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Early-Life Exposure to Air Pollution and Adverse Birth Outcomes in India: A Systematic Review

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Abstract

Air pollution and climate change pose major environmental threats in India, where rising levels of ambient and household pollutants disproportionately affect pregnant women and infants. Exposure to fine particulate matter, gaseous pollutants and biomass fuel emissions has been linked to adverse birth outcomes, yet evidence remains scattered. This systematic review and meta-analysis consolidates existing research to assess the association between prenatal and early-life exposure to air pollution and adverse birth outcomes in the Indian context. from 2010 to June 2025. Eligible studies examined at least two themes: air pollution, climate change, and adverse birth outcomes (low birth weight, preterm birth, mortality, or early-life exposure) within India. Data were synthesized across study designs, pollutant types, exposure sources and reported health outcomes. Household exposure from solid cooking fuels, poor ventilation and indoor smoke was independently linked to reduced mean birthweight, increased low birth weight (LBW) prevalence, higher occurrence of preterm birth and elevated risk of stillbirth. The evidence strongly supports integrated action like combining clean air policies, climate adaptation strategies, clean cooking initiatives and maternal–child health programs, to mitigate risk and protect vulnerable populations. Strengthening national frameworks such as NCAP and NPCCHH with maternal and neonatal health evidence is essential to reduce pollution-related inequities and improve long-term population health.

Keywords*:* Air pollution, adverse birth outcome, climate change.

I. Introduction

Air pollution and climate change represent two most critical environmental challenges deeply interconnected and jointly threatening human health and ecosystems worldwide. Air pollution arises mainly from anthropogenic activities such as fossil fuel combustion, industrial emissions and vehicular exhaust, releasing harmful pollutants including particulate matter (PM2.5), nitrogen oxides and sulphur dioxide (Orru et al., 2017; Ofremu et al., 2025). Simultaneously, these activities contribute to greenhouse gas emissions, accelerating climate change through global warming and extreme weather events (Ofremu et al., 2025; Xu et al., 2025). Climate change exacerbates air pollution by altering atmospheric conditions affecting pollutant dispersion and intensifying the formation of secondary pollutants like ground-level ozone (Orru et al., 2017). Higher temperatures and frequent heatwaves worsen air quality, increase the occurrence of wildfires and elevate ground-level ozone concentrations, further harming respiratory and cardiovascular health (Xu et al., 2025; Manisalidis et al., 2020). Moreover, PM2.5 exposures has been linked to increased risks of chronic respiratory diseases, cardiovascular diseases and adverse perinatal outcomes such as low birth weight and preterm birth (Manisalidis et al., 2020; Ghosh et al., 2021). In rapidly developing countries like India, urbanization and rapid industrial growth have compounded these issues, particularly in megacities where air quality frequently exceeds safe limits (Kaur & Pandey, 2021).

According to the Global Burden of Disease Study, air pollution contributed to approximately 1.24 million deaths in India in 2017, accounting for 12.5 per cent of total deaths. These include 0.67

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million from ambient and 0.48 million from household air pollution (Balakrishnan et al., 2019). This burden was high in northern states like Uttar Pradesh and Haryana, where PM2.5 concentrations exceeded 125 µg/m³ and it significantly reduced life expectancy (Balakrishnan et al., 2019). Short-term exposure to PM2.5 has been linked to spikes in daily mortality. A study across ten Indian cities found a 1.4 per cent increase in daily mortality for every 10 µg/m³ rise in PM2.5, with locally generated pollutants having an even stronger effect (de Bont et al., 2024). Moreover, cardiovascular and respiratory diseases including stroke, asthma and ischemic heart disease are strongly associated with prolonged exposure to polluted air (Yadav et al., 2021).

Notably, the impact is not limited to urban areas. Recent satellite-derived data reveal that rural and non-urban regions also face severe PM2.5 exposures, emphasizing the need for comprehensive national strategies and need for inclusive policies (Ravishankara et al., 2020). The Indo-Gangetic Plain, which includes densely populated states such as Uttar Pradesh, Bihar, and Delhi, remains a hotspot with consistently high pollution levels and associated health burdens (Balakrishnan et al., 2019; Sharma & Mauzerall, 2022). Air pollution has harmful effects on the entire population, but some groups are disproportionately affected because of higher exposure, weaker defences or existing health conditions. Elderly people due to age-related decline in lung function, higher prevalence of chronic diseases (e.g., COPD, cardiovascular disease, diabetes) and reduced physiological ability to detoxify pollutants are vulnerable to air pollution (Yap et al., 2019). Children, particularly those under five, breathe more per body weight, spend more time outdoors and their organs are still developing, making them more vulnerable (Baranyi et al., 2025).

Air pollution during pregnancy is linked to miscarriages, preterm birth, low birth weight, pregnancy-related complications, neonatal respiratory distress and impaired neurodevelopment (Ghosh et al., 2021; Desouza et al., 2022; Johnson et al., 2024; Rumrich et al., 2025). The burden of PM2.5-related preterm birth (PTB) remains high with an increase in age-standardized mortality and disability-adjusted life years between 1990 and 2019 (Bekkar et al., 2020; Fussell et al., 2024; Tang & Jia, 2022). Despite multiple studies, there remains a lack of comprehensive synthesis focusing on the combined effects of air pollution and climate change on birth outcomes in the Indian context. A systematic review and meta-analysis are essential to consolidate current evidence and inform public health interventions and policy planning. The systematic review seeks to determine whether worsening air pollution attributed to climate change is responsible for adverse birth outcomes in India. The main objective of the study is to systematically review and quantify the association between air pollution exposure during pregnancy and adverse birth outcomes in India. The hypothesis is that air pollution triggered by climate change is responsible for adverse birth outcomes in India.

II. Data and methods

This study is a systematic review and meta-analysis in accordance with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Figure 1). It performs a comprehensive literature search across electronic databases including Google Scholar, ResearchGate, PubMed and Scopus. Keywords “air pollution”, “birth outcomes”, “climate change” and “India” were included. Key data including study design, pollutants, climate change factors, health outcomes and mitigation measures were extracted and synthesized. The literature search was conducted using predefined inclusion and exclusion criteria to ensure a systematic and focused selection of studies.

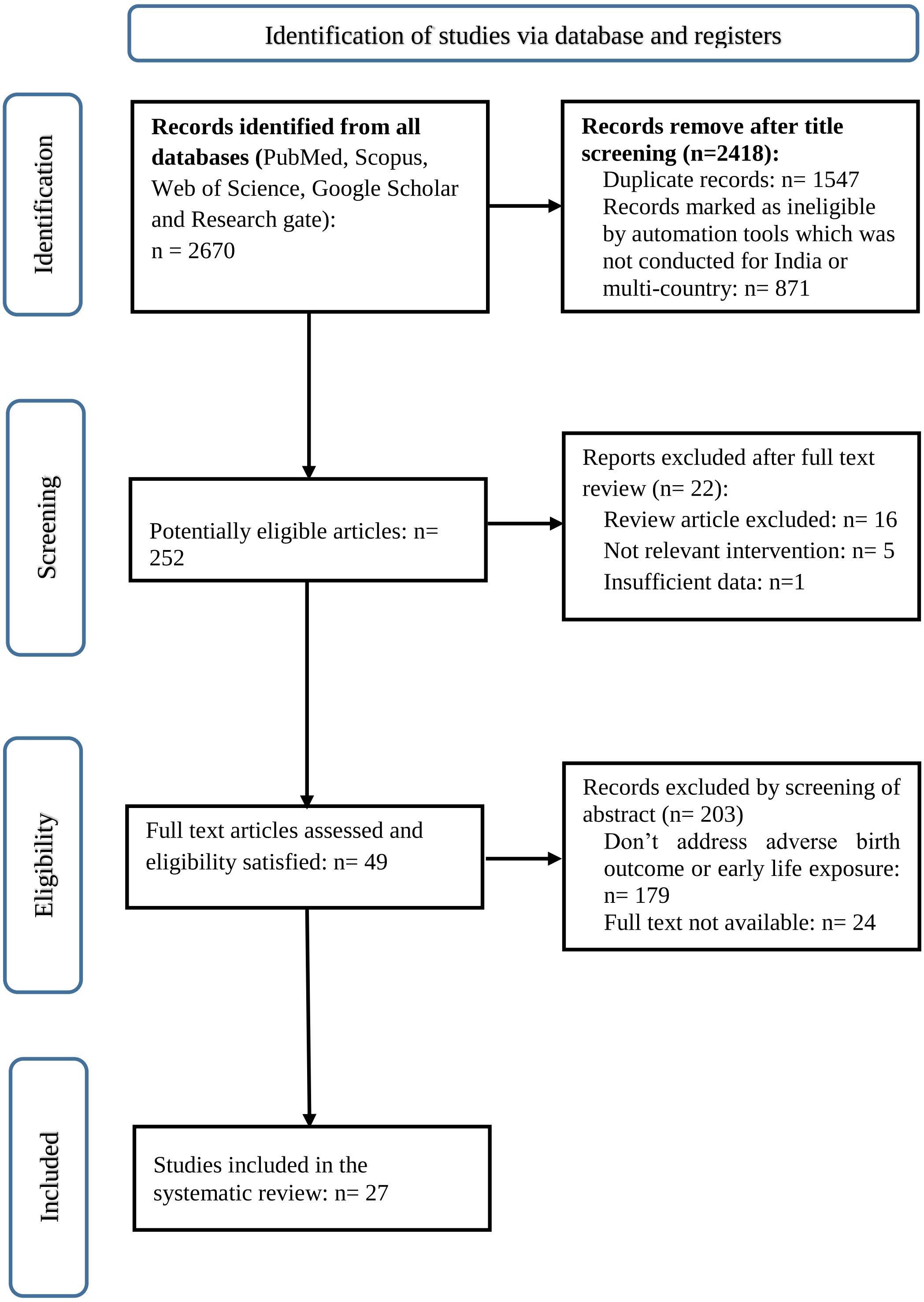
Inclusion criteria

Studies published between 2010 and June 2025 were considered for inclusion. Eligible studies were those conducted in the Indian context that examined at least two of the following themes: air pollution, climate change and adverse birth outcomes or early-life exposure including birth weight (BW), preterm birth (PTB) and mortality. Only articles published in English with full-text availability were included.

Exclusion criteria

During the screening process, titles and abstracts were reviewed to exclude studies that were clearly outside the scope of the review based on topic, methodology or geographic focus. Review articles were excluded. Subsequently, full-text articles were assessed for eligibility and excluded if they were conducted outside India or lacked sufficient data relevant to the objectives of the review.

Figure 1. PRISMA flow diagram for the selection of articles



Data extraction and statistical analysis

The articles were extracted from different sources and meta-analysis was done to analyse for relative risk of the study.

Quality assessment

Methodological quality of the included studies was assessed using standardized critical appraisal tools appropriate to the study design. Cohort and case–control studies were evaluated using the Newcastle–Ottawa Scale (NOS), while cross-sectional and observational studies were assessed using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for analytical observational studies.

Overall, the included studies demonstrated low to high methodological quality. Studies scoring 7 or above out of 9 on the NOS were classified as high quality; those scoring 4–6 were classified as moderate quality and studies scoring below 4 were rated as low quality. Among the 27 studies included in this review, 16 (59.3%) were rated as high quality, 9 (33.3%) as moderate quality and 2 (7.4%) as low quality (Table 1). Most studies clearly defined study population, exposure measures and adverse birth outcomes, and used appropriate statistical analyses with adjustment for important confounding variables such as maternal age, socioeconomic status, parity, education and antenatal care utilization. Large nationally representative studies based on NFHS/DHS datasets and satellite-derived PM2.5 exposure estimates showed stronger methodological rigor because of their extensive geographic coverage, large sample sizes and multivariable analytical approaches.

However, several limitations were observed across studies. Many household air pollution studies relied on proxy indicators such as cooking fuel type instead of direct measurement of indoor pollutant concentrations which may have resulted in exposure misclassification. Cross-sectional study designs used in several studies limited causal interpretation and temporal assessment between exposure and outcome. In some studies, residual confounding due to maternal nutrition, anaemia, smoking exposure, environmental tobacco smoke, housing conditions and healthcare access could not be completely excluded. Variability in exposure assessment methods, pollutant measurement techniques and outcome definitions also contributed to methodological heterogeneity across studies.

Despite these limitations, the direction of association across studies was largely consistent, particularly for low birth weight, preterm birth, stillbirth, neonatal mortality, respiratory illness and impaired child growth outcomes. The consistency of findings across different geographic settings, exposure assessment methods and study designs strengthens the overall evidence supporting the adverse effects of ambient and household air pollution on maternal and child health outcomes in India.

Table 1: Summary of selected studies

Study design	Ambient Air Pollution (AAP)	Household Air Pollution (HAP)	Total
Cross sectional study	7	9	16
Cohort study	3	3	6
Observational study	2	NA	2
Time series analysis	1	NA	1
Case control study	NA	2	2
Total	13	14	27

Note: NA- Not available.

III. Results

Air pollution is a critical public health challenge with substantial evidence linking it to adverse birth outcomes. Broadly, its impact can be categorized into two major groups: ambient air pollution

(AAP) and household air pollution (HAP). Ambient air pollution, primarily from vehicular emissions, industrial activity and fossil fuel combustion, exposes pregnant women to fine particulate matter (PM2.5, PM10), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone. Multiple studies included in the review indicate that prenatal exposure to these pollutants increases the risk of low birth weight, preterm birth, mortality and early life exposure (Table 2). In many low- and middle-income countries like India, household air pollution is still a serious problem because many families use wood, coal, crop waste or kerosene for cooking and heating. Women, especially in rural areas, are often exposed to this smoke for long hours every day while cooking. Breathing in this polluted air during pregnancy can harm both the mother and the unborn baby, increasing the chances of poor fetal growth, low birth weight, premature birth and even new born deaths (Balakrishnan et al., 2019). Climate change further exacerbates both ambient and household exposures by influencing pollutant dispersion and energy needs. Together, these dual pathways illustrate that addressing air pollution (indoors and outdoors) is crucial for safeguarding maternal and child health.

Table 2. WHO specified default value of Relative Risk (RR) per 10 µg m^{-3} increase of daily average for P2.5, PM10, SO2, and NO2 with 95 per cent Confidence Intervals

Pollutants	Morbidity/Mortality	Relative Risk (RR) (95% CI)	Baseline incidence/100000
PM2.5	Total mortality	1.0123 (1.0045-1.0201)	-
	Hospital admission respiratory diseases	1.0190 (0.9982-1.0402)	-
	Hospital admission COPD	1.0091 (1.0017-1.0166)	-
PM10	Total mortality	1.0074 (1.0062-1.0086)	1013
	Cardiovascular mortality	1.008 (1.005-1.018)	497
	Respiratory morbidity	1.012 (1.008-1.037)	66
	Hospital admission respiratory diseases	1.008 (1.0048-1.0112)	1260
	Hospital admission COPD	1.009 (1.006-1.013)	436
SO2	Total mortality	1.004 (1.003-1.0048)	1013
	Cardiovascular mortality	1.008 (1.002-1.012)	497
	Respiratory morbidity	1.01 (1.006-1.014)	66
	Hospital admission COPD	1.0044 (1-1.011)	101.4
NO2	Cardiovascular mortality	1.002 (1-1.004)	497
	Hospital admission COPD	1.0038 (1.004-1.0094)	101.4

Source: Nagpure et al., 2014; Maji et al., 2016; Gupta et al., 2019.

Ambient air pollution and adverse outcomes

Studies taken to answer the relation of ambient air pollution and adverse outcomes can be classified into cross sectional study, cohort study, observational study and time series analysis. Few studies taken for review used national survey data linked to satellite-derived PM2.5 (Desouza et al., 2022; Bera et al., 2025; Goyal & Canning, 2021; Jana et al., 2025; Mahapatra et al., 2020) and applied multivariable regression and spatial models. Major adverse outcomes due to ambient air pollution are identified as low birth weight, preterm birth, mortality and early life exposure.

Low birth weight (LBW)

Across multiple national-level studies, evidence consistently indicates a strong and dose-dependent association between prenatal PM2.5 exposure and low birth weight (LBW). A national-level analysis using DHS data and satellite-derived PM2.5 found a non-linear increase in LBW odds across exposure octiles: compared with the reference category (<26.7 $\mu g \cdot m^{-3}$), the adjusted OR rose to 1.24 (95% CI: 1.07–1.45) at mid-high exposure levels and to 1.41 (95% CI: 1.13–1.75) in the highest octile (>77.3 $\mu g \cdot m^{-3}$) indicating a consistent positive association (Goyal & Canning, 2021). Similarly, evidence from a geostatistical modelling study using DHS 2019–21 data indicates that each 10 $\mu g \cdot m^{-3}$ increment in PM2.5 was associated with approximately a 5% increase in LBW prevalence (OR = 1.37, 95% CI: 1.29–1.45) with spatially heterogeneous effects that were markedly stronger in northern districts (Jana et al., 2025). A complementary study further demonstrated that the effect across PM2.5 octiles was significant at higher exposures, with the first-to-last octile comparison yielding an AOR = 1.06 (95% CI: 1.01–1.12) confirming a consistent positive association even when the pattern is less strictly monotonic (Bera et al., 2025). Evidence from urban and industrial regions consistently indicates that mothers residing in high-pollution environments experience poorer birth outcomes compared with those in rural or less polluted settings. A case study from Odisha reported LBW prevalence of approximately 40.9 per cent in heavy-traffic zones, 27.3 per cent in industrial zones and 13.6 per cent in rural areas accompanied by elevated serum homocysteine and altered placental measures in higher-pollution zones—findings that support a biological pathway linking ambient PM2.5 to reduced fetal growth (Das et al., 2017). A time-trend analysis from Chennai found a strong positive correlation between ambient PM10 concentrations (rising from ~67 μg/m³ in 2000 to ~113 μg/m³ in 2013) and birthweight measures. However, the concurrent improvements in maternal care and nutrition limited causal inference (Rajeswari et al., 2015).

Hospital-based cohort evidence reinforces these associations and highlights trimester-specific windows of vulnerability. A retrospective cohort study from a tertiary hospital in New Delhi (n = 1,155 deliveries; January 2021–June 2022) that linked maternal residence to nearby government monitoring station data found significant associations between first-trimester PM2.5 and PM10 exposures and LBW ($p < 0.05$), with NO2 and O3 associations varying by trimester for PTB (Bhardwaj et al., 2023). An earlier hospital-based study at Sir Ganga Ram Hospital, Delhi also determined trimester-specific risks for LBW by linking delivery records to nearby ambient monitors for PM2.5, PM10, NO2, and O3, supporting the utility of routinely collected health records for detecting pollutant–birthweight signals (Magsumbol et al., 2014). Across these studies, evidence consistently indicates that first-trimester PM2.5 exposure represents a particularly sensitive window for fetal growth restriction.

Preterm birth (PTB)

Across multiple studies, increasing PM2.5 exposures during pregnancy was consistently associated with elevated risks of preterm birth (PTB). Studies reported increased odds of preterm birth with higher PM2.5 exposures, comparing lowest to highest octile the adjusted OR for PTB was ≈1.52 (95% CI: 1.43–1.61) and marginal effect curves suggested sharp rise in PTB risk at PM2.5 > ~40 μg·m⁻³ (Bera et al., 2025). Jana et al. reported a 12 per cent increase in preterm birth per 10 μg·m⁻³ PM2.5 and found PTB odds were spatially heterogeneous and higher in northern districts (AOR: 1.7; 95% CI: 1.57–1.77) compared with unexposed mothers in their model description (Jana et al., 2025). Hospital-based cohort studies from urban India further reinforced trimester-specific vulnerability to ambient pollutants. Significant associations of first-trimester PM2.5 with preterm birth (<34 weeks) and trimester-specific effects for NO2 and O3 (O3 in second trimester associated with 34–37-week PTB) suggesting that early and mid-pregnancy windows may be sensitive in this urban population (Bhardwaj et al., 2023). Magsumbol et al. determined trimester-specific risk for PTB (Magsumbol et al., 2014).

Mortality and still birth

Evidence consistently indicates that prenatal and early-life exposure to PM2.5 and PM10 substantially increases the risks of neonatal, infant and under-five mortality in India. A national cohort study found that third-trimester PM2.5 exposures was associated with increased odds of neonatal mortality (OR = 1.016, 95% CI: 1.003–1.030, per 10 μg/m³), with the effect concentrated in the neonatal period and with evidence of sex modification showing a greater impact for girls (De Souza et al., 2022). Consistent with these findings, a survey across 184 Indian cities demonstrated that each 10 μg/m³ increase in PM10 was associated with 6 per cent increase in neonatal mortality (RR = 1.06, 95% CI: 1.02–1.09) and 10 per cent increase in post-neonatal mortality (RR = 1.10, 95% CI: 1.05–1.16) with background neonatal mortality of 15 per 1,000 live births and post-neonatal mortality of 7 per 1,000 (Mahapatra et al., 2020). Across national and cohort-based studies, evidence indicates that even modest increases in PM2.5 exposure contribute substantially to childhood mortality burdens in India. A 10 μg/m³ increase in PM2.5 was associated with 9% increase in neonatal mortality (RR = 1.09), an 11% increase in infant mortality (RR = 1.11), and 8 per cent increase in under-five mortality (RR = 1.08) (Singh et al., 2019). A large retrospective cohort study (n = 246,001 live births, 2009–2016, followed until death or 5 years of age) reported that each 10 μg/m³ increase in PM2.5 was associated with elevated mortality hazard, with HR = 1.023 (95% CI: 1.008–1.038) for in-utero exposure and HR = 1.013 (95% CI: 1.001–1.026) for post-delivery exposure on under-five mortality (Liao et al., 2022). Evidence on stillbirth further corroborates the harm of air pollution: women using solid fuels had 34 per cent higher odds of stillbirth compared with those using clean fuels (OR = 1.34, 95% CI: 1.13–1.58) (Hammad et al., 2024) and stillbirth was significantly more common among wood-fuel users compared with non-wood-fuel users (4% versus 0%, $p < 0.001$) (Wylie et al., 2014).

Early life exposure

Evidence from both national datasets and community-based studies consistently indicates that exposure to ambient and household air pollution continues to adversely affect children's health beyond birth. Across multiple studies, PM10 and PM2.5 exposures in early childhood are associated with elevated risks of acute respiratory infections, anaemia, and growth faltering. A survey across 184 Indian cities found that 22 per cent children had experienced acute respiratory infection (ARI) symptoms in the preceding two weeks and each 10 μg/m³ increase in PM10 was associated with 7 per cent increase in ARI odds (AOR = 1.07, 95% CI: 1.03–1.12) demonstrating that ambient PM exposure continues to harm infants beyond birth (Mahapatra et al., 2020). Evidence on anaemia further reinforces this pattern: a national study linking satellite-derived PM2.5 to haematological outcomes in children aged 6–59 months found that each 10 μg/m³ increase in PM2.5 was associated with a 0.14 g/dL reduction in haemoglobin (95% CI: −0.16, −0.12) and a 9 per cent increase in odds of anaemia (OR = 1.09, 95% CI: 1.06–1.11) (Mehta et al., 2021).

Exposure to high ambient PM2Ambient PM2.5 also contributes to child growth faltering in India with effects that are stronger in rural areas and among lower socioeconomic households. Across studies, evidence consistently indicates that prenatal and early-life PM2.5 exposures is significantly associated with reduced height-for-age and weight-for-age. A national analysis found that a one-SD increase in PM2.5 during the first trimester was associated with a decrease in height-for-age of approximately 6.7 per cent and in weight-for-age of approximately 7.8 per cent (Singh et al., 2019). Corroborating these findings, a separate observational study reported that a 100 μg/m³ increase in PM2.5 in the month of birth was associated with a 0.05 standard deviation reduction in height-for-age, equivalent to an average height deficit of 0.24 cm in a 5-year-old girl with the last trimester in utero and the first few postnatal months identified as the most critical exposure windows ($p < 0.05$) (Spears et al., 2019).

Household air pollution and adverse outcomes

Studies examining the relationship between household air pollution and adverse outcomes can be classified into cross sectional study, cohort study and case control study. The use of unclean cooking fuels comprising wood, crop residues, dung cakes, coal and kerosene for cooking is a major source of household air pollution (HAP) (Islam & Mohanty, 2021u). Across studies, the major adverse outcomes attributed to indoor or household air pollution are identified as low birth weight, preterm birth, stillbirth and early life exposure.

Low birth weight (LBW)

Tamil Nadu Rural-Urban Mother-Child Cohort study found a 10 μg/m³ increase in pregnancy-period PM2.5 exposures ??? was associated with 2 per cent increase in prevalence of LBW (OR: 1.02, 95% CI: 1.005–1.041) and 4 g decrease in birthweight (95% CI: 1.08–6.76 g)

(Balakrishnan et al., 2018). It measured 24-h household PM2.5 across all trimesters and birth weight at delivery. It suggested that even relatively small increases in PM2.5 during pregnancy significantly raise the risk of LBW, highlighting combined burdens of ambient and household exposures in India. Across household air pollution studies, the use of solid cooking fuels consistently emerged as a major determinant of adverse birth outcomes, particularly in rural and socioeconomically disadvantaged households. Use of solid fuel for cooking is still a practice in many parts of country especially in rural sections. The study found users of clean cooking fuel (CCF) had 7 per cent lower risk of LBW compared with solid fuel users. However, protective effects of CCF diminished at higher ambient PM2.5, at 20–37 µg/m³ PM2.5, CCF users had lower odds of LBW (AOR = 0.83) whereas at ~93 µg/m³ PM2.5, the benefit disappeared (AOR = 1) (Parchure et al., 2024). NHFS data analysis suggested that children from households using clean cooking fuels (CCF) had ~80 g higher mean birth weight (MBW) compared with those in households using unclean cooking fuels (UCF): MBW CCF ≈ 2877g vs UCF ≈ 2797g (Islam & Mohanty, 2021m). Mothers using unhygienic fuels had higher prevalence of LBW and adverse pregnancy outcome (APO = LBW) or neonatal death; unadjusted odds indicated about 1.17× higher odds of LBW for unhygienic vs hygienic fuel users (Patel & Chauhan, 2020). However, ventilation and separate kitchen, these factors also matter (Islam & Mohanty, 2021u; Patel & Chauhan, 2020).

Across multiple studies, maternal household exposure to smoke from solid fuels is consistently associated with lower mean birthweight and higher prevalence of LBW, although effect sizes varied according to exposure assessment methods and adjustment for confounders. Studies show that maternal household exposure to pollutants from cooking correlates with lower birth weight and a higher prevalence of LBW, though strength and statistical significance vary by how exposure is defined and which confounders are included (Islam & Mohanty, 2021u; Islam & Mohanty, 2021m; Patel & Chauhan, 2020). Mothers exposed to household air pollution from solid fuels had higher risk of delivering low birth weight infants (Wylie et al., 2014). Compared with women who use gas (n = 265), women cooking with wood (n = 1,306) delivered infants that were on average 112 grams lighter (95% CI: -170.1, -54.6) and more likely to be preterm (OR: 3.11, 95% CI: 2.12 - 4.59) (Wylie et al., 2014). A hospital-based study from Maharashtra found that LBW prevalence was highest among wood fuel users (44.7%) compared to LPG users (24.2%), kerosene users (34.5%) and mixed LPG-and-wood users (40.7%), indicating a dose-related gradient by fuel cleanliness (Kadam et al., 2013). Evidence from Karnataka further reinforces these associations: across case–control studies, LBW was significantly associated with exposure to mosquito coil smoke (OR = 3.16), absence of exhaust kitchen ventilation (AOR = 3.76, 95% CI: 1.09–13.03), lack of cross-ventilation (AOR = 4.65, 95% CI: 1.60–13.51), and regular incense burning (AOR = 4.94, 95% CI: 1.12–21.73) with mean birth weight substantially lower among cases (2.16 kg) compared with controls (2.86 kg) (Andanigoudar et al., 2025; Sunny et al., 2019).

A longitudinal study from a rural area of Karnataka reported an LBW incidence of 24.6 per cent among exposed women. Logistic regression identified several independent predictors of LBW: a history of previous adverse pregnancy outcomes (AOR = 1.92, 95% CI not reported), dampness in the household (AOR = 1.68), and indoor PM2.5 concentrations above 40 µg/m³ (AOR = 1.07, 95% CI: 1.02–1.13). Notably, each 10 µg/m³ increase in indoor PM2.5 was associated with a 6.6 g reduction in mean birth weight (Kandula & Baliga, 2025). Collectively, across HAP studies, prenatal exposure to biomass fuel smoke is consistently linked to fetal growth restriction and LBW as a major adverse birth outcome that in turn predicts neonatal mortality, poor childhood growth and heightened vulnerability to infections, establishing a clear pathway from maternal fuel exposure to adverse early-life health trajectories.

Preterm birth (PTB)

Evidence consistently indicates that household combustion products ($PM_{2.5}$, CO, polycyclic aromatic hydrocarbons, black carbon) can impair placental function, reduce oxygen delivery and fetal growth and increase the risk of preterm birth (Patel & Chauhan, 2020). Corroborating this, a study in rural India found that a self-reported prior preterm birth was substantially more prevalent among biomass fuel users (approximately 40.6%) compared with LPG users (approximately 7.1%), linking household biomass exposure during pregnancy to maternal respiratory morbidity and to a history suggestive of increased preterm risk (Parikh et al., 2021). Across studies, the magnitude of association varied by cooking fuel type and duration of exposure but the direction of effect was consistently adverse.

Early life exposure

Evidence from community-based and modelling studies consistently indicates that household air pollution continues to harm children's health after birth, particularly through respiratory illness and growth impairment. A household survey in a Kolkata slum documented high prevalence of indoor exposure sources (approximately 60% kerosene use, widespread neighbourhood smoke, frequent use of mosquito coils, overcrowding, and poor ventilation) and found that the presence of HAP sources and poor housing conditions was associated with significantly higher odds of acute respiratory tract infections in children, supporting the concept of early-life respiratory vulnerability in HAP-burdened settings (Maharana et al., 2018). Across modelling analyses, evidence consistently indicates that in-utero and early-life exposure to ambient PM2.5 and polluting household fuels independently contribute to child linear growth impairment. A national projection study found that each 10 μg/m³ increase in in-utero PM2.5 was associated with 4 per cent increase in the odds of child stunting (OR = 1.04, 95% CI: 1.03–1.05), while use of clean cooking fuel was associated with 19 per cent lower risk of stunting compared to polluting fuel use (OR = 0.81, 95% CI: 0.79–0.84) (Dimitrova et al., 2022). Children in households relying on solid fuels showed higher rates of stunting and wasting, indicating growth faltering due to a combination of in-utero exposure and continued early-life exposure to indoor smoke (Wylie et al., 2014).

IV. Discussion

This review synthesizes evidence on the relationship between prenatal and early-life exposure to air pollution and adverse birth outcomes in India. The findings consistently demonstrate that both ambient air pollution (AAP) and household air pollution (HAP) significantly contribute to maternal and child health risks, though the magnitude and pathways of impact vary. Across studies, low birth weight (LBW) emerged as the most consistent adverse outcome. The findings align with national-level analyses showing that mothers in households using solid fuels deliver infants weighing on average 80–120 g less than those in clean-fuel households. The role of $PM_{2.5}$ is particularly critical. Fine particulate matter penetrates deeply into the lungs and can cross into the bloodstream, impairing placental function and reducing oxygen and nutrient transfer to the fetus. Higher in-utero exposure to ambient PM2.5 is associated with increased risks of low birth weight and preterm birth in India, with larger relative increases often observed at higher PM2.5 concentrations and stronger effects in northern regions subject to seasonal pollution peaks. Findings suggest that air pollution is a major environmental risk to early child survival and development. Elevated PM2.5 exposures during pregnancy and after birth is a significant, independent predictor of neonatal, infant and under-five mortality in India. Both prenatal and postnatal exposure to ambient PM2.5 significantly increase the risk of mortality in early childhood. Prenatal exposure exerts a stronger effect, particularly for neonatal deaths, underscoring pregnancy as a critical window of susceptibility. Even modest risk increases translate into large population impacts because of the extremely high PM2.5 levels in India.

Other pollutants also contribute Carbon monoxide (CO), produced by incomplete combustion of solid fuels, binds with haemoglobin to form carboxy haemoglobin, reducing oxygen delivery and creating a hypoxic environment for the fetus. Polycyclic aromatic hydrocarbons (PAHs), released from burning biomass and kerosene, can cross the placenta, cause oxidative stress, and disrupt DNA and cellular signalling. The analysis of articles also suggested that high ambient air pollution erodes the benefits of clean cooking interventions, showing the need to address both household and outdoor sources simultaneously. Together, these pollutants create a toxic mix that explains the consistent associations with stillbirth, preterm birth, and fetal growth restriction.

Early-life exposures further extend these risks. Studies from Kolkata and national modelling work indicate that infants and young children exposed to household smoke experience higher rates of acute respiratory infections, stunting, and anaemia. The cumulative effects of PM2.5, CO, and PAHs during pregnancy and early childhood likely act synergistically with maternal malnutrition, infections and socioeconomic disadvantage, amplifying risks for poor growth and survival. Air pollution and climate change represent dual threats to pregnancy health, contributing to preterm birth, low birth weight, pregnancy loss and maternal complications. Addressing these challenges requires integrated mitigation and adaptation strategies including reducing emissions, improving maternal healthcare access and protecting vulnerable populations. Without urgent action, the combined effects of worsening air pollution and accelerating climate change may perpetuate intergenerational cycles of poor health and inequality.

Findings from India are broadly similar to global evidence on ambient PM2.5 and adverse birth outcomes. A large global meta-analysis, covering 204 countries and territories, reported that each 10 µg/m³ increment in ambient PM2.5 during pregnancy was associated with approximately 22 g reduction in birth weight (95% UI: 12, 32 g), an 11% greater risk of LBW (OR: 1.11, 95% UI: 1.07–1.16), and a 12% greater risk of PTB (OR: 1.12, 95% UI: 1.06–1.19) (Ghosh et al. 2021). The India-specific estimates from this review such as a ~5 per cent increase in LBW per 10 µg/m³ PM2.5 (Jana et al., 2025) and a 12 per cent increase in PTB (Jana et al., 2025) are in close agreement with these global pooled estimates, affirming that the biological mechanisms linking PM2.5 to fetal growth restriction and premature delivery are universal. In 2019, globally an estimated 2.8 million LBW infants and over 5.9 million PTB cases were attributable to PM2.5 exposures during pregnancy (Ghosh et al., 2021). This shows the massive global burden of air pollution with India carrying a large share.

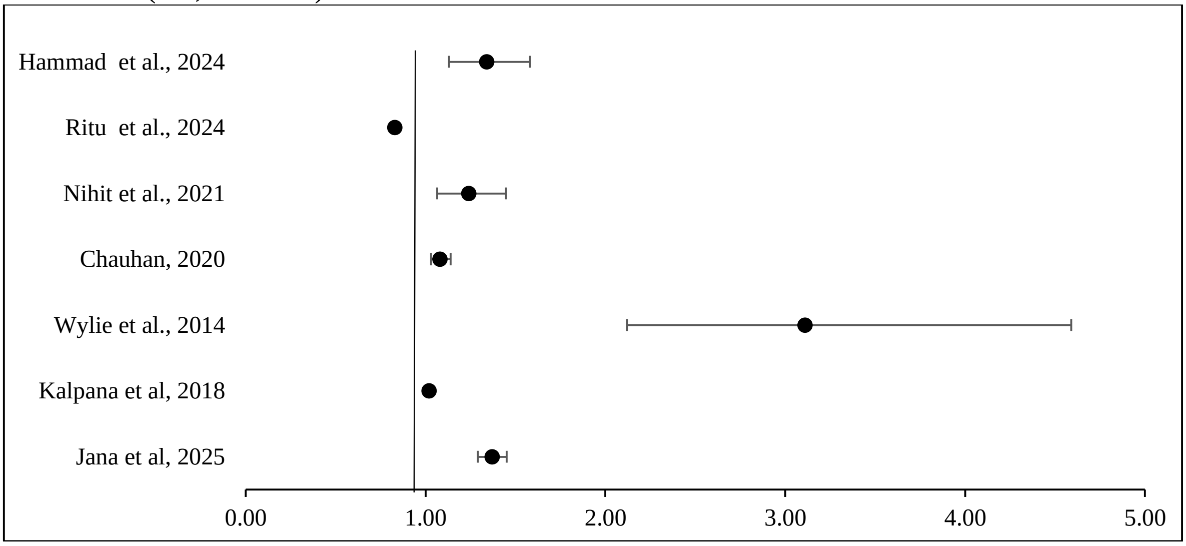
A more recent global systematic review and meta-analysis encompassing 49 epidemiological studies also supported these findings. Pooled estimates indicated that PM2.5 exposures during entire pregnancy increased the risk of PTB by 4 per cent (OR: 1.04, 95% CI: 1.03–1.05) at lower concentration ranges (≤10 µg/m³) (Desye et al. 2024). While PM10 exposure raised the PTB risk by 49 per cent (OR: 1.49, 95% CI: 1.41–1.56) at higher concentrations. For LBW, higher PM2.5 levels (>10 µg/m³) increased the risk by 28 per cent (OR: 1.28, 95% CI: 1.23–1.33). These findings are important for India because pollution levels are often higher than WHO guidelines. This means health impacts in India may be even more severe. Guo and Jiang (2025), in a meta-analysis specifically focused on China similarly found a significant association between atmospheric particulate matter exposure and preterm birth, consistent with findings from India. China and India share similar conditions, including rapid urbanisation, high PM2.5 exposures, and unequal access to clean fuels (State of Global Air, 2024).

For household air pollution, the findings from India are consistent with global evidence. A systematic review and meta-analysis, synthesising 32 studies worldwide found that polluting cooking fuels (biomass, coal, and kerosene) were associated with increased risks of LBW (OR: 1.37, 95% CI: 1.24–1.52), small for gestational age (OR: 1.48, 95% CI: 1.13–1.94), stillbirth (OR: 1.38, 95% CI: 1.23–1.55), and PTB (OR: 1.27, 95% CI: 1.19–1.36) (Luo et al. 2023). These global estimates are similar to the associations reported by studies from India reviewed here such as Wylie et al. (2014) reporting a PTB odds ratio of 3.11 (95% CI: 2.12–4.59) for wood versus gas cookers and Hammad et al. (2024) documenting a 34 per cent higher odds of stillbirth among solid fuel users (OR: 1.34, 95% CI: 1.13–1.58) (Table 3). An earlier global meta-analysis by Pope et al. estimated that household solid fuel combustion results in an approximate 86 g reduction in birth weight and 35 per cent increased risk of LBW. These findings are also consistent with the Indian studies, although the effects may be stronger in India because of higher pollution exposure and longer cooking durations with biomass fuels. Evidence from the United States also aligns directionally with the India-specific findings. The systematically reviewed evidence from the US and found consistent positive associations of PM2.5 and ozone exposure with PTB and LBW (Bekkar et al. 2020). Although PM2.5 exposure levels in the US are far lower than in India or China, the biological mechanisms remain similar across countries (Fussell et al., 2024).

Table 3. Impact of air pollution with adverse birth outcomes

Author(s)	Pollutants	Outcome indicator	Results & effect (95% CI)
Jana et al, 2025	PM2.5	LBW, PTB	PM2.5=> LBW: OR = 1.37 (95% CI: 1.29–1.45) PTB: OR= 1.67 (95% CI: 1.57–1.77)
Kalpana et al, 2018	PM2.5	LBW, Premature mortality	Birth weight reduction: −4 g (95% CI: −6.76 to −1.08) LBW: OR= 1.02 (95% CI: 1.005-1.041)
Wylie et al., 2014	Biomass	Preterm delivery, LBW, Stillbirth, SGA	PTB: OR= 3.11 (95% CI:2.12-4.59)
Unnati et al, 2021	PM2.5	Maternal mortality	OR= 1.09 (95% CI: 1.06-1.11) [Anaemia ODDS] OR: 1.90 (95% CI :1.43-2.36) [Anaemia prevalence ratio] Haemoglobin: 0.07 (95% CI : 0.09-0.05)
Mahapatra et al., 2020	PM10	Neonatal mortality, post-neonatal mortality, ARI, premature births, LBW	Neonatal mortality: RR= 1.06 (95% CI :1.02-1.09), ARI: AOR=1.07 (95% CI :1.03-1.12) Premature births: RR= 1.08 (95% CI :1.03-1.12)
Chauhan, 2020	Biomass	Low birth weight (LBW)	LBW: OR =1.08 (95% CI :1.03–1.14)
Asya et al, 2022	PM2.5	Child stunting, defined as height-for-age z-score below −2 SD of WHO standards.	PM2.5=> Stunting: OR=1.04 (95% CI :1.03–1.05)
Dean et al, 2019	PM2.5	Reduced Height for age z score	HAZ reduction: −0.05 SD (95% CI: −0.09 to −0.01) Girl height deficit: 0.24 cm (95% CI: 0.05–0.43)
Jiawen et al, 2022	PM2.5	Mortality (Neonatal mortality, Infant mortality, Child mortality)	PM2.5 concentrations: In-utero (9-month): 71.1 μg/m³ (95% CI: 20.9–153.5); Post-delivery: 73.7 μg/m³ (95% CI: 14.0–247.3) Under-5 mortality: HR = 1.023 (95% CI: 1.008–1.038) [in-utero]; HR = 1.013 (95% CI: 1.001–1.026) [post-delivery]
Priyanka et al, 2021	PM2.5	Mortality (Neonatal mortality, Infant mortality, Post-neonatal mortality)	Neonatal mortality: OR = 1.016 (95% CI:1.003-1.030)
Nihit et al., 2021	PM2.5	Low Birth weight	LBW : AOR= 1.241 (95% CI:1.065–1.447)
Sobin et al., 2019	Biomass	Low Birth weight	LBW: AOR = 3.76 (95% CI: 1.09–13.03) [absence of exhaust ventilation] AOR = 4.65 (95% CI: 1.60–13.51) [lack of cross ventilation] AOR = 4.94 (95% CI: 1.12–21.73) [regular incense use]
Ritu et al., 2024	PM2.5	Low Birth weight	LBW: AOR= 0.83 (95% CI:0.81–0.85) [clean fuel vs. solid fuel]
Hammad et al., 2024	PM2.5, PM10	Still birth	Stillbirth: OR= 1.34 (95% CI:1.13–1.58)

Figure 2. Forest plot of LBW studies (n = 7) have been classified according to the present outcome data in both arms (RR, risk ratio).



Studies from Europe and high-income countries generally report smaller effect sizes, which is expected given the much lower ambient pollution levels, yet even at concentrations below current WHO Air Quality Guidelines, significant associations with reduced birth weight have been reported (Rumrich et al., 2025). Together, these studies strengthen the evidence that PM2.5 is a risk factor for adverse birth outcomes and highlight the need for emission reduction in high-burden countries like India.

On neonatal and infant mortality, the global burden data are consistent with India-specific evidence reviewed here. The GBD 2019 estimates indicate that 135,000 neonatal deaths were attributable to ambient PM2.5 and 237,000 to household PM2.5 globally (Ghosh et al., 2021). Tang and Jia (2022) demonstrated in a 30-year global burden analysis (1990–2019) that the PM2.5 related preterm birth burden increased by over 7 per cent in age-standardised mortality and disability-adjusted life years, with this burden disproportionately concentrated in low- and middle-SDI regions including South Asia. India's high burden 1.24 million deaths attributed to air pollution in 2017 (Balakrishnan et al., 2019) is therefore consistent with global trends that identify South Asian countries as facing the greatest absolute toll of air pollution on early life health. Furthermore, the State of Global Air (2024) reported that in 2023, approximately 529,000 infants worldwide died in their first month from health effects associated with air pollution with over 20 per cent pollution-related newborn deaths in South Asia attributable to household air pollution, a pattern directly echoed in the present India-focused review.

Despite the overall consistency, several important inconsistencies and differences between the Indian evidence and the global literature merit discussion. First, the effect sizes for PM2.5-associated LBW and PTB observed in parts of northern India are substantially larger than global pooled estimates. For example, Jana et al. (2025) reported an adjusted odds ratio of 1.37 (95% CI: 1.29–1.45) (Figure 2) for LBW and 1.67 (95% CI: 1.57–1.77) for PTB per 10 μg/m³ PM2.5, markedly higher than the global pooled ORs reported by Ghosh et al. (2021) and Desye et al. (2024). These larger estimates in India are plausible given the context: India's ambient PM2.5 concentrations in northern states routinely exceed 125 μg/m³, placing exposures in the non-linear upper range of the dose-response curve where marginal effects are steeper. Second, whereas the majority of high-income country studies focus on ambient air pollution alone, the Indian evidence reviewed here highlights the compound and interacting effects of ambient and household air pollution, a co-exposure that is particularly pronounced in low- and middle-income settings. The finding that high ambient PM2.5 erodes the protective effects of clean cooking fuel transition (Parchure et al., 2024) is a uniquely important insight not yet adequately captured in most global analyses, and distinguishes the Indian exposure context from that of Europe or North America.
Third, there is a notable inconsistency in the trimester-specific vulnerability windows identified across global versus India-specific studies. While the global literature frequently identifies the first trimester as the most sensitive period for PM2.5-related adverse outcomes, Indian hospital-based studies

(Bhardwaj et al., 2023) suggest that both first and second trimester exposures confer risk for different pollutant-outcome combinations, and that third-trimester PM2.5 exposures are particularly relevant to neonatal mortality (DeSouza et al., 2022). This points to a need for trimester-stratified analyses within Indian datasets, which remain comparatively scarce relative to the global literature dominated by North American and European cohort studies. Fourth, globally ozone has emerged as an additional risk factor for PTB and other adverse birth outcomes (Bekkar et al., 2020; Desye et al., 2024), but the evidence from India on ozone-specific effects remains limited. Only one reviewed study examined trimester-specific ozone effects (Bhardwaj et al., 2023). This gap in Indian research is an inconsistency compared with the global evidence base and warranted future investigation, particularly as climate change was projected to increase ground-level ozone concentrations in South Asia.

Finally, cross-national comparisons underscore the role of socioeconomic and healthcare context in shaping outcomes. While the biological hazard of PM2.5 is consistent globally, the realised health impact in India is magnified by high baseline rates of maternal anaemia, malnutrition, limited antenatal care access and continued reliance on solid fuels are factors that are far less prevalent in high-income countries. Studies from sub-Saharan Africa demonstrate a similar pattern of compound vulnerability and large HAP-attributable birth outcome burdens (State of Global Air, 2024), aligning with the India findings and highlighting that low- and middle-income countries bear a fundamentally different and heavier burden than high-income countries, even when exposed to lower absolute pollution levels. Collectively the Indian evidence reviewed here aligns with and extends the global literature, confirming the universality of the PM2.5, adverse birth outcome relationship while revealing country-specific features including extreme pollution concentrations, dual ambient-household pollution burdens and socioeconomic vulnerability that amplify impacts beyond what was be predicted from global pooled estimates alone.

V. Conclusion

Exposure to ambient and household pollutants are consistently linked to reduced birthweight and increased LBW risk. Efforts to reduce LBW in India have target both household and ambient air pollution together. The review indicates that early-life exposure to household air pollution from cooking is associated with adverse birth outcomes, particularly reduced mean birth weight and increased odds of LBW. The effect magnitudes vary by exposure definition, outcome measurement quality and adjustment for confounders, but are substantial enough to support interventions that increase access to clean cooking, improve kitchen ventilation and cooking practices, and integrate these with maternal health programmes.

Research also aimed to inform data-driven policy decisions and public health interventions to simultaneously address the intertwined threats of degraded air quality and climate change. Findings from this review is leveraged to strengthen ongoing national initiatives. Specifically, integration of maternal and child health evidence into existing frameworks such as the National Clean Air Programme (NCAP) and the National Programme on Climate Change and Human Health (NPCCHH) is recommended.

Recommendation

Policymakers and stakeholders may use this context-specific evidence to embedded air quality considerations into maternal and public health strategies, and align maternal–child health priorities with climate adaptation policies. Also support and reinforce key national and global health and climate agendas through coordinated action on air pollution reduction.

Limitations

Evidence on specific pollutant components and critical windows remains limited and heterogeneous across studies.

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