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A SCOPING REVIEW ON UNDERSTANDING CLIMATE CHANGE'S EFFECTS ON PREGNANCY IN COASTAL REGIONS

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Abstract

Introduction: *Pregnancy increases vulnerability to environmental stressors. Climate change heightens risks for pregnant women, leading to adverse maternal and infant outcomes. Coastal regions, prone to sea-level rise, rising temperatures, saltwater intrusion, and extreme weather, face significant health impacts. This review summarises the effects of climate change on pregnant women in these areas, emphasising the need for targeted interventions to mitigate these risks.* ***Discussion:*** *This scoping review was conducted using the advanced Arksey and O'Malley framework. Utilizing several keywords, including 'climate change,' 'adverse pregnancy,' 'pregnant outcome,' 'coastal,' and 'island,' a thorough exploration was conducted on PubMed, ScienceDirect, Scopus and ProQuest. A thorough review of 660 articles from 2020–2024 on those online databases identified 34 relevant studies. The findings show that coastal residents face environmental challenges such as rising temperatures, air pollution, cyclones, hurricanes, ozone exposure, floods, and highly saline water. Prolonged exposure to these conditions exacerbates health risks. Climate change is linked to adverse pregnancy outcomes, including low birth weight, small gestational age, stillbirth, preterm birth, neonatal health problems, and increased the risk of pregnancy complications and miscarriages.* ***Conclusion:*** *Climate change significantly affects pregnant women, causing complications and adverse outcomes throughout pregnancy. Addressing these issues requires comprehensive policies and intervention programs. These insights provide a foundation for policymakers to develop strategies that support and protect pregnant women in vulnerable regions. Household-level efforts, such as providing a comfortable living environment, can help reduce the climate change impacts.*

INTRODUCTION

Given the limited and outdated information available on this subject, we are excited to explore the latest developments on how climate change in coastal areas is linked to pregnancy outcomes. As the global human population has surged tremendously, planetary issues have become a major global concern. The nearly 8 billion people on Earth have significantly influenced industrial activity, leading to emerging climate challenges driven by global warming (1). As a long-term consequence of uncontrolled anthropogenic and industrial activities, climate change undoubtedly exerts adverse effects on ecosystems, impacting both animal and human health. This phenomenon results in higher temperatures, more severe storms, rising sea levels, and increased droughts, all of which are directly linked to human health (2).

Climate change, characterised by the long-term rise in temperatures and alterations in weather patterns, has been occurring for centuries but has progressively intensified over time. It significantly impacts coastal areas, affecting sea level rise, warming ocean temperatures, ocean acidification, changes to rainfall and runoff, and more extreme weather events. Rising sea levels threaten to inundate low-lying regions, contribute to coastal flooding, and increase saltwater intrusion (3). Warmer temperatures drive changes in ocean pH, oxygen

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levels, and salinity levels, contributing to the loss of marine biodiversity (4). These combined effects not only endanger human populations but also compromise the resilience of coastal environments.

Prolonged climate problems alter the ocean environment and human quality of life. The most common direct impact of climate change is warmer seawater temperatures, which open the gate to further negative impacts such as triggering tropical storms, escalating coral reef bleaching, coastal flooding, rising sea levels, and coastal storm surges (5). Recent data reveal that Southeast Asia is confronting severe coastal erosion, primarily driven by rising sea levels linked to long-term climate change. Malaysia and Thailand, in particular, are facing considerable challenges in addressing this issue (6). These challenges underscore the importance for countries in regions like Southeast Asia and archipelagic nations to actively address climate change, as health serves as a vital indicator of a country's development and progress.

Furthermore, these environmental issues pose a major threat to human health, especially to vulnerable populations such as pregnant women, the elderly, infants, and children. Addressing these challenges remains a significant hurdle for developing countries, where the majority of the population resides at the lowest economic level. For example, over 72 million people in Indonesia are classified as poor. As an archipelagic nation, Indonesia has numerous coastal cities that are directly threatened by one of the key effects of climate change, namely rising sea levels. This situation poses environmental risks and creates additional burdens on health systems, economic stability, and sustainable development efforts.

As these countries are still in the process of development, their health facilities and systems remain vulnerable and often lack stability. This vulnerability increases the likelihood of disruptions in healthcare services, including supply chains, daily operations, and medical logistics. Additionally, extreme climate events can severely damage infrastructure and healthcare facilities, further compromising the delivery of essential services. These challenges highlight the critical need to prioritize climate change adaptation and resilience-building efforts to protect health systems and ensure their ability to function effectively amid future climate challenges (7). The changes lead to numerous infectious disease outbreaks, elevate the risk of cardiovascular and respiratory diseases, and ultimately increase overall morbidity and mortality (8). Unfortunately, pregnant women, infants, and children face significantly higher risks of adverse impacts.

Pregnant women and infants represent particularly vulnerable populations due to their compromised immune systems, increasing their susceptibility to the adverse effects of climate change (9). A review conducted in 2020 concluded that seasonal changes are significantly associated with reduced birth weight, preterm birth, diabetes and gestational hypertension, miscarriage and infant mortality, and neonatal development abnormalities (10). Elevated temperatures can alter body metabolism and homeostasis indirectly, leading to blood vessel vasoconstriction. This condition heightens the risk of pre-eclampsia in pregnant women, escalating the risk of getting miscarriage or even stillbirth. Moreover, this physiological response can also adversely affect foetal development, potentially resulting in low birth weight (LBW), small for gestational age (SGA), congenital defects or anomalies and preterm birth (11). Linking climate change to maternal and child health has revealed numerous important insights, though research in this area is still less developed than other emerging topics. These findings emphasize the need for a thorough examination of climate change and its implications, particularly within the maternal and child health context.

However, no existing reviews that specifically address the climate disruption in coastal areas and its impact on adverse pregnancy outcomes. This scoping review aims to fill this gap by detailing the studies conducted in coastal regions between 2020-2024. The primary objective of this study was to summarise the effects of climate change on pregnant women living in coastal regions. The secondary objectives were to identify the changes in coastal areas due to climate change and the adverse pregnancy outcomes resulting from these changes. This study also seeks to highlight the necessity for specific interventions to reduce these risks.

DISCUSSION

This study employed a scoping review of original research conducted between 2020 and April 2024, with a focus on assessing the influence of climate change on pregnancy outcomes. A literature search was performed using the PRISMA-ScR guideline (12) with the screening process outlined in the flow diagram in Figure 1.

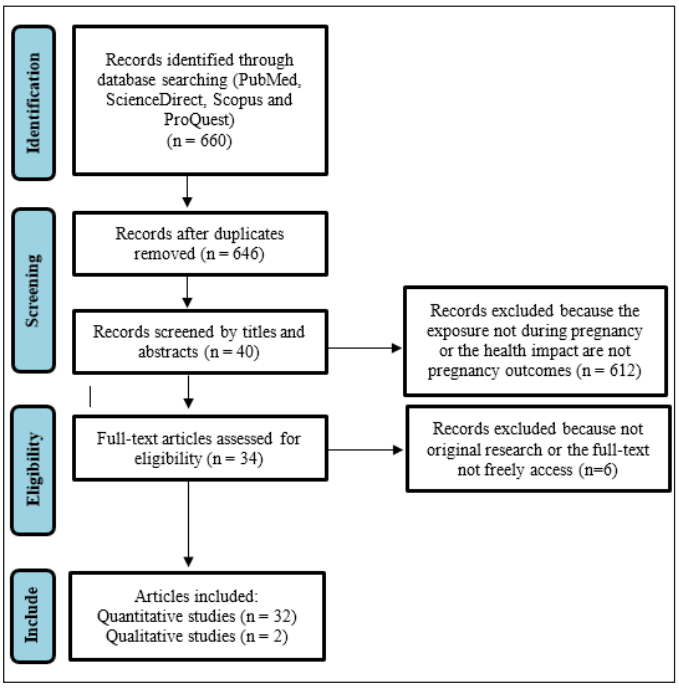

Figure 1. Flowchart Screening Articles From Online Scientific Databases

Additionally, we followed the advanced Arksey and O'Malley methodological framework for scoping review (13) as guidance. The five steps we followed are as follows:

Step one: identifying the research question. Developing a clear research question by considering the concept, target population, and health outcomes of interest clarifies the focus of the scoping study (13). The research question of this study is: '*What are the climate change's effects on pregnancy-related outcomes among pregnant women living in coastal areas?'*. We used '*the effects of climate change on pregnancy outcomes'* as the concept and '*pregnant women living in coastal areas*' as the target population, and *'pregnancy outcomes'* as the outcomes of interest.

Step two: identifying relevant studies. Decision-making process regarding the scope of the study should be based on the research question (13). All data related to the research question were collected from scientific databases such as PubMed, ScienceDirect, Scopus and ProQuest. The articles were searched using keywords, including *climate change, adverse pregnancy, pregnancy outcome, coastal,* and *island* with AND and OR Boolean operators to refine the search. The literature was conducted on 5 April 2024 and limited to the articles published during 2020–2024. Titles of articles were compiled in Microsoft Excel for record identification.

Step three: study selection. We conducted duplication-checking before screening the eligible articles by the title and abstract. The eligibility of the articles reviewed was based on the inclusion and exclusion criteria. The inclusion criteria were articles published between 2020 and 2024 that analysed climate change exposure during pregnancy and mentioning pregnancy outcomes, including maternal, neonatal, and perinatal health. The exclusion criteria were literature reviews or non-original research articles.

Step four: charting the data. The researchers collaboratively develop a data charting form and decide which variables to extract to address the research question (13). The primary variables in the data charting were any kind of climate change and pregnancy outcomes. Using Microsoft Excel, we documented our analysis matrix based on the categories of authorship, year of publication, methodology, study location, and main research findings.

Step five: collating, summarising, and reporting the results. We conducted this stage in three distinct steps recommendation to Arksey and O'Malley's framework. First, we collated the descriptive numerical analysis from the quantitative studies and thematic results from the qualitative studies, as presented in Table 1. Then, we summarised the findings to address the research question: the impacts of climate change on pregnancy-related outcomes. In the final step, we discussed the implications for future practice and policy to help pregnant women facing climate change during their pregnancies. From the literature search we retrieved 660 articles: 116 from PubMed, 129 from ScienceDirect, 3 from Scopus, and 412 from ProQuest. After screening, we removed 4 duplicate titles and 612 abstracts that did not focus on climate change exposure during pregnancy or maternal and neonatal health outcomes. We then assessed the full texts and excluded 6 articles based on our criteria, resulting in 34 eligible articles: 32 quantitative and 2 qualitative studies.

Table 1. The Main Findings From Reviewed Articles

Climate Change		Main Findings	Location	Author
Rising Temperatures	1.	Higher temperature variability (TV) exposure measured in three different actions during pregnancy was highly associated with an increased risk of LBW birth in African LMICs.	Africa	Wang *et al*, 2023 (33)
Rising Temperatures	2.	Warmer-than-average temperatures were associated with higher risk of Small for Gestational Age (SGA), OR 1.16 (95% CI: 1.06; 1.28) of	China	Chen *et al*, 2023 (46)
Rising Temperatures	3.	An average monthly temperature increased 5^{o}C (reference 19^{o}C) would decrease 13 grams average birth weight	Brazil, Chile, and Mexico	Bakhtisiyarava *et al*, 2022 (36)
Rising Temperatures	4.	Heat exposure during first 20 weeks of pregnancy was the strongest associated smaller foetal growth measures. Meanwhile cold temperatures did not seem to have an impact on foetal growth.	the USA	Leung *et al*, 2023 (15)
Rising Temperatures	5.	There was an association between increased mean weekly temperature and lower LBW. Mothers at younger ages are more susceptible to high temperatures	Republic of Cyprus, Europe	Liu *et al*, 2023 (37)
Rising Temperatures	6.	Second-trimester exposure had the greatest association, with an estimated increase of 5.16% (95% CI: 3.60; 6.74) in LBW per 1C increase in apparent temperature.	Brazil	Requia *et al*, 2022 (35)
Rising Temperatures	7.	Maternal exposure to one Extreme Heat Event (EHE) was associated with a 20.95 and 11.89 gram decrease in mean birthweight for EHE90 and EHE97, respectively.	the USA	Lawrence *et al*, 2020 (34)
Rising Temperatures	8.	Heatwave exposure during the final gestational week associated with increases the preterm births number. The hazard ratios (HRs) used range from 1.10 to 1.92.	China	Wang *et al*, 2020 (50)
Rising Temperatures	9.	Hazard ratio at high temperature (95th percentile or 24.5^{o} C) was 1.22 (95% ci: 1.16; 1.28) for overall spontaneous preterm birth (sPTB).	New South Wales (Australia)	Singh *et al,* 2023 (49)
Rising Temperatures	10.	Heat stress indices were significantly associated with foetal heart rate and foetal strain. Exposure to extreme temperatures caused maternal heat strain among pregnant mothers in Gambia that significantly associated with foetal strain.	Gambia (West Africa)	Bonell *et al,* 2022 (23)
Rising Temperatures	11.	Intense heatwave experienced by mothers at 28-34 weeks of gestation were associated with preterm birth.	China	Wang *et al*, 2020 (50)
Rising Temperatures	12.	Higher heat exposure during the last week of gestation was significantly associated with higher risk of preterm birth.	the USA	Son *et al*, 2022 (32)
Rising Temperatures	13.	The risk of preterm birth was consistently greater among mothers who experienced an extreme heat during their last week of gestation.	the USA	Ilango *et al*, 2020 (30)
Rising Temperatures	14.	High temperature was associated with 15% increased risk of spontaneous preterm birth in a highly acclimatised population, racialised economics that could increase the social inequities on preterm birth rates.	Texas	Cushing *et al*, 2022 (29)
Rising Temperatures	15.	The risk of preterm birth was increased among women who were encountered high temperature within one week prior to delivery.	LMICs	McElroy *et al*, 2022 (31)
Rising Temperatures	16.	Hot thermal stress significantly increased the risk of stillbirth in the 0-13 lag-time. Increase in temperature was associated with the elevated risk of preterm labour and stillbirth.	Iran	Khodadadi *et al*, 2022 (27)
Rising Temperatures	17.	Long-term to moderate heat stress exposure correlated with a higher risk of stillbirth, particularly during late pregnancy. The risk was slightly greater in winter than in summer.	Taiwan	Yang et al., 2022 (26)
Rising Temperatures	18.	High temperature exposure particularly in the third trimester of pregnancy significantly influenced pregnant women. The peak stillbirth rate in Taiwan occurred in summer (12.6 per 1000 births) that higher than average stillbirth rate (11.3 per 1000 births).	Ghana	Nyadanu et.al, 2023 (28)
Rising Temperatures	19.	High temperatures may increase the risk of morbidity and mortality associated with infectious diseases, such as diarrheal diseases and malaria, among infants in low-income settings.	Kenya	Lusambili *et al*, 2024 (40)
Rising Temperatures	20.	We found that a 1°C increase in mean ambient temperature was associated with a 10.0% increase in Adverse Pregnancy Outcomes (aOR = 1.100, 95%CI 1.006; 1.203) during early pregnancy period. Mean temperatures were positively associated with high White Blood Cells (WBCs) in the 3rd trimester with sustained effects lasting for up to four weeks.	China	Lin *et al*, 2023 (22)
Rising Temperatures	21.	Despite the overall cold climate, the impact of high temperatures on neonatal mortality is more significant, with mortality increases at high temperatures being steeper than the risks associated with cold. Boys were generally more vulnerable to high temperature and also cold, compared to girls.	Sweden	Junkka *et al*, 2021 (39)
Rising Temperatures	22.	Higher temperature exposure during first and second trimester were positively associated with Low-Birth Weight incidence, with risk ratio were RR 1.02 (95% CI 1.0; 1.04) and RR 1.02 (95% CI 1.01; 1.04), respectively. Whereas, the exposure in third trimester was associated with hypertension and severe preeclampsia in mothers (RR 1.07, 95% CI 1.02; 1.12).	India and Pakistan	Shankar *et al*, 2023 (20)
Rising Temperatures	23.	Most of pregnant and postpartum women experienced physical discomfort as the effects of extreme heat during pregnancy. They also mentioned mental wellbeing problem which was threatened by disturbed sleep and restlessness.	Kenya	Scorgie et al 2023 (25)
Air Pollution	1.	The risk of pregnancy loss increased 5.1% (95% CI: 3.5%; 6.7%) for each increment of 1 µg/m3 $PM_{2.5}$ caused by open fire in South Asia.	India, Pakistan, Bangladesh	Xue et al., 2021 (51)
Air Pollution	2.	$PM_{2.5}$ concentration exposure in the last gestational week also higher on women who experienced heatwave.	China	Wang *et al*, 2020 (50)
Air Pollution	3.	The strongest association of $PM_{2.5}$ exposure with SGA was in the 2nd gestational age-week (OR: 1.0017 95% CI: 1.0001; 1.0034)	China	Chen *et al*, 2023 (46)
Air Pollution	4.	A 1 µg/m3 increase of fire-sourced $PM_{2.5}$ exposure during nine months prior to birth was significantly associated with a 2.17gram (95% CI: 0.56; 3.77) birthweight reduction. The risks of LBW increased by 2.80% (95% CI: 0.97; 4.66) and VLBW increased by 11.68% (95% CI: 3.59; 20.40), for each 1 µg/m3 increase in fire-sourced $PM_{2.5}$ exposure.	LMICs	Li *et al*, 2021 (45)

Climate Change	Main Findings	Location	Author
Air Pollution	5. Exposure to wildfire smoke throughout pregnancy was associated with decreased quantity of placental Hofbauer Cells (HBCs) on the 1st trimester and suggests a similar trend in the 2nd trimester.	the USA	Basilio *et al*, 2023 (44)
Air Pollution	6. Exposure to $PM_{2.5}$ and ambient cold and heat air in the last gestational week during winter and summer in New South Wales elevating the risk of preterm births.	New South Wales (Australia)	Singh *et al,* 2023 (49)
Flooding	1. In flood impacted regions, there is a higher percentage of LBW and VLBW infants compared to non-flooded areas: 35.06% compared to 34.515 for LBW infants and 2.72% compared to 2.36% for VLBW infants.	India	Biswas *et al*, 2024 (62)
Flooding	2. There was a significant association of flood exposure during gestational with pregnancy loss (OR 1.08, 95% CI: 1.04-1.11) in LMICs. The most contributor of flood-related pregnancy loss was heavy rains or monsoon rains (89.84%), followed by tropical cyclones and levee/ dam failure.	LMICs	He et al. 2024 (64)
Cyclone	1. Exposure to Tropical Cyclones (TC) in early pregnancy was associated with significantly higher odds of preterm births in affected compared to unaffected during TC years (OR 1.28 CI=1.11-1.49). Moreover, LBW births in affected areas significantly high in than unaffected areas (OR 1.28 95% CI=1.01-1.63), particularly pregnant women in mid pregnancy (OR 1.38 95% CI=1.02-1.88).	Australia	Parayiwa *et al*, 2022 (54)
Cyclone	2. The correlation between maternal exposure to Tropical Cyclone and the risk of preterm birth was stronger in cases of early preterm births. The risk ratio is 1.04 (95% CI: 1.01-1.07); p-value for interaction = 0.018 and ARD is 36 (95% CI: 10-63) per 10,000 pregnancies; p-value for effect interaction = 0.017	the USA	Sun *et al*, 2020 (55)
Cyclone	3. Early-pregnancy exposure to cyclone Yasi and mid-pregnancy exposure to cyclone Marcia increases male live-births proportion in Australia.	Australia	Parayiwa *et al*, 2022 (77)
Hurricanes	Emergency department (ED) visits by pregnant mothers increased by estimated 8.8% (95% CI: 5.8-11.8) for each power outages (PO) level rise during hurricanes in New York City. The primary diagnosis of ED visits such as threatened or spontaneous abortion, threatened or early labour, complications due to hypertension, infections of genitourinary (GU) tract, acute or chronic renal diseases, gestational diabetes mellitus (GDM), mental health illnesses, and cardiovascular diseases.	the USA	Xiao et al 2021 (58)
Ozone Exposure	An IQR increase in O3-1 h and O3-8 h exposure during the 2nd trimester was associated to a higher risk of term low birth weight. Exposure during gestational weeks 15-26 was also associated with elevated risk of term low birth weight. The strongest association was observed for the 21 weeks (OR = 1.023, 95% CI: 1.008; 1.038).	China	Wang *et al*, 2021 (56)
Saline Water Intrusion	Miscarriage was highly and negatively correlated with salinity levels where less saline water significantly influenced miscarriage in Bangladesh.	Bangladesh	Hossain et al., 2024 (73)

Our review revealed significant implications of climate change, particularly in coastal areas. The most prevalent issue was increased ambient temperature analysed in 23 of the 34 articles focus on heat exposure during pregnancy. Air pollution ranked next, appearing in six articles, with three addressing wildfire smoke linked to ongoing global warming. Additionally, several weather events were covered, including cyclones (3 articles), hurricanes (2 articles), and ozone exposure (1 article), all of which impacted both pregnant women and infants. Flooding was discussed in 2 articles, while saline water intrusion, a specific consequence of climate change in coastal areas, was mentioned in 1 article.

Prolonged manifestations of climate change, such as cyclones, floods, droughts, and other extreme events, exacerbate disparities among vulnerable populations. Pregnant women, in particular, are at heightened risk from these environmental changes, as the consequences extend beyond maternal health to perinatal and neonatal outcomes**.** World Health Organization (WHO) defines maternal health as the well-being of women during pregnancy, childbirth and the postpartum phase. Perinatal health encompasses the period from 22 weeks of gestation to 7 days after birth, while neonatal health focus on the health of newborns on their the first month of life (14). According to the review, the two common adverse outcomes identified were preterm and Low Birth Weight (LBW) with more than 10 articles discussing these topics. The remaining articles focused on specific neonatal conditions (4 articles), pregnancy experience and complications (3 articles), pregnancy loss or miscarriages (3 articles), and stillbirth (2 articles). Stillbirth was also mentioned in other articles as a secondary pregnancy outcome affected by climate change.

Rising Temperatures

Global temperatures have been steadily increasing with eight of the ten warmest years on record manifesting within the last decade (15). Tis continuous rise in Earth's temperatures, often referred to as global warming, shows a marked acceleration over time. The average annual temperature rise elevated from 0.007 throughout a span of 172 years to 0.015 throughout 71 years and further increased to 0.020 throughout 51 years (16). The International Panel on Climate Change estimates that, compared to the 1850–1900 period, the global average temperature rise will exceed 1.5-2°C by the end of the century (17).

Geography factors including elevation, topography, proximity to water, and latitude far from the equator influence the climate in a region (18). According to the reviewed articles, research on extreme heat exposure has been conducted in almost all continents, including Africa, Asia, North America, South America, Europe, and Australia. However, Africa and East Asia were the region most frequently mentioned in this study. Extreme heat has the most significant impact in low-resource areas, where the poorest households often have limited access to cooling, and it can be challenging to avoid working in environments with high ambient temperatures (19-20).

Anthropogenic activities are the major cause of the intensified temperature rise since the middle of the 20th century (16). Those activities have led to the release of increasing amounts of carbon dioxide and other greenhouse gases, which in turn contribute to global climate change by further heating the atmosphere (2). Besides the industrial revolution, activities such as deforestation, the use of fossil fuels for transportation (especially aviation), and livestock production have contributed to the rise of an unbalanced amount of greenhouse gases in the atmosphere. Furthermore, the use of fossil fuels for general electronics has been a significant contributor to greenhouse emissions (21). As more heat becomes trapped, the average ambient temperature rises, leading to changes in weather patterns, melting ice caps, and more frequent heatwaves.

The rise in ambient temperature has several impacts on pregnancy outcomes both maternal and perinatal health status (22). Prolonged exposure to warmer temperatures during pregnancy affects acute heat stress in mothers and adverse foetal development (23). Pregnancy drives various physiological changes in women, including alterations in body mass, which may lead to uncompensated heat stress. Cardiovascular changes develop progressively during pregnancy, leading to nearly a 50% increase in plasma volume and cardiac output by the third trimester (24). The elevated metabolic rate and increased body mass during pregnancy generate more heat within the body, leading to a higher risk of hyperthermia. Elevated temperature influences blood pressure during pregnancy by impacting the blood vessels in the placenta after conception or by heightening stress levels in the later stages of pregnancy. Preeclampsia, hypertension, and eclampsia were the common manifestations of blood pressure disorder in pregnant women (10). This aligns with our findings that exposure to high temperatures, particularly during the third trimester of pregnancy, was associated with hypertension and severe preeclampsia. The increased risk of preeclampsia is due to inadequate placental function caused by heat stress in the mothers (19-20). Another finding from one reviewed qualitative article revealed that the majority of pregnant and postpartum women experienced physical discomfort; 'burning', 'really hot', 'scorched', and 'hit by the hot sun' were the most frequently mentioned among respondents. The high ambient temperature can disrupt sleep and cause restlessness, posing a threat to the mental well-being of pregnant women (25).

As previously stated, the quality of offspring is also affected. Hyperthermia during pregnancy can increase the risk of foetal stress, preterm birth, stillbirth, pre-eclampsia, and miscarriage (19-20). While the exact mechanisms by which temperature affects stillbirth remain unclear, potential factors include reduced amniotic fluid volume, placental damage, and temperature-induced uterine contractions (20, 26). Heat stress during pregnancy may lead to dehydration and counterregulatory hormonal changes, including the release of antidiuretic hormone and oxytocin, which can decrease uterine blood flow and disrupt foetal metabolism (20, 27-28). Several studies from our reviewed article indicates that extreme heat exposure in pregnant women, particularly during the last week of gestation, increases the risk of preterm birth (29-32).

Furthermore, we found that high temperature exposure correlated with LBW (33). Maternal exposure to one extreme heat event (EHE) was linked to a decrease in mean birth weight of 20.95 grams and 11.89 grams (34). Several studies also indicated that a 1°C increase in ambient temperature is positively correlated with reduced birth weight (35-36). Heat exposure during pregnancy was linked to reduced foetal growth, while cold temperatures appeared to have no effect. The strongest associations were observed with temperatures during the critical exposure window in the first 20 weeks of pregnancy (15). Younger mothers are also more vulnerable to the harmful effects of elevated temperatures (37). Pregnant women who work in high ambient temperatures have a risk of heat stress associated with miscarriages, premature birth, stillbirth, low birth weight (LBW), and congenital abnormalities (38).

The perinatal and neonatal period are marked by an underdeveloped immune system, difficulties in regulating body temperature, and limited independence, which renders newborns especially vulnerable to slightest environmental changes (17). Neonatal mortality rates in Sweden rise significantly with higher temperatures, with boys typically being more susceptible than girls (39). Another finding from a qualitative indicated that neonates are at the highest risk from extreme temperatures; skin and mouth injuries as direct impact of heat exposure on

neonates. It also affects the well-being and neonate's behaviour, such as causing distress and crying make it difficult for the baby to breastfed and sleep (40).

Air Pollution

This literature review covered studies related to air pollution conducted in China, the United States of America (USA), countries in South Asia, and several Low-and Middle-Income Countries (LMICs). The rapid expansion of construction, manufacturing, and other industrial activities has markedly increased the emission of various toxic substances into the atmosphere (41). Wildfire events, which have intensified significantly due to climate change, are an additional contributor to air pollution (34). Among the prominent pollutants are $PM_{2.5}$, PM_{10}, and NO_2, which are frequently detected in ambient air (41). These pollutants are directly associated with premature mortality and an elevated risk of developing chronic conditions such as asthma, respiratory inflammation, infections, and cancer. Individuals particularly susceptible to these adverse effects include infants, children, pregnant women, and the elderly.

Air pollution contributes to a heightened stress environment, exacerbating oxidative stress and systemic inflammation, disrupting placental growth and function and consequently affecting the overall health and quality of offspring (42). We collected evidence indicating that gestational exposure to air pollutants is linked to abnormal placental vascular function, which in turn contributes to low birth weight (43). Our findings indicate that air pollution from wildfire smoke is far more toxic than other sources of air pollution. This exposure triggers the release of IL-6 as the major pro-inflammatory cytokine, which decreases the human chorionic gonadotropin secretion and compromises the trophoblasts membrane. As a result, nutritional transport from mother to foetus is reduced, potentially causing intrauterine growth restriction and LBW in the long term (44). An increase 1 µg/m3 $PM_{2.5}$ exposure during pregnancy was significantly reduced birthweight 2.17gram (95% CI: 0.56; 3.77) (45). Consistent with the previous statement, the inflammatory process can also disrupt angiogenesis by causing inappropriate gene expression of vascular endothelial growth factors. This alteration results in increased placental vascular resistance and reduced foetal weight (46).

Moving forward to the impact of climate change in exacerbating air pollution, it also contributes significantly to the health burden on neonatal health (47). Additionally, air pollution contributes to premature births and low birth weights, which heighten the risk of infections due to immature immune systems, ultimately contributing to neonatal mortality (48). Our findings reveals that systematic reviews consistently show the strongest evidence of PM2.5's adverse effects on preterm birth (PTB) occurs with exposure spanning the entire pregnancy (49). Research indicates that exposure to air pollutants, particularly $PM_{2.5}$, increases the risk of neonatal hearing loss, often as a result of infection (22). Further analysis showed that elevated temperatures on the second trimester found to be strongly associated with a higher risk of preterm birth, though the effect tends to lessen over time but remains significant (50).

A severe condition of foetal growth restriction caused by open fire exposure is increasing the risk of foetus death and eventually to pregnancy loss, either miscarriage or stillbirth. Additionally, environmental shocks can elevate maternal stress levels during conception, which has been linked to an increased risk of miscarriage and stillbirth (10). The findings of this review shows that the risk of pregnancy loss increased 5.1% (95% CI: 3.5%; 6.7%) for each increment of 1 µg/m3 $PM_{2.5}$ caused by open fire in South Asia. The study conducted by Xue et al (2021) also found that pregnant women at age ≥ 35 years were more susceptible with an excess 11.1% of pregnancy loss risk. Pregnancy loss can be particularly dangerous as it raises the risk of complications in future pregnancies, such as an increased risk of preterm birth (51).

Extreme Weather (Cyclone, Hurricanes, Ozone Exposure)

The long-term effects of climate change increasingly influence natural disasters such as cyclones, hurricanes, and typhoons. Australia and the USA were the study locations in the articles discussing cyclones and hurricanes. Intensified anthropogenic activities, particularly in the industrial sector, have led to a rise in global temperatures, indirectly contributing to the incident and severity of these natural events. Tropical cyclones, in particular, form through several mechanisms. *First*, elevated ocean temperatures (typically above 26°C) provide the necessary heat and energy for cyclone development. *Second*, as temperatures rise, increased humidity leads to the formation of low-pressure systems, which, combined with the Coriolis effect, causes the surrounding air to converge and initiate cyclone formation (52).

Countries in Southeast Asia are geographically located in tropical zones, making them highly susceptible to tropical cyclones, also known as typhoons. In Myanmar and Vietnam, for instance, approximately 631,000 residents were displaced, and over 500 lives were lost due to these disasters. Similarly, around 441,000 people

had to be evacuated in Jiangsu Province, Mainland China due to severe winds. These extreme weather events are driven by rising temperatures, particularly along coastlines, and their effects extend inland, exacerbating the risks and impacts on vulnerable populations. This issue is compounded by the fact that many coastlines in Southeast Asia have densely populated, low-lying areas. The combination of tropical cyclone development, intensification, and related factors plays a critical role in affecting these vulnerable coastal communities. This not only poses risks to the environment but also disrupts economic activities. Given that a significant portion of the population in coastal areas depends on marine resources for their livelihoods, the impact of these climate-driven disasters on economic growth is substantial (53).

Reports indicate that Southeast Asia has experienced the most significant increase in ozone concentration. This trend can be attributed to several factors, including prolonged and intense sunlight exposure typical of tropical zones, rising temperatures, and heightened ozone sensitivity at lower latitudes. As a result, Southeast Asia faces elevated levels of ozone pollution. It is essential to address this challenge by emphasizing the need for climate change penalties related to ozone in Asia to effectively manage and mitigate future health impacts (43). These natural disasters significantly impact vulnerable populations through physical injury, psychological stress, and infections. Additionally, they can lead to long-term nutritional deficiencies due to food scarcity caused by the disaster.

Maternal mental health is also adversely affected, with increased stress potentially leading to reduced oxygen supply to the foetus, resulting in growth retardation and elevated cortisol levels, which can trigger premature birth. Our finding reveals that exposure to tropical cyclones (TC) during early pregnancy was linked to significantly higher odds of preterm births among those affected compared to those who were not affected during TC years (54). Another review we evaluated indicated that maternal exposure to tropical cyclones is associated with an increased risk of preterm birth (55). One of the unexplored areas is the effect of ozone exposure on pregnancy-related outcomes. A plausible hypothesis suggests that inadequate acclimatisation to high temperature variations, coupled with altered thermoregulatory responses, escalated physiological demands to support the foetus and placenta, and immunological and hormonal changes throughout pregnancy, may all contribute to adverse outcomes (56).

This review also finds that the rising frequency and intensity of extreme weather incident have resulted to an increase in the frequency of widespread power outages (57). which are correlated with various adverse impacts on maternal health. There was a rising trend in emergency department (ED) visits by pregnant mothers corresponding to hurricanes-related PO, particularly during the first week of the outages. The primary diagnosis of ED visits such as threatened or miscarriages, threatened or preterm labour, complications due to hypertension, infections of genitourinary (GU) tract, acute or chronic renal diseases, gestational diabetes mellitus (GDM), mental health illnesses, and cardiovascular diseases. Maternal psychological stress caused by disasters or extreme weather events may contribute to the increased risk of pregnancy complications (58). Psychological stress during pregnancy can elevate placental corticotropin-releasing hormone, increase circulating inflammatory markers, raise the risk of blood pressure disorders, and lead to preterm labour (55).

Flooding

Tropical countries often experience higher temperatures and increased precipitation, leading to a higher incidence of flooding caused by heavy rainfall and inadequate drainage systems, particularly in densely populated Southeast Asian areas. Excessive rainfall can saturate the soil, leading to runoff and overwhelmed drainage systems, further exacerbating the risk of flooding in these vulnerable regions (59). Climate change plays a significant role in this process by raising global temperatures, which increases the atmosphere's capacity to hold moisture. Persistent heavy rains can overwhelm drainage systems (60). Floods can also be caused by snowmelt, storm surges, or dam releases (61). Additionally, reduced vegetation due to deforestation and urbanisation limits natural water absorption, exacerbating flooding and contributing to drought conditions in some areas (60).

Global climate change also contributes to the increasing incident and severity of natural disasters, including landslides, floods, droughts, heatwaves, and storms (62). As sea levels rise due to climate change, coastal areas are at greater risk of flooding, creating serious challenges for both people and the environment. Low-lying regions could become permanently submerged, threatening homes, infrastructure, and local economies. Coastal defences like levees and seawalls are becoming harder to design and maintain, as stronger storm surges push seawater further inland, often overwhelming these barriers. Rising sea levels also block natural drainage systems, leading to increased flooding during heavy rain, while saltwater can seep into freshwater supplies, impacting drinking water. Erosion weakens natural

protections like beaches and marshes, which are crucial for reducing flood risks (63).

This literature review discussed flooding in research conducted in India (62) and 33 other developing countries (64). South Asia had the highest proportion of flood-related pregnancy losses, with 89.84% affected by heavy rains or monsoon rains (64). Floods might directly cause pregnancy loss due to exacerbating accidental injuries, physiological stress, and infectious disease transmission. Floods can lead to food scarcity and nutritional deficiencies due to the destruction of crops and food supplies. Poor maternal nutrition is a known risk factor for adverse pregnancy outcomes, including preterm birth and low birth weight (65). Pregnant women experiencing floods during mid-pregnancy and late pregnancy have the highest risk of pregnancy loss, with OR 1.07 and OR 1.05, respectively. Additionally, pregnant mothers who experienced prolonged flood exposure of more than 16 days have a significant risk of pregnancy loss (OR 2.00, 95% CI: 1.01-1.15) (64).

Poor maternal nutrition is a known risk factor for adverse pregnancy outcomes, including preterm birth and low birth weight (65). According to the review, the rates of low birth weight (LBW) and very low birth weight (VLBW) infants in regions affected by flooding are notably higher than in non-flooded areas, at 35.06% compared 34.51% for LBW and 2.72% compared to 2.36% for VLBW. This highlights the increased vulnerability of infants born in regions with higher risk of flood incident. In the main unadjusted model, the relative risk ratio (RRR) indicates a 7% increase for LBW (RRR: 1.07; CI: 1.04, 1.09) in these areas compared to non-flooded regions, relative to normal birth weight (NBW) infants. The risk increase for VLBW even reached 21% (RRR: 1.21; CI: 1.12, 1.30) (62).

Saline Water Intrusion

One often overlooked impact on coastal areas is saltwater intrusion. Currently, more than 100 nations face challenges related to seawater intrusion, particularly in coastal areas, due to inadequate and irregular monitoring. Salinized water is unsuitable for drinking and cooking, as it can have significant adverse health effects on human populations (66). This phenomenon occurs due to rising sea levels caused by melting ice and increased temperatures near the shore, which allows seawater to infiltrate freshwater aquifers, leading to contamination of water sources (67). Bangladesh is an example of a coastal country that discussed this phenomenon in this review. Additionally, anthropogenic activities such as uncontrolled coastal development can alter environmental characteristics, particularly hydrological patterns, exacerbating the effects of saltwater intrusion (67). While this issue may not significantly affect the general population, it poses considerable risks for pregnant women. Excessive sodium intake from contaminated water can lead to elevated blood pressure, increasing the risk of preeclampsia and causing electrolyte imbalances, resulting in symptoms like swollen feet (oedema). These conditions can negatively impact kidney function and disrupt the delivery of oxygen and nutrients to the foetus, thereby affecting foetal growth (68-69).

Climate change, which causes numerous natural disasters, alters various aspects of health, particularly access to clean water. Sea-level rise, increased flooding, and changes in rainfall and drought in coastal areas will lead to changes in the quantity, chemical content, and groundwater flow. Therefore, coastal areas in temperate and tropical climates may be more affected by seawater intrusion (70). Several factors contribute to the mechanism of saltwater intrusion, including sea level rise due to climate change, and extreme weather events that increase saltwater pressure, leading to saltwater infiltration into aquifers (71). Saltwater intrusion into coastal aquifers raises groundwater salinity, altering its chemical properties, which affects colour, taste, and safety, making it unsuitable for long-term consumption (72).

Excessive salt intake during pregnancy is correlated with the advancement of inflammation through the enlistment of the T helper-17 pathway and their inflammatory cytokines. Inflammatory and autoimmune conditions are risk factors for miscarriage and eclampsia. Additionally, drinking high-saline water can result in hypertension, which can trigger late pregnancy loss or miscarriage if not controlled (73). Chronic hypertension is associated with a higher risk of pre-eclampsia (OR 5.76, 95% CI: 4.93–6.73) (74) and miscarriage (OR 1.19, 95% CI: 1.13-1.26) (61). However, the reviewed article showed that drinking lower salinity levels in Bangladesh has a more significant influence on miscarriage than higher salinity levels. This discrepancy might be because the study did not consider other variables correlated with miscarriage rates, such as sociodemographic and socioeconomic factors, number of infants ever born, age of pregnant mothers, employment status, marital status, body mass index (BMI), level of education of parents, age at the time of childbirth, desire for pregnancy, and access to media (75).

Public Health Implications

Our results found that climate change phenomena are risk factors for adverse pregnancy outcomes that are considered to be mitigated through

several public health strategies. Public health intervention should focus on prevention, education, preparedness, and healthcare system strengthening. This intervention can be carried out at the household level to policy-makers level.

At household level, creating a comfortable environment by ensuring proper ventilation and or using modern climate control (e.g., air conditioning) can help reduce the impact of heat exposure on pregnant women (18). Compared to the general adult population, pregnant women are more vulnerable to environmental hazards (51). Therefore, it is essential that they attend regular prenatal visits to monitor their own conditions as well as the foetus, especially those living in high-exposure areas (46). Maintaining a safe drinking water supply and encouraging a healthy and promoting a healthy, nutritious diet are important for ensuring their health during pregnancy. Pregnant women whose families can provide better living conditions, nutritious food intake, and access healthcare service contribute to healthier pregnancies and better birth outcomes (62).

Policymakers need to improve clinical care guidelines for pregnancy and public policies to protect vulnerable populations from environmental exposure due to climate change (58). The WHO has developed a framework for climate-resilient healthcare, which is structurally and functionally capable of withstanding climate hazards. Long-term planning is needed to ensure that healthcare facilities are designed to function effectively in hotter climates in the future. Healthcare facilities should be equipped to handle sudden increases in demand, such as a rise in NICU admissions during heatwaves (76). Additional planning is also required to address the healthcare requirements of expectant mothers during evacuation process and in evacuation centres, which encompass the necessity for dedicated areas, particularly in areas frequently affected by extreme weather or disasters. Furthermore, providing information to pregnant women and their families about precautions for extreme weather and warning signs of health problems, such as heat-related illnesses, is essential, possibly through public health campaigns (58). Improving healthcare infrastructure, water, sanitation, and hygiene (WASH) facilities, enhancing housing, fostering community emergency planning and early disaster warning systems, and promoting healthy behaviours would be effective measures to mitigate the impact of climate change (76).

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AUTHORS' CONTRIBUTION

ERS: Conceptualised the idea of the study, designed review's methodology, led data analysis, and drafted the article. NRAR: Performed data analysis, assisted with result interpretation, also reviewed and formatted the article. AW: Reviewed and corrected the draft critically for substantive content.

CONCLUSION

The scoping review on the effects of climate change on adverse pregnancy outcomes in coastal regions reveals a multifaceted threat to maternal, perinatal, and neonatal health. Exposure to high temperatures during pregnancy increases the risk of preeclampsia, disrupts mental well-being of mothers, and interfered foetal development, leading to perinatal health problems (e.g., LBW, preterm birth, and stillbirth) and neonatal health disorders (e.g. newborn hearing loss). Air pollution, particularly from open fire smoke, can lead to miscarriage, LBW, and preterm birth. The risk of preterm birth and LBW also rises with extreme weather events like cyclone and ozone exposure, while hurricanes are correlated with an increase in pregnancy complications. More frequent flooding events can elevate the risk of miscarriage and low birth weight. The threat of miscarriage is also heightened when pregnant women consume highly saline water caused by seawater intrusion.

The evidence underscores the importance of targeted interventions and adaptive strategies to mitigate the impacts of climate change on pregnant women in coastal areas. Targeted interventions should be implemented through multi-helix collaboration to ensure that all efforts are curated with expertise and evidence-based policy-making. Improving healthcare infrastructure, enhancing emergency response systems, and addressing environmental risks are critical steps to protect maternal and foetal health overcoming climate challenges nowadays. Family members can also help pregnant mothers by providing a comfortable environment that protects them from the adverse effects of climate change, such as ensuring adequate ventilation and cooling systems, maintaining a drinking water supply, and encouraging a healthy and nutritious diet.

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