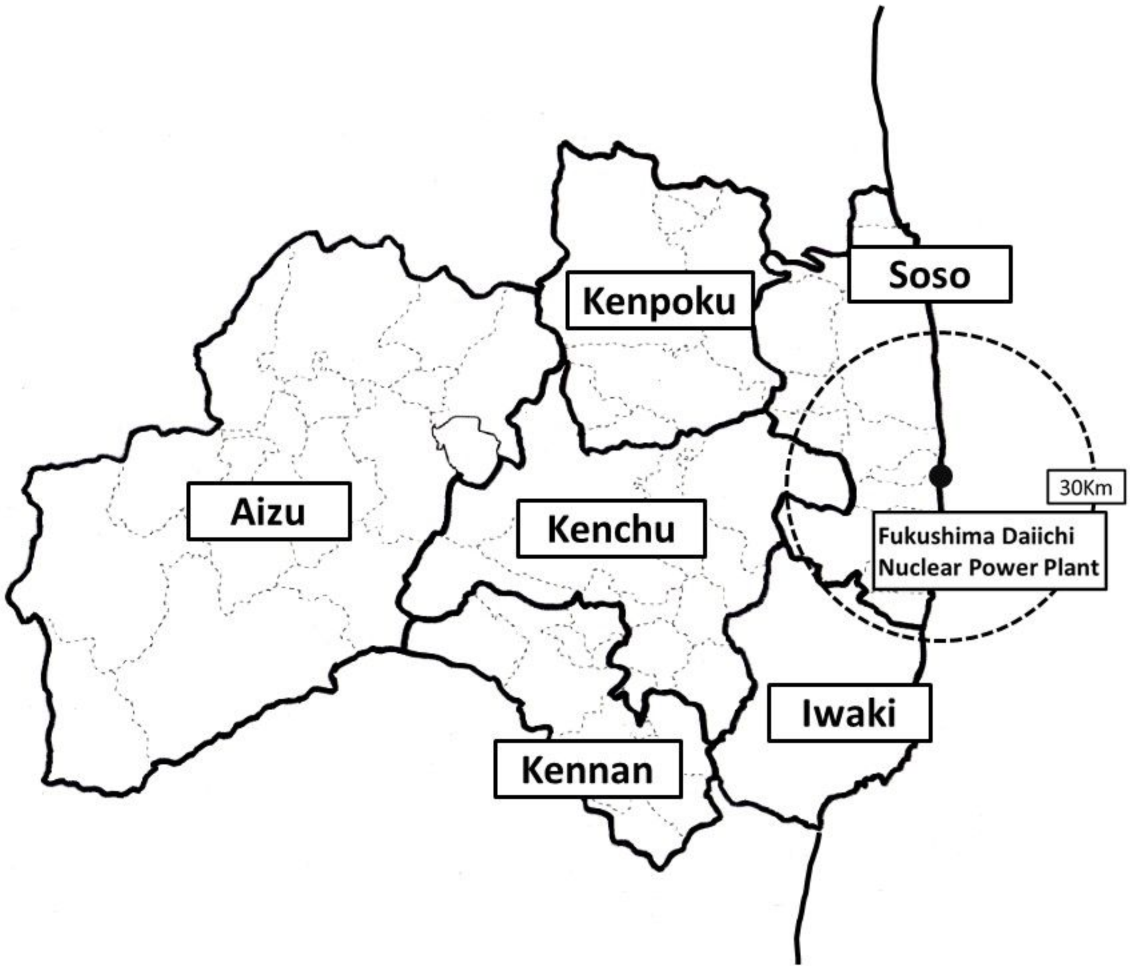

Figure 1

Geographic information of Fukushima Prefecture.

Geographic districts were classified into seven areas (Kenpoku, Kenchu, Kennan, Soso, Iwaki, Aizu, and Minami-Aizu). Aizu and Minami-Aizu areas were combined and called the Aizu area.

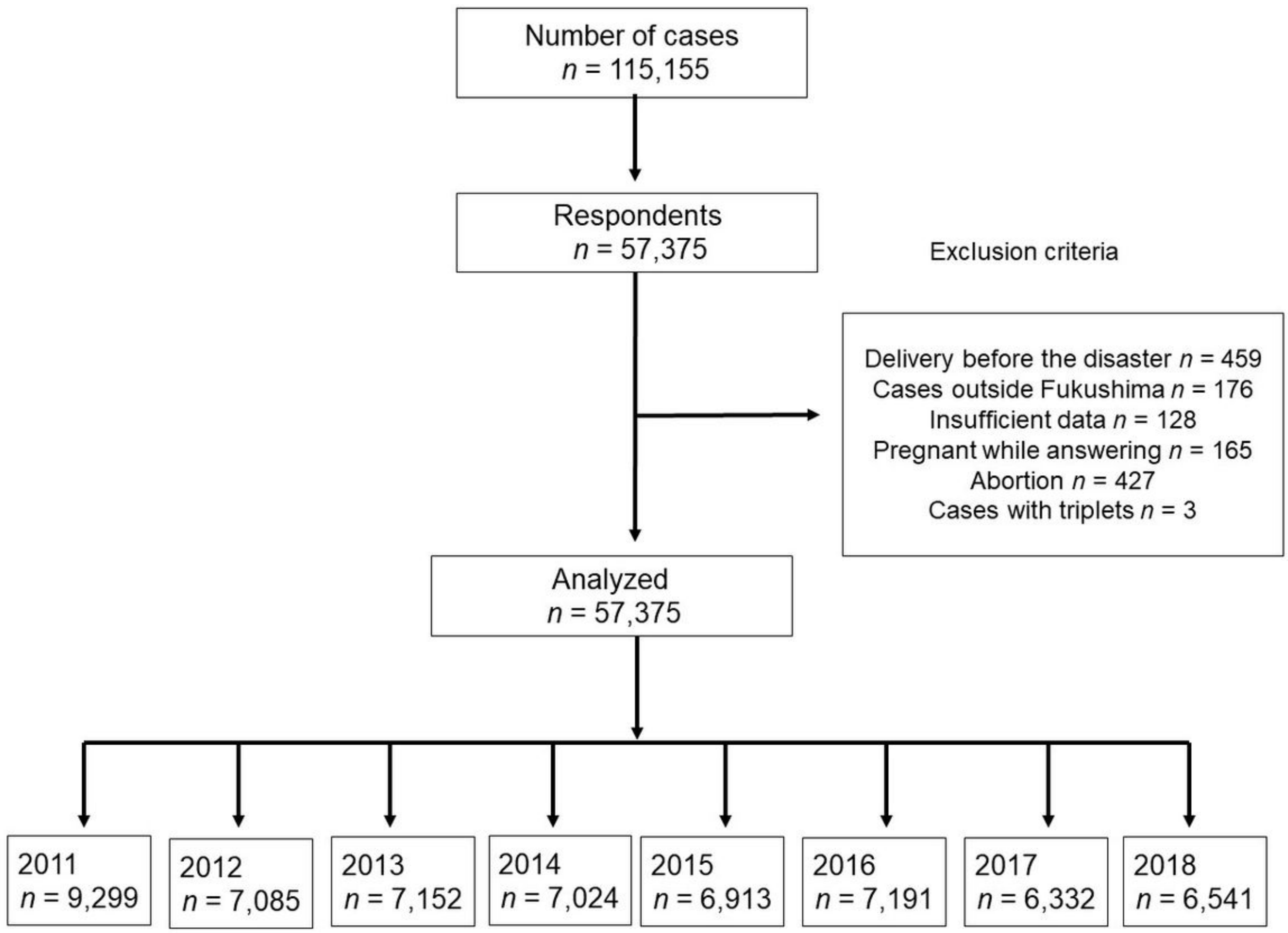

Figure 2

Flowchart of the study