Gestational co-exposure to extreme heat and fine particulate air pollution and the risk of preterm birth: A systematic review and meta-analysis

Published: 08 June 2026

Volume 19, article number 146 (2026) Cite this article

Air Quality, Atmosphere & Health

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Abstract

Climate change intensifies environmental hazards threatening maternal and neonatal health. Although heatwaves and $PM_{2.5}$ independently affect pregnancy outcomes like preterm birth (PTB) and low birth weight, their co-exposure health impacts remain poorly understood, requiring further investigation. This systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards. Literature searches were performed across PubMed, Scopus, and ScienceDirect to retrieve studies published between 2000 and 2025 that assessed the joint impact of heatwave events and $PM_{2.5}$ exposure on PTB. Pooled odds ratios were determined using random-effect models. Meta-regression was employed to examine trimester-specific differences in effect estimates. Heterogeneity was quantified using the I^2 statistic, and potential publication bias was assessed through Egger's test. Seven studies met the inclusion criteria for meta-analysis. Co-exposure to heatwaves and fine particulate matter ($PM_{2.5}$) was associated with a significantly increased risk of PTB (pooled OR: 1.14; 95% CI: 1.12–1.17; I^2 = 75.9%). Subgroup analysis by national income level demonstrated stronger associations in upper-middle-income countries (OR: 1.17; 95% CI: 1.14–1.20; I^2 = 28.4%) compared to high-income countries (OR: 1.12; 95% CI: 1.09–1.14; I^2 = 66.9%), with significant between-group heterogeneity (p = 0.003). Trimester-specific analyses indicated the highest risk during the third trimester (OR: 1.18; 95% CI: 1.11–1.24), followed by the second (OR: 1.15; 95% CI: 1.10–1.19) and first trimesters (OR: 1.12; 95% CI: 1.08–1.15). Meta-regression revealed a significant interaction between $PM_{2.5}$ exposure and gestational timing, underscoring increased vulnerability in late pregnancy. High heterogeneity was observed (I^2 = 75.9%), and minimal publication bias was detected. Study quality was generally high, with six of seven included studies scoring ≥ 7 points on the Newcastle-Ottawa Scale (NOS). These findings highlight the urgent need for integrated climate and air quality interventions to protect maternal and fetal health, particularly during late pregnancy and in resource-limited settings.