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REVIEW ARTICLE

Consequences of Natural and Man-made Disasters on Pregnancy Outcomes and Complications: A Systematic Review

Yousef Pashaei Asl[1], Solmaz Ghanbari-Homaie[2], Nasim Partash[3], Alireza Pakzad[4], Gholamreza Faridaalaee[4,5]*

1. Department of Health Policy& Management, Tabriz University of Medical Sciences, Tabriz, Iran
2. Department of Midwifery, Faculty of Nursing and Midwifery, Tabriz University of Medical Sciences, Tabriz, Iran
3. Department of midwifery, Maragheh University of Medical Sciences, Maragheh, Iran
4. Department of Emergency Medicine, Faculty of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran
5. Emergency Medicine and Trauma Research Center, Faculty of Medicine, Tabriz University of Medical Sciences, Tabriz, Iran

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Abstract: **Introduction:** Due to their unique circumstances, pregnant women face a heightened risk of experiencing pregnancy complications during and after catastrophic events. This study aims to investigate the consequences of both natural and man-made disasters on pregnancy outcomes. **Methods:** This study is a systematic review. Searches were performed until May 31, 2024, in the electronic databases including Medline, Web of Science, Embase, and Scopus. Outcomes such as preterm birth, low birth weight (LBW), small for gestational age (SGA), stillbirth, spontaneous abortion, and pregnancy-related blood pressure complications were studied. **Results:** The search conducted in the databases yielded 3307 non-duplicate records. After reading the abstracts, 3204 articles were excluded based on inclusion and exclusion criteria. Full texts of 103 article were obtained. However, upon reading the full texts of articles, 13 of them did not meet the inclusion criteria for the study. Consequently, 90 articles were ultimately included. **Conclusions:** Natural and man-made disasters exert significant influence on adverse pregnancy outcomes. While it is impossible to prevent the incidence of natural disasters and often man-made disasters occur abruptly, the negative consequences of disasters, particularly natural ones, can be mitigated by enhancing prenatal care and avoiding detrimental elements such as smoking and alcohol.

Keywords: Systematic review; Disasters; Premature birth; Abortion, spontaneous; Infant, low birth weight

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1. Introduction

The frequency of disasters has been on the rise globally in recent decades, with reports indicating an increase in their destructive impact.

Between the years 1980 and 2015, a staggering total of 11,538 natural disasters were documented across the world (1). In addition to causing damage to infrastructure and destruction of human habitats, disasters also lead to a surge in both communicable and non-communicable diseases (2). Also disasters cause many injuries to pregnant women, fetuses, and newborns (3). Due to their unique circumstances, pregnant women face a heightened risk of experiencing pregnancy complications during and after catastrophic events and suffer various health issues (3). Psychological and physiological stress, limited access to healthcare facilities, and disruptions in prenatal care during disasters pose significant risks for pregnant women and lead to a higher incidence of pregnancy-related complications (3, 4). These complications encompass preterm birth, low birth weight (LBW), small for gestational age (SGA), stillbirth, spontaneous abortion, and more (3, 4).

Our previous studies have focused on examining the impact of man-made and natural disasters on cardiovascular diseases, and floods on pregnancy outcomes (2, 3, 5). This study aims to investigate the consequences of both natural and man-made disasters, including floods, earthquakes, volcanoes, wildfire, storms, chemical hazard release, radioactive hazard release, weapons of mass destruction, etc. on pregnancy outcomes.

2. Methods

This study is a systematic review based on Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol. The objective of this research is to examine the impact of natural and man-made disasters on preg-

***Corresponding Author:** Gholamreza Faridaalaee, Department of Emergency Medicine, Department of Emergency Medicine, Daneshgah Street, Tabriz, Iran. Tel: +98-4133829540, Tel: 00989146677876, Email: faridaalaee@tbzmed.ac.ir, grf.aalae@yahoo.com, faridaalaee@tbzmed.ac.ir, ORCID: https://orcid.org/0000-0002-9990-4936.

nancy complications and outcomes, including preterm birth, LBW, SGA, stillbirth, spontaneous abortion, and pregnancy-induced hypertension.

2.1. Eligibility criteria

In the present study, we included articles published until 31.05.2024 that focused on pregnancy complications in both natural and man-made disasters. Criteria for inclusion in the study encompassed natural and man-made disasters like wildfires, as well as complications associated with pregnancy. Articles written in languages other than English were excluded from the study due to the unavailability of a proficient non-English language translator. Additionally, articles whose full text was not accessible and were only presented as an abstract at a congress were also excluded from the study. Original articles in English or Persian Languages were included in this study. The case reports, editorial comments, etc. were excluded.

2.2. Search strategy

This study was conducted under the guidance of an expert and researcher in the field of emergency and disaster medicine, alongside a master of midwifery and doctorate of disaster health management, to ensure comprehensive exploration and attainment of the research objectives.
The relevant keywords were identified utilizing the MeSH and Emtree databases. Subsequently, thorough searches were performed until May 31, 2024, in the electronic databases including Medline, Web of Science, Embase, and Scopus. The search strategy employed in the Medline database is outlined in table 1.

2.3. Study selection and data collection process and outcome measurement

Articles that examined the pregnancy outcomes and complications related to natural and man-made disasters were included in this study. Following eliminating duplicate articles, the abstracts of the articles were read by two independent researchers to exclude any unrelated articles based on predefined inclusion and exclusion criteria. Two researchers read all title and abstracts and chose eligible articles based on aim of the study and pretermitted the rest of the articles. The full text of the remaining articles was further examined to ensure they met the inclusion and exclusion criteria, and the final selection of eligible articles was made. In instances where discrepancies arose concerning the articles, a third researcher was consulted to resolve any conflicts. In addition to the study characteristics (design, year, country, and etc.), the findings of the articles about preterm birth, LBW, SGA, stillbirth, spontaneous abortion, and pregnancy-related blood pressure complications were extracted and summarized.
Preterm birth refers to delivering a baby before completing 37 full weeks of gestation (6). Preterm birth has significant impacts on the health, morbidity, and survival rates of infants (6). In 2010, the rates of preterm birth varied across different regions, with European countries reporting an average rate of about 5%, while some African countries recorded rates as high as 18%. On a global scale, the average rate of preterm birth was 10.6% (6, 7). LBW refers to the birth of a baby weighing less than 2500 grams. It was found to have a prevalence of approximately 9% and was more commonly observed among non-white populations (8, 9). Stillbirth is defined as the death of a fetus before the start of labor and the birth of a baby without vital signs (antepartum stillbirth) or the death of a fetus during labor or delivery (intrapartum stillbirth) with a gestational age greater than 22 weeks or a birth weight of at least 500 grams (10, 11).

2.4. Quality control and risk of bias assessment

The quality of articles and risk of bias were assessed using the "Newcastle-Ottawa Scale for Assessing the Quality of Non-randomized Studies"(12). Patient group, control group, and exclusion criteria for selection, as well as outcome and statistical analysis for comparability were investigated in all included studies. We also added ethic approval to the quality control checklist.

2.5. Statistical analysis

Data were analyzed descriptively. Obtaining an ethical code in systematic review studies is often considered unnecessary due to the pre-existing publication of articles.

3. Results

3.1. Study selection and study characteristics

The search conducted in the databases yielded 3307 non-duplicate records. After reading the abstracts, 3204 articles were excluded based on inclusion and exclusion criteria. Full texts of 103 article were obtained. However, upon reading the full texts of articles, 13 of them did not meet the inclusion criteria for the study. Consequently, 90 articles were ultimately included. To visualize this process, please refer to Figure 1, which presents the PRISMA flow diagram outlining the selection of articles.

3.2. Quality control and risk of bias assessment

The chosen articles underwent an assessment of their quality and risk of bias. To provide an overview of each study, table 2 displays the quality control and risk of bias of included articles, based on Newcastle-Ottawa Scale.

3.3. Findings

3.3.1 Preterm birth and disaster

Most of the studies conducted on earthquakes have indicated a significant correlation between seismic activity and an increase in preterm births. However, when it comes to the impact of the 2011 great earthquake in Japan on preterm births, the findings from different studies present contradictory results. Several studies have reported varied outcomes regarding the impact of the earthquake on preterm births. While some studies indicated an increase in preterm births, there were also cases where the incidence of preterm births either remained unaffected or even declined following the earthquake (13-33). Also storms, wildfire and volcanoes lead to a rise in preterm birth (29, 34-56). In contrast, according to numerous research studies, it has been widely observed that there is no significant increase in the prevalence of preterm birth following floods (57-60). Man-made disasters may also influence pregnancy outcomes; however, after a radioactive accident, it was found that there was no notable difference in the rate of preterm birth (20, 61-63).

3.3.2 LBW and disaster

Earthquakes increase LBW rate (13-16, 18, 19, 22, 24, 26, 31, 64-66). Similar to preterm birth, most of the studies conducted on earthquakes have indicated a significant correlation between seismic activity and an increase in LBW rate. However, when it comes to the impact of the 2011 great earthquake in Japan on LBW, the findings from different studies present contradictory results. Similar to earthquake, most of the storms increase likelihood of LBW (34, 35, 38, 40, 41, 43, 49, 56), just like flooding (57, 67-69). The impact of wildfire occurrence on birth weight has been inconsistent across in various studies. Some studies indicate a decrease in birth weight when exposed to wildfire, while others demonstrate no significant effect on neonatal birth weight (46, 53, 70-77). The eruption of a volcano does not appear to have any impact on birth weight, according to scientific research (44, 45). Man-made disasters also seem to increase LBW rate. After a radioactive accident and September 11, 2001 attack on the twin towers of the world trade center, LBW increased (21, 78-80).

3.3.3 SGA, gestational hypertension, stillbirth, and disaster

Natural disasters can contribute to high blood pressure and preeclampsia during pregnancy (26, 27, 29, 30, 46, 59, 67, 81). Also natural disasters increase the rate of SGA, spontaneous abortion, and stillbirth (13, 15, 29, 31, 46, 48, 56, 68, 81-86). Spontaneous abortion rate raised after earthquake but spontaneous abortion rate didn't change after the great East Japan earthquake (30, 31, 87).

The effect of man-made disaster, such as radiation, on spontaneous abortion is controversial (88-92). Also, most of studies indicate that man-made disaster such as radiation increase stillbirth (90, 93-97).

4. Discussion

This is a systematic review study conducted by a team of researchers, examining the effects of both natural and man-made disasters on pregnancy outcomes, specifically focusing on adverse birth outcomes such as preterm birth. The findings of these studies affirm that natural and man-made disasters significantly influence pregnancy outcomes, leading to higher rates of adverse birth outcomes. It is evident that perinatal care plays a crucial role in determining pregnancy outcomes amidst such disasters. Providing adequate and timely perinatal care becomes one of the most vital factors to mitigate the negative impacts of these situations on expectant mothers and their babies.

4.1. Preterm birth and natural disaster

4.1.1 Preterm birth in earthquake-stricken areas

The investigation of the Sichuan earthquake in China revealed that mothers who were exposed to the earthquake had a preterm birth rate of 14.4%, which was significantly higher than the rate of 7.32% in non-exposed mothers (13). Additionally, when comparing the pre-earthquake and post-earthquake periods, the rate of preterm birth increased from 5.63% to 7.41% after the earthquake occurred (14). These findings indicate a clear impact of the earthquake on the frequency of preterm births. During the Chile earthquake, studies have shown that women who experienced pregnancy after the seismic event had an increased incidence of preterm births compared to before the earthquake. This trend was particularly notable in women who were exposed to the earthquake during the first and second trimesters of their pregnancies, as they had a higher occurrence of preterm births (15, 16). During the 1994 Northridge, California earthquake, research indicates that women exposed to the earthquake had a higher prevalence of preterm birth, particularly during the first trimester of pregnancy in comparison to the third trimester (17). Similarly, in the case of the New Zealand earthquake, it was observed that the rate of preterm births increased compared to the period before the earthquake occurred (18). In contrast, another study didn't show higher prevalence of preterm birth after New Zealand earthquake and the authors didn't explain the reason for unincreased rate of preterm birth (98).

Numerous studies analyzing the impact of the 2011 earthquake in Japan have consistently indicated the absence of significant changes or a potential decrease in the rate of preterm birth (19-22, 27, 28, 32). A study conducted by Fujimori examined 8,600 births both before and after the earthquake and found no notable variance in premature birth occurrences (23). This unchanged preterm birth rate has been attributed to the comprehensive and well-executed post-disaster care and support systems in place within Japan (23). These findings emphasize the effective and adequate response by the Japanese healthcare system following such adversities. In fact, there has been evidence suggesting that enhanced care can lead to improvements in situations and outcomes. For instance, Junichi Sugawara et al. conducted a study to investigate the impact of the 2011 great earthquake in Japan on 12,808 patients (24). This study revealed that the rate of premature birth was 4.6%. Remarkably, the author of the article stated that the rate of preterm birth in Japan during this period was the lowest in the world (24).

This can be attributed to prompt medical interventions following the earthquake, such as early interventions, increased bed rest (as work and travel were restricted), and expedited transfer of high-risk mothers to areas with advanced care facilities in 2011 (24). As a result, the occurrences of preterm birth post-earthquake were significantly lower compared to subsequent years. In a quantitative study conducted by Kohta Suzuki, a total of 5,593 births were examined (25). The study revealed that women who changed their prenatal care center experienced a shorter duration of pregnancy compared to those who continued visiting the same center from the beginning. Additionally, this study found that women with a history of cesarean section had a shorter pregnancy duration compared to women with a history of normal delivery (25). It is worth noting that there was only one study that reported different results (26). This study indicated that there was an increase in preterm births after the great earthquake in Japan, surpassing the usual and pre-earthquake figures. However, these findings contradicted the results of another study conducted by the same authors. In this second study, it was revealed that there was no significant difference in the rate of preterm births compared to before the earthquake (19).

4.1.2 Preterm birth in flooded areas

The incidence of preterm birth does not necessarily rise following exposure to floods, according to available research (57-60). While only one study has reported a contrasting outcome, indicating a significant increase in preterm birth rates after the North Dakota flood in America, it is essential to note that not all regions experienced a similar rise in preterm births (67).

The reason for the lack of significant increase in preterm birth rate in these counties is attributed to the notable improvement in prenatal care during the first trimester of pregnancy following the flood (67). Additionally, there has been a substantial decrease in the consumption of cigarettes and alcohol in these counties, compared to the pre-flood period (67). However, despite the absence of significant difference in the whole state concerning early prenatal care initiation and smoking reduction before and after the flood (67), it is important to note that there were higher rates of preterm births among non-white, unmarried, elderly, and low-educated individuals (67).

4.1.3 Preterm birth in areas affected by storms (hurricanes, typhoons, cyclones, and tornadoes)

Hurricane Katrina had a significant impact on the rate of preterm births, nearly doubling it. Studies have shown that women who experienced severe exposure to hurricanes during this time had a preterm birth rate of 14%, compared to 6.3% in women who were either not exposed or had less exposure (34). It is important to note that this doubling of preterm birth was particularly observed in women who had pre-existing conditions such as depression or post-traumatic stress disorder (PTSD) (34). Concerns regarding the recurrence of the storm was an additional influential factor impacting the incidence of preterm birth post-Hurricane Katrina (35). Findings from the analysis conducted on Hurricane Andrew demonstrated that the rate of preterm birth remained elevated during the span of two to three years following the calamity. Notably, within one month subsequent to the hurricane, there was a notable surge in the prevalence of preterm births (36). An increase in the number of preterm neonates has been observed. However, this increase is not observed among individuals of white ethnicity, but rather predominantly among African Americans (36). A study conducted on Hurricane Charlie demonstrated that exposure to wind speeds exceeding 39 miles per hour resulted in a 9 percent rise in extreme preterm births (birth before 32 weeks). Furthermore, if wind speeds exceeded 74 miles per hour, the increase in extreme preterm births escalated to 21 percent (37). Severe cyclones that occurred in Australia from 2008 to 2018 have highlighted an important finding: individuals who experienced storms during the early stages of pregnancy had a notably higher occurrence of preterm births. Additionally, when considering all three trimesters, it was observed that the affected area experienced a slight rise in the rate of preterm births (38). A comprehensive analysis of data from 19,529,748 births across 378 counties in the United States, spanning the years 1989 to 2002, has revealed significant insights (39). During this period, which also witnessed 58 cyclones, it was observed that approximately 10% of the births were classified as preterm. Furthermore, it was found that the rate of preterm birth during cyclone occurrences was 5 per 10,000 higher compared to non-cyclone periods. These findings shed light on the impact of cyclones on preterm birth rates, highlighting the need for further research in this area. If the speed of the cyclone exceeds a threshold of 17.2 m/s and it brings precipitation of over 100 mm within a distance of less than 60 kilometers, there is an elevated risk of preterm birth (39). Insufficient prenatal care further increases the likelihood of preterm birth (40). Furthermore, it should be noted that ice storms can also lead to premature births. Mothers who were exposed to an ice storm during their first and second trimesters experienced a reduction in the duration of their pregnancy (41). Yasi and Marcia were severe cyclones but didn't increase the rate of preterm birth (99). Additionally, tornadoes in Alabama and Missouri were found to have a minor impact on preterm births, and their increase was not statistically significant (42). This observation can be attributed to the shorter duration of the effects and the limited geographical area affected by these tornadoes. Similarly, Hurricane Harvey showed a slight increase in preterm births; however, this increase was not considered statistically significant (43). According to a single study, it has been suggested that hurricanes may potentially lead to a reduction in pre-term births. This could be attributed to the possibility of missing births during such extreme weather events (100).

4.1.4 Preterm births in volcano-affected regions

Researchers have observed a correlation between volcanic activity and elevation in the number of preterm births. In their research on the influence of the Puyehue Volcano, Ana Ines Balsa et al. discovered a correlation between volcanic smoke exposure and higher rates of preterm births (44). Similarly, Geoff Kushnick et al., in their study on the Sinabung volcano, observed that expectant mothers who were exposed to the volcano during pregnancy experienced an elevated number of preterm births (45).

4.1.5 Preterm birth and its relation to wildfires

The incidence of wildfire has been observed to correlate with a rise in the number of preterm births. Most studies focusing on the impact of wildfire on pregnancy outcomes suggest a correlation with higher rates of preterm birth (29, 46-48, 50, 52-55). Various factors within a wildfire incident can potentially contribute to this increase. The frequency of prenatal visits is a crucial determinant impacting the incidence of preterm births. Women who had more than 10 prenatal visits demonstrated a preterm birth rate of 11.3%. On the other hand, those who had less than 10 prenatal visits had a higher preterm birth rate of 18.01%. This data suggests a clear correlation between preterm birth and receiving appropriate prenatal care (46). A variety of other factors also contribute to preterm birth, such as individuals with low incomes and low socio-economic status, Hispanic and non-white ethnic backgrounds, mothers who smoke or consume alcohol during pregnancy, low educational levels, pregnancies occurring under the age of 18 -20 or over the age of 35-40 years, mothers with asthma, and exposure at second trimester (46, 53, 55).

However, it is worth noting that there is only one study, with a considerably small sample size, suggesting that wildfire does not significantly increase the risk of preterm birth (73). It is important to mention that these same authors conducted another study, which found a minor increase in preterm birth rates due to wildfire (47). The inconsistency in these results could potentially be attributed to factors such as the country or region under study, racial demographics, and characteristics of the residents in the specific area.

A study conducted by Mona Abdo et al., analyzed 535,895 singleton births occurring during 2007-2015 in Colorado. Their findings revealed that wildfires increased the likelihood of preterm births. Similarly, another study by Seema Jayachandran investigated the fires in Indonesia during the late 1997 period, and identified a correlation between wildfires and increased rates of preterm births (46, 48). Contrarily, a study conducted by M. H. O'Donnell and A. M. Behie during the 2003 Canberra wildfires, involving 4,107 births, demonstrated that wildfire did not have a significant impact on the rate of preterm births (73). However, these same authors conducted a study during the Black Saturday fires in Victoria in 2009, and concluded that there was a brief, yet notable increase in the prevalence of preterm births (47). It is important to note that these studies provide insights into the relationship between wildfires and preterm births, but further research is necessary to fully understand the underlying mechanisms and potential variations in different contexts.

4.2. LBW and natural disasters

4.2.1 LBW in earthquake area

The earthquake leads to a decline in newborns' weight. The occurrence of an earthquake is associated with an increase in LBW (13-16, 18, 19, 22, 24, 26, 64, 65). After an earthquake, there are several risk factors that contribute to the occurrence of LBW. LBW rates are observed to be higher among individuals with lower educational levels, those living in poverty, and those with limited access to prenatal healthcare (64).

Proximity to the center of the earthquake and the severe affected area or the high intensity of the earthquake is another factor in increasing the rate of LBW (22, 65). If the earthquake occurs in the first trimester of pregnancy or if earthquake has moderate to high intensity, the neonate will have a lower birth weight (15, 16). The age of the mother at the time of pregnancy, particularly being over 40 years old, is recognized as a risk factor that can increase the likelihood of LBW (19). Interestingly, a study revealed that the gender of the neonate, specifically being male, is also identified as a risk factor for LBW (22). Moreover, the place of residence played a role in LBW cases following the Great Japan Earthquake, with a higher prevalence observed in the inland region compared to the coastal region. In addition, infants born in the inland region generally exhibited lower weights (24). However, it is worth noting that various studies conducted after the 2011 Great Japan Earthquake have yielded different outcomes and findings, for instance, in research conducted by Fujimori and another research by Ishikuro, which assessed 21,748 births affected by the Great Japan Earthquake. Surprisingly, no notable disparities were observed in terms of LBW (23, 27, 32). The rationale behind this outcome lies in Japan's commendable post-disaster care system, which proves to be highly effective and comprehensive. In fact, the availability of enhanced medical attention positively impacts the infant's weight and has no detrimental effect on birth weight. It is worth mentioning that Hyo Kyozuka et al, in one study, reported an increase in LBW following an earthquake [ref]. However, their two (75) alternative studies yielded different findings, leading them to conclude that LBW did not exhibit any significant differences (19, 26, 28).

4.2.2 LBW in flooded area

Floods have been found to be associated with an increased risk of LBW (57, 60, 67-69). It has been observed that women who were compelled to relocate as a result of flooding events tend to have a higher incidence of giving birth to neonates with LBW (57). These adverse effects are more prevalent in certain demographic groups including non-white individuals, unmarried individuals, older individuals, and those with lower levels of education (67, 69).

4.2.3 LBW in storm area (hurricane, typhoon, cyclone, and tornado)

After Hurricane Katrina, there was a significant negative impact on birth weight, leading to a notable decrease in birth weight among newborns. Furthermore, the rate of LBW has more than doubled in comparison to the period before the hurricane struck (34, 35, 38, 40, 41, 43).

Inadequate prenatal care, including a sharp drop in access to prenatal care, is considered one of the contributing factors to the rising incidence of LBW. It was particularly prevalent among black, non-Hispanic women due to significant reductions in prenatal care within this demographic (40). This unfavorable outcome can be attributed to heightened apprehension about the recurrence of the storm and the subsequent development of post-traumatic stress disorder (PTSD) (35). In contrast, in a study examining the impact of Hurricane Katrina, it was unexpectedly observed that the rate of LBW and very low birth weight (VLBW) decreased following the disaster. This decrease may be attributed to missing births during the incident (100).

Between 2008 and 2018, an investigation was conducted to examine the impact of severe cyclones in Australia. The findings revealed significant associations between exposure to some storms such as cyclone Marcia and birth weight outcomes. It was found that individuals exposed to this hurricane in the middle of pregnancy had a significantly higher incidence of low birth weight (38). Furthermore, a study on ice storms demonstrated that mothers exposed to ice storms during the first and second trimesters had neonates with lower birth weights (41). On the other hand, Hurricane Harvey had a relatively minimal effect on birth weight, resulting in only a slight decrease (43). Also, although Yasi and Marcia were severe cyclones but didn't increase rate of LBW (99). Through extensive analysis disregarding any confounding factors, it has been observed that increased exposure of mothers to hurricanes directly correlates with a subsequent rise in both preterm delivery and low birth weight (34).

Distinct results were observed in studies examining other storms. For instance, Hurricane Andrew did not appear to cause LBW (36). Likewise, an analysis of four hurricanes—Charley, Frances, Ivan, and Jeanne—revealed no correlation with LBW (101). Additionally, no increase in LBW was observed in Alabama and Missouri (42). These findings suggest that the intensity and extent of the storm, as well as the duration of its impact on an area, are additional influential factors in determining birth weight outcomes.

4.2.4 Volcano and LBW

The eruption of a volcano does not appear to have any impact on birth weight, according to scientific research. In the research conducted on the impact of the Puyehue volcano, Ana Ines Balsa discovered that exposure to volcanic smoke did not have any influence on the likelihood of LBW occurrences (44). Similarly, in a separate study focusing on the Sinabung volcano, Geoff Kushnick et al. observed that expectant mothers who were exposed to the volcano during pregnancy did not experience a noteworthy variance in LBW outcomes (45).

4.2.5 LBW in wildfire area

The impact of wildfire occurrence on birth weight has been inconsistent across various studies. Some studies indicate a decrease in birth weight when exposed to wildfire (46, 53, 55, 70-72, 74, 76, 77), while others demonstrate no significant effect on neonatal birth weight (46, 73).

However, prenatal care emerges as the most influential factor regarding birth weight in the context of wildfires. A study conducted by Mona Abdo et al. found that women who received fewer than 10 prenatal visits had neonates with a lower birth weight (by approximately 97 grams) compared to those who had more than 10 prenatal visits. Therefore, the number of prenatal care visits directly correlates with fetal weight at birth (46). Exposure to wildfires during the first trimester of pregnancy also poses a risk for an increased incidence of LBW (70). LBW is more prevalent among individuals with low income, non-white ethnicities, maternal smokers and alcoholics, individuals with limited literacy skills, mothers under the age of 18 years, mothers with asthma, male neonates, and during hot seasons like summer (46, 71). According to a study conducted by David M. Holstius, exposure to wildfire smoke during the second trimester of pregnancy was found to be associated with LBW. However, the study did not report a direct correlation with LBW (72). In contrast, a study conducted by M. H. O'Donnell in 2003, focusing on the Canberra wildfires, found no conclusive evidence linking the occurrence of wildfire to LBW. These findings suggest that the relationship between smoke exposure and LBW requires further research and investigation. In this study, researchers investigated the impact of wildfires on birth weight by comparing data from a moderately affected area to a severely affected area over time. The findings indicated that exposure to wildfires resulted in a significant increase in the birth weight of male babies by 197 g in the severely affected area during the year of the wildfire (2003). However, subsequent years demonstrated a decline in this weight gain, with a decrease to approximately 56 grams by 2010. In the wildfire year, there was no noticeable distinction between moderately affected areas and severely affected areas in terms of female neonates. However, in subsequent years, the prevalence of severely affected areas surpassed that of moderately affected areas. One possible explanation for this trend is that mothers residing in severely affected areas reported lower smoking rates compared to those in moderately affected areas (9.02% versus 13.79%) (73). In another study conducted by Anna Claire G Fernández et al., wildfire caused high birth weight. Most of the investigated papulation were white and educated. Also, they excluded mothers who did not receive prenatal care (75).

4.3. SGA and natural disasters

Most studies indicate a rise in SGA after the incidence of natural disasters (13, 15, 46, 102). However, it is worth noting that several studies demonstrate no apparent elevation in SGA cases subsequent to natural disasters (19, 73). Furthermore, a study found that mothers exposed to wildfire smoke during their first trimester experienced a significant increase in SGA (46). However, another study presented contradictory findings (73). While some studies have demonstrated a higher incidence of SGA in mothers who were exposed to earthquakes, other studies have not shown any significant increase in SGA. For example, research conducted after the earthquakes in Wenchuan, China, and Chile indicated a higher prevalence of SGA among exposed mothers as opposed to non-exposed mothers (13, 15). Conversely, a study carried out after the great earthquake in Japan found no significant rise in the occurrence of SGA (19).

4.4. Hypertension (gestational hypertension, eclampsia, preeclampsia) and disasters

Natural disasters can contribute to high blood pressure and Eclampsia during pregnancy (26, 29, 46, 59, 67, 81). Exposure to wildfire smoke during pregnancy, whether in the first, second, or throughout the entire trimester, has been found to increase the likelihood of gestational hypertension (46). These adverse effects are observed more frequently among non-white individuals, unmarried individuals, older mothers, and those with low levels of education (46). Research indicates that floods and storms can also contribute to pregnancy-related hypertension (59, 81). However, the effects of earthquakes on pregnancy hypertension differ. Certain studies suggest that earthquake occurrences do not show a significant impact on gestational hypertension (15, 19). On the other hand, another study reveals that pregnant women under 20 years old and those with low socioeconomic status may experience higher rates of gestational hypertension following an earthquake (26). Also, Mami Ishikuro study showed that in areas with full destroyed homes rate of hypertensive disorders of pregnancy increase (27). Additionally, one study found an increased incidence of preeclampsia following a flood (67). However, two other studies did not observe a rise in the prevalence of preeclampsia after exposure to floods and earthquakes (15, 59).

4.5. Stillbirth and natural disasters

Both wildfire and flood cause an increase in stillbirth, especially in low-income countries and people with low economic status (48, 68, 84, 86).

Similarly, the occurrence of an earthquake has been associated with higher rates of perinatal mortality as well as stillbirths (13, 14). It is important to note that if pregnant individuals receive appropriate and high-quality care following an earthquake, the risk of stillbirths may not rise significantly (23). In the aftermath of hurricanes Charley, Frances, Ivan, and Jeanne, no notable changes in stillbirth rates were reported (43, 101). However, following hurricanes Katrina and Andrew, an increase in stillbirth rates has been documented, with the severity correlating with the extent of house destruction (82, 83). Also, after cyclones Yasi and Marcia, rate of male still birth increased (99).

4.6. Man-made disasters

4.6.1 Preterm birth

Examining the impact of the Chernobyl nuclear accident on pregnancy duration and premature birth in Finland and Stockholm, it was found that there was no notable difference in the rate of preterm birth However, it was observed that the duration of pregnancy was slightly shorter in mothers who experienced anxiety. Despite this, none of the neonates were born preterm (61, 62). In Finland, a study revealed a higher incidence of preterm birth with congenital anomalies among pregnant mothers who were exposed to storms during the first trimester. This phenomenon was more prevalent in mothers residing in Zones 2 and 3 (61). Shifting our focus to the investigation of the Fukushima nuclear accident, which occurred three years prior to and after the significant earthquake of 2011, it was concluded that this particular accident did not have a substantial impact on preterm birth rates (20, 63). Please note that these findings are based on studies and should be interpreted within the context of the available research.

4.6.2 LBW

Examining the recent radiation leak at the Indian Point nuclear power plant reveals potential consequences of exposure to ionizing radiation.

Studies indicate that such exposure has led to increased risks of LBW and premature birth. It is important to note that this event is not directly associated with the risk zone (21). Similarly, examining the effect of radiation leakage from the Fukushima accident, which occurred after the 2011 Great Japan Earthquake, studies have focused on birth outcomes in the area up to 7 years after the incident. Comparisons with the period before the accident have indicated an increase in LBW up to 9.04%, with the amount of radiation dose received showing a direct linear relationship with LBW outcomes (78). However, it is worth noting that another study, conducted with a smaller sample size, examined LBW rates three years before and after the accident, revealing no significant difference. This calls for more extensive research and investigation into the long-term effects of radiation exposure on birth outcomes (20). Another study, conducted with 6,875 participants that were exposed to <2mSv of radiation in the 4 months following Fukushima Daiichi Nuclear Power Plant Accident, revealed no significant difference (63).

4.6.3 Stillbirth

Numerous studies have examined the relationship between the Chernobyl accident and prenatal death and stillbirth, yielding conflicting results.

Investigations conducted in Kiev, Finland, and Germany both pre and post-accident did not reveal a significant difference in prenatal death and stillbirth rates (61, 92, 95). However, a separate study in Germany focused on the impact of the Chernobyl accident specifically on stillbirth and suggested a correlation between stillbirths and cesium-137, indicating that an increase in exposure to this element could potentially lead to more cases of stillbirth. It is important to note that the researchers themselves expressed uncertainty about their findings and advised interpreting the conclusion cautiously (103). Additionally, other studies conducted in Norway, Finland and Ukraine examined the impact of the Chernobyl accident and found a notable increase in prenatal death and stillbirth as a result (90, 95-97). Furthermore, an increase in stillbirths was observed in the years following the atomic bombing of Hiroshima (94). Another notable incident involving radioactivity was the Fukushima nuclear power plant accident in Japan following the massive earthquake of 2011. In the heavily radioactively contaminated area, prenatal death significantly rose within the first 10 months after the Fukushima accident, while a minor increase was observed in the moderately contaminated area (93).

4.6.4 Spontaneous abortion

Studies conducted in Norway, Hungary, and Finland before and after the Chernobyl accident revealed an increase in the rate of spontaneous abortion following the incident (85, 88-90). However, in other studies, no significant change was observed in the rate of spontaneous abortion before and after the Chernobyl accident in Kiev and Finland (91, 92).

4.6.5 The September 11, 2001 attacks on the Twin Towers of the World Trade Center

Only two studies have been conducted to examine the impact of the September 11, 2001 attack on the Twin Towers of the World Trade Center on pregnancy outcomes. These studies specifically focused on mothers who either worked or resided within a 2-mile radius of the World Trade Center. The findings indicated that these mothers experienced shorter pregnancies compared to those who lived farther away, especially if the exposure occurred during the first trimester. Additionally, the rate of LBW infants was higher following the 9/11 incident, and the average height of the newborns was reduced by approximately 8 millimeter (79, 80).

4.6.6 Chemical attack

In relation to the effects of chemical bombs on pregnancy outcomes, only one study has explored this topic. The study observed an increase in spontaneous abortions among mothers whose husbands were exposed to mustard gas during Saddam Hussein's deployment of the gas against Iranian soldiers (104).

5. Limitations

Regrettably, as we did not have a qualified translator for non-English languages, we were unable to incorporate articles in languages other than English or Persian in our study. In Addition, the type of most of the included articles is descriptive and there isn't any randomized clinical trial. For this reason, our conclusion should be interpreted with caution.

6. Conclusions

Natural and man-made disasters exert significant influence on adverse pregnancy outcomes. While it is impossible to prevent the incidence of natural disasters and man-made disasters often occur abruptly, the negative consequences of disasters, particularly natural ones, can be mitigated by enhancing prenatal care and avoiding detrimental elements such as smoking and alcohol.

7. Declarations

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7.2. Authors complications

All authors: Conceptualization, methodology, and software, Yousef Pashaei Asl, Nasim Partash, Solmaz Ghanbari-Homaie and Gholamreza Faridaalaee: Abstract reading and data extraction, Gholamreza Faridaalaee and Alireza Pakzad: Writing original draft.

All authors: Reviewing, editing, and approving final manuscript

7.3. Availability of data

The data that support the findings of this study are available on request from the corresponding author.

7.4. Using artificial intelligence chatbots

None.

7.5. Funding and supports

The authors declare that they have no known financial interests or personal relationships that could have appeared to influence the work reported in this paper. The study was supported by Tabriz University of Medical Sciences, Tabriz, Iran (Code: 73279).

7.6. Competing Interests

The authors declare that they have no known competing interests.

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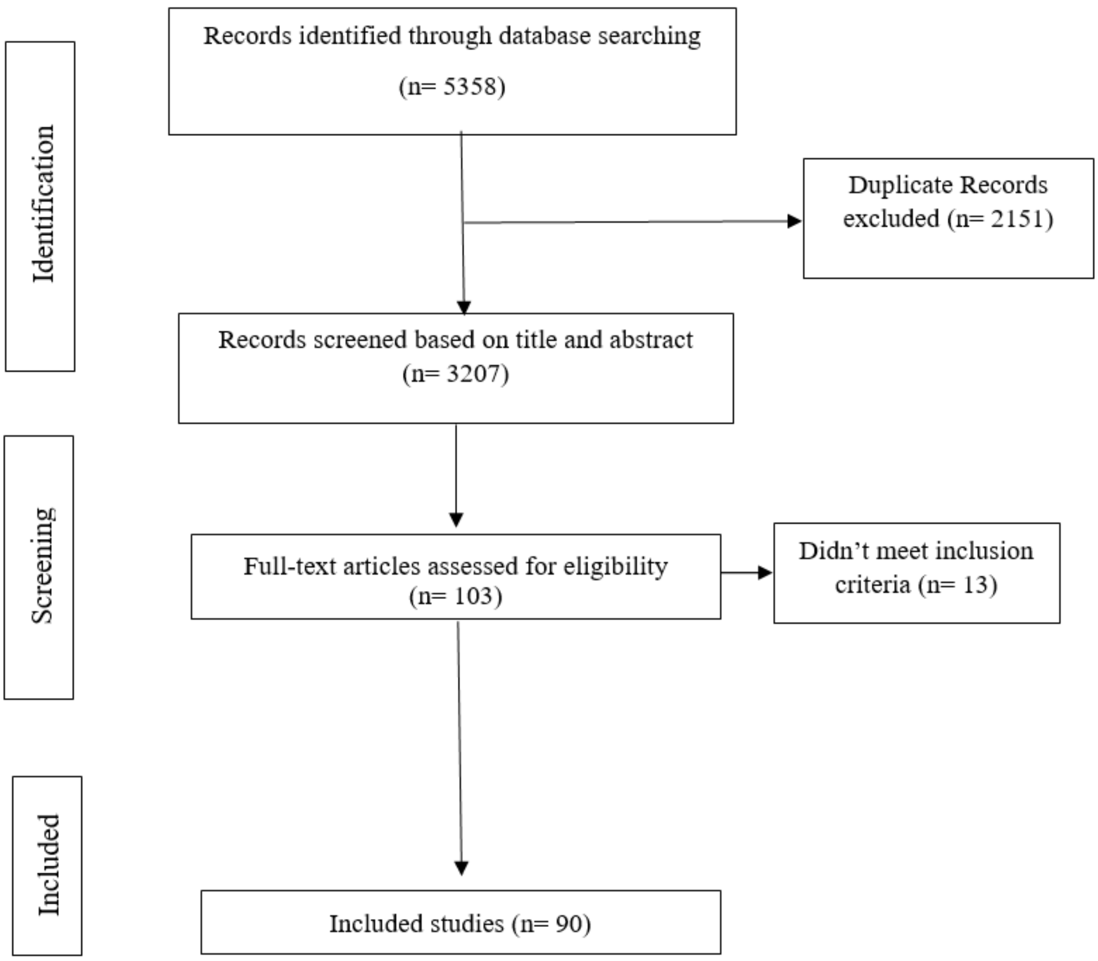

Figure 1: The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) flow diagram of the study.

Table 1: Search strategy of this systematic review for different databases

Database	Search terms
MEDLINE (PubMed)	1) “Pregnancy Outcome”[Mesh] OR “Pregnancy Complications”[Mesh] OR “Stillbirth”[Mesh] OR “Fetal Death”[tiab] “Pregnancy”[Mesh] OR “Abortion, Spontaneous”[Mesh] OR “Eclampsia”[Mesh] OR “Pre-Eclampsia”[Mesh] OR “Infant, Low Birth Weight”[Mesh] OR “Extremely Low Birth Weight”[Mesh] OR “Premature Birth”[Mesh] OR “Small for Gestational Age”[Mesh] OR “Pregnancy Outcome”[tiab] OR “Pregnancy Complications”[tiab] OR “Pre-Eclampsia”[tiab] OR “Preeclampsia”[tiab] OR “Pregnancy Toxemia”[tiab] OR “Toxemia Of Pregnancy”[tiab] OR “Toxemia Of Pregnancies”[tiab] OR “Abortion, Spontaneous”[tiab] OR “Maternal Weight Gain” OR “Gestational Weight Gain”[tiab] OR “Spontaneous Abortion”[tiab] OR “Low Birth Weight”[tiab] OR “Extremely Low Birth Weight”[tiab] OR “Premature Birth”[tiab] OR “Stillbirth”[tiab] OR “preterm”[tiab] OR “Small for Gestational Age”[tiab] OR “Birth Weight”[tiab] 2) “Earthquake”[Mesh] OR ”Floods”[Mesh] OR ”Cyclonic Storms”[Mesh] OR ”Tornadoes”[Mesh] OR ”Wildfires”[Mesh] OR “Volcanic Eruptions”[Mesh] OR ”Natural Disasters”[Mesh] OR “Earthquake” [tiab] OR “Floods”[tiab] OR “Cyclonic Storm”[tiab] OR “Cyclone”[tiab] OR “Cyclones”[tiab] OR “Hurricanes”[tiab] OR “Hurricane”[tiab] OR “Tropical Storm”[tiab] OR “Tropical Storms”[tiab] OR “Typhoons”[tiab] OR “Typhoon”[tiab] OR “Tornado”[tiab] OR “Tornados”[tiab] OR “Natural Disaster”[tiab] OR “Wildfires”[tiab] OR “Forest Fire”[tiab] OR “Brush Fire”[tiab] OR “Wild Fire”[tiab] OR “Volcanic Eruptions”[tiab] OR “Disasters”[Mesh] OR “Chemical Hazard Release”[Mesh] OR “Radioactive Hazard Release”[Mesh] OR “Chemical Warfare Agents”[Mesh] OR “Weapons of Mass Destruction”[Mesh] OR “Biological Warfare Agents”[Mesh] OR “Mass Casualty Incidents”[Mesh] OR “Mass Gatherings”[Mesh] OR “Mass Gatherings”[tiab] OR “Chemical Hazard Release”[tiab] OR “Chemical Accidental”[tiab] OR “Chemical Incident”[tiab] OR “Radioactive Hazard Release”[tiab] OR “Nuclear Accident”[tiab] OR “Chemical Warfare Agents”[tiab] OR “Weapons of Mass Destruction”[tiab] OR “Biological Warfare Agents”[tiab] OR “Mass Casualty Incidents”[tiab] 3) 1 &2
Scopus	1) (TITLE-ABS-KEY (pregnancy AND outcome) OR TITLE-ABS-KEY (pregnancy AND complications) OR TITLE-ABS-KEY (stillbirth) OR TITLE-ABS-KEY (fetal AND death) OR TITLE-ABS-KEY (spontaneous AND abortion) OR TITLE-ABS-KEY (pre AND eclampsia) OR TITLE-ABS-KEY (eclampsia AND complications) OR TITLE-ABS-KEY (low AND birth AND weight) OR TITLE-ABS-KEY (premature AND birth) OR TITLE-ABS-KEY (preterm AND birth) OR TITLE-ABS-KEY (small AND for AND gestational AND age) OR TITLE-ABS-KEY (pregnancy AND induced AND hypertension)) 2) (TITLE-ABS-KEY (earthquake) OR TITLE-ABS-KEY (flood) OR TITLE-ABS-KEY (cyclonic AND storms) OR TITLE-ABS-KEY (tornado) OR TITLE-ABS-KEY (tornadoes) OR TITLE-ABS-KEY (wildfire) OR TITLE-ABS-KEY (volcanic AND eruptions) OR TITLE-ABS-KEY (natural AND disasters) OR TITLE-ABS-KEY (chemical AND hazard AND release) OR TITLE-ABS-KEY (radioactive AND hazard AND release) OR TITLE-ABS-KEY (chemical AND warfare AND agents) OR TITLE-ABS-KEY (weapons AND of AND mass AND destruction) OR TITLE-ABS-KEY (biological AND warfare AND agents) OR TITLE-ABS-KEY (mass AND casualty AND incidents) OR TITLE-ABS-KEY (mass AND gatherings) OR TITLE-ABS-KEY (chemical AND accidental) OR TITLE-ABS-KEY (chemical AND incident) OR TITLE-ABS-KEY (nuclear AND accident)) 3) 1 &2
Web of Science	1) Pregnancy Outcome (Abstract) and Pregnancy Complications (Abstract) or Stillbirth (Abstract) or "Pre-Eclampsia" (Abstract) or Low Birth Weight (Abstract) or Premature Birth (Abstract) or Small for Gestational Age (Abstract) or Spontaneous Abortion (Abstract) or “Pregnancy hypertension” (Abstract) or hypertension (Abstract) and Eclampsia (Abstract) 2) Earthquake (Abstract) and flood (Abstract) or Storm (Abstract) or Tornado (Abstract) or Wildfire (Abstract) or Volcanic Eruptions (Abstract) or Hurricane (Abstract) or Typhoon (Abstract) or “Chemical Hazard Release” (Abstract) or “Radioactive Hazard Release” (Abstract) or “Weapons of Mass Destruction” (Abstract) or “Mass Casualty” (Abstract) or “Mass Gatherings” (Abstract) or Nuclear (Abstract) 3) 1 &2
Embase	1) ’pregnancy’/exp OR ’pregnancy disorder’/exp OR ’pregnancy disorder’ OR ’pregnancy complication’/exp OR ’pregnancy complication’ OR ’abortion’/exp OR ’abortion’ OR ’spontaneous abortion’/exp OR ’spontaneous abortion’ OR ’eclampsia’/exp OR ’eclampsia’ OR ’eclampsia and preeclampsia’/exp OR ’eclampsia and preeclampsia’ OR ’eclampsia therapy’/exp OR ’eclampsia therapy’ OR ’eclampsia diagnosis’/exp OR ’eclampsia diagnosis’ OR ’eclampsia prevention and control’/exp OR ’eclampsia prevention and control’ OR ’eclampsia complications’/exp OR ’eclampsia complications’ OR ’preeclampsia’/exp OR ’preeclampsia’ OR ’pregnancy outcomes’/exp OR ’pregnancy outcomes’ OR ’hyperemesis gravidarum’/exp OR ’hyperemesis gravidarum’ OR ’hyperemesis gravidarum therapy’/exp OR ’hyperemesis gravidarum therapy’ OR ’gestational weight gain’/exp OR ’gestational weight gain’ OR ’hydatidiform mole’/exp OR ’hydatidiform mole’ OR ’pregnancy toxemia’/exp OR ’pregnancy toxemia’ OR ’pregnancy toxemias therapy’/exp OR ’pregnancy toxemias therapy’ OR ’pregnancy toxemias complications’/exp OR ’pregnancy toxemias complications’ OR ’pregnancy toxemias diagnosis’/exp OR ’pregnancy toxemias diagnosis’ 2) ’flooding’/exp OR ’earthquake’/exp OR ’hurricane’/exp OR ’tornado’/exp OR ’wildfire’/exp OR ’volcano’/exp OR ’natural disaster’/exp OR ’forest fire’/exp OR ’chemical accident’/exp OR ’nuclear accident’/exp OR ’chemical warfare agent’/exp OR ’weapon of mass destruction’/exp OR ’biological warfare agent’/exp OR ’mass disaster’/exp OR ’mass gathering’/exp 3) 1 &2

Table 2: Quality control and risk of bias assessment of included studies

First author and publication year	Type of study	Description of control group	Definition of exclusion criteria	Definition of outcome	Ethical approval	Statistical analysis	Description of patient group
Xu Xiong, MD, DrPH, 2009	Cohort	+	+	+	+	+	+
Mona Abdo, 2019	Observational	+	+	+	_	+	+
M. H. O'Donnell, 2021	Observational	+	+	+	+	+	+
Georgina Hawkins, 2018	Retrospective cohort	+	+	+	+	+	+
David M. Holstius, 2012	Observational	+	+	+	_	+	+
M.H. O'Donnell, 2013	Cohort	+	+	+	_	+	+
Taiane S. Prass, 2019	Observational	+	+	+	+	+	+
Seema Jayachandran, 2008	Observational	+	_	+	_	+	+
Anzhelika Antipova,1993	Observational	+	+	+	+	+	+
Ana Ines Balsa, 2016	Observational	+	+	+	_	+	+
Shawn J. Mccoy, 2020	Observational	_	_	_	_	_	+
Hseuh-Ling Chang, 2002	Observational	+	+	+	_	+	+
Kenneth E. Christopher, 2018	Observational	+	_	+	_	+	+
Janet Currie, 2012	Observational	+	+	+	_	+	+
Kelsey N. Dancause, 2011	Observational	+	+	+	+	+	+
Geoff Kushnick, 2021	Cohort	+	+	+	+	+	+
Hyo Kyozuka, 2018	Observational	+	+	+	+	+	+
Hyo Kyozuka, 2019	Observational	+	+	+	+	+	+
Claire Leppold, 2017	Observational	+	+	+	+	+	+
R. Levi, U. Lundberg, 2009	Observational	+	+	+	+	+	+
Qiguo Lian, 2020	Cross-sectional	+	+	+	+	+	+
Rolv Terje Lie, 1992	Observational	+	+	+	_	+	+
Tania Mangones, 2013	Observational	+	+	+	+	+	+
Hector Mendez-Figueroa, 2019	Observational	+	+	+	-	+	+
Carolina Oyarzo, 2012	Observational	+	+	+	+	+	+
Parayiwa, C, 2022	Observational	+	+	+	+	+	+
Weeberb J. Requia, 2022	Observational	+	+	+	+	+	+
Natthananporn Sanguanklin, 2014	Observational	+	+	+	_	+	+
Hagen Scherb, 2020	Observational	+	+	+	+	+	+
Hagen Scherb, 2000	Observational	+	+	+	_	+	+
Hagen Heinrich Scherb, 2011	Observational	+	+	+	+	+	+
Miranda J. Spratlen, 2022	Observational	+	+	+	+	+	+
Junichi Sugawara, 2018	Observational	+	+	+	+	+	+
Shengzhi Sun, 2020	Observational	+	+	+	_	+	+
Kohta Suzuki, 2016	Observational	+	+	+	+	+	+
Kohta Suzuki, 2016	Observational	+	+	+	+	+	+
Cong E. Tan, 2009	Observational	+	+	+	+	+	+
Van T. Tong, 2011	Observational	+	+	+	_	+	+
Florencia Torche, 2011	Observational	+	+	+	_	+	+
Magnar Ulstein, 1990	Observational	+	_	+	_	+	+
Jianpeng Xiao, 2019	Observational	+	+	+	+	+	+
Yasuda, Shun, 2017	Observational	+	+	+	+	+	+
Sammy Zahran, 2014	Observational	+	+	+	+	+	+
Shahla Baloch, 2012	Observational	+	+	+	_	+	+
Sammy Zahran, 2011	Observational	+	+	+	_	+	+
Keiya fujimori, 2014	Observational	+	+	+	+	+	+
Glynn, LM, 2021	Observational	+	+	+	+	+	+
Shannon C. Grabich, 2016	Cohort	+	+	+	+	+	+
Shannon C. Grabich, 2017	Observational	+	+	+	+	+	+
B. Grosche, 1997	Observational	+	+	+	_	+	+
T Harjulehto,1989	Observational	+	+	+	_	+	+
T Harjulehto, 1991	Observational	+	+	_	_	+	+
Emily W. Harville, 2015	Observational	+	+	+	+	+	+
Yasna K. Palmeiro-Silva, 2018	Observational	+	+	+	+	+	+

Table 2: Quality control and risk of bias assessment of included studies (continue)

First author and publication year	Type of study	Description of control group	Definition of exclusion criteria	Definition of outcome	Ethical approval	Statistical analysis	Description of patient group
Emily W. Harville, 2010	Observational	+	+	+	+	+	+
Emily W. Harville, 2015	Observational	+	+	+	-	+	+
Emily W. Harville, 2020	Observational	+	+	+	+	+	+
Georgina Hawkins, 2018	Retrospective cohort	+	+	+	+	+	+
LM Irgens', 1991	Observational	+	_	+	_	+	+
Leila Karimi, 2020	Retrospective, cohort	+	+	+	+	+	+
Buzhievsk, et al, 1995	Cohort	+	+	+	-	+	+
Sally Ann Lederman, 2008	Observational	+	+	+	-	+	+
Erin Hetherington, 2021	Cohort	+	+	+	+	+	+
Anssi Auvinen, 2001	Observational	+	+	+	_	+	+
Anna Claire G Fernández, 2023	Observational	+	+	+	+	+	+
Mami Ishikuro, 2023	Cohort	+	+	+	+	+	+
Hyo Kyozuka, 2023	Cohort	+	+	+	+	+	+
En-Joo Jung, 2022	Observational	+	+	+	+	+	+
Cynthia Parayiwa, 2022	Observational	+	+	+	+	+	+
Jacob Hochard, 2022	Observational	+	+	+	+	+	+
Jiajianghui Li, 2022	Observational	+	+	+	-	+	+
Sam Heft-Neal, 2022	Observational	+	+	+	-	+	+
Tao Xue, 2023	Observational	+	+	+	-	+	+
Yiwen Zhang, 2023	Cohort	+	+	+	+	+	+
Sarolta Szalai, 2022	Observational	+	+	+	-	+	+
Yuta Inoue, 2023	Observational	+	+	+	+	+	+
Sourav Biswas, 2023	Observational	+	+	+	+	+	+
Cheng He, 2024	Observational	+	+	+	-	+	+
Zeinab Rezae, 2022	Observational	+	+	+	+	+	+
Weeberb J. Requia, 2022	Observational	+	+	+	+	+	+
Sandie Ha, 2024	Observational	+	+	+	-	+	+
Xinyue Liu, 2024	Cohort	+	+	+	-	+	+
Sally Picciotto, 2024	Cohort	+	+	+	-	+	+
Margaret M. Sugg, 2023	Quasi-experimental	+	+	+	+	+	+
P. Jiang, 2024	Observational	+	+	+	+	+	+
Hossein Amarpoor Mesrkanlou 2022	Observational	+	+	+	+	+	+
Hyo Kyozuka, 2022	Observational	+	+	+	+	+	+
Emily W. Harville, 2022	Observational	+	+	+	-	+	+
Shun Yasuda, 2022	Observational	+	+	+	+	+	+
Alfred Ko¨rblein, 2024	Observational	+	+	+	-	+	+
Yuta Inoue, 2023	Observational	+	+	+	+	+	+