REVIEW ARTICLE

The impact of high temperatures on spontaneous abortion: A systematic review and meta-analysis

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Abstract

Spontaneous abortion occurs in approximately one in five pregnancies and may be influenced by environmental factors, particularly heat exposure. This study reviewed and synthesized research on the relationship between high temperatures and spontaneous abortion. A systematic literature search identified eight studies from various regions. Data were extracted and analyzed using standardized methods, with quality assessed through Joanna Briggs Institute tools. Meta-analysis showed a pooled spontaneous abortion rate of 13.1%, with higher temperatures consistently linked to increased pregnancy loss. Seasonal variations, regional differences, and socioeconomic factors also influenced the findings. Vulnerable groups, including African Americans and those from lower socioeconomic backgrounds, were disproportionately affected. These findings highlight the potential impact of climate change on early pregnancy outcomes, emphasizing the need for targeted interventions to protect at-risk populations. *(Afr J Reprod Health 2025; 29 [11]: 233-248).*

Keywords: Climate change; high temperatures; spontaneous abortion; meta-analysis

Résumé

L'avortement spontané survient dans environ une grossesse sur cinq et peut être influencé par des facteurs environnementaux, notamment l'exposition à la chaleur. Cette étude a passé en revue et synthétisé les recherches sur le lien entre températures élevées et avortement spontané. Une recherche documentaire systématique a permis d'identifier huit études provenant de différentes régions. Les données ont été extraites et analysées à l'aide de méthodes standardisées, et leur qualité a été évaluée grâce aux outils du Joanna Briggs Institute. Une méta-analyse a montré un taux d'avortement spontané global de 13,1 %, les températures élevées étant systématiquement associées à une augmentation des fausses couches. Les variations saisonnières, les différences régionales et les facteurs socio-économiques ont également influencé les résultats. Les groupes vulnérables, notamment les Afro-Américains et les personnes issues de milieux socio-économiques défavorisés, ont été touchés de manière disproportionnée. Ces résultats mettent en évidence l'impact potentiel du changement climatique sur les grossesses précoces, soulignant la nécessité d'interventions ciblées pour protéger les populations à risque. *(Afr J Reprod Health 2025; 29 [11]: 233-248).*

Mots-clés: Changement climatique ; températures élevées ; avortement spontané ; méta-analyse

Introduction

Spontaneous abortion, defined as spontaneous pregnancy loss before 12 weeks of gestation, is a common and severe complication during early pregnancy.[1,2] It occurs in approximately one in five pregnancies, and recent data suggests an upward trend in its morbidity, making it a significant concern for pregnant individuals and healthcare providers alike.[3,4] Additionally, spontaneous abortion poses significant physical and psychological hardships for patients and their families, along with substantial medical and economic burdens on society.[5,6] Given the considerable impact of spontaneous abortion on individuals and society, there is an urgent need to unravel its pathogenesis and develop effective prevention strategies.

Previous literature has identified various factors contributing to the occurrence of spontaneous abortion, including chromosomal abnormalities, genetic factors, anatomical issues, endocrine disruptions, and immunologic alterations.[7,8] Recent studies have underscored the growing impact of environmental factors on pregnancy outcomes, with particular attention to climate change and heat exposure.[9–11] They

suggested that heat exposure during pregnancy may adversely affect embryo and fetal development, increasing the risk of adverse outcomes such as stillbirth, low birth weight, and preterm birth.[9–11]
Yang *et al*. proposed that exposure to environmental factors, such as temperature extremes and air pollution, may contribute to premature rupture of membranes during pregnancy.[12] A case-crossover analysis in Western Australia revealed an association between temperature fluctuations and an elevated risk of spontaneous preterm birth[13]. Moreover, several studies have linked ambient temperature exposure to spontaneous abortion, highlighting the potential impact of temperature on early pregnancy outcomes.[14,15] They found an association between heat exposure and spontaneous abortion.[14,15] However, the evidence was limited and may be influenced by regional differences. Indeed, to the best of our knowledge, no previous meta-analyses have specifically investigated the impact of high temperatures on spontaneous abortion. Therefore, our study aims to address this research gap by systematically reviewing and synthesizing the available evidence to assess the effect of high temperatures on spontaneous abortion.

Methods

The study design adhered to the Cochrane Handbook and the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines.[16,17]

Literature search

An extensive literature search was conducted across major databases (Web of Science, Cochrane CENTRAL, PubMed, Scopus) from their inception to April 2024. The search strategy combined keywords and phrases with reference list reviews for a comprehensive approach as follows: (“ambient temperature” OR "Hot Temperature*" OR "High Temperature*" OR "Extreme Heat" OR Heat OR "Extreme Hot Weather" OR "Climate Change" OR "Global Warming" OR "Heat Shock Response" OR "Heat-Shock Response" OR "Heat-Stress Reaction" OR "Heat Stress Reaction" OR “Heat Shock Reaction" OR “Heat-Shock Reaction” OR "Heat Shock Stress" OR "Heat Shock*” OR “Heat stress*” OR “Extreme Weather” OR “Extreme Temperature” OR “Hot Weather” OR “Extreme Environment*” OR “High-temperature exposure” OR “High temperature exposure” OR “heat exposure” OR “increased temperatures” OR “increased temperature”) AND (Abortion* OR “Spontaneous Abortion” OR “Early Pregnancy Loss” OR “Early Pregnancy Losses” OR Miscarriage* OR “Embryo Loss” OR “Fetal Death” OR “Fetal Deaths”).

Eligibility criteria

Two independent reviewers assessed reference relevance using predefined eligibility criteria. The included studies were limited to human subjects, published in English, and focused on heat exposure from weather events rather than artificial sources like saunas. All study designs, except systematic reviews, were considered, and no date restrictions were imposed. The scope was further refined in our analysis to exclusively examine spontaneous abortion during the first 3 months of pregnancy.

Data collection

A standardized data extraction template was employed to gather relevant information from each included study systematically. Extracted data encompassed bibliographic details (author, publication year), study location, design, climate zone, study population, primary endpoints, and conclusions.

Quality assessment

The Joanna Briggs Institute Critical Appraisal Tools were used to assess the risk of bias and evaluate the quality of the included studies[18]. These tools consist of a series of questions with scores indicating the study's adequacy in addressing potential bias domains.[18] One reviewer assessed the risk of bias, with a second reviewer verifying for consistency. Studies with scores of 9 or higher out of 11 for cohort studies, 6 or higher out of 8 for analytical cross-sectional studies, and 9 or higher out of 10 for case-control studies were deemed high-quality.[19,20]

Data synthesis

Meta-analysis utilized pooled proportions of the spontaneous abortion outcome with a 95% confidence interval (CI) as a single-arm analysis

- using random-effects. Heterogeneity was assessed using I^2 statistic and χ^2 test; p-value < 0.1 or $I^2 \geq 50\%$ indicated heterogeneity. OpenMeta Analyst was used for single-arm analyses.

Results

Literature search

A comprehensive literature search across four databases yielded 2768 studies, narrowed down to 2409 unique articles after removing duplicates. After screening titles and abstracts, 15 studies underwent full-text assessment, and eight studies were ultimately included in the systematic review, with four of them eligible for single-arm analysis[4,14,15,21–25]. The PRISMA flow diagram visually summarizes the study selection process, highlighting the steps taken to identify relevant research. **(**Figure. 1**)**

Included studies characteristics

Our systematic review and meta-analysis encompassed eight studies, including three cross-sectional, three retrospective cohorts, and two case-control studies, offering a comprehensive perspective on the relationship between climate and pregnancy outcomes. The geographic scope of the studies was broad, covering various climate zones, from humid tropical to temperate seasonal regions. Notably, Wesselink *et al*. and Davenport et al. did not specify a particular climate zone. The primary endpoints of the studies were predominantly focused on pregnancy outcomes, including the prevalence of spontaneous abortions, stillbirths, and other pregnancy complications. This unified focus on pregnancy health provides valuable insights into the potential impacts of climate on maternal and fetal well-being. The baseline and summary of the characteristics of the included studies are depicted in Table 1.

Quality assessment

The analytical cross-sectional studies scored 6 or higher, indicating high quality. Two cohort studies were high quality. All case-control studies exhibited high quality. Supplementary Table 1 provides detailed critical appraisals.

Outcomes:

Meta-analysis findings:

Spontaneous abortion:

This outcome was assessed in four studies with a pooled proportion of 13.1% with 95% CI ranging from 4.4% to 21.8%. The pooled studies were heterogenous, with X^2-p and I^2 being$<$ 0.001 and 99.96%, respectively. (Figure. 2)

Systematic-review findings:

Temperature exposure and pregnancy loss

Our included studies have consistently identified a correlation between temperature exposure and an elevated risk of pregnancy loss. Wesselink *et al*. reported increased spontaneous abortion occurrence with high temperatures, particularly during late summer.[25] This finding aligns with the conclusions drawn by Qu *et al*. found extreme heat exposure was associated with heightened risk of pregnancy complications including spontaneous abortion.[24] Furthermore, Zhao *et al*. identified a nonlinear relationship between temperature exposure and spontaneous abortion risk, with elevated temperatures showing higher risk.[4] Sun *et al.* demonstrated a positive correlation between temperature exposure and miscarriage risk[15]. Lastly, Hajdu *et al.* reported heat exposure elevated spontaneous pregnancy loss risk, while cold temperatures showed a mitigating effect.[23] (Figure. 3)

Seasonal patterns and regional variations

The literature in this domain underscores the critical importance of considering seasonal fluctuations and regional disparities when examining the intricate relationship between temperature exposure and pregnancy outcomes. Wesselink *et al*. reported peak spontaneous abortion risk during late August, with stronger associations in Southern and Midwestern United States regions.[25] This regional variation highlights potential geographic factors that may moderate the impact of temperature exposure on pregnancy health.

Table 1: Summary and baseline characteristics of the included studies

Study ID	Study design	Country	Climate zone	Year of study	Study Population	Primary endpoint	Conclusion
Asamoah 2017	Cross-sectional study, Time series	Ghana	Humid Tropical	2004-2007	Women of 15–49 years in a subsample of households to collect information on maternal health-related issues including pregnancies, live births, abortions and miscarriages, and utilization of health services about these events.	To test the hypothesis that maternal heat exposure during pregnancy in hot regions is associated with increased prevalence of spontaneous abortions or stillbirths and to develop an analytical strategy to use existing data from maternal health surveys and existing data on historical heat levels at a geographic grid cell level.	"Environmental heat exposures may be associated with adverse pregnancy outcomes, but this study was inconclusive, possibly because the heat exposure range was small. Historical records of routine observations in existing databases can be used for epidemiological studies on the health effects of heat, although data from properly and purposively designed studies might be more suitable for further studies."
Davenport 2020	Cross-sectional study, Time series	15 countries of Sub-Saharan African	Not Specific	1999-2010	DHS survey respondents.investigate miscarriage or stillbirth of pregnant women)	To investigate the linkages between climate and pregnancy outcomes using linear probability models with fixed effects to minimize confounding due to factors that vary by location, season, and year.	"Our results indicate that pregnancy outcomes are indeed impacted by exposure to hot days even after considering other individual-level characteristics. This research provides insight into the linkages between climate and a major adverse health outcome faced by women. In doing

							so, this research expands the scientific understanding of the impact of environmental factors on fertility outcomes."
Hajdu 2021	Cross-sectional study, Time series	Hungary	Temperate seasonal climate	1981-2015	Administrative data from Hungary with full coverage of the clinically observed pregnancies (conceptions) recorded by the country's health care system.	To estimate the impact of early pregnancy temperature exposure on the clinically unobserved pregnancy loss rate.	"We can conclude that early pregnancy exposure to hot temperature causes an increase in the total number of pregnancies ending in pregnancy loss."
Hajdu 2023	Retrospective Cohort	Hungary	Temperate seasonal climate	1984-2018	Administrative data from Hungary with full coverage of the clinically observed pregnancies (conceptions) recorded by the country's health care system.	To investigate relationship between temperatures and the pregnancy loss rate	"Changing spontaneous fetal loss rate following in utero exposure to heat or cold implies a change in the composition of fetuses that survive to live birth. The survivors represent a selected sample of conceptions that are affected by the temperature shocks. Importantly, increased temperature, like other adverse events, is likely to remove fetuses with below-average health which has been recognized by the literature. As mentioned before, several papers examine the impacts of temperature exposure during pregnancy and climate change on health at

							birth, while others analyze the effects on long-term outcomes. Our estimates provide hard evidence that these estimations are likely to be lower bounds of the actual impact ("scarring" effect) due to a temperature-induced in utero selection. However, the extent of the bias is unclear and remains a subject for future studies."
Sun 2020	Case-control study	China	Humid subtropical climate	2014-2016	Maternal information were provided by Guangdong Women and Children Hospital, which is one of the largest hospitals providing gynecology and obstetrics services for people across the Guangdong province.	To examine the association of maternal exposure to temperature with the risk of miscarriage and further assessed the modifying effects of surrounding residential greenness.	"Maternal exposure to moderately high temperature during pregnancy may increase the risk of miscarriage, but the modifying effects of greenness on these associations remain inconclusive. As global temperatures rise, our findings have critical public health implications. Pregnant women should be informed of the risk of heat exposures on their fetus's health and encouraged to take actions to protect themselves from high temperatures. More researches are needed in the future to further confirm the modifying

							effects of greenness on the associations between maternal exposures to temperatures and miscarriage risk."
Qu 2021	Retrospective Cohort	USA	Humid subtropical climate	2005-2013	The population was identified from the New York Statewide Planning and Research Cooperative System (SPARCS), a legislatively mandated database covering over 95% of hospital records in NYS. We retained hospital admissions and ED visits reporting with a principal diagnosis of pregnancy complication as	To examine the extreme heat exposure pregnancy complications associations by lag days, subtypes, sociodemographic characteristics, and areas in New York State	"Our results suggest a possible immediate and prolonged effect of EHE on pregnancy complications in summer, but an immediate and stronger effect of EHE in transitional months. EHE, mostly in transitional months, was significantly associated with increased risks of multiple subtypes of pregnancy complications, including threatened/spontaneous abortion, renal disease, infectious and parasitic conditions, diabetes, and hypertensions. African American and women living in lower SEP counties were most vulnerable to EHE. Early warning and education against EHE, especially during transitional months may help decrease a wide spectrum of these pregnancy complications."

Wesselink 2022	Retrospective Cohort	USA and Canada	Not Specific	2013-2020	Data from Pregnancy Study Online—a preconception cohort study of pregnancy planners from the United States and Canada—to examine seasonal variation in spontaneous abortion risk. Women are of 21 to 45 years of age.	To investigate the season at risk (from the date of each gestational week) in relation to spontaneous abortion; in a secondary analysis, to investigate season of conception about spontaneous abortion.	" Environmental or lifestyle factors more prevalent in late summer may be associated with increased risk of early spontaneous abortion"
Zhao 2023	Case-control study	China	Humid subtropical climate	2017-2021	Women were diagnosed with miscarriage based on clinical examination, including urinary or serum β-human chorionic gonadotropin (β-hCG) concentrations and fetal ultrasound scans. A total of 18,269 clinical data were collected from Nanjing Maternity and Child Health Care Hospital.	To evaluate the association between temperature exposure and the risk of spontaneous abortion by using distributed lag nonlinear model (DLNM)	"Thus, our findings highlight the potential risk of short-term high-temperature exposure during early pregnancy, and more evidence was given for the effects of climate change on maternal health."

Supplementary table 1: Quality assessment of the included studies by JPI

Study ID	Were the criteria for inclusion in the sample clearly defined?	Were the study subjects and the setting described in detail?	Was the exposure measured in a valid and reliable way?	Were objective, standard criteria used for measurement of the condition?	Were confounding factors identified?	Were strategies to deal with confounding factors stated?	Were the outcomes measured in a valid and reliable way?	Was appropriate statistical analysis used?	Total
Asamoah 2017	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
Davenport 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Unclear	7
Hajdu 2021	Yes	Unclear	Yes	Yes	No	No	Yes	Yes	6
Hajdu 2023	Yes	Yes	Yes	Unclear	No	No	Yes	Yes	6
Sun 2020	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
Qu 2021	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	8
Wesselink 2022	Yes	Yes	Unclear	Yes	No	No	Yes	Yes	6
Zhao 2023	Yes	Yes	Yes	Unclear	Yes	Yes	Yes	Yes	7

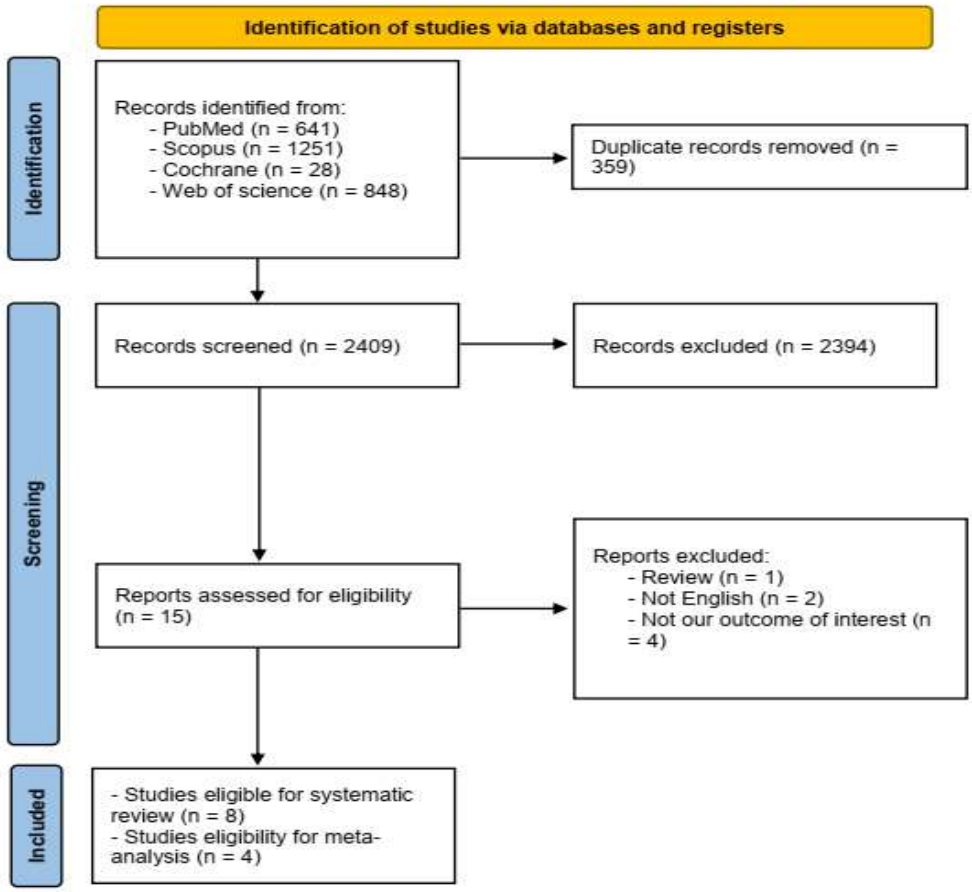

Figure 1: PRISMA flow diagram showing studies' selection process

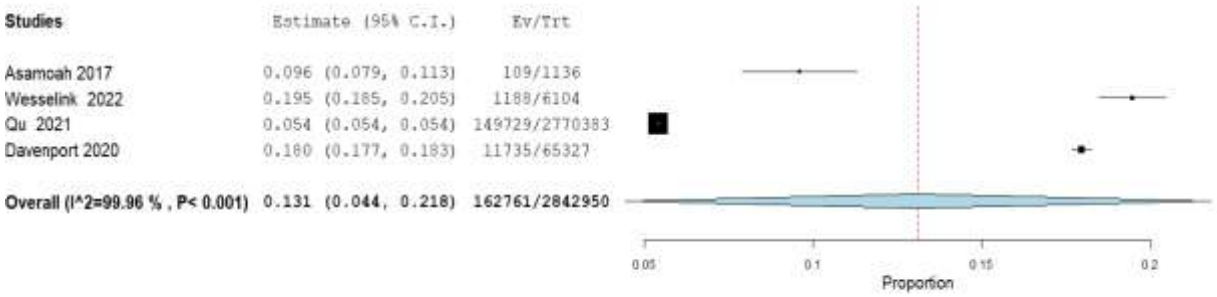

Figure 2: Forest plot showing proportions of spontaneous abortion outcome

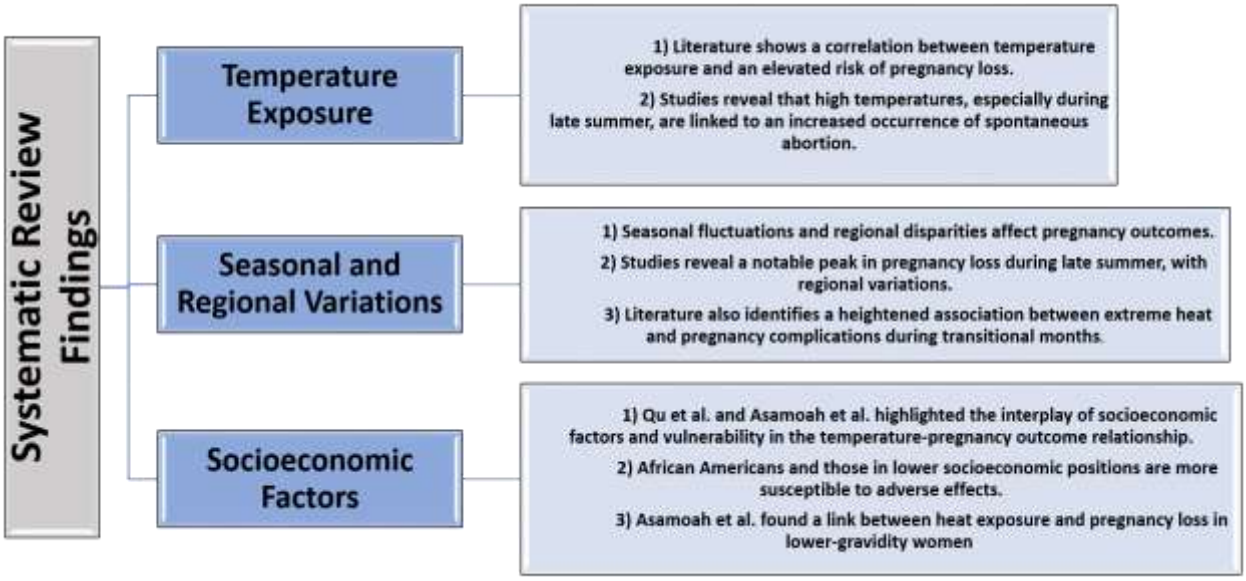

Figure 3: Summarizes the key findings of our systematic review

Furthermore, Qu *et al*. identified heightened associations between extreme heat and pregnancy complications during May and September.[24] These findings suggest that periods of shifting temperatures may present unique challenges for pregnant individuals. Asamoah *et al*. found stronger associations between heat exposure and pregnancy loss in regions with high ambient heat.[14] (Figure. 3)

Socioeconomic factors and vulnerable populations

The studies conducted by Qu *et al*. and Asamoah et al. provide valuable insights into the intricate interplay of socioeconomic factors and the vulnerability of certain populations in shaping the relationship between temperature exposure and pregnancy outcomes.[14,24] Qu *et al*. reported African Americans and individuals in lower socioeconomic counties showed heightened susceptibility to extreme heat effects during pregnancy.[24] This finding underscores the intersectional nature of health disparities and highlights the need for targeted interventions within these vulnerable communities. Furthermore, Asamoah *et al*. found stronger associations between heat exposure and pregnancy loss among women with lower gravidity.[14]

Assessment techniques for climate effects

Davenport *et al*. utilized fine-scale climate data with reproductive data from sub-Saharan Africa.[21] Asamoah *et al*. employed Ghana Maternal Health Survey data with historical heat level data.[14] Hajdu *et al*. combined Hungarian administrative data with climate models.[23] (Figure. 3)

Discussion

Our reviewed studies provide insights into the relationship between temperature exposure and pregnancy outcomes, specifically focusing on spontaneous abortion. The pooled proportion of spontaneous abortion across four studies was approximately 13.1%. The research consistently identified a correlation between temperature exposure and an elevated risk of pregnancy loss, with higher temperatures increasing the likelihood.[4,14,15,21–25] Regional variations were also noted, with studies highlighting potential geographic factors influencing temperature-related pregnancy health outcomes.[4,14,15,21–25] The systematic review findings demonstrate consistent patterns across studies. The correlation between temperature exposure and elevated pregnancy loss risk identified

across multiple studies suggests a robust relationship. The alignment between Wesselink *et al*.'s findings and those of Qu *et al*. reinforces the association between extreme heat and spontaneous abortion. The nonlinear relationship identified by Zhao *et al*. and the positive correlation demonstrated by Sun *et al*. further strengthen this evidence base. These converging findings from diverse geographic regions underscore the critical importance of considering seasonal fluctuations and regional disparities when examining temperature-pregnancy outcome relationships. The regional variations highlight potential geographic factors that may moderate temperature exposure impacts on pregnancy health. The vulnerability of specific populations, particularly African Americans and those from lower socioeconomic backgrounds, reveals the intersectional nature of health disparities and emphasizes the need for targeted interventions within these communities. The periods of shifting temperatures identified by Qu *et al*. as presenting unique challenges warrant particular attention in public health planning.[4,14,15,21–25] Socioeconomic factors and vulnerable populations are also critical considerations, as certain groups, such as African Americans and individuals from lower socioeconomic backgrounds, may be more susceptible to the adverse effects of extreme heat during pregnancy.[4,14,15,21–25]

Maternal heat exposure during early pregnancy has been associated with birth defects, even without maternal hyperthermia. This suggests that heat exposure during early development may have teratogenic effects, potentially leading to spontaneous abortion[26]. Extreme heat has been implicated in sperm DNA fragmentation, which may contribute to an increased risk of spontaneous abortion. The critical window for this effect is 2 to 3 months before conception, highlighting the importance of pre-conception paternal heat exposure as a potential factor in pregnancy outcomes.[27–30] The relationship between heat exposure and spontaneous abortion may also be mediated by behavioral responses to heat, such as changes in diet and physical activity. Alternatively, seasonal exposures could enhance the survival of affected embryos early in gestation, leading to their detection at later stages, thereby creating an apparent association between heat exposure and spontaneous abortion.

Elevated temperatures can induce alterations in maternal hormone levels and increase circulatory demands on the fetus.[31] These changes may enhance a pregnant woman's susceptibility to heat-related ailments. Specifically, inefficiencies in the mother's sweating mechanism can cause dehydration, reducing uterine blood flow and potentially triggering premature labor.[31] Thus, high temperatures are implicated in the potential induction of premature labor, with maternal and fetal consequences. Embryos and early fetuses are particularly susceptible to hyperthermia's detrimental effects.[32] Heat exposure can induce cellular, placental, and vascular damage, impairing fetal nutrition and potentially causing long-term harm. Additionally, Schifano *et al*. proposed that heat exposure may initiate inflammatory responses during pregnancy, leading to the production of oxytocin and prostaglandin, which are known to induce preterm labor.[33] Thus, heat exposure during pregnancy can significantly affect maternal and fetal health, underscoring the importance of thermal regulation during this critical period.

Previous research has established significant associations between climate change, particularly extreme heat exposure, and various adverse pregnancy outcomes, including stillbirth, preterm birth, low birth weight, and birth defects.[20,34–37] Elevated ambient temperature exposure during gestation in southern Israel has been linked to a heightened likelihood of premature and early-term parturition.[38] Additionally, Qu *et al*. revealed that exposure to extreme heat events during pregnancy is associated with an increased incidence of multiple pregnancy-related morbidities, encompassing hypertensive disorders, infectious diseases, nephropathies, and gestational diabetes mellitus, among others.[24]

Epidemiological investigations into adverse pregnancy outcomes have yielded evidence suggesting that elevated ambient temperature exposure during gestation poses a significant risk to fetal well-being, with a notable increase in the incidence of spontaneous abortion, as demonstrated by Sun *et al*.[15] In contrast to the prevailing evidence, the study by Bogan *et al*. did not detect a statistically significant correlation between maximum temperature and the incidence of spontaneous abortions spontaneous abortion.[39] This disparity may

be attributed to the widespread adoption of mitigating measures, such as using air conditioning in indoor settings and increased awareness of heat-related precautions. Consistent with the majority of published research, Zhao *et al*. study also revealed a significant positive correlation between high-temperature exposure during pregnancy and the occurrence of spontaneous abortion, suggesting that elevated thermal stress may contribute to the onset of spontaneous abortion.[4]

The study conducted by Asamoah *et al*. in Ghana revealed a significant positive correlation between maternal exposure to elevated wet-bulb globe temperatures and the risk of adverse fetal outcomes, with a notable 12-15% increment in the likelihood of stillbirth or miscarriage per degree Celsius increase in maternal thermal exposure.[14] Also, the study by Strand *et al*. in Brisbane demonstrated a significant correlation between elevated maternal temperature exposure and an increased risk of stillbirth and a shorter duration of gestation.[40] Literature has shown that the human embryo and fetus are vulnerable to thermal stress during specific windows of developmental sensitivity, including periods of rapid cell proliferation, migration, differentiation, and apoptosis, which occur at distinct times for various organ systems.[15] Moreover, the embryo and developing fetus possess limited thermoregulatory capabilities, rendering them reliant on maternal temperature regulation to maintain a stable thermal environment. As a consequence, even modest increments in maternal thermal stress can have devastating consequences for the developing embryo or fetus, potentially resulting in irreversible structural or functional anomalies, growth restriction, or embryonic/fetal demise, ultimately leading to spontaneous abortion.[14,41]

Notably, Sun *et al*. study revealed a slightly diminished risk of miscarriage associated with high temperatures throughout pregnancy and during the last two months preceding hospitalization, compared to moderately high temperatures, which was similar to the findings of Strand *et al*. [15,40] This phenomenon suggests that pregnant women may have instinctively adopted coping strategies and taken adaptive measures to mitigate the effects of extremely high temperatures, such as the use of air conditioning. Previous research has demonstrated that air conditioning can significantly alleviate the adverse health impacts of hot weather and heat waves.[42,43] Chersich *et al.*, in their systematic review and meta-analysis, suggested that heat exposure during pregnancy increases the likelihood of adverse outcomes such as preterm births and stillbirths. Their review also indicated that the odds of a preterm birth increased by 1.16-fold during heatwaves.[20] Associations between heat exposure and preterm birth appear more consistent and robust than those with birth weight, with only 18 out of 28 studies finding a link between temperature and birth weight.[20] However, their study focused on pregnancy-related outcomes other than spontaneous abortion during climate change. They also could not identify specific windows of vulnerability during pregnancy, except that heat exposure in the final weeks seems to be crucial for preterm births and stillbirths.[20] Pregnant women in low- and middle-income countries may be vulnerable to heat exposure throughout their pregnancy, while vulnerability in high-income countries is mostly limited to the last weeks.[20]

To our knowledge, our study was the first meta-analysis to assess the effect of high climate temperature on spontaneous abortion. Nevertheless, many limitations were encountered, as follows.The interpretation of studies on the impact of environmental exposures on spontaneous abortion is challenging due to potential confounding factors such as air pollution and heat action planning. Additionally, the effectiveness of adaptation measures such as air conditioning use might attenuate the strength of associations between heat exposures and adverse outcomes, leading to inconsistent findings. Limitations were also encountered due to publication bias, multiple testing, and selective reporting of positive associations. Future reviews should consider stratifying analyses by factors like air conditioning use. Additionally, the included studies varied in design, introducing potential biases and variability in findings. Considering the methodological differences across studies, the evidence presented should be interpreted with caution.

Strengths and limitations

This study has notable strengths, including being the first meta-analysis to specifically examine the effect of high temperatures on spontaneous abortion, the use of a comprehensive literature search across

major databases, rigorous appraisal of study quality, and inclusion of diverse geographic and socioeconomic contexts, which enhances the generalizability of the findings. However, several limitations must be acknowledged: the small number of eligible studies and their concentration in a few countries, high heterogeneity due to differences in study design and exposure definitions, limited control for confounders such as air pollution and adaptation strategies, and the potential for publication bias. Furthermore, limited attention was given to paternal pre-conceptional heat exposure and maternal behavioral responses, which may influence pregnancy outcomes. These factors indicate that while the evidence suggests a link between heat exposure and spontaneous abortion, the findings should be interpreted with caution.

Conclusion

Our review highlighted the association between high temperature and the risk of spontaneous abortion. Regional variations and seasonal fluctuations influence pregnancy health outcomes, indicating the need for location-specific interventions and awareness campaigns. Socioeconomic factors and vulnerable populations, such as African Americans and individuals from lower socioeconomic backgrounds, may be more susceptible to heat-related pregnancy complications. However, interpreting the results is challenging due to potential confounders like air pollution and heat action planning. Future studies need to consider stratifying analyses based on factors like air conditioning use and other possible confounders. They also should focus on vulnerable populations to develop targeted interventions and policies to mitigate the impact of heat exposure on pregnancy outcomes in these at-risk groups.

Conflict of interest

The authors confirm that there are no financial or personal relationships with other people or organizations that could inappropriately influence (bias) their work. This includes no employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, or grants or other funding.

Declaration of generative AI in scientific writing

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Credit authorship contribution statement

Muayad Albadrani: Conceptaliztion, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Shyamkumar Sriram:** Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Ethical approval

Not applicable because this study is a meta-analysis.

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