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Post-Disaster Reproductive Health Outcomes

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Abstract

We examined methodological issues in studies of disaster-related effects on reproductive health outcomes and fertility among women of reproductive age and infants in the United States (US). We conducted a systematic literature review of 1,635 articles and reports published in peer-reviewed journals or by the government from January 1981 through December 2010. We classified the studies using three exposure types: (1) physical exposure to toxicants; (2) psychological trauma; and (3) general exposure to disaster. Fifteen articles met our inclusion criteria concerning research focus and design. Overall studies pertained to eight different disasters, with most (n = 6) focused on the World Trade Center attack. Only one study examined pregnancy loss, i.e., occurrence of spontaneous abortions post-disaster. Most studies focused on associations between disaster and adverse birth outcomes, but two studies pertained only to post-disaster fertility while another two examined it in addition to adverse birth outcomes. In most studies disaster-affected populations were assumed to have experienced psychological trauma, but exposure to trauma was measured in only four studies. Furthermore, effects of both physical exposure to toxicants and psychological trauma on disaster-affected populations were examined in only one study. Effects on birth outcomes were not consistently demonstrated, and study methodologies varied widely. Even so, these studies suggest an association between disasters and reproductive health and highlight the need for further studies to clarify associations. We postulate

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that post-disaster surveillance among pregnant women could improve our understanding of effects of disaster on the reproductive health of US pregnant women.

Keywords

Disaster; Birth outcomes; Low birth weight; Preterm birth; Fertility

Disasters, both natural and man-made, cannot be controlled by usual means for managing routine emergencies, necessitate immediate coordination and continuous response by diverse agencies, and are evaluated by how they affect people [1]. From 1980 through 2010 the United States (US) averaged 43 major declared disasters per year [2]. Largescale, weather-related disasters have become more frequent, and the impacts and losses from natural disasters have grown as populations have increased in vulnerable areas [3, 4]. As of October, overall damages and economic costs in 2011 from 10 separate natural disasters have exceeded $45 billion [5].

Disasters may impact women's reproductive health (RH) and their pregnancy outcomes through early pregnancy loss, birth defects, low birth weight (LBW) or preterm births (PTB) [6-10]. Post-disaster fertility may also change [11-14]. However, the underlying mechanisms for the observed associations between disaster and RH outcomes are not well understood. With the purpose of guiding obstetric practice, Harville et al. [10] reviewed international studies to determine impacts of different types of disaster on pregnant women and found inconsistent associations between disasters and perinatal health. In this paper we build on their work by focusing on methodological issues in US studies examining disaster-related effects on RH outcomes and fertility and postulate that post-disaster surveillance among pregnant women could improve our understanding of these associations.

Methods

To assess US disaster-related effects on RH outcomes and fertility, we conducted a systematic literature review of articles and reports published from 1981 through December 2010. The search focused on women or mothers and infants and disasters in the US and was limited to English language. The search terms included *reproductive health outcomes* (e.g., pregnancy, maternal risk, miscarriage), *birth outcomes* (e.g., birth weight, gestational age, birth defects), and *disaster* terms (e.g., hurricane, flood, terrorist). The search queried four databases: Medline (Ovid), the Cumulative Index to Nursing and Allied Health (CINAHL), Sociological Abstracts, and Web of Science. We also reviewed the reference lists in relevant review articles and in articles that met our inclusion criteria to identify additional citations of interest. We did not include abstracts of conference presentations, dissertations, or unpublished studies. We decided not to incorporate articles on birth defects since less severe defects may not be evident at birth [14].

Abstracts yielded from the search were screened for inclusion by a team of two researchers. To qualify for inclusion, studies had to: (1) pertain to Federal Emergency Management Agency (FEMA) major disaster declarations in the geographic area of the study, (2) examine the association between disaster and RH birth outcomes or fertility, (3) describe disaster

effects on pregnant women and on infants <28 days, (4) be published in a peer reviewed journal or government report, (5) be conducted in the US, (6) describe research methods, including design, setting, population and sample, outcomes of interest, data collection instruments and procedures, and data analysis techniques, and (7) be a prospective cohort or contain a comparison group.

First we appraised titles and sources, eliminating articles that did not meet our selection criteria. Then we read through the remaining abstracts to identify relevant articles. If the abstract was not provided, we requested the article and reviewed it to determine if it met our selection criteria. Lastly, we followed the same process as we evaluated articles listed in the reference lists described above.

Results

In our search we identified 1,635 articles, of which 15 articles met inclusion criteria from 1981 through 2010 (Table 1). There was only one study published prior to 2000. Overall the studies pertained to eight different disasters, with the largest number (n = 6) in response to the World Trade Center (WTC) attack. Only one study examined pregnancy loss, i.e., the occurrence of spontaneous abortions post-disaster [16]. Most studies focused on associations between disaster and adverse birth outcomes, but two studies pertained only to post-disaster fertility [11, 12] while another two examined it in addition to adverse birth outcomes [13, 14]. We classified the studies based on three types of exposure: (1) physical exposure to toxicants; (2) psychological trauma; and (3) general exposure to disaster. Regarding psychological trauma, most authors postulated that disaster-affected populations experienced psychological trauma, but there were only four studies [17-20] where exposure to trauma was measured. Furthermore, effects of both physical exposure to toxicants and psychological trauma on disaster-affected populations were examined in only one study [20].

Table 2 gives additional information on the 15 studies. Although Table 2 is organized by disaster and publication date (matching Table 1), the discussion below is organized by outcome and exposure because this approach seemed best to highlight the progression of scientific knowledge.

Pregnancy Loss

Physical exposure to toxicants has been postulated to affect RH and pregnancy loss. In the single study that focused on pregnancy loss, the investigators examined the relationship between physical exposure and spontaneous abortion.

Physical Exposure to Toxicants—In four New York counties during 1973, while investigating a cluster of leukemia and lymphoma cases thought to be related to high background radiation and a flood following Hurricane Agnes in 1972, Janerich et al. [16] also investigated a rise in spontaneous abortions (Table 2). The authors found a statistical increase in spontaneous abortions during 1973 (60.9 per 1,000 live births) compared with the other annual rates from 1970 to 1977 (ranging from 39.7 to 54.7 per 1,000 live births) even though radiation levels were not found to be elevated either in the water supply or at a

local school. The authors postulated that the increase could have been due to evacuation experiences or stress but were unable to document any association with the outcome.

It is difficult to interpret the results of this study, particularly in the light of current literature. The authors used the official definition for reporting fetal deaths, i.e., “the spontaneous expulsion from the mother’s body of dead products of conception of all gestational ages” as the definition of spontaneous abortion (12, p. 353). However, since 1950 ‘fetal death’ has been the preferred term since there are separate definitions of the terms ‘stillbirth’ and ‘induced abortion’ [21, 22]. Also, during 1970–1977, this ‘all gestational ages’ definition to report fetal deaths was only used in eight states since the other states included ≥20 weeks in their definitions, and New York City (NYC) limited reporting of fetal deaths to those that occurred ≥16 weeks of gestation [21, 23]. Furthermore, measuring spontaneous abortions is very difficult due to underreporting of losses before 20 weeks [21, 24], and even in studies using the most sensitive assays to detect human chorionic gonadotropin, some losses are not detectable [25]. Lastly, fetal loss rates are now derived from pregnancy history data in several cycles of the National Survey of Family Growth [26]. These estimates show that about 17 % of all pregnancies end in loss (not including induced abortions), making it a common outcome even without disaster exposure.

Birth Outcomes

Table 3 summarizes the results of birth outcomes studied. Only one study [27] focused on fetal distress. All others focused on dichotomous and/or continuous variables pertaining to gestation (n = 10) and birth weight (n = 10). Table 3 is also organized by disaster and publication dates (matching Table 1) but the discussion below is organized by outcome and exposure.

Physical Exposure to Toxicants—Four studies [20, 28-30] were conducted in response to the WTC attack where a toxic plume containing soot, benzene, polycyclic aromatic hydrocarbon (PAH), heavy metals, pulverized glass and concrete, and alkaline particulates was released into the atmosphere. These authors all studied the effects of exposure to the toxic atmosphere on birth outcomes. Berkowitz et al. [28] and Lederman et al. [29] used resident and work addresses to identify exposures while Perera et al. [30] studied BaP-DNA adducts (a proxy for PAH) in cord blood. Outcomes included: a twofold increased risk of intrauterine growth restriction (IUGR) but no increase in PTB or LBW [28]; significantly lower birth weights and lengths among infants with nonsmoking mothers living within two miles of the WTC [29]; and no independent effects on birth weight or length among infants of mothers living within 1 mile of the WTC [30]. Lederman et al. [29] also found that women exposed to the WTC attack early during the first trimester delivered an average of 3.6 days earlier compared with women exposed later in pregnancy. In the Lipkind et al. [20] study of 446 pregnant women enrolled in the WTC Health Registry, a woman was classified as physically exposed to toxicants if she reported being caught in a dust or debris cloud on September 11, 2001. In this study no associations were found between exposure and birth weight and gestational age distributions.

These studies suggest that exposures to toxicants may affect intrauterine growth but the effects are not consistent even though there is growing evidence of toxicants' impact on fetal growth in non-disaster studies [31]. In the studies above, except for examining cord blood, the exposures often were not measured but were inferred based on locations of the toxic plume associated with the disaster and maternal residences or places of employment– yielding possible misclassification that could dilute any effects that were seen. All of these methods for assessing exposure are common when studying environmental toxicant exposures and PTB [32]. However, the link between toxicants and PTB or fetal growth may be poorly understood due to lack of information about individual exposures, the distribution of the toxicant in the body during pregnancy, cumulative exposures, and thresholds needed to produce adverse effects [32, 33].

Psychological Trauma—Psychological trauma is another factor that has been studied to determine its effect on pregnancy outcomes (Table 2). In a study of 40 women who experienced an earthquake during pregnancy or early postpartum, psychological trauma (classified as how 'upsetting' or 'aversive' the earthquake was perceived to be) was rated differently based on the trimester in which it occurred (most stressful in first trimester, least stressful in third trimester) [17]. Furthermore, stress experienced in the first trimester was associated with significantly shorter gestation than in other trimesters, and gestation was longest among women who did not experience the earthquake.

Two studies examining effects of stress were conducted in response to the WTC attack. Engel et al. [18] measured post-traumatic stress symptomatology (PTSS) as a continuous variable using the Post-traumatic Stress Disorder (PTSD) Checklist, and used standard Beck Inventory of Depression cut-points to categorize depression ranging from normal to severe among 52 women who were pregnant on or shortly after September 11, 2001 and present at or near the WTC within 3 weeks of that date. Their study revealed that PTSS and moderate depression were associated with longer gestational duration compared with women exhibiting mild or no symptoms when adjusted for maternal age. In the Lipkind et al. [20] study, the PTSD Checklist was also used, and women were classified as having PTSD if they scored ≥44. Among these women, PTSD was associated with both LBW and PTB. They also conducted an historical comparison to examine exposure by trimester; their results suggested a seasonal effect rather than trimester of disaster exposure.

In a study of 301 Louisiana women exposed to Hurricane Katrina [19], the following instruments were used to measure psychological trauma: PTSD Checklist (PTSD); the Edinburgh Depression Scale (depression); and an adapted instrument from the Social and Cultural Dynamics of Disaster Recovery study after Hurricane Andrew (hurricane exposure). The authors found no associations between PTSD or depression and LBW or PTB. Instead these authors found an association between LBW and high hurricane exposure, i.e., reporting three or more of eight severe hurricane experiences.

These studies demonstrated that the association between psychological trauma and birth outcomes is not consistent. Furthermore, these studies suggest that this type of trauma may affect LBW and PTB, but the best approach to measuring trauma to predict risk is not clear. Beginning with the WTC attack, authors used standard measurements for PTSS, PTSD, and

depression but associations were inconsistent with LBW and PTB. The Xiong et al. [19] study suggests that measuring hurricane exposure may be a better method for examining associations. Lastly, it is not clear that timing of trauma during the pregnancy may affect outcomes. The Glynn et al. [17] study indicated that trimester of exposure was an important factor, but the study by Lipkind et al. [20] did not verify that relationship.

General Exposure to Disaster—For all five general exposure (ecological) studies, the investigators used birth certificate data to examine exposure to disaster and birth outcomes (Table 2). Zahran et al. [27] used monthly time series, logistic regression and spatial techniques to examine effects of Hurricane Andrew on fetal distress in four separate analyses of very large birth files. Increased fetal distress was found during the hurricane exposure period compared with nonexposure periods and in areas of high hurricane destruction. Second and third trimester of exposure was also associated with increased odds of fetal distress.

In a study of the 1997 North Dakota Red River flood [14], investigators compared pre-disaster to post-disaster births (N = 57,007) using logistic regression to detect birth outcomes associated with the disaster. LBW and PTB significantly increased statewide, but these outcomes differed in the geographic areas where significant increases occurred—LBW in six counties most affected by the disaster but PTB in areas not directly affected. Furthermore, these authors reported a significant increase in medical risks, such as hypertensive disorders and anemia, among the women giving birth.

To examine whether the WTC attack was associated with changes in LBW or PTB, Eskenazi et al. [34] used 1,660,401 births to New York residents from January 1996 through December 2002, excluding residents with diabetes, in lower Manhattan in zip codes with greatest potential exposure to physical toxicants, or with missing birth weights. They compared the week beginning with September 11 with the prior three week period and these same time periods during the preceding 2 years. In addition, they compared birth outcomes among residents of NYC and in upstate New York. There was an increase of risk for births of infants 1,500–1,999 g among NYC residents during the first week after the WTC attack but that effect was not observed among upstate residents. The authors postulated that stress may have contributed to these outcomes.

Investigators in two different studies examined birth outcomes in geographic areas affected by Hurricane Katrina. Hamilton et al. [13] studied 62,368 births in 14 selected FEMA designated counties or parishes within the hurricane path to look for changes in PTB, LBW and very low birth weight (VLBW), comparing 12 months before the hurricane to the 12 months after. Overall, changes were not observed in any of the three outcomes even though very PTB increased in Alabama and VLBW decreased in Louisiana while VLBW increased in Alabama. The results suggested that Louisiana women with higher risk of poor birth outcomes may have relocated after the hurricane to areas outside the selected parishes and counties. Using 254,665 Louisiana births, Harville et al. [35] examined PTB and LBW statewide and in areas most affected by Hurricane Katrina, comparing the 2 years following the storm to 2 years before it. Statewide LBW rose, but PTB did not. In areas most affected by the storm, LBW remained constant while PTB fell. The analyses revealed that the

changes were partially due to changes in the risk profile of the population but not completely. The authors hypothesized that other factors, such as changes in Medicaid coverage, fertility and unknown patterns of population shifts, may have affected birth outcomes.

The above studies suggested associations between disaster and LBW, but the associations were not consistent. Furthermore, some studies revealed that only certain categories of LBW were significant, such as moderate LBW [34] or VLBW among selected populations [13]. There was inconsistency in effects on PTB, and only very PTB was significant among selected populations in the study by Hamilton et al. [13].

Although the analytic methods of the Zahran et al. [27] paper are compelling, using fetal distress as the outcome is problematic because the term fetal distress “is imprecise and nonspecific” [36]. For example, in a Washington study of the validity of variables on birth certificates among women with low-risk pregnancies, only 21.5 % of fetal distress was accurately reported on the birth certificate compared with hospital records, much lower than other conditions [37]. The authors speculated that this low sensitivity was partly due to differing standards for recording the diagnosis of fetal distress on the birth certificate. Thus, the birth certificate item of ‘fetal distress’ used on the 1989 revision [38] was revised on the 2003 revision to clarify its definition [39].

Most authors above used the standard measures of LBW (<2,500 g) [40] and PTB (<37 weeks of gestation) [41] as outcomes. These measures on the birth certificate are likely to agree with hospital data [37]. However, birth weight is more completely and accurately recorded than gestational age [42].

Overall, the authors above postulated that stress from the disasters could affect birth outcomes, but birth certificate files do not contain measures of stress or other exposures. Therefore it is not possible to know what factors were associated with poor birth outcomes. Furthermore it was not possible to determine if the observed rise in LBW and/or PTB resulted from the disasters or was part of the US secular trend of these outcomes [43, 44].

Fertility

There were four studies that addressed fertility after different types of disasters. After Hurricane Hugo, Cohan and Cole [11] conducted time series analyses on birth certificate files to compare 24 hurricane-affected counties to 22 comparison counties. In the year following Hurricane Hugo, birth rates significantly increased. After the bombing, Rodgers and Coleman [12] used birth certificate data from 1990 to 1999 in 12 Oklahoma (OK) counties to compare fertility in the six metropolitan Oklahoma City bomb-affected counties to six other metropolitan OK counties. There was a significant rise in births in the six bomb-affected counties beginning about nine and one half months after the bombing and persisted throughout the study period. In the 1997 Red River Flood study, Tong et al. [14] used the birth certificate files to compare pre- and post-disaster fertility rates, finding a significant decrease in birth rates both in the six flood-affected counties and all other counties from 1998 to 2000. In the Hurricane Katrina study above, Hamilton et al. [13] used birth

certificate files from the storm path to compare fertility rates. In the year following Hurricane Katrina, total births in this area decreased 19 % compared to pre-disaster.

Because the studies above involved use of birth certificate files, they do not clarify factors affecting post-disaster fertility. They suggest that disasters can affect post-disaster fertility, but study results are contradictory about whether fertility increases or decreases. One possible explanation could relate to differences in the geographic magnitude of the events. In the studies by Cohan and Cole [11] and Rodgers et al. [12], the investigators were able to compare the disaster-affected counties to a selection of similar counties in their respective states. However, in 1997, North Dakota had two Presidential Major Disaster Declarations due to severe winter storms and blizzards (January) and severe storms and flooding (April). Recovery from flooding was statewide although the most severely affected area was around Grand Forks, and the authors found decreased fertility rates statewide, not just in the most heavily affected area [14]. Similarly, the area affected by Hurricane Katrina encompassed several states and involved unknown population movement [13].

Summary

Consistent with the international review of disasters and perinatal health by Harville, Xiong, and Bueckens [10], our review revealed that even though authors often studied a variety of indicators of fetal growth, associations were not consistently found even when using the same measures such as PTB or LBW (Table 3). Furthermore, it was not clear that significant effects in continuous measurements of birth weight or gestation length would make a clinical difference in infant outcomes.

However, here we have focused on methodological issues that may prevent us from observing consistent associations between disasters and RH. For example, there were different definitions of exposure such as location [13, 14, 28, 29, 34, 35] or reactions to exposure [17, 19, 20], which may have contributed to observing associations for some groups of the disaster-affected populations and not others. The seven prospective studies described here provided more information about physical and psychological effects of disaster among affected women than the ecological studies, but effects on birth outcomes were not consistently demonstrated. Ecological studies reinforced that disaster may affect RH through associations with birth outcomes and fertility, but these studies were not able to clarify factors affecting these relationships. Yet, even with these inconsistencies, the above studies suggest an association between disasters and RH and highlight the need for further studies to clarify associations.

Due to the disparate study designs, measures of exposure and outcomes, and sample sizes, increased surveillance of RH outcomes post-disaster is an important first step toward understanding the effects of disaster on the RH of US pregnant women. Surveillance would enable us to apply consistent exposure criteria and examine exposure effects on maternal risk factors, behaviors, exposure to physical abuse, and birth outcomes. Having this constellation of information would enable us to examine factors that may put pregnant women and their infants at risk. However, an obstacle to studying pregnant women post-disaster is that they are difficult to survey using a population-based approach [45] because

they comprise only about 1 % of the general population [46] and <5 % of women of reproductive age [47]. Therefore we suggest that adapting the Pregnancy Risk Assessment Monitoring System (PRAMS) [48] for use in disaster-affected areas would be beneficial in building our knowledge of post-disaster effects on pregnant women. PRAMS is an ongoing, state- and population-based surveillance system that collects information about selected maternal experiences and behaviors, such as information on prenatal care, maternal tobacco and alcohol risk behaviors, physical abuse, pregnancy-related morbidity, and contraceptive use, before, during, and after pregnancy among women who deliver a live birth. The survey data are then linked to selected birth certificate data so the analysis file includes birth outcomes. PRAMS is currently operational in 41 sites (40 states and NYC), and up to three states implement PRAMS-like projects.

Adaptations to PRAMS would include creation of a disaster-specific module consisting of standard questions to assess women's disaster exposures, and adapted sampling approaches, and data collection procedures, resulting in the development of a parallel system to oversample women in disaster-affected counties. The goal would be to acquire information for one year on at least 400 women in the disaster stratum for each disaster.

The primary barriers to overcome for this adaption would be financial support for implementing the parallel system and decreased state level capacity for implementing the surveillance system after a catastrophic event (as was experienced by Louisiana and Mississippi PRAMS after Hurricane Katrina). Even so, overcoming these barriers could be beneficial in helping us to gain understanding of the post-disaster health of US pregnant women and their infants and guide public health practice for this at-risk group.

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Table 1

Studies examining post-disaster reproductive health outcomes in the United States, published between 1981 and 2010

Disaster name and year	Author and publication date	Exposures*			Outcomes		
		Physical[1]	Psychological[2]	General[3]	Pregnancy loss	Birth outcomes	Fertility
Hurricane Agnes (1972)	Janerich et al. (1981)	X			X		
Hurricane Hugo (1989)	Cohan and Cole (2002)			X			X
Hurricane Andrew (1992)	Zahran et al. (2010)			X		X	
Northridge Earthquake (1994)	Glynn et al. (2000)		X			X	
Oklahoma City Bombing (1995)	Rodgers et al. (2005)			X			X
North Dakota Red River Flood (1997)	Tong et al. (2010)			X		X	X
World Trade Center Attack (2001)	Berkowitz et al. (2003)	X				X	
	Lederman et al. (2004)	X				X	
	Engel et al. (2005)		X			X	
	Perera et al. (2005)	X				X	
	Eskenazi et al. (2007)			X		X	
	Lipkind et al. (2010)	X	X			X	
Hurricane Katrina (2005)	Xiong et al. (2008)		X			X	
	Hamilton et al. (2009)			X		X	X
	Harville et al. (2010)			X		X	

*Exposures:

[1]Physical exposure to toxicants;

[2]Psychological trauma (measured);

[3]General exposure to disaster

Matern Child Health J. Author manuscript; available in PMC 2015 August 18.

Table 2

Studies of disaster effects on birth outcomes in the United States

Disaster and authors	Design	Methods	Results
Disaster: Hurricane Agnes (1972) *Authors:* Janerich et al. [15]	Description of environmental exposure to radiation and epidemiologic investigation of increased leukemia and lymphoma and spontaneous abortions after a flood disaster that followed Hurricane Agnes in New York (NY)	*Sample:* Reproductive statistics for four counties in NY from 1970 to 1977 *Source:* Live birth and fetal death records *Analysis:* Examination of reproductive health statistics. Test of differences not stated	No increases in exposures to radiation were found. An excess of spontaneous abortions ($p < 0.01$) occurred in 1973, the year following the flood, as compared to average rates in other years. Investigators also used birth and fetal death records from 1972 to 1973 to compare age-matched residents of towns involved in evacuations. They found no increased risk for spontaneous abortions associated with evacuation
Disaster: Hurricane Hugo (1989) *Authors:* Cohan and Cole [10]	Ecological study of marriage, birth, and divorce rates in South Carolina (SC) following Hurricane Hugo	*Sample:* Births in all 46 SC counties from 1975 to 1997 *Source:* Vital statistics for births from annual South Carolina Statistical Abstract *Analysis:* Autoregressive integrated moving average models were used to perform a time series analysis	Before the hurricane birth rates decreased. One year after Hurricane Hugo (1990), birth rates increased ($p < 0.001$) in the 24 disaster declared counties compared with the undeclared counties in the state
Disaster: Hurricane Andrew (1992) *Authors:* Zahran et al. [26]	Ecologic study of maternal exposure to Hurricane Andrew and fetal distress	*Sample:* Four separate analyses: births from 1991 to 1997 in (1) all Florida (FL) Counties, (2) high impact areas (Miami-Dade and Broward counties) (n = 352,462), (3) in all FL Counties with large populations (n = 1,097,409), and births from 1992 to 1993 (4) along the hurricane path from Southern FL through Louisiana and Mississippi (n = 59,056) *Source:* Maternal exposure, demographics, health and birth information are derived from the National Center for Health Statistics Vital Statistics Natality Birth Data. Hurricane destructive force determined using property damage data from the Spatial Hazard Losses and Events Database *Analysis:* A monthly time series was used to examine the proportion of infants born distressed in high impact areas versus unaffected counties. Logistic regression and spatial techniques were used to examine maternal hurricane exposure effects on fetal distress. Regression models were adjusted for maternal medical risk factors, risk behaviors, race and age, plus selected complications of labor such as cord prolapsed, and infant birth weight	The risk of fetal distress among infants was significantly higher in high impact areas during the hurricane exposure period of late August 1992 to May 1993 ($p \leq 0.001$) compared to nonexposure periods (analysis 1). Maternal hurricane exposure in the second and third trimesters increased the odds of fetal distress (OR: 1.20, 95 % CI [1.08, 1.33] and OR: 1.26, 95 % CI [1.15, 1.38]), respectively in analyses 2 and 3. Fetal distress risk also correlated with hurricane destruction path, with $10 million increases in property damage increasing the odds of fetal distress among hurricane exposed expectant mothers (OR: 1.01, 95 % CI [1.01, 1.02])
Disaster: Northridge Earthquake (1994) *Authors:* Glynn et al. [16]	Cohort study assessing the effects of the timing of stress during pregnancy on emotional responses and length of gestation among women exposed to the Northridge Earthquake in California (CA)	*Sample:* n = 40 women exposed to earthquake while pregnant (n = 29) or within 6 weeks of delivery (comparison group; n = 11) receiving prenatal care at a teaching hospital associated with the University of California, Irvine, and living in the Orange County area. The exposed group (n = 281) is a subsample of pregnant women in larger study *Source:* Stress was measured by one item (how upsetting the earthquake was) on the life-events inventory completed at 34 weeks' gestation and again at 6 weeks postpartum	Timing of the earthquake during pregnancy, i.e., trimester of occurrence, was associated with the amount of perceived stress ($p < .05$). Stress ratings were highest if it occurred during the first trimester and least if it occurred during the third trimester. Stress experienced early in pregnancy was associated with shorter gestation (first-trimester $x = 38.06$ weeks, second-trimester $x = 38.69$ weeks, third-trimester $x = 38.99$ weeks) compared with $x = 39.50$ weeks among the group who did not experience the earthquake during pregnancy

Disaster and authors	Design	Methods	Results
		Analysis: Hierarchic regression model used to determine the effects of earthquake timing (stress) on length of gestational age at birth, controlling for obstetric risk and corticotrophin-releasing hormone	
Disaster: Oklahoma City bombing (1995) *Authors:* Rodgers et al. [11]	A control group interrupted time-series design and a difference-in-differences design to examine the influence of the Oklahoma (OK) City bombing on fertility patterns	*Sample:* Births in two areas of OK from 1990-1999. Bomb-affected counties: six OK City metropolitan areas; Control group: six OK metropolitan counties located in other parts of OK *Source:* County-level birth counts from vital statistics records *Analysis:* Logistic regression models were used to analyze birth data. Dummy variables were used to control for variability due to county differences and monthly seasonal patterns	An increase of 9.9 births per county per month was observed in the 4 years following the OK City bombing ($p < 0.001$), with the immediate effects appearing in the OK metropolitan area and persistence of the effect primarily in OK County (urban OK City)
Disaster: Red River flood (1997) *Authors:* Tong et al. [13]	Ecological study to assess changes in birth rates, outcomes, and maternal risk factors after the Red River flood in North Dakota (ND)	*Sample:* N = 57,007 singleton births pre-disaster (1994–1996) and post-disaster (1997–2001) *Source:* County level birth files for ND *Analysis:* Logistic regression was used to examine birth outcome associations with the disaster. Models were adjusted for maternal demographics, behavioral risks, trimester at entry to prenatal care. Examination of crude birth rates (births per 1,000 population) and adjusted fertility rates (i.e., births per 1,000 women aged 15–44)	Statewide, significant increase in medical risks (5.1–7.1 %) ($p < 0.0001$) were observed. Statewide LBW (LBW) (4.2–4.7 %) ($p = 0.0031$) increased although its rise was only significant in the six counties most affected by the disaster. Statewide, preterm delivery increased (8.2–8.9 %) ($p = 0.0018$), but the rise was only significant in the rest of the state that was not directly affected by the disaster. A significant decrease in birth rates statewide was observed when compared to pre-disaster (pre: 13.1 births/1,000; post: 12.2 births/1,000). This decrease was observed both in the disaster area and the rest of the state
Disaster: World Trade Center (2001) *Authors:* Berkowitz et al. [27]	Prospective cohort study to examine if exposure to the September 11, 2001 (9/11) World Trade Center (WTC) toxic plume in lower Manhattan was associated with impaired fetal growth or adverse pregnancy outcomes	*Sample:* n = 182 women pregnant and present in one of five exposure zones near the WTC on 9/11 or within succeeding 3 weeks; n = 2367 pregnant women in upper Manhattan who were not known to be in the exposure zones near the WTC on 9/11 *Source:* Medical records for birth outcomes and a Post Traumatic Stress Disorder checklist *Analysis:* Test for differences was not named. Control variables included in the intrauterine growth restriction (IUGR) model were race/ethnicity, sex of infant, maternal age, parity, and cigarette smoking	There were no significant differences in gestation length or birth weight of frequency of PTB ($p = 0.76$) or LBW ($p = 0.47$). The cohort near the WTC disaster had an increased risk of IUGR (OR: 1.90, 95 % CI [1.05, 3.46]) versus the cohort of women not known to be near the WTC on 9/11. No association was found between probable PTSD and relative risks of PTB ($p = 0.88$), LBW ($p = 0.22$) or IUGR ($p = 0.94$)
Disaster: World Trade Center (2001) *Authors:* Lederman et al. [28]	Cohort study of impact of gestational timing of the September 11, 2001 (9/11) World Trade Center (WTC) attack and distance from the WTC (proxy for environmental exposure to toxins) during 4 weeks after the disaster on singleton birth outcomes among women in the New York City (NYC) area	*Sample:* N = 300 nonsmoking women pregnant on 9/11 delivering term singletons at three downtown hospitals with maternity units close to the WTC site *Source:* Medical records of mother and newborn and maternal interviews post delivery *Analysis:* Multiple linear regression was used to assess the effect of proximity to the WTC and pregnancy stage on birth outcomes. Control variables were sociodemographic and biomedical risk factors	Women in their first trimester of pregnancy on 9/11 delivered infants with significantly shorter gestation ($p = 0.001$) than women in later pregnancy stages. Significantly lower birth weights ($p = 0.02$) and lengths ($p = 0.04$) occurred among infants born to women living within two miles of the WTC site compared to women living outside the area after controlling for gestation duration
Disaster: World Trade Center (2001) *Authors:* Engel et al.	Prospective study of psychological trauma associated with the September 11, 200f (9/11) World Trade Center (WTC) attack and its effect on birth outcomes	*Sample:* n = 52 pregnant women living or working in five exposure zones near the WTC, who were pregnant on 9/11 or shortly thereafter and completed psychological screening instruments before delivery.	In a model adjusted for maternal age, post-traumatic stress symptoms (PTSS) and moderate depression were associated with longer gestational duration ($p = 0.03$ and $p = 0.05$, respectively). PTSS was

Disaster and authors	Design	Methods	Results
[17]		This is a subsample of N = 187 pregnant women in a larger study *Source:* Medical records for birth outcomes, maternal interviews prior to delivery, and the Post-traumatic Stress Disorder Checklist, Life Events Inventory, State-Trait Anxiety Inventory, and Beck Inventory of Depression for baseline information and psychological variables *Analysis:* Multivariable linear regression assessed the effects of psychological trauma on birth outcomes	not associated with birth weight
Disaster: World Trade Center (2001) *Authors:* Perera et al. [29]	Cohort study on the influence of polycyclic aromatic hydrocarbons (PAH) from the September 11, 2001 (9/11) World Trade Center (WTC) attack and genetic damage and effects on fetal growth in pregnant women and newborns	*Sample:* n = 186 nonsmoking pregnant women who were living or working within one mile of the WTC and on whom the investigators had infant cord blood data. Sample is a subset of Lederman et al. [29] (N = 300) nonsmoking women pregnant on 9/11 delivering term singletons at three downtown hospitals with maternity units close to the WTC *Source:* Medical records of mother and newborn and maternal interviews post delivery. Maternal and umbilical cord blood was used as a measure of chemical–specific genetic damage (PAH-DNA adducts) *Analysis:* Differences in adduct levels across the various exposure levels (residing within one mile, working within one mile, and neither) were tested by *t* test and Wilcoxon rank sum. Multiple regression was used to assess PAH-DNA adducts effects on birth outcomes, controlling for sociodemographic and biomedical risk factors	Among newborns of mothers living within one mile of WTC site, levels of cord blood PAH were inversely correlated with linear distance from WTC ($p = 0.02$). PAH-DNA adducts did not have an independent effect on birth weight or length but in combination with in utero environmental tobacco smoke exposure was associated with an 8 % reduction in birth weight ($p = 0.03$)
Disaster: World Trade Center (2001) *Authors:* Eskenazi et al. [33]	Ecological study of pregnancy outcomes trends in New York City (NYC) and upstate New York (NY) after the September 11, 2001 World Trade Center (WTC) attack	*Sample:* N = 1,666,401 live singleton infants delivered between January 1996 and December 2002 by NY residents without gestational diabetes, excluding births to residents of lower Manhattan where there was greatest likelihood of environmental exposure *Source:* Birth certificate data *Analysis:* Multiple logistic regression was used to assess the WTC disaster's impact on birth outcomes. Models adjusted for infant sex, maternal demographics, smoking, insurance, initiation of prenatal care in first trimester, and hypertensive disorder	One week after WTC attack increases in births 1500-1999 g (OR: 1.67, 95 % CI [1.11, 2.52]) was observed in NYC compared to the previous 3 weeks but was not observed in upstate NY. Interrupted time-series analyses confirmed the above findings. There was not significant effect on PTB
Disaster: World Trade Center (2001) *Authors:* Lipkind et al. [19]	Cohort study examining effects of the September 11, 2001 (9/11) WTC attack, i.e., psychological stress and exposure to dust, on birth outcomes	*Sample:* Exposed group: n = 466 nonsmoking women (aged 18–49) without gestational diabetes, not on Medicaid, delivering live singleton infants between 500 and 5,000 g, and enrolled in the WTC Health Registry (WTC Registry); Controls: n = 49,616 matched on factors above, not in the WTC Registry, and residing >5 miles from the WTC *Source:* WTC Registry, birth certificate data, and Post Traumatic Stress Disorder (PTSD) Checklist *Analysis:* Multivariable linear and logistic regression was used to model birth outcomes. Models were	Women with probable PTSD had higher odds of LBW (OR: 2.49, 95 % CI [1.02, 6.08]) and preterm delivery (OR: 2.48 95 % CI [1.05, 5.84]) compared to mothers without PTSD. No differences in birth weight and gestational age distributions were observed among women with self reported dust cloud exposure in the WTC Registry and comparison women. The historical analysis revealed the same association between pregnancy trimester at 9/11 and birth outcomes, suggesting that the trimester association in the Lederman et al. [29]

Matern Child Health J. Author manuscript; available in PMC 2015 August 18.

Disaster and authors	Design	Methods	Results
		adjusted for demographics, maternal and pregnancy characteristics. The authors also conducted a historical comparison analyzing birth outcomes in a similar population delivering between September 12, 1999 and October 14, 2000 (n = 60,819) to examine trimester effects	study was not causally related to the WTC attack but may be a seasonal effect
Disaster: Hurricane Katrina (2005) *Authors:* Xiong et al. [18]	Prospective study of mental health and birth outcomes of women exposed to Hurricane Katrina	*Sample:* N = 301 women visiting prenatal care clinics in New Orleans (n = 220) and Baton Rouge (n = 81) between January 2006 and June 2007. The Baton Rouge women were a comparison group who did not have extensive experience of the hurricane, such as evacuating or having a relative die *Source:* Medical records for birth outcomes, maternal interviews for hurricane experience (questions adapted from questionnaire used in the Social and Cultural Dynamics of Disaster Recovery study after Hurricane Andrew) and psychological response (Post-traumatic Stress Checklist—Civilian Version and Edinburgh Depression Scale) *Analysis:* Multiple logistic regression was used to assess the effects of the disaster on birth outcomes. Models were adjusted for maternal demographics, education, reproductive history, substance use, and income	LBW was more frequent in women with high hurricane exposure, defined as having three or more of eight severe hurricane experiences such as feeling that one's life was in danger, than women without high hurricane exposure (OR: 3.3 ($p < 0.01$), 95 % CI [1.13, 9.89]). Neither PTSD nor depression were associated with significant increases in LBW or PTB
Disaster: Hurricane Katrina (2005) *Authors:* Hamilton et al. [12]	Report on birth data for the region affected by Hurricane Katrina comparing 12 months before and after the storm	*Sample:* 62,368 births in 14 selected Federal Emergency Management Agency (FEMA) designated coastal counties and parishes within a 100 mile radius of Katrina storm path in Alabama (AL), Louisiana (LA), and Mississippi (MS) *Source:* Birth certificate data from August 2004 to 2006 *Analysis:* Tabulations of descriptive statistics on birth data, and differences were tested	Overall the 14 counties revealed a 10 % decrease in very preterm (before: 3.1 %; after: 2.8 %), but the AL counties increased 23 % (before: 3.1 %; after: 3.8 %) while the LA counties decreased 25 % (before: 3.2 %; after: 2.4 %). When comparing the time periods, overall the 14 counties did not demonstrate significant changes in PTB, LBW or very low birth weight (VLBW), despite a 22 % decrease in VLBW in LA (before: 2.3 %; after: 1.8 %). Demographic changes were observed in women giving birth in these states, suggesting that women with higher risks of poor birth outcomes in the LA selected counties before the storm were relocated outside the selected counties in LA after the storm. In the 12 months post-Katrina total births decreased 19 % compared to the 12 months before Katrina
Disaster: Hurricane Katrina (2005) *Authors:* Harville et al. [34]	Ecological study relating population changes and demographic changes to birth outcomes in Louisiana (LA) after Hurricane Katrina	*Sample:* Births to LA women in the 2 years before Hurricane Katrina (N = 128,624) and in the 2 years after Katrina (N = 126,041) *Source:* 2003–2007 LA birth records and Medicaid linked data *Analysis:* Multivariate logistic regression was used to model birth outcomes before and after the storm. Models adjusted for demographics, health behaviors, and biological risk factors	For the state as a whole in the 2 years after Hurricane Katrina, rates of LBW (LBW) rose slightly compared to the 2 years before the hurricane (OR: 1.03, 95 % CI [1.00, 1.06]) but remained unchanged in the most affected areas. In the four parishes most strongly hit by the hurricane and flooding in the 2 years after Katrina, rates of PTB declined compared to the 2 years before the hurricane (OR: 0.85, 95 % CI [0.80, 0.90]) while rates in the state and Orleans Parish remained unchanged. Thus, risk for LBW and PTB did not rise in the most affected areas. This finding was attributed partly to a change

Disaster and authors	Design	Methods	Results
			in the risk profile of women giving birth in the most affected areas after the hurricane

Table 3

Birth outcomes in disaster-affected areas by disaster, year of publication and findings

Disaster name and year	Author and publication date	Dichotomous variables				Continuous variables		
		Intrauterine growth restriction[1]	Preterm birth[2]	Low birth weight[3]	Fetal distress[4]	Gestation length	Birth weight	Birth length
Hurricane Andrew (1992)	Zahran et al. (2010)	–	–	–	S	–	–	–
Northridge Earthquake (1994)	Glynn et al. (2000)	–	–	–	–	S[5]	–	–
North Dakota Red River Flood (1997)	Tong et al. (2010)	–	S	S	–	–	–	–
World Trade Center Attack (2001)	Berkowitz et al. (2003)	S	NS	NS	–	NS	NS	–
	Lederman et al. (2004)	–	–	–	–	S[6]	S	S
	Engel et al. (2005)	–	–	–	–	S	NS	–
	Perera et al. (2005)	–	–	–	–	–	NS	NS
	Eskenazi et al. (2007)	–	NS	S[7]	–	–	–	–
	Lipkind et al. (2010)	–	S[8]	S[8]	–	NS[8]	NS[8]	–
Hurricane Katrina (2005)	Xiong et al. (2008)	–	NS	S	–	–	–	–
	Hamilton et al. (2009)	–	S[9]	S[10]	–	–	–	–
	Harville et al. (2010)	–	S[11]	NS	–	–	–	–

S significant, *NS* not significant; – not studied

[1] Birth weight <10th percentile for gestational age

[2] <37 weeks

[3] <2,500 g

[4] Reported under ‘complications of labor and/or delivery’ on US birth certificate, revision 1989

[5] Gestation shortest when disaster exposure was early in pregnancy

[6] Significant only among women in first trimester at time of World Trade Center attack

[7] Significant increase only occurred during first week after WTC bombing and among moderate low birth weight (1,500–1999 g)

[8] Significant among women with probable PTSD, not physical exposure

[9] Significant changes only occurred among very preterm (<32 weeks) and in selected parishes of Louisiana and counties of Alabama

[10] Significant changes only occurred among very low birth weight (<1,500 g) in selected parishes of Louisiana

[11] Significant decrease in Region 1, directly affected area