Impact of climate change on pregnancy outcomes: A systematic review

A Capstone project submitted to
Johns Hopkins Bloomberg School of Public Health & IIHMR University
in partial fulfilment of the requirements for
the award of the degree of
Master of Public Health

by

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MPH - Cohort IX (2021-23)

Under the guidance of
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October 2022

Abstract

Objective: To investigate the effect on pregnancy outcomes, due to the increase in temperature because of the climate change, to identify the windows of exposure susceptible to adverse effects of heat and to also identify the gaps among the existing research by synthesizing the available literature.

Methods: A search strategy was formulated using the key terms such as climate change, pregnancy outcomes, heatwaves, global warming. Search was carried out in databases of, COCHRANE, SCOPUS and PUBMED. Number of articles retrieved were 259.Also snowballing backward referencing of systematic reviews were done to include articles. Total 41 articles were included that met the inclusion criteria.

Data extraction: Total 41 articles were included and were tabulated according to the exposure measured, the pregnancy outcomes, study design, sample size, location of the study, authors, journals, and publishing year. Included articles were checked for quality through the "Critical Appraisal Skills Programme" guidelines checklist.

Conclusions: High temperature especially in the third trimester increased the risk of preterm birth. Exposure to extreme heat events does cause the reduction of birthweight. Still birth was linked with exposure to severe temperatures cold or hot especially the week before delivery. The association of spontaneous abortion was not strong and warranted more research for this outcome. The increase in temperature does show a possible association with incidences of congenital anomalies. More single country research is needed in Low- and middle-income country as most of the studies are being conducted in high income countries.

Acknowledgement

First and foremost, I would like to thank Johns Hopkins Bloomberg School of Public health and IIHMR University for giving me this amazing opportunity. I would like to express my special thanks of gratitude to my faculty advisor Dr. D.K. Mangal for his valuable feedback and support in completion of this capstone. I would also like to thank Dr. Seema Mehta for being the pillar of strength and her constant guidance. In the end I would like to thank my mother, fiancé and friends who supported me and were always there for me whenever I needed them.

Nandita Bhatnagar

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1. Introduction

On 11-Nov-2021, a Canadian woman was diagnosed to be suffering from 'climate change' as she developed difficulties in breathing due to a heatwave, becoming the first patient to be diagnosed with climate change in the world. Global warming is a threat to entire planet, affecting every sector, such as biodiversity loss, loss of soil productivity, ecosystem degradation and many more[1]. According to the "Lancet Count down on health and climate change", it is now "code red" which means climate change is an immediate danger for our tommorrow[2]. It is an emergency; we all need to focus on. One of the most at risk populations affected due to change in climate are pregnant mothers and new-born. And a major threat of climate change is an increase in adverse birth outcomes. According to estimates, between 1969 and 1988, heat exposure caused 25,000 new-borns per year to be born preterm (at 39 to 40 weeks' gestation), resulting in a loss of 150,000 gestational length annually[3]. There would be further loss of 250,000 days every year, if no action is taken, by the end of century is estimated[3]. 88% of disease burden due to climate change lies among the children less than 5 years of age as per World Health Organization[3]. In Barcelona a study was done on the women who were pregnant, which showed evidence that exposure to excessive heat index preceding delivery decreased the average gestational age by 2 days and elevated extreme temperatures reduced it by 5 days, implying a relation between the response and the amount of exposure [4]. Toxicological effects of heat on health are known to be humans since ages in the form of heat stroke, but the exact mechanism of its impact on birth outcomes is yet unknown[5]. A study in animal showed that exposure to heat causes the secretions of Oxytocin and antidiuretic hormone that causes decreased blood flow to uterus causes foetal hypoxia or leads to premature birth[5].

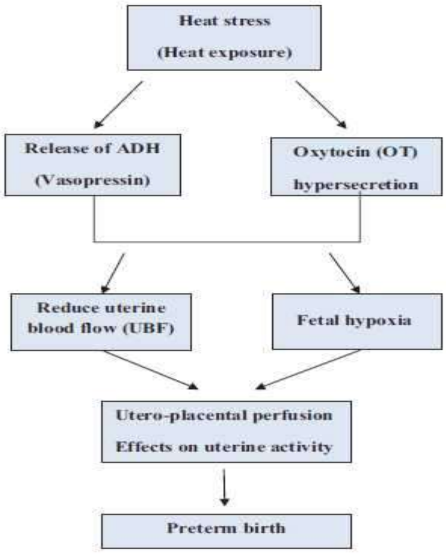

Figure 1: Possible biological mechanism of effect of heat on birth outcomes[5].

In Ahmedabad, India, heat waves led to an increase in admissions in a research that examined NICU admissions on days with high heat where births take place outside of hospitals and excessive heat is defined as above 42 degree Centigrade[6]. In California's warm-season months, it was discovered by Basu et al. modification of effect within new-born fatality rates, showing that black children had higher risk of mortality than other ethnic subgroups[7]. The objective of this paper is to investigate the effect on pregnancy outcomes, of the increase in temperature caused due to the climate change, identify the windows of exposure susceptible to harmful effects of change in climate and to also identify gaps among the existing research by synthesizing the available literature.

2. **Materials and Method**

Climate change for the purpose of this paper is defined as severe weather phenomena, consisting of heat waves, temperature increases, hot season, and global warming. The term pregnancy outcome for this paper is defined as the result of pregnancy that is in the form of live birth, still birth, abortion, preterm birth or congenital anomalies.

A search strategy was developed using the key terms of climate change, pregnancy outcomes for each database. Using the search strategy, a search was carried out, in the databases of Scopus, PubMed and Cochrane.

2.1 SEARCH STRATEGY

For PubMed

“"Climate Change"[mesh] OR "climate change*"[tw] OR "global warming"[tw] OR "heat wave*"[tw] OR "rising temperature*"[tw]”

“AND "Pregnancy Outcome"[mesh] OR "Premature Birth"[mesh] OR "Abortion, Spontaneous"[mesh] OR "Pregnancy Outcome*"[tw] OR "Live Birth*"[tw] OR "still birth*"[tw] OR "preterm birth*"[tw] OR "Premature Birth*"[tw] OR "spontaneous abortion*"[tw] OR "Early Pregnancy Loss*"[tw] OR "miscarriage*"[tw]”

For Scopus

“Concept #1 "Climate Change*" OR "global warming" OR "heat wave*" OR "rising temperature*"”

“Concept #2 "Pregnancy Outcome*" OR "Premature Birth*" OR "Live Birth*" OR "still birth*" OR "preterm birth*" OR "spontaneous abortion*" OR "Early Pregnancy Loss*" OR "miscarriage*"”

Then both the concepts were merged, and search was conducted with #1 AND #2

For Cochrane

“Concept 1# MeSH: Pregnancy outcome ("pregnancy outcome" OR "Birth outcome"):ti,ab,kw OR (“Still birth”):ti,ab,kw OR (“Preterm birth”):ti,ab,kw OR (“Abortion”):ti,ab,kw OR ("live birth"):ti,ab,kw”

“Concept 2# MeSH: [Climate Change] ("climate change"):ti,ab,kw OR ("global warming"):ti,ab,kw OR ("heat waves"):ti,ab,kw OR ("rising temperatures"):ti,ab,kw”

Then both the concepts were merged, and search was conducted with #1 AND #2

Inclusion criteria:

Articles where study population was considered as neonates or pregnant women,

Articles that studied the adverse pregnancy outcomes like spontaneous abortion, preterm birth, still birth,

Articles that studied link between pregnancy and delivery outcomes at any stage of gestation, and high ambient temperatures (e.g., heatwave, extreme temperature, hot weather),

Articles published between the year 2010 to the date of 01-SEP-2022,

Articles published in English language were considered.

Exclusion criteria:

Articles that studied other climate change indicators such as wildfires or studied combined association of two or more indicators such as air pollution and heatwave on pregnancy outcomes,

Articles with animal studies, cell studies or physiological studies,

Articles that were systematic review or scoping review, grey literature, or book pages or editorials, The articles were reviewed systematically from PubMed, Scopus, and Cochrane in line with the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)" guide. Total of 259 articles were retrieved. 56 duplicates were found and removed. After removing the duplicated articles were uploaded on to Rayyan software, that helped in independently reviewing the articles and hastens the screening process. Based on their potential relevance, two unbiased reviewers assessed the papers based on titles and abstracts, for inclusion in the review, pertinent papers were selected. Conflict was resolved by mutual discussion. After the initial screening, full texts were retrieved and screened for inclusion. Publication bias was kept in mind while including the article. The included articles were assessed for quality with the help of "Critical appraisal skill programme" checklist[8]. This checklist comprises of 12 questions which help us determine three things through the following sections:

"A) Are the results of the study valid?

B) What are the results?

C)Will the results help locally?"[8]

As most of the study designs were retrospective, question number 6 was not included in the checklist[8]

Table 1. The checklist used for quality assessment according to CASP guidelines[8].

S.no.	Questions	Response		
1	Did the study address a clearly focused issue?	Yes	No	Can't tell
2	Was the cohort recruited in an acceptable way?	Yes	No	Can't tell
3	Was the exposure accurately measured to minimise bias?	Yes	No	Can't tell
4	Was the outcome accurately measured to minimise bias?	Yes	No	Can't tell
5 (a)	(a) Have the authors identified all important confounding factors?	Yes	No	Can't tell
5 (b)	(b) Have they taken account of the confounding factors in the design and/or analysis?	Yes	No	Can't tell
6 (a)	(a) Was the follow up of subjects complete enough?	**Not Applicable**		
6 (b)	(b) Was the follow up of subjects long enough?	**Not Applicable**		
7	What are the results of this study?	Yes	No	Can't tell
8	How precise are the results?	Yes	No	Can't tell
9	Do you believe the results?	Yes	No	Can't tell
10	Can the results be applied to the local population?	Yes	No	Can't tell
11	Do the results of this study fit with other available evidence?	Yes	No	Can't tell
12	What are the implications of this study for practice?	Yes	No	Can't tell

3. Data Extraction

Full texts of the articles based on initial screening were extracted and screened according to the inclusion and exclusion criteria. Articles that were identified as scoping reviews or systematic reviews, were excluded and through the method of backward snowballing, reference of systematic review articles were checked for eligibility and 15 articles were included. After screening the full text, articles that had studied the combined association of temperature and air pollution were excluded. Articles that studied the association of seasons on pregnancy outcomes or the effect of cold temperature alone were excluded. Total 41 articles were included and were tabulated according to the exposure measured, the pregnancy outcomes, study design, sample size, location of the study, authors, journals, and publishing year. To minimise the publication bias, all studies irrespective of results that met the inclusion criteria were included. Both negative and positive results were included. Grey literature bias and language bias was identified, as grey literature was not included and articles available in English were included.

3.1 Quality assessment of included articles

All the included articles addressed an issue distinctly and cohort was recruited in a proper manner. However, to minimise bias exposure was measured correctly in only 28 articles and outcome was measured correctly in 38 articles. Confounding factors were identified in 37 articles and considered in 37 articles. Results were mentioned clearly in all the 41 articles. Results of the articles were believable in all the articles. Results could be applied to local population in most of the articles as the study is conducted from population registry or the sample size is quite large. Results of articles matched the available evidence in 37 articles. The implications of study were mentioned in articles 21 articles. Overall, the quality assessment of the included was assessed as good, as results were valid, clearly stated and could be applied to local population is most studies.

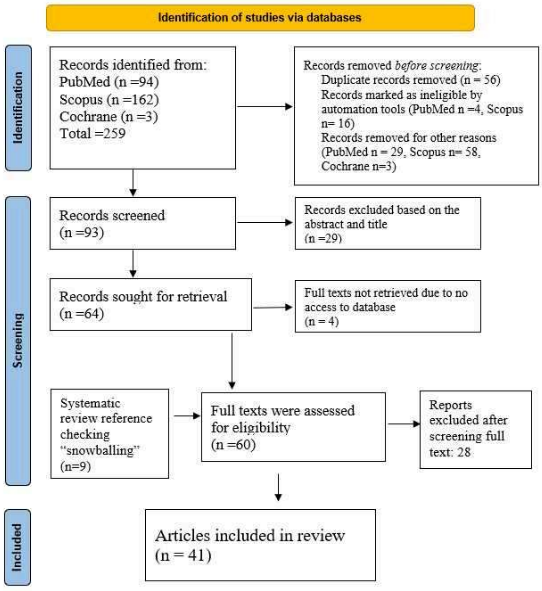

Figure 2: Flowchart of inclusion of articles following the PRISMA guidelines[9].

4. Results

Exposure assessments

The studies used different temperature exposures to study the effect of elevated temperature on the outcomes of pregnancy. Out of 41 studies, 11 studies considered mean daily temperature as the measure of exposure followed by heatwaves/ extreme heat events and daily maximum temperature. It was noticed that most of the studies defined extreme heat event as the presence temperature above the 90th percentile of maximum temperature. Richards et al defines heatwaves for the purpose of study, based on daily temperature exposure in the last week and were divided into three categories accordingly[10]. The categories were total number of days with high temperature, sustained hot temperature over consecutive days and third took into consideration of both the intensity and duration of high degrees. Van et al considered a universal apparent temperature with continuous 3 days of temperature above 90th part as a heat wave[11]. Another important temperature metric used in two studies was, the "universal thermal climate index (UTCI)", which is calculated on the basis of different environmental factors that directly contribute to the apparent temperature of an area such as ground albedo, insulation of cloth, altitude of sun[12,13]. One study used wet globe temperature as the index for temperature, that includes data about wind speed, temperature, solar radiation and humidity over an extended period of time[14].

Table 2. Summary of the temperature metrics being used in the studies.

Temperature Exposure	Temperature Metrics	Number of Studies
Daily temperature exposure	Maximum daily temperature	7
	Minimum daily temperature	3
	Mean daily temperature	11
Weekly temperature exposure	Maximum weekly temperature	1
	Mean weekly temperature	4
Monthly temperature exposure	Maximum monthly temperature	1
	Mean monthly temperature	3
Yearly temperature exposure	Mean yearly temperature	3
Apparent temperature exposure	Minimum Apparent temperature	1
	Daily maximum apparent temperature (MAT)	1
	Mean apparent daily temperature	5
	Mean apparent weekly temperature	1
Heatindex/Heatwave/ Extreme heat events exposure	Heat index (HI)	2
	Heatwave/extreme heat events	7
	Universal thermal climate index	2
	Wet Bulb globe temperature	1

4.1 *Identification of research gaps*

Out of 41 articles, it was observed that 18 of the research studies were conducted in United states that is 44% of the included articles, followed by China 12%, Europe 10%, and Australia 10%. With this we can infer that 76% of the research is being conducted in the high-income countries. This highlights the major gap in research that exists between the high income and low- and middle-income countries (LMIC) regarding the impact of climate change. According to the World Economic Outlook 2017, most affected due to climate change would be low- and middle-income countries as most of them are situated in the hottest regions of the world and housing the 75% of the total population of the world[15,16]. And yet, very few single country studies are being carried out in the LMIC to study the impact of change in climate.

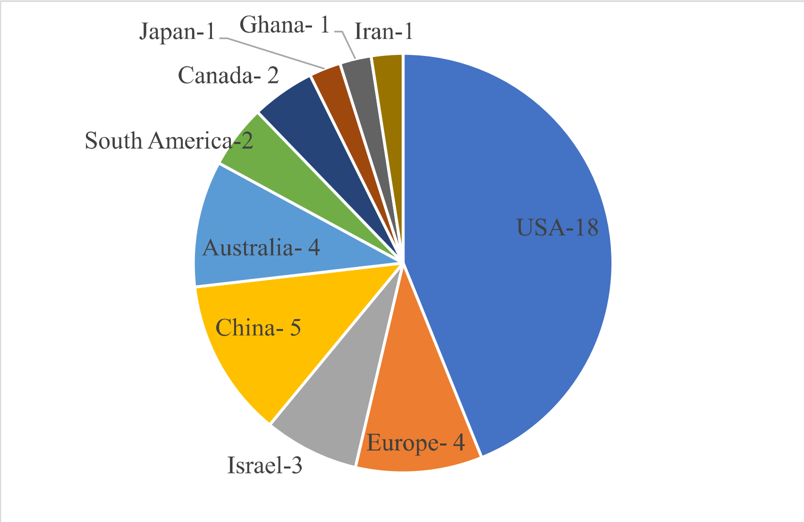

Figure 3: Geographical coverage of the included studies (n=41).

Most of the articles were published in the year 2022. According to the graph below we can see that there has been a rise in the number of studies after the year 2015. Although there has been an increasing trend to find more evidence in the recent years associated to the change in climate on the outcomes of pregnancy, yet out of 7 studies only 1 was conducted in the low- and middle-income countries. This suggests that current drift is towards the developed countries and strengthens our finding to create more evidence in LMIC.

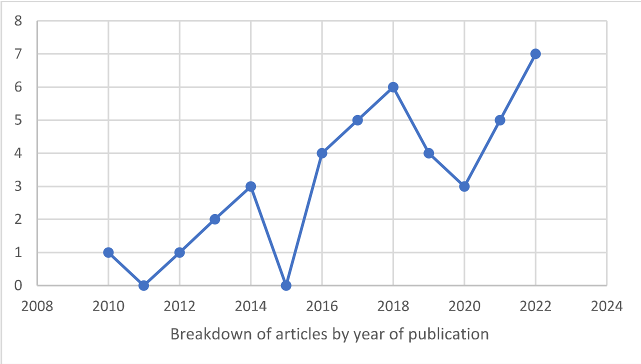

Figure 4. Number of articles published

4.2 Congenital anomalies

Congenital anomalies are the leading factor of mortality among neonates. Three studies out of 41 articles measured the association of temperature and congenital anomalies [17–19]. Congenital heart defects were associated with the presence of higher ambient temperature in two studies whereas study done by Van Zutphen et al found no link between the heart defect and elevated temperature[17–19]. Instead, the case-control study done by Van Zutphen et al in 6,422 infants in New York showed increased risk of congenital cataract[18]. This evidence shows possible association of incidence of congenital anomalies and change in climate. More research is warranted to design interventions to prevent the occurrence of congenital anomalies.

4.3 Spontaneous abortion/ miscarriages and neonatal death

Three studies studied the impact of temperature on spontaneous abortion/ miscarriages and neonatal death, out of the 41 articles included in this review. Two studies, found positive association, between the spontaneous abortion and increased temperature and one study inferred no significant association[12,14,20]. In study conducted in Ghana, a 1 degree rise in the

Wet Bulb globe temperature increases the risk up to 15%[14]. The study conducted by Khodadadi et al found no significant association between the impact of universal climate thermal index on the pregnancy outcome of spontaneous abortion[12]. The study conducted in Japan, concluded that climate extremes alter the sex ratio as increased susceptible to heat stress was present in male foetus, hence an increased number of deaths of male foetus. This led to low male to female sex ratio in Japan [20].

4.4 Still birth

Out of the 41 included articles, 9 articles studied the relationship between the elevated degrees of temperature and adverse pregnancy outcome of still birth [7,8,10–12,19–22]. Most of studies defines still birth as the death of foetus after the 20 weeks of gestation before the completion of term[21–23]. One study, included stillbirth as death of foetus after 23 weeks of gestation[24]. All the studies showed that the high temperatures increased the risk of still birth[10,12–14,21–25] . Li et al., found that the risk of stillbirth was more if the exposure is in second or third trimester[21]. Whereas rest of the studies found that risk was highest if exposed to extremes of temperature during the week before delivery[21,228,10,11,18–20]. Five studies found evidence that higher risk was associated with extreme cold temperatures than hot temperatures[10,13,21,23,24]. This calls for attention that exposure to any temperature extreme cold or hot, especially in the third trimester may lead to still birth in pregnant women.

4.5 Low birthweight

Out of 41 articles, 10 studied the impact of temperature on birthweight[12,26–34]. Low birthweight neonates were identified as the infants with less than 2500 grams of weight at birth[26,31]. Seven studies found that the exposure to extreme heat events reduced the birthweight significantly. Study done in Andean region revealed that the highest effect of exposure was during first trimester and reduced the birthweight by 42.5 g and long term exposure causes an increase in 0.7 percent probability of baby with low weight at birth[34]. Two studies found that the risk was highest in the third trimester as the association was strongest with hotter temperatures[31,33]. From the study conducted on "United States national birth data from 2009 to 2018", it was also found that the adverse impact is more on Hispanic and black pregnant women, thus revealing an added factor for the cause of widening health disparities[30]. Three studies found that there was an impact of extreme heat events on the birthweight, but the link was weak and did not significantly alter the weight. Such as in the study in Georgia, USA in the year 2000, birthweight decreased by 4.9 g, for the increase in exposure to total amount of hot days above 80 degrees Fahrenheit[28]. Study conducted in Iran found no significant association of birthweight and increase in temperature[12].Another study found that the colder temperature had a protective effect on the birthweight however the association was not statistically signiifcant[32].

4.6 Preterm birth

Children born prematurely have a greater predisposition for many health related disorder such as cognitive problems, respiratory illness etc[35]. In most of the studies the outcome of preterm birth was established as birth prior to the 37 weeks of gestation, early term birth was marked as birth between 36 to 38 weeks. 23 articles out of 41 included articles studied the association of preterm birth or early term and the ambient temperature or heatwaves[5,12,21,29,30,35–52]. 17 articles found that that there was a statistically strong significant association between the preterm births and the high temperature[5,30,36,37,39–50,52]. In a research carried out, in Australia, found that exposure to elevated temperature had delayed and immediate effect on preterm birth[36]. Exposure to temperature above 41 degrees Celsius had an immediate effect and increased the risk of preterm birth by 2 percent and continuous exposure to temperatures above 41 degrees Celsius raised the risk by 8 percent[36]. Highest risk of preterm birth was in the final trimester weeks before delivery, acute exposure causes distress and reduces the gestational age as evidenced by four studies[40–42,44]. Three studies found that the association was weak with heat[27,33,50]. One study in China found that the elevated temperatures safeguard against the risk of preterm birth, the reason of this result was also attributed to Shenzhen's rich economic status of people, with access to cooling systems[51].Two studies found no significant association between the ambient air temperature and the incidence of preterm birth[12,38]. Study conducted in Sweden stated that no significant effect could be due to the fact that Sweden has good housing conditions, with access to air conditioning and healthcare centres[38].

5. Limitations

The limitations of this systematic review were that the studies included were heterogenous in nature, used different exposures such as heatwaves or daily maximum temperature, assessing different windows of exposure, such as first trimester or days before delivery, different sample size, different populations most of the studies being conducted in United States of America, China which makes the generalization of results difficult. Second limitation was that we excluded the grey literature, or editorials or reports or blogs, hence limiting our results to the search formulated, and might have omitted important research that did not emerge in our search. Third limitation was the articles that were available in English language were only included, due to lack of a translation assistance.

6. Conclusion

Effects of climate change are significant on the adverse outcomes of pregnancy, depending upon the amount of exposure and intensity of extremes. Our findings are similar to previous review[53]. High temperatures especially in the third trimester increased the risk of preterm birth. Exposure to extreme heat events does cause the reduction of birthweight. Still birth was linked with exposure to severe temperatures cold or hot especially the week before delivery.

The association of spontaneous abortion was not so strong, as the available evidence was not so compelling. The increase in temperature does show a possible association with incidences of congenital anomalies but the available evidence was very less. Thus, for spontaneous abortion and for congenital anomalies, more research is warranted. We also identify that more primary research studies, as single country studies are needed in low- and middle-income countries for the impact of climate change on birth outcomes. Incidence of congenital anomalies due to climate change also compels us to create evidence to reduce the infant mortality. In some studies, we found that the effect of heat was negatively associated on pregnancy outcomes, one reason of which was identified with the better socioeconomic status and housing conditions. Climate change is an urgency, we need to create more evidence for, to find climate resilient interventions and to protect the most vulnerable maternal and child health for the future.

Appendix

Table 1. Summary of studies showing the association of congenital anomalies

Publication Year	Author	Journal	Sample size	Study design	Windows of exposure	Location	Birth defects and congenital anomalies
2012	Van Zutphen et al[18]	Environmental health perspectives	6,422 cases and 59,328 controls	Case–control study design	Weeks 3–8 post conception	New York, United States	Significantly associated
2013	Agay-Shay et al[19]	Human Reproduction	135 527 live and stillbirths	Population registry-based cohort study	Weeks 3–8 of pregnancy	Tel-Aviv region of Israel	Significant association
2017	Nathalie Auger et al[17]	Environmental Health Perspectives	704,209 foetuses	retrospective cohort study	between 2- and 8-weeks post conception	Quebec, Canada	Significant association

Table 2. Summary of studies associating Spontaneous abortion/ miscarriages/ neonatal death							
Publication Year	**Author**	**Journal**	**Sample size**	**Study design**	**Windows of exposure**	**Location**	**Spontaneous Abortion**
2014	Fukuda et al[20]	Fertility and Sterility	Not reported	A population-based cohort study.	Entire gestation period up to 12 weeks	Japan	Significant positive association with fetal deaths
2018	Asamoah et al[14]	International Journal of Biometeorology	1136 women	Cross sectional study	Second month of pregnancy.	Ghana	Increased risk of abortion
2022	Khodadadi et al[12]	Reproductive Health	1,50,766	Not reported	Entire pregnancy	Ahvaz, Iran	No significant association

Table 3. Summary of studies showing the association with still birth							
Publication Year	**Author**	**Journal**	**Sample size**	**Study design**	**Windows of exposure**	**Location**	**Still birth**
2022	Richards et al[10]	Environmental health: a global access science source	140,428 stillbirths (553,928 live birth controls)	Case–control	6 days prior to delivery and the date of delivery	California, Florida, Georgia, Kansas, New Jersey, and Oregon	Significant association
2017	Ha et al[24]	Environmental Health Perspectives	223,375 singleton births	Retrospective observational cohort study	Chronic exposure for three-months preconception, first and second trimester, and whole-pregnancy. For acute exposure, the week preceding delivery	United States	Significant association
2018	Asamoah et al[14]	International Journal of Biometeorology	1136 women	Cross sectional study	Second month of pregnancy.	Ghana	Increased risk of stillbirth

Table 4. Summary of studies associating low birthweight							
Publication Year	Author	Journal	Sample size	Study design	Windows of exposure	Location	Low birthweight (LBW)
2021	Lawrence et al[26]	Journal of Developmental Origins of Health and Disease	22,615 cases and 139,168 controls	Population-based case–control study	First trimester	New York state (excluding New York city), United States	Significant association with extreme heat events
2022	Bakhtsiyaraya et al[27]	Environment International	8,079,872 live births in Brazil; 6,405,777 live births in Mexico; and 890,156 live births in Chile	Population based Retrospective study	Every month of pregnancy	Brazil, Mexico, and Chile	Significant association to high temperature above 19 degrees centigrade
2017	Yin, P.[28]	Southeastern Geographer	753,890 full-term singleton live births		Entire pregnancy	Georgia, USA	Significant association
2016	Ngo, N.S.; Horton, R.M.[29]	Environmental Research	For birth weight 514,104 and for gestational age was 510,781	Retrospective study	Three trimesters of pregnancy	New York, USA	Significant association that decreases in birth weight resulting from exposure to extreme heat and cold."
"2022	Cil, Gulcan; Kim, Jiyoon[30]	Health economics	34.7 million births		Prenatal temperature exposures	U.S. A	Small but statistically significant
2021	Hajdu, T.; Hajdu, G.[32]	Population and Environment	1,532,661 singletons new-born.		Entire pregnancy and all trimester specific	Hungary	Small impact on birthweight
2017	Molina, O.; Saldarriaga, V[34].	Economics and Human Biology	86,021 children		All the trimesters	Bolivia, Colombia, and Peru	Significant association

Table 5. Summary of studies showing the association preterm birth							
Publication Year	Author	Journal	Sample size	Study design	Windows of exposure	Location	Preterm birth
2021	Huang et al[35]	Environmental Health: A Global Access Science Source	615,329 preterm and 1,005,576 early-term case-control	case-control design	7 days preceding birth	United States	Significant association
2019	Sun et al[37]	Environment International	31,921,046 singleton births	Retrospective observational study	Days preceding her delivery	United States	Significant association
2016	He et al[52]	Environmental Health Perspectives	838,146 singleton birth		1 week (the last week of the pregnancy), 4 weeks (the last 4 weeks of the pregnancy), late pregnancy (gestational week 20 onward), and the entire pregnancy.	China	Significant association with extreme heat

2016	Ngo, N.S.; Horton, R.M.[29]	Environmental Research	Birth weight 514,104 and gestational age 510,781	Retrospective study	Three trimesters of pregnancy	New York, USA	No significant impact
2017	Mathew et al[36]	International Journal of Environmental Research and Public Health	16,870 single natural births		Last 3 weeks of pregnancy	Australia	Significant association with both extremes of temperature hot and cold
2014	Vicedo-Cabrera et al[39]	Environmental Research	20,148 singleton natural births		3 weeks before delivery	Valencia	Significant association especially in last two days of delivery
2022	Cushing et al[40]	Paediatric and Perinatal Epidemiology	1,98,013	Retrospective cohort study	week prior for each day of pregnancy	Texas, USA	Increased risk above 40-degree centigrade temperature
2020	Ilango et al[41]	Environment International	1,967,300 mothers	Population-based cohort time-to-event analysis	The last week of gestation	California, USA	Significant association
2022	Cil, Gulcan; Kim, Jiyoon[30]	Health economics	34.7 million births		Prenatal temperature exposures	U.S. A	Increased risk above 90-degree Fahrenheit
2018	He et al[42]	Environment International	17,172	case-crossover study design	During the week before abruption	Canada	Significant association with temperature higher than 30 degrees Celsius

2014	Kent et al[43]	Environmental Health Perspectives	60,466 PTBs	time-stratified case-crossover design	Week before the delivery	Alabama, USA	Significant association with heatwaves
2010	Basu et al[44]	American Journal of Epidemiology	60,000 births	case-crossover study design	1 week before a birth	California, USA	Small but significant association
2013	Wang et al[5]	BJOG: An International Journal of Obstetrics and Gynaecology	50 848 spontaneous births	Ecological study	Entire pregnancy	Brisbane Australia	A statistically significant
2020	Spolter et al[45]	Environment International	62,547 singleton births		During the week of birth	Israel	Significant association
2021	Tsymbaliuk et al[46]	Medicni Perspektivi		Ecological study		Ukraine	Significant association
2018	Guo et al[47]	Science of the Total Environment	1,020,471 singleton births	Ecological study	3 months before pregnancy (91 days before the last menstrual date), the first 1–7 weeks of pregnancy, weeks 8–14 of pregnancy, weeks 15–21 of pregnancy, and the entire pregnancy period	China	Significant association

2019	Ward et al[48]	International journal of biometeorology	29854 preterm births	Case-crossover study	1 and 2 weeks prior to birth	North Carolina, USA	Increasing odds of preterm birth at increasing temperatures
2022	Khodadadi et al[12]	Reproductive Health	1,50,766	Not reported	Entire pregnancy	Ahvaz, Iran	No significant association
2019	Song et al[49]	Science of the Total Environment	29,608 singles birth	Time-series study		Xinxiang, China	Significant association with extreme hot temperature
2018	Zheng et al[50]	Journal of Thermal Biology	3604 children	Cohort study	Conception month, three trimesters, and birth month.	Changsha, China	Significantly associated
2016	Liang et al[51]	Environmental Health	1,040,638 singleton live births	time-series study	Gestational age (20–44 weeks)	Shenzhen, China	A negative association of high temperature
2018	Li et al[21]	Science of the Total Environment	289,351 births	Population-based study	Three trimesters of pregnancy	Brisbane, Australia	Significant association

References:

1. Rossati A. Global Warming and Its Health Impact. *Int J Occup Environ Med*. 2017;8(1):7-20. doi:10.15171/ijoem.2017.963

2. Romanello M, McGushin A, Napoli CD, et al. The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future. *The Lancet*. 2021;398(10311):1619-1662. doi:10.1016/S0140-6736(21)01787-6

3. Barreca A, Schaller J. The impact of high ambient temperatures on delivery timing and gestational lengths. *Nat Clim Chang*. 2020;10(1):77-82. doi:10.1038/s41558-019-0632-4

4. Dadvand P, Sunyer J, Basaga ña X, et al. Surrounding Greenness and Pregnancy Outcomes in Four Spanish Birth Cohorts. *Environmental Health Perspectives*. 2012;120(10):1481-1487. doi:10.1289/ehp.1205244

5. Wang J, Williams G, Guo Y, Pan X, Tong S. Maternal exposure to heatwave and preterm birth in Brisbane, Australia. *BJOG: An International Journal of Obstetrics and Gynaecology*. 2013;120(13):1631-1641. doi:10.1111/1471-0528.12397

6. Kakkad K, Barzaga ML, Wallenstein S, Azhar GS, Sheffield PE. Neonates in Ahmedabad, India, during the 2010 Heat Wave: A Climate Change Adaptation Study. *J Environ Public Health*. 2014;2014:946875. doi:10.1155/2014/946875

7. Basu R, Pearson D, Sie L, Broadwin R. A Case-Crossover Study of Temperature and Infant Mortality in California. *Paediatr Perinat Epidemiol*. 2015;29(5):407-415. doi:10.1111/ppe.12204

8. CASP Checklists. CASP - Critical Appraisal Skills Programme. Accessed October 13, 2022. https://casp-uk.net/casp-tools-checklists/

9. PRISMA. Accessed October 15, 2022. https://www.prisma-statement.org//PRISMAStatement/FlowDiagram

10. Richards M, Huang M, Strickland MJ, et al. Acute association between heatwaves and stillbirth in six US states. *Environ Health*. 2022;21(1):59. doi:10.1186/s12940-022-00870-y

11. Van Zutphen AR, Hsu WH, Lin S. Extreme winter temperature and birth defects: A population-based case-control study. *Environmental Research*. 2014;128:1-8. doi:10.1016/j.envres.2013.11.006

12. Khodadadi N, Dastoorpoor M, Khanjani N, Ghasemi A. Universal Thermal Climate Index (UTCI) and adverse pregnancy outcomes in Ahvaz, Iran. *Reproductive Health*. 2022;19(1). doi:10.1186/s12978-022-01344-7

13. Nyadanu SD, Tessema GA, Mullins B, Pereira G. Maternal acute thermophysiological stress and stillbirth in Western Australia, 2000-2015: A space-time-stratified case-crossover analysis. *Sci Total Environ*. 2022;836:155750. doi:10.1016/j.scitotenv.2022.155750

14. Asamoah B, Kjellstrom T, Östergren PO. Is ambient heat exposure levels associated with miscarriage or stillbirths in hot regions? A cross-sectional study using survey data from the Ghana Maternal Health Survey 2007. *International Journal of Biometeorology*. 2018;62(3):319-330. doi:10.1007/s00484-017-1402-5

15. THE EFFECTS OF WEATHER SHOCKS ON ECONOMIC ACTIVITY: CHAPTER 3 HOW CAN LOW-INCOME COUNTRIES COPE?

16. Overview. World Bank. Accessed October 8, 2022. https://www.worldbank.org/en/country/mic/overview

17. Auger N, Fraser WD, Sauve R, Bilodeau-Bertrand M, Kosatsky T. Risk of Congenital Heart Defects after Ambient Heat Exposure Early in Pregnancy. *Environmental Health Perspectives*. 2017;125(1):8-14. doi:10.1289/EHP171

18. Van Zutphen AR, Lin S, Fletcher BA, Hwang SA. A population-based case-control study of extreme summer temperature and birth defects. *Environ Health Perspect*. 2012;120(10):1443-1449. doi:10.1289/ehp.1104671

19. Agay-Shay K, Friger M, Linn S, Peled A, Amitai Y, Peretz C. Ambient temperature and congenital heart defects. *Human Reproduction*. 2013;28(8):2289-2297. doi:10.1093/humrep/det244

20. Fukuda M, Fukuda K, Shimizu T, Nobunaga M, Mamsen LS, Andersen CY. Climate change is associated with male: Female ratios of fetal deaths and newborn infants in Japan. *Fertility and Sterility*. 2014;102(5):1364-1370.e2. doi:10.1016/j.fertnstert.2014.07.1213

21. Li S, Chen G, Jaakkola JJK, Williams G, Guo Y. Temporal change in the impacts of ambient temperature on preterm birth and stillbirth: Brisbane, 1994–2013. *Science of the Total Environment*. 2018;634:579-585. doi:10.1016/j.scitotenv.2018.03.385

22. Basu R, Sarovar V, Malig BJ. Association between high ambient temperature and risk of stillbirth in California. *American Journal of Epidemiology*. 2016;183(10):894-901. doi:10.1093/aje/kwv295

23. Kanner J, Williams AD, Nobles C, et al. Ambient temperature and stillbirth: Risks associated with chronic extreme temperature and acute temperature change. *Environmental Research*. 2020;189:109958. doi:10.1016/j.envres.2020.109958

24. Ha S, Liu D, Zhu Y, et al. Ambient temperature and stillbirth: A multi-center retrospective cohort study. *Environmental Health Perspectives*. 2017;125(6). doi:10.1289/EHP945

25. Rammah A, Whitworth KW, Han I, Chan W, Hess JW, Symanski E. Temperature, placental abruption and stillbirth. *Environment International*. 2019;131:105067. doi:10.1016/j.envint.2019.105067

26. Lawrence WR, Soim A, Zhang W, et al. A population-based case-control study of the association between weather-related extreme heat events and low birthweight. *Journal of Developmental Origins of Health and Disease*. 2021;12(2):335-342. doi:10.1017/S2040174420000392

27. Bakhtsiyarava M, Ortigoza A, Sánchez BN, et al. Ambient temperature and term birthweight in Latin American cities. *Environ Int*. 2022;167:107412. doi:10.1016/j.envint.2022.107412

28. Yin P. Association of high outdoor temperature and full-term birth weight in Georgia, USA, 2000-2006. *Southeastern Geographer*. 2017;57(2):179-196. doi:10.1353/sgo.2017.0016

29. Ngo NS, Horton RM. Climate change and fetal health: The impacts of exposure to extreme temperatures in New York City. *Environmental Research*. 2016;144:158-164. doi:10.1016/j.envres.2015.11.016

30. Cil G, Kim J. Extreme temperatures during pregnancy and adverse birth outcomes: Evidence from 2009 to 2018 U.S. national birth data. *Health Econ*. 2022;31(9):1993-2024. doi:10.1002/hec.4559

31. Basagaña X, Michael Y, Lensky IM, et al. Low and high ambient temperatures during pregnancy and birth weight among 624,940 singleton term births in israel (2010–2014): An investigation of potential windows of susceptibility. *Environmental Health Perspectives*. 2021;129(10). doi:10.1289/EHP8117

32. Hajdu T, Hajdu G. Temperature, climate change, and birth weight: evidence from Hungary. *Population and Environment*. 2021;43(2):131-148. doi:10.1007/s11111-021-00380-y

33. Basu R, Rau R, Pearson D, Malig B. Temperature and Term Low Birth Weight in California. *American Journal of Epidemiology*. 2018;187(11):2306-2314. doi:10.1093/aje/kwy116

34. Molina O, Saldarriaga V. The perils of climate change: In utero exposure to temperature variability and birth outcomes in the Andean region. *Economics and Human Biology*. 2017;24:111-124. doi:10.1016/j.ehb.2016.11.009

35. Huang M, Strickland MJ, Richards M, et al. Acute associations between heatwaves and preterm and early-term birth in 50 US metropolitan areas: a matched case-control study. *Environmental Health: A Global Access Science Source*. 2021;20(1). doi:10.1186/s12940-021-00733-y

36. Mathew S, Mathur D, Chang AB, et al. Examining the Effects of Ambient Temperature on Pre-Term Birth in Central Australia. *Int J Environ Res Public Health*. 2017;14(2):147. doi:10.3390/ijerph14020147

37. Sun S, Weinberger KR, Spangler KR, Eliot MN, Braun JM, Wellenius GA. Ambient temperature and preterm birth: A retrospective study of 32 million US singleton births. *Environment International*. 2019;126:7-13. doi:10.1016/j.envint.2019.02.023

38. de Bont J, Stafoggia M, Nakstad B, et al. Associations between ambient temperature and risk of preterm birth in Sweden: A comparison of analytical approaches. *Environ Res*. 2022;213:113586. doi:10.1016/j.envres.2022.113586

39. Vicedo-Cabrera AM, Iñíguez C, Barona C, Ballester F. Exposure to elevated temperatures and risk of preterm birth in Valencia, Spain. *Environmental Research*. 2014;134:210-217. doi:10.1016/j.envres.2014.07.021

40. Cushing L, Morello-Frosch R, Hubbard A. Extreme heat and its association with social disparities in the risk of spontaneous preterm birth. *Paediatric and Perinatal Epidemiology*. 2022;36(1):13-22. doi:10.1111/ppe.12834

41. Ilango SD, Weaver M, Sheridan P, et al. Extreme heat episodes and risk of preterm birth in California, 2005–2013. *Environment International*. 2020;137. doi:10.1016/j.envint.2020.105541

42. He S, Kosatsky T, Smargiassi A, Bilodeau-Bertrand M, Auger N. Heat and pregnancy-related emergencies: Risk of placental abruption during hot weather. *Environment International*. Published online 2018:295-300. doi:10.1016/j.envint.2017.11.004

43. Kent ST, McClure LA, Zaitchik BF, Smith TT, Gohlke JM. Heat waves and health outcomes in Alabama (USA): The importance of heat wave definition. *Environmental Health Perspectives*. 2014;122(2):151-158. doi:10.1289/ehp.1307262

44. Basu R, Malig B, Ostro B. High ambient temperature and the risk of preterm delivery. *American Journal of Epidemiology*. 2010;172(10):1108-1117. doi:10.1093/aje/kwq170

45. Spolter F, Kloog I, Dorman M, Novack L, Erez O, Raz R. Prenatal exposure to ambient air temperature and risk of early delivery. *Environment International*. 2020;142. doi:10.1016/j.envint.2020.105824

46. Tsymbaliuk VI, Vadziuk SN, Tolokova TI, Tabas PS. PREVALENCE of PREMATURE BIRTH in CONDITIONS of GLOBAL WARMING. *Medicni Perspektivi*. 2021;26(3):152-161. doi:10.26641/2307-0404.2021.3.242167

47. Guo T, Wang Y, Zhang H, et al. The association between ambient temperature and the risk of preterm birth in China. *Science of the Total Environment*. 2018;613-614:439-446. doi:10.1016/j.scitotenv.2017.09.104

48. Ward A, Clark J, McLeod J, Woodul R, Moser H, Konrad C. The impact of heat exposure on reduced gestational age in pregnant women in North Carolina, 2011-2015. *Int J Biometeorol*. 2019;63(12):1611-1620. doi:10.1007/s00484-019-01773-3

49. Song J, Lu J, Wang E, et al. Short-term effects of ambient temperature on the risk of premature rupture of membranes in Xinxiang, China: A time-series analysis. *Science of The Total Environment*. 2019;689:1329-1335. doi:10.1016/j.scitotenv.2019.06.457

50. Zheng X, Zhang W, Lu C, Norbäck D, Deng Q. An epidemiological assessment of the effect of ambient temperature on the incidence of preterm births: Identifying windows of susceptibility during pregnancy. *Journal of Thermal Biology*. 2018;74:201-207. doi:10.1016/j.jtherbio.2018.04.001

51. Liang Z, Lin Y, Ma Y, et al. The association between ambient temperature and preterm birth in Shenzhen, China: a distributed lag non-linear time series analysis. *Environ Health*. 2016;15(1):84. doi:10.1186/s12940-016-0166-4

52. He JR, Liu Y, Xia XY, et al. Ambient Temperature and the Risk of Preterm Birth in Guangzhou, China (2001–2011). *Environ Health Perspect*. 2016;124(7):1100-1106. doi:10.1289/ehp.1509778

53. Dehdashti B, Bagheri N, Amin MM, Hajizadeh Y. Impacts of Climate Changes on Pregnancy and Birth Outcomes: A Review. *International Journal of Environmental Health Engineering*. 2020;9. doi:10.4103/ijehe.ijehe_40_20