Prenatal Exposure to Ambient Air Pollution and Adverse Birth Outcomes: An Umbrella Review of 36 Systematic Reviews and Meta-analyses

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Abstract

Multiple systematic reviews and meta-analyses linked prenatal exposure to ambient air pollutants to adverse birth outcomes with mixed findings, including results indicating positive, negative, and null associations across the pregnancy periods. The objective of this study was to systematically summarise systematic reviews and meta-analyses on air pollutants and birth outcomes to assess the overall epidemiological evidence. Systematic reviews with/without meta-analyses on the association between air pollutants (NO_2, CO, O_3, SO_2, $PM_{2.5}$, and PM_{10}) and birth outcomes (preterm birth; stillbirth; spontaneous abortion; birth weight; low birth weight, LBW; small-for-gestational-age) up to 30th March 2022 were included. We searched PubMed, CINAHL, Scopus, Medline, Embase, and the Web of Science Core Collection, systematic reviews repositories, grey literature databases, internet search engines, and references of included studies. The *consistency* in the directions of the effect estimates was classified as more consistent positive or negative, less consistent positive or negative, unclear, and consistently null. Next, the *confidence* in the direction was rated as either *convincing, probable, limited-suggestive, or limited non-conclusive* evidence. Final synthesis included 36 systematic reviews (21 with and 15 without meta-analyses) that contained 295 distinct primary studies. $PM_{2.5}$ showed more consistent positive associations than other pollutants. The positive exposure-outcome associations based on the entire pregnancy period were more consistent than trimester-specific exposure averages. For whole pregnancy exposure, a *more consistent positive association* was found for $PM_{2.5}$ and birth weight reductions, particulate matter and spontaneous abortion, and SO_2 and LBW. Other exposure-outcome associations mostly showed *less consistent positive associations* and few *unclear directions* of associations. Almost all associations showed *probable evidence*. The available evidence indicates plausible causal effects of criteria air pollutants on birth outcomes. To strengthen the evidence, more high-quality studies are required, particularly from understudied settings, such as low-and-middle-income countries. However, the current evidence may warrant the adoption of the *precautionary principle*.

Keywords: air pollution, birth outcomes, birth weight, stillbirth, preterm birth, umbrella review.

1. **Introduction**

Increasing urbanisation and modernisation contribute to higher levels of environmental toxicants, among which air pollution is a significant contributor (Burnett et al., 2018; Rojas-Rueda et al., 2021). Globally, air pollution is ranked as the 5th leading risk factor for mortality. Air pollution causes one in every nine deaths worldwide from non-accidental mortality due to noncommunicable diseases such as lung cancer, chronic obstructive pulmonary disease, ischemic heart disease, stroke, and lower respiratory infections (Burnett et al., 2018; WHO, 2018) with a high economic burden (Di Renzo et al., 2015). As a ubiquitous environmental risk factor, air pollution has impacts on everyone with no geopolitical boundaries (Burnett et al., 2018; WHO, 2018). Notably, there is early evidence that some subpopulations such as people with chronic diseases, children, older adults, and pregnant women and their children *in utero* are more susceptible to the health outcomes associated with air pollution exposure (Di Renzo et al., 2015; Mannucci and Franchini, 2017; WHO, 2018). Air pollutants vary in chemical composition and physical characteristics and can have negative impacts on vulnerable groups differently and at multiple stages in the life course (Pereira et al., 2014; Slama et al., 2008; WHO, 2018). The general physiological changes associated with pregnancy (e.g., changes in the endocrine system, increased rates of inhalation and cardiac outputs) put pregnant women and the developing fetus at a potentially greater risk of air pollution exposure. This results in adverse pregnancy outcomes and elevated risk of morbidity from cardio-respiratory and neurodevelopmental disorders later in the life course (Di Renzo et al., 2015; Mannucci and Franchini, 2017; WHO, 2018).

Many air pollutants have negative impacts on human health and the environment (Manisalidis et al., 2020). Commonly regulated markers of ambient air pollution, the criteria air pollutants are nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), sulphur dioxide (SO_2), and particulate matter (PM) with aerodynamic diameter ≤ 2.5 µm ($PM_{2.5}$) and ≤10 µm (PM_{10}) (WHO, 2006). Prenatal exposure to the criteria ambient air pollutants (hereon *pollutants*) has been documented as a potentially modifiable risk factor for adverse birth outcomes (Di Renzo et al., 2015; WHO, 2018). For example, even at concentrations lower than the 2005 World Health Organization (WHO) guideline annual average of 10 µg/m^3, $PM_{2.5}$ has been found as a contributor to the risk of birth outcomes (Slama et al., 2008; WHO, 2006; WHO, 2018). There are multiple relevant biological mechanisms by which pollutants can influence birth outcomes (Slama et al., 2008). Prenatal exposure to pollution initiates a sequence of pathophysiological responses, including oxidative stress, metabolic, cardiovascular, and immuno-inflammatory alterations (Saenen et al., 2019; Slama et al., 2008). These responses have the potential to disrupt normal fetal development, resulting in adverse birth outcomes (Saenen et al., 2019; Slama et al., 2008). The associations can be modified by climatic factors, infection, obstetric conditions, socio-economic status, nutrition, and psychosocial environment (Dadi et al., 2020; Erickson and Arbour, 2014; Kannan et al., 2006).

Systematic reviews and meta-analyses (SRMAs) have the potential to improve upon precision, provide answers to unanswered questions, and settle conflicting findings in primary studies (Higgins et al., 2021). However, meta-analysis "also have the potential to mislead seriously, particularly if specific study designs, within-study biases, variation across studies, and reporting biases are not carefully considered." (Higgins et al., 2021). Several SRMAs have been conducted on the pollutants and birth outcomes with findings indicating greater risks, but also with inconsistent findings, including null association, and lower risks (Glinianaia et al., 2004; Lamichhane et al., 2015; Sapkota et al., 2010; Shah et al., 2011; Stieb et al., 2012; Sun et al., 2015; Zhang et al., 2016). As the number of SRMAs increase with varied quality, scope, and conclusions, umbrella reviews are recommended to systematically compare, contrast, and synthesise the emerging evidence from the SRMAs to provide overall concise direction and strength of the observed associations (Aromataris et al., 2015; Hartling et al., 2012). Except for one related broad summary of meta-analyses (Nieuwenhuijsen et al., 2013) that included only one meta-analysis (Sapkota et al., 2010), to our knowledge, no umbrella review has been conducted to systematically evaluate the exposure-outcome associations for ambient air pollution and adverse birth outcomes. This study aimed to provide an overall clear synthesis of the available epidemiological evidence through an umbrella review to evaluate if sufficient evidence is available to adopt the *precautionary principle*; protecting the health of pregnant women and their fetuses by minimising air pollution while scientific uncertainty is resolved (Martuzzi and Tickner, 2004).

2. Methods

2.1 Umbrella review methodology

This umbrella review involved a critical evaluation of SRMAs on the association between criteria air pollutants and adverse birth outcomes. The review was based on a published protocol (Nyadanu et al., 2020), prospectively registered in PROSPERO (CRD42020200387), and followed reporting guidelines, including PRISMA statement (Moher et al., 2009; Page et al., 2021) and JBI umbrella review guideline (Aromataris et al., 2015; Aromataris et al., 2020).

2.2 Eligibility criteria

Eligibility criteria were defined according to the PECOS (Participants, Exposures, Comparators, Outcomes, and Study design) statement (Woodruff and Sutton, 2014) as described in the published protocol (Nyadanu et al., 2020). Briefly, the 'Population' was pregnant women or *in utero* infants. 'Exposures' were the pollutants: NO_2, CO, O_3, SO_2, $PM_{2.5,}$ and PM_{10}. 'Comparators' were pregnant women unexposed or exposed to lower levels of the exposures as compared to those with higher exposures. 'Outcomes' were the birth outcomes: preterm birth (PTB), pregnancy loss (spontaneous abortion or stillbirth), reduced birth weight, and fetal growth restriction (low birth weight, LBW; and small-for-gestational-age, SGA), and related outcomes such as very low birth weight. 'Study' designs were systematic reviews with or without meta-analyses that included quantitative human epidemiologic studies on the exposure-outcome associations of interest. Assisted reproductive technology studies were excluded. A review study was included if the review article specified inclusion or exclusion criteria, was based on the search of at least one electronic database and described the search strategy or protocol, reported results on the exposure-outcome association as the main objective, provided sufficient information on the included primary studies (Pieper et al., 2014) and included no fewer than three primary studies for the exposure-outcome association (Beltran et al., 2013).

2.3. Data Sources

We conducted a systematic search in (i) six major bibliographic databases: PubMed, CINAHL, Scopus, Medline/Ovid, Embase/Ovid, and Web of Science Core Collection; (ii) systematic reviews repositories: Cochrane Database of Systematic Reviews, JBI Database of Systematic Reviews and Implementation Reports, and Epistemonikos (www.epistemonikos.org/); (iii) electronic grey literature databases: OpenGrey (http://www.opengrey.eu/) and WorldWideScience.org; (iv) Internet search engines: Google and Google Scholar in Incognito mode, screening the first 200 search results (Bramer et al., 2017); (v) the World Health Organization website; and (vi) manually searched references of the identified eligible studies.

2.4. Study selection and data extraction

Searches were restricted to the English language with no limitations on the date of publication. We developed comprehensive search terms with the relevant medical subject heading (MeSH) terms, keywords, and previous reviews' search terms for advanced search in the databases (Table S1). An experienced librarian from the Faculty of Health Sciences, Curtin University was consulted to refine the search strategies. The literature search was conducted for the broader umbrella review described in the protocol (Nyadanu et al., 2020). The databases were searched on September 21, 2020, and with weekly alerts and updates up to 30th March 2022 using the same criteria. The titles and abstracts of all identified citations were imported into the *EndNote* library and duplicated records were excluded.

Studies were first screened for relevant titles and abstracts. The full texts of potentially eligible studies were retrieved and assessed comprehensively per the eligibility criteria. The JBI SUMARI was used to aid the selection process at the full-text level (Munn et al., 2019). Data were extracted from the selected studies with the data extraction tool (Nyadanu et al., 2020) and was piloted by two investigators (SN and JD). Study selection and data extraction were conducted independently by two investigators (SN and JD) and any disagreements were resolved by discussion or with a third investigator (GT, BM, and GP). Authors were contacted for additional or unclear information where necessary.

2.5. Risk of bias assessment

Two authors independently assessed the risk of bias (SN and JD) of the included reviews and any disagreements were resolved by discussion or with a third investigator (BD). The JBI standardised critical appraisal tool (Aromataris et al., 2020) for review studies and the JBI SUMARI software (Munn et al., 2019) was used. The 11 items were checked as 'yes' (1), 'unclear' or 'no' (0). Item 9 was scored not applicable (NA) for reviews without meta-analyses. The 'yes' items were summed to total scores, which were categorised as 0-5, 6-8, and 9-11 and rated 'high', 'moderate', and 'low' risk of bias, respectively.

2.6. Data Synthesis

The general characteristics and scope of the included reviews were presented using tables and figures such as forest plots and a map with textual descriptions. To account for multiple inclusion of primary studies (overlaps) in the review articles, we constructed separate citation matrices for systematic reviews with and without meta-analyses for computing the overlaps according to Corrected Covered Area (CCA) algorithm (Pieper et al., 2014);

$$CCA = \frac{N-r}{rc-r},$$

where *N* is the sum of the number of included primary studies (the total number of times studies appeared in the reviews) in the umbrella review, *r* is the total number of distinct indexed primary studies and *c* is the number of reviews. The CCA score ≤ 5% implies slight, 6-10% moderate, 11-15% high, and >15% very high degrees of overlaps (Pieper et al., 2014). Overlap of primary studies across the reviews is unavoidable. However, higher overlap indicates that synthesised evidence in the umbrella review is based on different review studies that largely integrated the same primary studies. This could bias the results or decrease the confidence in the evidence as compared to low overlap (Pieper et al., 2014).

Systematic reviews without meta-analyses (hereon *systematic reviews*) were narratively synthesised. For systematic reviews with meta-analyses (hereon *meta-analyses*), we adapted the similar approaches described elsewhere (O'Donoghue et al., 2018; Rojas-Rueda et al., 2021; Sleddens et al., 2015a; Sleddens et al., 2015b) to provide overall epidemiological evidence. Specifically, the two updated grading scales (O'Donoghue et al., 2018) were adapted as described in our protocol (Nyadanu et al., 2020). Briefly, by considering the *consistency* in the direction and statistical significance of the meta-analyses results, each pollutant-outcome association was graded as demonstrating a *more consistent positive association* (++) in all results and without null in the confidence intervals, or a *less consistent positive association* (+) for which there was agreement in at least 75% of the results in the direction, otherwise a *mixed/unclear or contradictory direction (0)*. Similarly, lower risks were graded more (--) or less (-) *consistent negative associations*. Consistently *null association* in all meta-analyses was graded (00). Where only one meta-analysis was available for a particular pollutant-outcome association, the criteria were applied to the included primary studies in the meta-analysis while considering agreement in the direction of association in at least 80% of the included primary studies (Zeiher et al., 2019). Next, informed by the benchmarks developed using Bradford Hills' guidelines for causation (Hill, 2015) as applied previously (O'Donoghue et al., 2018; Sleddens et al., 2015a;

Sleddens et al., 2015b), the *confidence* in the observed direction or plausible causation was rated as; i)'convincing evidence' (Ce), ii) 'probable evidence' (Pe), iii) 'limited-suggestive evidence' (Lse) and iv) 'limited, no conclusive evidence' (Lnce) by considering the level of strengths and weaknesses in the reported associations, including imprecision and heterogeneity in the meta-analyses results, and the number and quality/study designs of the pooled primary studies. Here, 'convincing evidence' of an observed direction or causality is that there is low heterogeneity and high precision in all pooled estimates and included at least two cohort studies of large sample sizes, and experimental studies (Nyadanu et al., 2020; O'Donoghue et al., 2018). Before the evidence synthesis, all effect estimates (odd ratios for dichotomous outcomes and beta coefficient for continuous outcomes) were standardised as an increase in exposure per 10 µg/m^3 for $PM_{2.5}$ and PM_{10}; 10 parts per billion (ppb) for NO_2, SO_2, and O_3; and 100 ppb for CO as described elsewhere (Klepac et al., 2018) and applied in one of the included meta-analyses (Li et al., 2020).

7. Protocol Amendments

Few amendments were made to the published protocol (Nyadanu et al., 2020). We did not use the AMSTAR2 critical appraisal tool for the further assessment of the methodological quality. Given that AMSTAR2 was originally developed for randomised and non-randomised intervention studies (Shea et al., 2017), modifying it within the context of environmental health studies may create discrepancies. Moreover, the JBI critical appraisal tool (Aromataris et al., 2020), which was more general as compared to the AMSTAR2, captured the necessary items for assessing the risk of bias of the included systematic reviews or meta-analyses. Also, considering the small number of meta-analyses for each pollutant-outcome association for each pregnancy period, we applied at least 75% agreement of meta-analyses in each direction of association for grading the *less consistent associations* as reported previously (O'Donoghue et al., 2018; Sleddens et al., 2015a; Sleddens et al., 2015b) instead of the 80% stated in the protocol (Nyadanu et al., 2020). We, however, maintained the 80% agreement in the direction of association for the included primary studies in instances where only one meta-analysis was available.

3. Results

3.1 Systematic literature search results

The initial literature search in the electronic databases identified a total of 3,663 records, of which 1,513 were retrieved after deduplications. Title and abstract screening excluded 1,460 records. An additional six potentially eligible studies were identified from the other search sources. The full-text assessment included 59 studies and 34 were further excluded for other reasons, including retraction (n =1), non-English (n = 4), a summary of reviews or general literature reviews (n = 16), unrelated outcomes or pollutants (n = 4), and fewer than three or insufficient details on the included primary studies (n = 9). From the prospective literature search based on the weekly databases' alerts and updates using the same criteria after the initial search up to 30th March 2022, we added 11 additional reviews (Edwards et al., 2022; Gong et al., 2022; Ju et al., 2021; Luo et al., 2021; Rappazzo et al., 2021; Simoncic et al., 2020; Uwak et al., 2021; Walter et al., 2021; Xie et al., 2021; Zhang et al., 2021; Zhu et al., 2022). Thus, 36 systematic reviews, 15 (42%) without and 21 (58%) with meta-analyses were included in the final synthesis (Figure S1). The full lists of excluded studies after the full-text examination with reasons were provided (Table S2)**.**

3.2 Characteristics of the included reviews

The detailed descriptions of the general characteristics of the included reviews were summarised (Tables 1 and 2 and Tables S3 and S4). The 36 SRMAs were published between January 2004 (Glinianaia et al., 2004) and October 2021 (Edwards et al., 2022; Gong et al., 2022) by authors from multiple countries (Figures S2 and S3). Most of the reviews (30 of 36, 83%) included primary studies from several countries, although some countries and regions of the world were more represented in the included studies than others. The other six reviews were restricted to the USA (Bekkar et al., 2020; Heo et al., 2019; Thayamballi et al., 2020), China (Jacobs et al., 2017), Europe (Simoncic et al., 2020), and Australia (Walter et al., 2021). The 36 SRMAs included a total of 295 distinct primary studies that included eight multi-country studies (including one each from 33 African countries (Xue et al., 2019) and three South Asian countries (Xue et al., 2021), both based on Demographic Health Survey data) and 287 country-specific studies from 31 countries. The geographical distribution of the 287 country-specific primary studies was skewed towards studies from the USA, 113 (39%), and China, 44 (15%). South Asia and Africa each contributed only one study from India and Tanzania, respectively (Figure 1).

The included systematic reviews sourced literature from an average of four databases. Out of the 15 systematic reviews, three searched the literature in both English and Chinese languages (Jacobs et al., 2017; Luo et al., 2021; Yuan et al., 2019) while the remaining were restricted to only English. The number of primary studies included in each systematic review ranged from three (Edwards et al., 2022) to 82 (Tsoli et al., 2019), with an average of 27 primary studies. The 15 systematic reviews included a total of 211 unique primary studies with a moderate overlap of 6.8% (Table S5). Most of the systematic reviews (n=13) investigated the association between $PM_{2.5}$ and LBW while only one review investigated the association between the pollutants with spontaneous abortion (SAB) (Grippo et al., 2018). Study design classifications varied among reviews. The total sample sizes studied ranged from 146,271 births (Ghosh et al., 2007) to 41,793,876 births (Heo et al., 2019) with an average of 12,792,818 births. The reported average ranges of the concentrations for particulate matter were 1.1-71.9 µg/m^3 for $PM_{2.5}$ and 3.2-889.7 µg/m^3 for PM_{10}. The exposure levels of the gaseous pollutants reported (most likely for entire pregnancy periods, although specific pregnancy periods were not clearly stated) ranged from 9.4 -117.9 µg/m^3 for NO_2, 3.8 - 308 µg/m^3 for SO_2, 33 - 91.4 µg/m^3 for O_3, and 0.5 -17.8 mg/m^3 for CO. The majority, 9/15 (60%) of the systematic reviews did not assess the risk of bias in the included primary studies. The majority, 9/15 (60%) of the systematic reviews explicitly stated having used systematic review guidelines, mostly PRISMA. Only one review had a protocol registered which is available at Open Science Foundation (Edwards et al., 2022). Two reviews, however, stated that a pre-specified review method was available but not registered or published prior to the conduct of the review (Shah et al., 2011; Tsoli et al., 2019) (Table 1). Other details were provided in Table S3.

The earliest meta-analysis, published in 2010 analysed the association between $PM_{2.5}$/PM_{10} and LBW and PTB (Sapkota et al., 2010). The number of meta-analyses increased over time with 15 published between 2016-2021 (Figure S2) that investigated the various pollutants and birth outcomes. The majority, 14 of 21 (67%) meta-analyses (Table 2) were restricted to only $PM_{2.5}$/PM_{10}. Only one meta-analysis searched one electronic database (PubMed) (Simoncic et al., 2020) and the rest searched in two or more databases. Restriction to only English articles was typical but six meta-analyses included both English and Chinese (Gong et al., 2022; Ji et al., 2017; Li et al., 2017; Liu et al., 2017; Sun et al., 2015; Sun et al., 2016). The number of included primary studies per meta-analysis ranged from six to 62 with an average of 27. A total of 228 different primary studies were included with a moderate overlap of 7.6% (Table S5). The average number of births or pregnancies per meta-analysis was 12,149,542 births, ranging from 735,719 natural pregnancies (Zhu et al., 2022) to 57,960,152 births (Uwak et al., 2021). There were few unreported sample sizes for some included primary studies. From 11/21 (52%) of the meta-analyses that provided the exposure levels for the included primary studies, the reported mean concentrations of pollutants in the primary studies (most likely for entire pregnancy periods, although specific pregnancy periods were not clearly stated) ranged from 1.8-70.8 µg/m^3 for $PM_{2.5}$, 3.0-142.1 µg/m^3 for PM_{10}, 6.2-36.6 ppb for NO_2, 1.1-12.2 ppb for SO_2, 13.4 -57.0 ppb for O_3, and 0.5 - 4.6 ppm for CO.

Two meta-analyses provided the prevalence ranges of 3.5-17.3% for LBW (Stieb et al., 2012) and 2.8-11.76% for PTB (Ju et al., 2021). The majority, 15/21 (71%) of the meta-analyses reported the risk of bias in the included primary studies, which were mostly rated low. Two meta-analyses had registered their protocols *a priori* (Uwak et al., 2021; Xie et al., 2021). Effect estimates were often reported as odds ratios and most meta-analyses did not indicate if other effect estimate metrics were converted or not. The pooled odds ratios were often reported as per 10 µg/m^3 increment for particulate pollutants but the reference units for the gaseous pollutants differed greatly among meta-analyses (Table S4).

3.3 Risk of bias assessment

Out of the 10 maximum scorable points for systematic reviews using the JBI critical appraisal checklist, 12 systematic reviews scored 6-8 points (moderate risk of bias) and three reviews scored 9-10 points (low risk of bias). The major areas of weaknesses were limited sources of literature searched, searching a single electronic database (n = 5), lack of risk of bias assessment for included primary studies (n = 8), and critical appraisal (n = 12) or data extraction (n = 11) were not conducted independently by at least two authors (Figure S4). Out of the 11 scorable points for meta-analyses, 19 meta-analyses scored 9-11 points (low risk of bias) and two scored 6-8 points (moderate risk of bias). The main reasons for lower scores were failure to appraise and report the risk of bias in the included primary studies (n = 5) and lack of at least two independent authors appraising the risk of bias (n = 7) (Figure S5).

3.5 Major findings

The detailed results from the systematic reviews were summarised in the supplemental material (Table S3). Earlier global systematic reviews indicated that there were some associations between the pollutants and birth outcomes, particularly for $PM_{2.5}$/$PM_{10.}$ and SO_2 but concluded that the available findings were generally either of “no effect”, “very small”, or “inconclusive” to provide convincing epidemiological evidence (Bonzini et al., 2010; Bosetti et al., 2010; Glinianaia et al., 2004; Shah et al., 2011). Three recent global systematic reviews showed that particulate matter, especially $PM_{2.5,}$ had been consistently linked in many observational studies to a higher risk of birth outcomes at varied prenatal periods (Grippo et al., 2018; Tsoli et al., 2019; Yuan et al., 2019). However, another recent systematic review restricted the inclusion to only primary studies that utilised the land-use regression model for exposure assessment that mainly investigated $PM_{2.5}$ and NO_2 (Luo et al., 2021) and concluded otherwise. That review found that prenatal $PM_{2.5}$ exposure increased the risk of reduced birth weight but with an unclear link with other birth outcomes investigated (Luo et al., 2021). The authors also observed that although NO_2 consistently showed an increase in the risk of reduced fetal growth and development, its association with PTB was unclear and the associations of other pollutants with birth outcomes were found to be generally uncertain (Luo et al., 2021). Similarly, another systematic review also found “insufficient or conflicting evidence” for an association of NO_2 and SO_2 with stillbirth and SAB (Grippo et al., 2018). However, a recent systematic review of the USA population indicated higher risks of PTB, LBW, and stillbirth following prenatal exposure to $PM_{2.5}$ and ozone and with heightened risk among infants of Black-American mothers (Bekkar et al., 2020). A systematic review of studies from the Chinese population on the impacts of the six pollutants on birth weight, LBW, PTB, and stillbirth found only SO_2 to be consistently associated with LBW and PTB (Jacobs et al., 2017). Another systematic review that included nine primary studies conducted in Australia also indicated that there was some evidence for PTB and intrauterine growth retardation (IUGR) but stated that the discrepancies in the results hindered overall firm conclusions (Walter et al., 2021). A review on maternal relocation during pregnancy included three studies and found limited evidence of the influence of relocating into environments of different concentrations of pollutants on birth outcomes (Edwards et al., 2022).

Three systematic reviews (Ghosh et al., 2007; Heo et al., 2019; Westergaard et al., 2017) explored the associations between the pollutants and birth outcomes by maternal or neonatal underlying sociodemographic or obstetrical conditions. It was found that while females were at a higher risk of LBW, males were at a higher risk of PTB (Ghosh et al., 2007). Furthermore, a higher risk of term LBW was observed for neonates whose mothers smoked tobacco during pregnancy, were under/overweight or obese, or had lower socio-economic status (Westergaard et al., 2017). The third review that included studies from the USA population on exposure to particulate matter concluded "suggestive evidence" of higher risk of PTB and LBW in infants of Black-American mothers but "weak evidence" of higher risk for neonates of mothers with lower educational attainments (Heo et al., 2019).

The most frequently pooled exposure-outcome association was $PM_{2.5}$ with LBW and PTB (n=7) during the entire pregnancy period. There was only one meta-analysis on the association between gaseous pollutants (O_3, SO_2, CO) and reduced birth weight (Stieb et al., 2012) (Table 2). The meta-analyses reported the pooled effect estimates based on single-pollutant models and the effect metric for dichotomous birth outcomes were odd ratios (ORs) with random effect model. The pooled effect estimates showed inconsistencies in terms of direction and magnitude of effects, statistical significance, precisions, and heterogeneities but publication bias was often found to be absent based on Egger's or Begg's test with funnel plots (Table S4). By geographical regions (defined as Asia, North or South America, Europe, Oceania), although with varied magnitude of the effect estimates, positive associations between particulate matters and birth weight (Gong et al., 2022; Uwak et al., 2021) and all pollutants and PTB (Ju et al., 2021) were found across all regions (Table S4). The direction of effect estimates, and consistency differed for each exposure-outcome association at different pregnancy periods, resulting in different gradings in the overall direction of the association. However, high heterogeneity, as high as 99% (Sun et al., 2015; Sun et al., 2016; Zhu et al., 2022), and imprecision were reported across almost all meta-analyses. Also, due to the nature of the exposure, no study included an experimental or randomised controlled trial (RCT). Consequently, the maximum possible confidence of the evidence according to the adopted classification was *probable evidence* (Pe). Thus, unless stated otherwise, the confidence of the evidence observed across exposure-outcome associations described below was *probable evidence.*

i) *Birth weight reduction*

$PM_{2.5}$: Six meta-analyses examined the association with exposure over the entire pregnancy period, and the overall results showed a *more consistent positive association*. The largest pooled effect estimate was -28 g (95% CI = -48, -7) per 10 µg/m^3 increase in exposure with heterogeneity of 94%, from 15 studies of 15,424,198 births (Uwak et al., 2021). For trimester-specific exposures, *less consistent positive associations* were observed for each trimester (Table 3, Figure 2).

PM_{10}: Entire pregnancy exposure from three meta-analyses (Lamichhane et al., 2015; Stieb et al., 2012; Uwak et al., 2021) showed a *less consistent positive association* with birth weight reduction. The largest reported pooled effect estimate was -10 g (95% CI = -14, -7) per 10 µg/m^3 increase in exposure with 0% heterogeneity based on five cohort studies of 477,123 births that adjusted for prenatal tobacco smoking (Lamichhane et al., 2015). All trimester-specific results showed *less consistent positive associations* (Table 3, Figure S6).

NO_2: The overall evidence from the results of one global study (Stieb et al., 2012) and one SRMA from Europe (Simoncic et al., 2020) was graded with a *less consistent positive association* for the entire pregnancy period, first and third trimesters. However, the second-trimester exposure showed an *unclear* or *contradictory direction* (Table 3 and Figure S7).

O_3: Only one meta-analysis (Stieb et al., 2012) was conducted that found a positive association between exposure during the entire pregnancy period with high heterogeneity; the effect estimate was -5 g (95% CI = -16, 6; I^2 = 81%) per 10 ppb increase in exposure. This meta-analysis pooled four

cohort studies where two of the cohort studies each reported positive and negative associations with the change in birth weight. Given that only one meta-analysis was identified, applying the grading criteria to the results of the included primary studies (available in the original meta-analysis) indicated *unclear or contradictory direction* for the entire pregnancy period, first and third trimesters. However, the second-trimester exposure showed a *less consistent positive association* (Table 3).

SO_2: Only one meta-analysis was included that pooled three to six studies and found lower risks for the entire pregnancy period, second and third trimesters but higher risk for the first trimester (Stieb et al., 2012). In all pregnancy periods, the results of the included primary studies (available in the original meta-analysis) showed both higher and lower risks. Hence overall evidence was considered *unclear or contradictory direction* for each pregnancy period (Table 3).

CO: Only one meta-analysis pooled this exposure-outcome association for each pregnancy period based on four to eight cohort studies (Stieb et al., 2012). The pooled effect showed a 1 g decrease in birth weight for the entire pregnancy but no association for trimester-specific effects per 100 ppb increase in the exposure. However, less than 80% of the included primary studies reported both higher and lower risks for each pregnancy period. Hence the overall evidence was graded in *unclear or contradictory directions* for each pregnancy period (Table 3).

$PM_{2.5}$ or PM_{10} by r*ace/ethnicity*: Two meta-analyses pooled the effect estimates by race or ethnicity for $PM_{2.5}$ and PM_{10} over the entire pregnancy exposure, dominated by studies conducted in the USA (Thayamballi et al., 2020; Uwak et al., 2021). Applying the grading criteria, the overall evidence for $PM_{2.5}$ showed a *more consistent positive association* for White persons, a *less consistent positive association* for Hispanic persons and Black persons but an *unclear or contradictory direction* for Asian persons. The largest pooled effect estimate was -32 g (95% CI = -60, -4) per 10 µg/m^3 increase in exposure among the White population (Uwak et al., 2021). Only one meta-analysis pooled results for PM_{10} and birth weight association (Uwak et al., 2021). The overall evidence based on the results of the primary studies showed a *less consistent positive association* for White persons and *unclear or contradictory directions* for both Black and Hispanic persons (Table S6, Figure S8).

ii) Low birth weight (LBW)

$PM_{2.5}$: Applying the grading criteria, the findings from seven meta-analyses based on 4 to 29 cohort studies for the entire pregnancy period were found to have a *less consistent positive association*. The largest pooled OR was 1.09 (95% CI =1.03, 1.15) per 10 µg/m^3 increase in exposure with high heterogeneity (I^2 = 93%) based on 19 cohort studies that included 10,405,729 births (Sun et al., 2016). Considering four meta-analyses for each trimester, the overall evidence for each trimester showed a *less consistent positive association* (Table 4 and Figure S9).

PM_{10}: For the entire pregnancy period, four meta-analyses reported positive associations which included the null (Ji et al., 2017; Sapkota et al., 2010) and without the null (Li et al., 2020; Stieb et al., 2012) in the confidence intervals. The largest pooled effect estimate indicated a higher risk of 5% per 10 µg/m^3 increase in the exposure based on 23 cohort studies with 286,188 LBW cases, with OR of 1.05 (95% CI=1.03, 1.08; I^2= 70%) (Li et al., 2020). The overall evidence was graded as a *less consistent positive association* for the entire pregnancy exposure. Regarding the trimester-specific risks, the overall evidence was *less consistent positive associations* for first and second trimesters but an *unclear or contradictory direction* for the third trimester (Table 4 and Figure S10).

CO: From the results of two meta-analyses (Li et al., 2020; Stieb et al., 2012), the overall evidence of *less consistent positive association* was found for the entire pregnancy. The same pooled OR of 1.01 (95% CI=1.00, 1.01) per 100 ppb increase in exposure based on six and eight cohort studies with low to moderate heterogeneities were reported. The same two meta-analyses reported similar findings of *less consistent positive association* for the second trimester, but an *unclear or contradictory direction* for the first-trimester exposure and consistently *null association* for the third trimester (Table 4, Figure S11).

NO_2: Two meta-analyses reported on this exposure-outcome association (Li et al., 2020; Stieb et al., 2012). The overall evidence for the entire pregnancy period, first and second trimesters were found to

be *less consistent positive associations*. For the entire pregnancy exposure, the larger pooled OR was 1.03 (95% CI=1.01, 1.05) per 10 ppb increase in exposure with high heterogeneity (I^2 = 90%) based on 23 cohort studies of 509,997 LBW cases (Li et al., 2020). The third trimester showed an *unclear or contradictory direction* (Table 4, Figure S12).

O_3: The results of two meta-analyses (Li et al., 2020; Stieb et al., 2012) indicated overall evidence of *unclear or contradictory directions* for the entire pregnancy period, first and second trimesters while the third trimester showed a *less consistent positive association* (Table 4, Figure S13).

SO_2: Two meta-analyses were reported for each pregnancy period (Li et al., 2020; Stieb et al., 2012) and found a *more consistent positive association* across the entire pregnancy exposure period. The larger OR of LBW was 12% with high heterogeneity (I^2= 83%) based on 13 cohort studies of 171,360 LBW births with pooled OR of 1.12 (95% CI= 1.02, 1.24) per 10 ppb increase in exposure (Li et al., 2020). The results of both first and second trimesters showed *less consistent positive associations* while the third trimester was a *less consistent negative association* (Table 4, Figure S14).

iii) Small-for-gestational age (SGA)

$PM_{2.5}$: The two meta-analyses on the association between SGA and $PM_{2.5}$ considered the same primary studies (Zhang et al., 2016; Zhu et al., 2015). We, therefore, considered the two pooled results as one. The entire pregnancy period result from six cohort studies on 1,515,887 births indicated positive association with pooled OR of 1.15 (95% CI= 1.10, 1.20; I^2= 0%) per 10 µg/m^3 increase in exposure. The overall evidence was graded as a *less consistent positive association* for the entire pregnancy period based on the results of the included primary studies. Similarly, applying the grading criteria to the results of the primary studies, we graded the overall evidence as *unclear or contradictory direction* for the first trimester and *less consistent positive associations* for both second and third trimesters (Table S7).

iv) ***Preterm birth (PTB)***

$PM_{2.5}$: There were seven meta-analyses based on 4 to 31 cohort studies. The overall evidence for the entire pregnancy period was graded as a *less consistent positive association* and the largest pooled OR of PTB was 1.16 (95% CI=1.07,1.26; I^2=17%) per 10 µg/m^3 increase in the exposure based on four cohort studies conducted on 197,980 births (Stieb et al., 2012). The *unclear or contradictory direction* was observed for the first trimester. Both second and third trimesters, however, showed *a less consistent positive association*. The largest pooled OR of PTB per 10 µg/m^3 increase in the exposure for second trimester was 1.09 (95% CI=0.82, 1.44; I^2 = 99%) based on five cohort studies conducted on 1,340,807 births and third trimester was 1.08 (95% CI= 0.99, 1.17; I^2 = 92%) based on nine cohort studies conducted on 2,208,883 births (Sun et al., 2015) (Table 5, Figure 3).

PM_{10}: From the reported pooled OR of three meta-analyses (Lamichhane et al., 2015; Sapkota et al., 2010; Stieb et al., 2012), the overall evidence showed a *less consistent positive association* for the entire pregnancy period. The largest pooled OR indicated 24% increased odds of PTB per 10 µg/m^3 increase in the exposure with an OR of 1.24 (95% CI= 1.03, 1.45) with no heterogeneity (I^2 = 0%) based on two cohort studies of 9,294 births that adjusted for maternal tobacco smoking (Lamichhane et al., 2015). Regarding the trimester-specifics, we observed *less consistent negative associations* for both first and second trimesters but a *less consistent positive association* for the third trimester (Table 5 and Figure S15).

NO_2: Two global meta-analyses based on 20 primary studies (Ju et al., 2021) and six primary studies (Stieb et al., 2012), and one for the European region based on four studies (Simoncic et al., 2020) reported on this exposure-outcome association. The overall evidence was a *less consistent positive association* for the entire pregnancy period and the larger OR of PTB was 1.14 (95% CI= 0.81, 1.64) per 10 ppb increase in the exposure from four cohort studies of 80,458 European births with moderate heterogeneity (I^2 = 72%) (Simoncic et al., 2020). From two meta-analyses for each trimester exposure period, the overall evidence was a *less consistent negative association* for the first trimester, *unclear or contradictory direction* for the second trimester, and a *less consistent positive association* for the third trimester (Table 5, Figure S16).

CO: From the findings of two meta-analyses (Ju et al., 2021; Stieb et al., 2012), both entire pregnancy and first trimester exposure periods showed *unclear or contradictory directions* while the third trimester consistently showed a *null association*. One meta-analysis (Ju et al., 2021) evaluated the second trimester and the results of the three included primary studies indicated an *unclear or contradictory direction* (Table 5, Figure S17).

O_3: Two meta-analyses were reported for the entire pregnancy, and second and third trimesters (Ju et al., 2021; Stieb et al., 2012), and three meta-analyses were reported for the first trimester (Ju et al., 2021; Rappazzo et al., 2021; Stieb et al., 2012). The entire pregnancy and first and second trimesters showed *less consistent positive associations* while the third trimester was an *unclear or contradictory direction* (Table 5, Figure S18).

v) Stillbirth

$PM_{2.5}$: The pooled OR from three meta-analyses (Siddika et al., 2016; Xie et al., 2021; Zhang et al., 2021) showed a *less consistent positive association* for the entire pregnancy period. The largest reported pooled OR was 1.15 (95% CI=1.07, 1.25) per 10 µg/m^3 increase in the exposure with high heterogeneity (I^2 = 75%) based on six primary studies of 3,222,578 births (Xie et al., 2021). Trimester-specific exposures showed a *less consistent positive association* for the second trimester but *unclear or contradictory directions* for both the first and third trimesters (Table 6, Figure S19).

PM_{10}. This was reported in three meta-analyses (Siddika et al., 2016; Zhang et al., 2021; Zhang et al., 2016) where two (Siddika et al., 2016; Zhang et al., 2016) published in the same year were duplicated (i.e., based on the same primary studies) and were considered as one result. The overall evidence for the entire pregnancy showed a *less consistent positive association* with a 1% higher risk per 10 µg/m^3 increase in the exposure based on either two or four cohort studies. Regarding the trimester-specific associations, both first and second trimesters showed *unclear or contradictory directions* while the third trimester was a *less consistent positive association* (Table 6, Figure S20).

NO_2: This was investigated in two meta-analyses based on three to six cohort studies (Siddika et al., 2016; Zhang et al., 2021). The overall evidence for the entire pregnancy period and each of the three trimesters showed *less consistent positive associations*. The larger risk was 7% higher with OR of 1.07 (95% CI= 0.97, 1.18; I^2 = 80%) per 10 ppb increase in the exposure based on three primary studies of 3,847,818 births for the entire pregnancy (Siddika et al., 2016). The pooled effect estimates were roughly similar for the first and third trimesters based on three to six primary studies (Table 6, Figure S21).

SO_2: The results of two meta-analyses (Siddika et al., 2016; Zhang et al., 2021) for the entire pregnancy period, pooled from three and six primary studies, showed a *less consistent positive association*. The larger pooled OR was 1.08 (95% CI= 0.95, 1.22; I^2 = 20%) per 10 ppb increase in the exposure from three primary studies of 3,847,818 births (Siddika et al., 2016). Both first and second trimesters indicated *unclear or contradictory directions* of associations while the third trimester was *a less consistent positive association* (Table 6, Figure S22).

CO: This was examined in two meta-analyses (Siddika et al., 2016; Zhang et al., 2021). The overall evidence across the entire pregnancy and the third trimester showed *unclear or contradictory directions* while both first and second trimesters consistently indicated *null association* based on three to six primary studies (Table 6, Figure S23).

O_3: Two meta-analyses pooled two to five primary studies for this exposure-outcome association (Siddika et al., 2016; Zhang et al., 2021). The overall epidemiological evidence was graded in *unclear or contradictory directions* for the entire pregnancy period and each of the three trimesters (Table 6, Figure S24).

vi) Spontaneous abortion (SAB)

$PM_{2.5}$: One meta-analysis reported on this exposure-outcome association and found a pooled OR of 1.20 (95% CI=1.01, 1.40) based on five primary studies conducted on 69,507 natural pregnancies with

high heterogeneity (I^2 = 99%) (Zhu et al., 2022). Findings from the included primary studies showed a *more consistent positive association*.
PM_{10}: Pooled OR from two meta-analyses (Zhang et al., 2016; Zhu et al., 2022) indicated a *more consistent positive association.* The larger pooled OR for 10 μg/m^3 increment based on three primary studies (one each for cohort, case-control, and cross-sectional) on 515,932 total pregnancies during the first trimester found 34% higher odds of SAB, 1.34 (95% CI= 1.04, 1.72) with moderate heterogeneity (I^2 = 62.4%) (Zhang et al., 2016) (Table 6). There were no meta-analyses for the gaseous pollutants.

4. Discussion

4.1 Characteristics and quality of the reviews

The 36 included reviews published from January 2004 (Glinianaia et al., 2004) to October 2021 (Edwards et al., 2022; Gong et al., 2022) organised their evidence from 295 distinct observational studies (published between 1984-2021) of varied study designs, included eight multi-country studies and 287 country-specific studies from 31 countries. The included primary studies were dominated by studies from the USA (39%) and China (15%) and the limited or lack of studies from many regions, particularly in developing countries could introduce potential selection bias. This could impact the generalisability of the findings but may not necessarily change the overall epidemiological evidence. This is because subgroup analyses reported positive associations, particularly between the pollutants and birth weight and PTB across all geographical regions defined as South or North America, Europe, Asia, and Oceania (Ju et al., 2021; Uwak et al., 2021). For instance, subgroup analysis of 13 studies in the USA and four studies from "Other" countries indicated reduced birth weight by -19 (95% CI= -31, -6; I^2= 99%) and -2 (95% CI= -12, 9; I^2= 26%) per 10 μg/m^3 increment in $PM_{2.5}$ exposure during the entire pregnancy, respectively. Similarly, the authors reported pooled OR of LBW per 10 μg/m^3 increment in $PM_{2.5}$ exposure during the entire pregnancy as 1.08 (95% CI=1.02, 1.14; I^2= 94%) based on 14 studies in USA and 1.14 (95% CI=1.04, 1.25; I^2= 36%) based on five studies in "Other" countries, respectively (Sun et al., 2016). Africa and South Asia each contributed only two studies to the evidence. Generally, regions with limited evidence that require particular attention from the academic and research community are Africa, Pacific Island, South Asia, Latin America, and the Caribbean. Some developed countries such as Germany, Russia, Finland, Israel, and Uruguay also contributed only one study each. Particulate matter was more studied than gaseous pollutants. The most extensively researched exposure-outcome associations were $PM_{2.5}$ with LBW and PTB while stillbirth, SGA, and SAB were less frequently studied for all criteria pollutants.

Comparatively, review guidelines were more closely adhered to in systematic reviews with meta-analyses than those without meta-analyses. A previous overview study also observed similar non-adherence to available review guidelines for environmental health studies (Nieuwenhuijsen et al., 2013). The purpose of review guidelines is to aid consistency and systematic assessment, yet they have limitations and there is no consensus on the degree to which systematic reviews or meta-analyses should adhere to the available review guidelines. One key limitation is that such review guidelines were mainly designed for medical sciences (e.g., clinical trials) rather than environmental health sciences. Notable examples include the development and use of protocols, the approach to critical appraisal or risk of bias assessment of included studies, and methods for assessment of confidence in the body of evidence (Whaley et al., 2020). Another limitation is that the risk of bias assessment severely discounts work from rapidly developing areas of the world where the best available data are often of lower quality than that in more developed regions. An example of a review guideline for research synthesis in environmental health sciences is the Navigation Guide systematic review methodology (Woodruff and Sutton, 2014). This guideline was applied by one of the included studies (Uwak et al., 2021) while three other included studies adopted its risk of bias assessment tool (Edwards et al., 2022; Walter et al., 2021; Xie et al., 2021). A standard guideline specifically designed for systematic reviews in toxicology and environmental health research (COSTER) is now available for the planning and conduct of systematic reviews or meta-analyses in the field (Whaley et al., 2020).

Many of the included review studies were conducted collaboratively by experts from different parts of the world, including investigators from non-English language countries, although few studies included non-English articles. For example, some (25%) of the reviews searched articles written in Chinese languages in addition to English. The focus on English articles could also contribute to why some countries such as Germany and Russia contributed only one study each to the current epidemiological evidence. This means that although excluding non-English articles is considered a systematic bias with minimal effects (Dobrescu et al., 2021; Morrison et al., 2012), the inclusion of non-English studies, if resources allow, could contribute to further reducing selection bias and enhancing the generalisability of the findings (Jackson and Kuriyama, 2019).

4.2 Overall summary of the epidemiologic evidence and implications

4.2.1 Summary of the overall epidemiologic evidence

There was little detected publication bias across meta-analyses via funnel plots and Egger or Begg tests. However, some authors have recently suggested that instead of investigating publication bias with the p-value-based tests that are underpowered due to their dependency on the number of studies included in the meta-analyses, non-p-value-based methods (e.g., Luis Furuya-Kanamori; LFK index) should be used (Furuya-Kanamori et al., 2020). Also, publication bias could be further reduced if "negative results" have an equal chance of publication, irrespective of p-values, effect sizes, and statistical significance (Wasserstein et al., 2019). Another critical issue is the barrier to publishing due to high article processing charges (Vervoort et al., 2021). Rethinking the business model of the scientific publication to enhance "free-to-publish and free-to-access research" regardless of one's funding status or organisational affiliation has been suggested to promote the dissemination of evidence-based information for scientific and public health benefits (Vervoort et al., 2021).

The overall epidemiologic findings differed largely depending on the pollutant, birth outcome, and pregnancy period. Specifically, $PM_{2.5}$ showed a *more consistent positive association* with reduced birth weight across the entire pregnancy exposure but *less consistent positive associations* for each trimester. Reduction in birth weight for trimester-specific exposure showed *less consistent positive associations* for $PM_{2.5}$, PM_{10}, and NO_2 during the first trimester, for $PM_{2.5}$, PM_{10}, and O_3 during the second trimester, and $PM_{2.5}$, PM_{10}, and NO_2 during the third trimester. For risk from exposure based on the whole pregnancy period, SO_2 showed a *more consistent positive association* with LBW but a *less consistent positive association* for the other criteria pollutants except O_3 which indicated *contradictory or unclear direction*. First-trimester exposure showed *less consistent positive associations* with the odds of LBW for all criteria pollutants except for CO and O_3 showing *contradictory or unclear directions*. For the second trimester, all criteria pollutants showed *less consistent positive associations* except for O_3 which showed *contradictory or unclear direction* with LBW. Except for $PM_{2.5}$ and O_3 found to be *less consistent positive associations*, other pollutants showed *contradictory or unclear directions* (PM_{10} and NO_2), no association (CO), and *less consistent negative association* (SO_2) with the odds of LBW during third-trimester exposure. Similar findings were observed in related overviews (Lee, 2021; Steinle et al., 2020). There were *less consistent positive associations* of PTB with exposure to $PM_{2.5}$, PM_{10}, O_3, and NO_2 during the whole pregnancy period, only O_3 for first-trimester exposure, O_3 and $PM_{2.5}$ for second-trimester exposure, $PM_{2.5}$, PM_{10}, and NO_2 for third-trimester exposure. For stillbirth, *less consistent positive associations* were observed for all criteria pollutants during the entire pregnancy period except for CO and O_3 which indicated *contradictory or unclear directions*. The trimester-specific exposure association with stillbirth showed *less consistent positive associations* for only NO_2 during the first trimester, for $PM_{2.5}$ and NO_2 during the second trimester but for three pollutants (PM_{10}, NO_2, and SO_2) during the third trimester. Only particulate matter pollutants were reported for SAB and both $PM_{2.5}$ and PM_{10} showed *more consistent positive associations*. For SGA, the pooled result was available for only $PM_{2.5}$ and with *less consistent positive association* for the entire pregnancy, second and third trimesters but the direction of association was *contradictory or unclear* for the first-trimester exposure. Reduction in birth weight among different races/ethnicity across the entire pregnancy period with $PM_{2.5}$ showed a *more consistent positive association* in White persons but *less consistent positive associations* in both Hispanic and Black/African-American persons. PM_{10} showed a *less consistent positive association* in White persons but *contradictory or unclear directions* in Hispanic and Black/African-American persons. The results indicate that different criteria pollutants may have different critical exposure windows of susceptibility for each birth outcome and are also likely to be heterogeneous across different levels of the population and maternal characteristics.

4.2.2 Exposure-outcome associations across pregnancy periods

Generally, there was more evidence for associations between adverse birth outcomes and exposure to particulate matter than gaseous pollutants. This could be attributable to more observational studies or higher toxicity of the particulate matter as compared to the gaseous pollutants (Han et al., 2021; Manisalidis et al., 2020; Shaddick et al., 2020). This could also be due to greater measurement errors in the assessment of the gaseous as compared with the particulate matter pollutants. The overall epidemiologic evidence was largely stronger across the entire pregnancy than trimester-specific exposure averages. There are several possible explanations for this observation. Firstly, the tendency for pregnant women to be cautious of exposure to environmental stressors is high during early pregnancy (after pregnancy is recognised) but this consciousness decreases over time (Liu et al., 2017). As a result, time exposed to outdoor pollutants might increase when approaching the date of delivery and would result in higher risks for the whole pregnancy period and third-trimester exposures being more observable than those for first and second trimester exposures. Secondly, the potential of exposure misclassification for trimester exposure assignments is likely to be higher than that for the entire pregnancy due to the uncertainties in defining the pregnancy period, especially using the last menstrual period with known imprecision by relying on maternal self-reporting (Quinn et al., 2016). Moreover, although pregnancy may be counted from the first day of the last menstrual period, conception begins two weeks later, and uncertainties regarding the start of pregnancy could bias estimates observed for first trimester exposures, not necessarily towards the null. Finally, regressing a birth outcome in separate models for each trimester using trimester-specific averaged exposures without adjusting for the other trimesters was found to bias the estimates with the identification of inaccurate susceptible windows because each susceptible window can potentially span multiple windows (Wilson et al., 2017). Exposures of air pollution across different trimesters can be highly correlated in some locations and not in others. Furthermore, the potential aetiology of the pollutant may not strictly follow the obstetrically defined trimester calendars (Wilson et al., 2017). Hence accurate measurement of the gestational period and a shorter temporal exploration (e.g., days or weeks) is required and the specific definition of pregnancy time should be defined e.g., obstetric versus embryonic weeks (Quinn et al., 2016; Wilson et al., 2017). This could improve the identification of critical windows of susceptibility, help elucidate the biological mechanisms of specific stages of fetal development (Warren et al., 2020b; Wilson et al., 2017) and improve the ability to synthesise results of multiple studies. Additionally, a recent molecular epidemiologic study had indicated associations in pre-conception periods with a critical window spanning from 12 weeks before and 13 weeks into the gestational period for maternal $PM_{2.5}$ exposure and reduced birth weight (Deyssenroth et al., 2021). There is therefore the need to include some pre-conception exposure periods to capture the full impacts of the pollutants on the birth outcomes when assessing chronic effects. Also, the available evidence was solely based on single-pollutant models which do not fully characterise the complex associations and interactions of multiple time-varying mixtures of the pollutants on birth outcomes (Wilson et al., 2019). There are emerging approaches to identify critical exposure windows and convoluted associations of multi-pollutants in exposure-lag-response associations such as the Bayesian kernel machine regression distributed lag model (Wilson et al., 2019) or a regression tree-based model for mixtures of exposures (Mork and Wilson, 2021). Despite the advantages of assessing exposure mixtures, a recent review identified the potential for increasing the existing measurement errors and biases in environmental exposure mixture research (Tanner et al., 2020).

4.2.3 Heterogeneity and sources

Inevitably, heterogeneity is expected in SRMAs (Higgins, 2008). This was quantified with I^2 statistics in the included meta-analyses and found to be high across almost all meta-analyses with values as high as 99% (Sun et al., 2015; Sun et al., 2016). Variability among the observational studies could be clinical heterogeneity (variability in characteristics of the participants, exposures, and outcomes) or methodological heterogeneity (variability in study designs, exposure assessment methods, and outcome definitions or assessments, risk of bias, and confounding adjustments) (Higgins et al., 2021). These variabilities from either clinical or methodological heterogeneity consequently manifest in the non-random differences in the effect estimates from the different studies pooled in the meta-analyses (Higgins et al., 2021). The high heterogeneity indicated that the observational studies were estimating different quantities of the effects but do not necessarily imply that the true exposure effect estimate varies (Higgins et al., 2021). The major sources of heterogeneity acknowledged in the included SRMAs and related previous overviews (Lee, 2021; Nieuwenhuijsen et al., 2013; Steinle et al., 2020) are differences in methodology and study designs, statistical analyses, sample size, population demographics, birth, and exposure data collections, including outcome definitions (especially stillbirth) and exposure assessment methods, adjusted confounding factors, geographical variability, and sources and chemical compositions of particulate matter. Where data permitted, the included SRMAs attempted to account for some of the sources of heterogeneity by restricting to cohort studies (Ju et al., 2021; Li et al., 2020; Liu et al., 2017) or 'low' or 'probably low' risk of bias studies (Uwak et al., 2021); stratifying by adjustment for maternal tobacco smoking (Lamichhane et al., 2015), exposure assessment methods (Gong et al., 2022; Ji et al., 2017; Sun et al., 2015; Sun et al., 2016), exposure dosage using WHO thresholds (Liu et al., 2017), region (Gong et al., 2022; Uwak et al., 2021); and many other subgroup analyses, but the heterogeneity persisted in most instances. Gong *et al*, however, observed very low heterogeneity with the closest effect estimates to the overall estimates for subgroup analysis of studies that assessed exposure with land-use regression models among other exposure assessment methods (Gong et al., 2022). This suggests the need for improved exposure assessment methods (Gong et al., 2022; Uwak et al., 2021). It is worth noting that subgroup analyses are observational by nature and non-randomised, hence findings from multiple subgroup analyses may also be difficult to interpret (Higgins et al., 2021). On the other hand, the high heterogeneity between studies could also be considered a strength to some extent as the epidemiological evidence on the ubiquitous air pollutants covers different levels of risks in different populations with diverse physical, biological, sociodemographic, and medical conditions, and genetic constitutions (Ghosh et al., 2021).

In the absence of RCTs, prospective cohort studies in which participants are recruited with a detailed collection of confounding factors and personalised space-time-activity exposure assessment could address some of the challenges (Steinle et al., 2013; Zhang et al., 2021). Population-based retrospective cohort designs provide the opportunity to recruit a large sample size to detect small effects at the population level. Therefore, improvement in the availability, coverage, and quality of routine perinatal data collections for retrospective cohort designs serves as a practical alternative because prospective cohort designs can be very costly in terms of funding and time, and infringement of privacy. Related SRMAs and overviews disclosed that maternal tobacco smoking (Gould et al., 2020; Stock and Bauld, 2020), illicit drug or alcohol intake (Patra et al., 2011), pregnancy complications (Liu et al., 2019), infections (Niyibizi et al., 2020; Thompson et al., 2019), nutritional status (Young and Ramakrishnan, 2020), and psychosocial conditions (Dadi et al., 2020) are known risk factors for birth outcomes. These factors have potential modification and mediation effects but are rarely investigated in observational studies or SRMAs due to the dearth of information. Most of these and other important confounders could be collected by healthcare practitioners in the routine data as a collective effort towards a common goal of improving maternal and neonatal health, although other challenges would remain (e.g., the accuracy of maternal smoking data). One of the reviewed meta-analyses specifically found larger reductions in birth weight per 10 $\mu g/m^3$ increased in the particulate matter after adjusting for maternal tobacco smoking (Lamichhane et al., 2015). Thus, our observed overall epidemiological evidence is likely to be higher if relevant residual confounding, modifying, or mediating factors are adjusted. As reported previously, the 2008 Beijing Olympics ‘natural experiment’ due to air pollution reduction provided an opportunity to reduce residual confounding and exposure misclassification from which more convincing evidence of the higher risk of air pollution exposure on birth outcomes was found (Rich et al., 2015). The recent COVID-19 pandemic also offered another unique opportunity for the ‘natural experiment’ at a larger scale for both national and international collaborative investigations (Stock et al., 2021).

4.2.4 Combined associations and geodemographic variability

Other critical, yet unexplored areas are the synergistic associations of the pollutants with other closely related environmental stressors and the spatiotemporal exposure-outcome associations. The combined impacts of the criteria pollutants with related environmental exposures such as green vegetation and meteorological factors, especially extreme temperatures on birth outcomes (Zhang et al., 2021) has been evidenced recently (Sun et al., 2020). Also, despite the evolving spatiotemporal exposure assessments with modern advanced machine learning technology and integration of land-use regression models (Luo et al., 2021) and the distributed lagged effect modelling (Gasparrini et al., 2010; Wilson et al., 2017), empirical incorporation of the spatiotemporal variations in the exposure-outcome analysis has not received expected attention in the current body of evidence. Warren and colleagues (Warren et al., 2020a) recently demonstrated that ignoring spatial variation in the lagged effect of the parameters nullified the elevated association between $PM_{2.5}$ and term LBW in selected gestational weeks. This implies that spatiotemporal variations also need to be considered in future studies and this could include geographically weighted regression models as exemplified elsewhere (Tu et al., 2016), an effective and efficient technique for targeted local public health interventions.

Another means of having a broader view of the spatial variability and relevant information on the sources and chemical compositions of the pollutants is by broadening the geodemographic coverage of the evidence. Geodemographically, the current evidence was heavily based on epidemiologic studies from the USA and China with limited studies from other developed countries. Paradoxically, the low-and-middle-income countries (LMICs) which are socio-demographically vulnerable and with invariably high exposure levels and high incidence of birth outcomes are missing in the current evidence. A global estimated PTB rate across 107 countries was recently estimated at 10.6% (14.84 million live PTB) and 81.1% (12. 0 million) of these PTB were from Sub-Saharan Africa (SSA) and Asia (Chawanpaiboon et al., 2019). The LMICs also accounted for 98% of stillbirths, with three-quarters in SSA and South Asia (Lawn et al., 2016). Notably, these regions are experiencing increasingly high concentrations of the criteria pollutants above WHO Air Quality Guidelines (AQGs) (Shaddick et al., 2020). The SSA region is suffering from 10 to 20-fold higher levels than the 2005 AQGs (Katoto et al., 2019) due to Saharan desert dust and biomass burning (Agbo et al., 2021). Thus, the LMICs are heavily polluted and have high burdens of birth outcomes but lacked related epidemiologic evidence, largely due to a lack of functional and reliable air quality monitoring data (Agbo et al., 2021; Amegah, 2018; Nyadanu et al., 2020) and population-based health registries for the related high-quality epidemiologic investigations (Frøen et al., 2016). A new global attributable burden analysis estimated that over 5.9 million PTB and 2.8 million LBW infants could be attributable to $PM_{2.5}$ exposure during the entire pregnancy period in 2019 and the highest attributable burdens were estimated for SSA (Ghosh et al., 2021). Those authors further suggested that these burdens could have been prevented if $PM_{2.5}$ was reduced to theoretical minimum risk exposure levels of 2.4 to 5.9 $\mu g/m^3$ in 2019 (Ghosh et al., 2021). It was also estimated that about a 78% reduction in the global LBW and PTB in 2019 could have been achieved by South Asia and SSA combined since they suffered the highest attributable burden (Ghosh et al., 2021). Similar disproportionate elevated impacts of $PM_{2.5}$ on health outcomes in LMICs were reported in another recent global study (Han et al., 2021). All these findings indicate that our observed epidemiological evidence of mostly *less consistent positive associations* could be an underestimation in the absence of evidence in high-exposure, high-outcome, and most vulnerable settings. Therefore, despite the known challenges in conducting related studies in these under-resourced regions, a call for an innovative investigation to have a glimpse of the state of pollutants and birth outcomes in LMICs as illustrated by Xue *et al* (Xue et al., 2021; Xue et al., 2019) cannot be overemphasised.

4.3 Plausible biological pathways and interdisciplinary approach

A complex interaction of environmental, maternal, placental, and fetal factors regulating fetal growth and development (Erickson and Arbour, 2014; Street and Bernasconi, 2020) makes the pathoaetiology of the air pollutant-birth outcome associations very complex to be postulated in a single biological pathway (Slama et al., 2008). Physiologically, suppressed maternal immunity, higher blood volume, greater metabolic rate, and the added nutritional requirements from the fetus among other factors increase maternal sensitivity and thus intensify the vulnerability of pregnant women and the developing fetuses to air pollutants (Westergaard et al., 2017). As a very sensitive period of susceptibility, exposure to any harmful substance during fetal development can have both *in* and *ex utero* adverse effects at birth and later in the life course (Di Renzo et al., 2015; Erickson and Arbour, 2014; WHO, 2018).

The pollutants enter the mother's cardiovascular system by inhalation and reach the embryo or fetus by way of fetoplacental translocation (Slama et al., 2008; WHO, 2018). Upon entry, the pollutants interact with the maternal biologic environment to generate excess oxidative free radicals and endocrine-disrupting chemicals (Li et al., 2019; Marczylo et al., 2016; Saenen et al., 2019). These trigger a cascade of maternal biological and physiological processes, including alterations in immuno-inflammatory, cardiovascular, and respiratory systems, and induce placental modifications with negative impacts on fetal development and growth (Li et al., 2019; Marczylo et al., 2016; Saenen et al., 2019). Recent molecular epidemiologic mechanisms also showed that oxidative stress, global DNA methylation, mitochondrial DNA content alteration, and endocrine perturbations that cause placental reprogramming are potential pathways for the induced adverse association of particulate matter and birth outcomes (Deyssenroth et al., 2021; Li et al., 2019; Street and Bernasconi, 2020). Generally, the associations are more profound in the particulate matter than the gaseous pollutants, resulting in comparatively higher risks in particulate matter (Manisalidis et al., 2020). Again, this could also be due to more studies on the particulate matter as compared to gaseous pollutants and greater measurement errors in gaseous pollutants. Of particular interest among the gaseous pollutants is CO with a well-documented mechanism where CO binds to the haemoglobin to be transported across the placenta and reduces the availability of oxygen to the fetus (Ghosh et al., 2007; Glinianaia et al., 2004). Environmental epigenetics also indicated that birth outcomes are phenotypic manifestations of environmentally induced epigenetic toxicity through environment-gene interactions (Marczylo et al., 2016; Saenen et al., 2019). The impacts are shared synergistic interactions among maternal biologic, psychosocial, sociodemographic, and behavioural risk factors, obstetric or health conditions, and pollutants (Erickson and Arbour, 2014; Kannan et al., 2006; Slama et al., 2008). There can also be interplay among the exposures on the birth outcomes where the impacts of $PM_{2.5}$ on birth weight and gestational age, could in turn make a considerable contribution to the LBW and PTB (Ghosh et al., 2021).

While advances in epidemiological methodologies, statistical analyses, and environmental exposure science technology are key, interdisciplinary approaches could contribute to understanding the biological mechanisms and providing convincing evidence of causal inference (Stingone et al., 2021). This is largely due to the complexities of environmental health science (Stingone et al., 2021) and the inability to conduct RCTs owing to ethical issues (Woodruff and Sutton, 2014). Stingone *et al* recently proposed an interdisciplinary framework for environmental health research that provides the opportunity to integrate epidemiology, clinical science, pathophysiology, toxicology, epigenetics, and bioinformatics (examples; genomics, proteomics, metabolomics) (Stingone et al., 2021), and social and biophysical sciences (Eisenhauer et al., 2021). As a result, causal inference on the associations between population-level environmental exposures and birth outcomes may be achievable (Eisenhauer et al., 2021; Stingone et al., 2021) even from under-resourced settings. For instance, Wang and colleagues demonstrated how DNA methylation measurement in cord blood or bloodspot can be used to predict prenatal exposures to NO_2 and $PM_{2.5}$ in cohorts without explicitly measuring the exposures (Wang et al., 2021). We, therefore, require not only well-designed longitudinal studies but possibly integrating the environmental exposomes with the different *omics* to ascertain the biological signatures of the *in utero* exposures for prevention, diagnosis, and treatment of birth outcomes (Eisenhauer et al., 2021; Stingone et al., 2021; Street and Bernasconi, 2020).

5. Strengths and Limitations

This study is accorded with several strengths. To the best of our knowledge, this is the first umbrella review that comprehensively assessed, evaluated, and provided an overall global state of the epidemiological evidence on prenatal exposure to the six criteria air pollutants and birth outcomes, for which we assessed 36 systematic reviews and meta-analyses. We also developed a protocol registered in PROSPERO and elaborated it as a peer-reviewed article before the conduct of the review (Nyadanu et al., 2020). The literature search was comprehensive and conducted prospectively by activating database alerts which ensured regular updates of the results with new eligible studies. The review process followed standard guidelines. To depict the geographical variability of contributing countries or regions to the current epidemiological evidence, we mapped the locations with the number of the distinct primary studies included in the included reviews. The degree of overlap of the primary studies was also quantified with a validated index. We adapted a semi-quantitative objective approach to grade the overall direction of associations and the confidence for each pollutant-outcome association at differing pregnancy periods. We also summarised key themes that emerged from the included reviews' recommendations.

Some limitations are also associated with this study. The current epidemiological evidence is highly representative of two regions (the USA and China) and a few highly industrialised countries which may introduce selection bias and weaken the generalisation of the findings. However, this also indicated that evidence exists in both low-level (USA) and high-level (China) exposure settings. The limited evidence from the most vulnerable regions such as Africa, South Asia, and other LMICs is a serious limitation that requires urgent attention. We included only reviews reported in English which could result in potential English-based publication bias. This is, however, expected to be very minimal (Dobrescu et al., 2021; Morrison et al., 2012), particularly for an umbrella review. Multiple inclusion of primary studies is a known limitation of umbrella review but was estimated to be moderate in our study. All meta-analyses identified substantial heterogeneity of varied sources in the primary studies and there were no RCTs by default. Consequently, the available epidemiological evidence indicated *probable evidence* of causality for most of the pollutant-outcome associations. The grading approach might not be entirely objective, was limited to the number of studies, and consistency in direction of effect estimates and could not provide the overall magnitude of the effect estimates. We standardised the effect estimates across meta-analysis to compare results across studies. However, the implications of a given increment (e.g., 10 ppb O_3) can differ across the regions. For example, that increment may be a small increase relative to baseline conditions for some areas and a large increase for others. Similarly, caution would be used when comparing results for PM_{10} and $PM_{2.5}$ as a given increment (e.g., 10 $\mu g/m^3$) has a different relative meaning for these particle size fractions. The conclusions and recommendations evolving from this umbrella review should therefore be interpreted and applied within the context of the outlined strengths and limitations based on the available scientific evidence gathered from the 36 SRMAs.

6. Recommendations for research, practice, and policy

6.1 For primary studies

Further studies are required, particularly from LMICs and other developed countries that contributed a limited number of studies. Additional studies are also required on gaseous pollutants, small-for-gestational-age, stillbirth, and spontaneous abortion. More well-designed and standardised observational studies with high-quality data, harmonised outcome definitions, and spatiotemporal exposure assessments could minimise the high heterogeneity. This could highlight where such heterogeneity reflects the true underlying systems (e.g., different effects due to different sources of particulate matter and thereby different chemical composition) versus heterogeneity that is not a reflection of true variation. Given that RCTs are unethical in this field, prospective cohorts with personal time-activity trajectory exposure monitoring are gold-standard and should be pursued if funding and time allow. However, acknowledging the logistical and practical issues for large-scale prospective cohort design, liaising with healthcare providers to improve the quality and volume of the routine health data collection and emerging advancements in epidemiological methodologies and analyses will help strengthen the evidence. Even here, important limitations exist (e.g., the additional burden to health care providers, the accuracy of some variables such as maternal smoking). Considering the peculiar multifactorial nature and complexities in this field, a multisectoral approach is urgently needed. This, including extensive exploration of the *omics* technologies, will help illuminate the biological pathways but also has potential for diagnosis, prevention, and treatment (Stingone et al., 2021). More detailed recommendations for observational studies provided by the included reviews are available (Tables S3 and S4). Briefly, the review authors recommended more refined methodological designs, including prospective or large population-based retrospective cohort studies for chronic effects and time-series or case-crossover studies for short-term effects on acute events (e.g., PTB, stillbirth, and SAB) using high-quality data and individual level spatiotemporal exposure assessment. Further approaches to reduce residual and spatial confounders and account for residential mobility were suggested. More studies at finer temporal scales for identifying the critical susceptible periods and biological pathways, potential effect modifications, and chemical compositions of particulate matter were also recommended.

6.2 For Systematic reviews and meta-analyses

The increment in exposure used to present effect estimates needs to be unified across meta-analyses. For systematic reviews without meta-analyses, counting of findings for the specific statistical direction of association with median or range of the effect estimates as exemplified in one of the included reviews (Bekkar et al., 2020) together with graphical displays, such as forest plots, and a concise level of evidence as indicated in Heo *et al* (Heo et al., 2019) is recommended. This will be more helpful than the general 'narrative synthesis' which has been associated with serious weaknesses (Campbell et al., 2020). Rather than the narrative synthesis, we recommend a semi-quantitative approach for a more objective synthesis of the evidence as applied elsewhere (Zeiher et al., 2019). This approach, however, should not be considered entirely objective. Future review authors may refer to the recently developed comprehensive guideline for synthesis without meta-analysis (SWiM) for systematic reviews examining quantitative effects (Campbell et al., 2020). The methodological quality of future systematic reviews or meta-analyses needs to be improved by better adherence to the standard review guidelines, particularly the new COSTER guideline (Whaley et al., 2020). Also, the availability of review protocol could contribute to reducing the duplication or near-duplication of review studies in addition to other advantages reported in the review guidelines (Moher et al., 2009; Page et al., 2021; Whaley et al., 2020).

6.3 Policy action

The probable epidemiological evidence of cause-and-effect of prenatal exposure to the criteria air pollutants and birth outcomes warrants consideration of the *precautionary principle* which states that "*when an activity raises threats of harm to human health or the environment, precautionary measures should be taken even if some cause-and-effect relationships are not fully established scientifically*" (Martuzzi and Tickner, 2004). The precautionary action to prevent harm may be particularly necessary for particulate matter and to some extent SO_2 and NO_2 which often showed consistent positive associations with adverse birth outcomes, despite the difficulty in establishing causality with certainty. Clinicians and public health workers have a unique opportunity to educate pregnant women or women of reproductive age and raise the awareness about the potential risk of exposure to air pollutants and some precautions to be taken such as minimising outdoor activities or using particulate filter masks in polluted areas and consider pollution levels when choosing residential locations. Environmental policy and legislation such as enforcing new WHO air quality guidelines (WHO, 2021), increased investment into renewable energy sources, and transitioning towards "clean" fuels or new technologies to reduce or eliminate anthropogenic ambient air pollution may be helpful (Han et al., 2021; Pereira et al., 2021). Although there is no safe level, reducing the pollutants could substantially improve perinatal health and save lives (Pereira, 2021).

7. Conclusion

The toxic effects of the criteria air pollutants on human health are well known for outcomes such as mortality and hospital admissions, with growing evidence for reproductive and neonatal health. We found five *more consistent positive associations* for entire pregnancy period exposure, including exposure to $PM_{2.5}$ and reduced birth weight (all populations and among White persons), both $PM_{2.5}$ and PM_{10} and SAB, and exposure to SO_2 and LBW. We observed several *less consistent positive associations* and few *contradictory or unclear directions* of association. We also found one each of *more* and *less consistent negative associations* and three instances where CO consistently showed no association. However, due to the high heterogeneity, imprecision, and absence of RCTs, the observed epidemiological pieces of evidence were classified as '*probable evidence*', differing greatly among the pollutants, birth outcomes, and pregnancy periods. Particulate matter ($PM_{2.5}$ or PM_{10}), particularly $PM_{2.5}$ was most studied and found to show a higher risk than gaseous pollutants. Among the gaseous pollutants, NO_2 and SO_2 often showed more *consistent positive associations* than CO and O_3. The positive associations across the entire pregnancy period showed more consistency than the trimester-specific exposure averages. The supporting biological causal mechanisms are also currently limited, particularly for gaseous pollutants. The omics technologies and environmental epigenetics are, however, unfolding strong aetiological pathways for the particulate matter pollutants. Interdisciplinary research approaches and well-planned standardised epidemiological studies with broader geodemographic coverage, and biological mechanisms are recommended to strengthen the current evidence. This will contribute to providing evidence-based guidance or direction for mitigating the adverse associations of the pollutants on birth outcomes. In the interim, the current level of evidence and the large populations involved warrant the adoption of the *precautionary principle*. Health practitioners could play an active role in integrating and communicating the risks of prenatal air pollution exposure to women and policymakers.

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References

Agbo, K. E., Walgraeve, C., Eze, J. I., Ugwoke, P. E., Ukoha, P. O., Van Langenhove, H. 2021. A review on ambient and indoor air pollution status in Africa. Atmos. Pollut. Res. 12(2), 243-260. https://doi.org/https://doi.org/10.1016/j.apr.2020.11.006.

Amegah, A. K. 2018. Proliferation of low-cost sensors. What prospects for air pollution epidemiologic research in Sub-Saharan Africa? Environ. Pollut. 241, 1132-1137. https://doi.org/https://doi.org/10.1016/j.envpol.2018.06.044.

Aromataris, E., Fernandez, R., Godfrey, C. M., Holly, C., Khalil, H., Tungpunkom, P. 2015. Summarizing systematic reviews: methodological development, conduct and reporting of an umbrella review approach. Int. J Evid. Based Healthc. 13(3), 132-140. https://doi.org/10.1097/xeb.0000000000000055.

Aromataris, E., Fernandez, R., Godfrey, C. M., Holly, C., Khalil, H., Tungpunkom, P. (2020). Chapter 10: Umbrella Reviews. In: JBI Manual for Evidence Synthesis (E. Aromataris andZ. Munn, Eds.). The Joanna Briggs Institute, Australia. Available at https://synthesismanual.jbi.global. Accessed on 21 May 2020.

Bekkar, B., Pacheco, S., Basu, R., DeNicola, N. 2020. Association of Air Pollution and Heat Exposure With Preterm Birth, Low Birth Weight, and Stillbirth in the US: A Systematic Review. JAMA Network Open, 3(6), e208243-e208243. https://doi.org/10.1001/jamanetworkopen.2020.8243.

Beltran, A. J., Wu, J., Laurent, O. 2013. Associations of meteorology with adverse pregnancy outcomes: a systematic review of preeclampsia, preterm birth and birth weight. Int. J. Environ. Res. Public Health. 11(1), 91-172. https://doi.org/10.3390/ijerph110100091.

Bonzini, M., Carugno, M., Grillo, P., Mensi, C., Bertazzi, P. A., Pesatori, A. C. 2010. Impact of ambient air pollution on birth outcomes: systematic review of the current evidences. Med. Lav. 101(5), 341-363.

Bosetti, C., Nieuwenhuijsen, M. J., Gallus, S., Cipriani, S., La Vecchia, C., Parazzini, F. 2010. Ambient particulate matter and preterm birth or birth weight: a review of the literature. Arch. Toxicol. 84(6), 447-460. https://doi.org/10.1007/s00204-010-0514-z.

Bramer, W. M., Rethlefsen, M. L., Kleijnen, J., Franco, O. H. 2017. Optimal database combinations for literature searches in systematic reviews: a prospective exploratory study. BMC Syst. Rev. 6(1), 245. https://doi.org/10.1186/s13643-017-0644-y.

Burnett, R., Chen, H., Szyszkowicz, M., Fann, N., Hubbell, B., Pope, C. A., et al. 2018. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. PNAS. 115(38), 9592-9597. https://doi.org/10.1073/pnas.1803222115.

Campbell, M., McKenzie, J. E., Sowden, A., Katikireddi, S. V., Brennan, S. E., Ellis, S., et al. 2020. Synthesis without meta-analysis (SWiM) in systematic reviews: reporting guideline. BMJ, 368, l6890. https://doi.org/10.1136/bmj.l6890.

Chawanpaiboon, S., Vogel, J. P., Moller, A.-B., Lumbiganon, P., Petzold, M., Hogan, D., et al. 2019. Global, regional, and national estimates of levels of preterm birth in 2014: a systematic review and modelling analysis. Lancet. Glob. Health. 7(1), e37-e46. https://doi.org/10.1016/S2214-109X(18)30451-0 .

Dadi, A. F., Miller, E. R., Bisetegn, T. A., Mwanri, L. 2020. Global burden of antenatal depression and its association with adverse birth outcomes: an umbrella review. BMC Public Health. 20(1), 173. https://doi.org/10.1186/s12889-020-8293-9.

Deyssenroth, M. A., Rosa, M. J., Eliot, M. N., Kelsey, K. T., Kloog, I., Schwartz, J. D., et al. 2021. Placental gene networks at the interface between maternal PM2.5 exposure early in gestation and reduced infant birthweight. Environ. Res. 199, 111342. https://doi.org/https://doi.org/10.1016/j.envres.2021.111342.

Di Renzo, G. C., Conry, J. A., Blake, J., DeFrancesco, M. S., DeNicola, N., Martin, J. N., Jr., et al. 2015. International Federation of Gynecology and Obstetrics opinion on reproductive health impacts of exposure to toxic environmental chemicals. Int. J Gynaecol. Obstet. 131(3), 219-225. https://doi.org/10.1016/j.ijgo.2015.09.002.
Dobrescu, A. I., Nussbaumer-Streit, B., Klerings, I., Wagner, G., Persad, E., Sommer, I., et al. 2021. Restricting evidence syntheses of interventions to English-language publications is a viable methodological shortcut for most medical topics: a systematic review. J. Clin. Epidemiol. 137, 209-217. https://doi.org/https://doi.org/10.1016/j.jclinepi.2021.04.012.
Edwards, L., Wilkinson, P., Rutter, G., Milojevic, A. 2022. Health effects in people relocating between environments of differing ambient air pollution concentrations: A literature review. Environ. Pollut. 292, 118314. https://doi.org/https://doi.org/10.1016/j.envpol.2021.118314.
Eisenhauer, E., Williams, K. C., Margeson, K., Paczuski, S., Hano, M. C., Mulvaney, K. 2021. Advancing translational research in environmental science: The role and impact of social sciences. Environ. Sci. Policy. 120, 165-172. https://doi.org/https://doi.org/10.1016/j.envsci.2021.03.010.
Erickson, A. C., Arbour, L. 2014. The Shared Pathoetiological Effects of Particulate Air Pollution and the Social Environment on Fetal-Placental Development. J. Environ. and Public Health. 2014, 901017. https://doi.org/10.1155/2014/901017.
Frøen, J. F., Myhre, S. L., Frost, M. J., Chou, D., Mehl, G., Say, L., et al. 2016. eRegistries: Electronic registries for maternal and child health. BMC Pregnancy and Childbirth. 16(1), 11. https://doi.org/10.1186/s12884-016-0801-7.
Furuya-Kanamori, L., Xu, C., Lin, L., Doan, T., Chu, H., Thalib, L., et al. 2020. P value–driven methods were underpowered to detect publication bias: analysis of Cochrane review meta-analyses. J. Clin. Epidemiol. 118, 86-92. https://doi.org/https://doi.org/10.1016/j.jclinepi.2019.11.011
Gasparrini, A., Armstrong, B., Kenward, M. G. 2010. Distributed lag non-linear models. Stat. Med. 29(21), 2224-2234. https://doi.org/10.1002/sim.3940.
Ghosh, R., Causey, K., Burkart, K., Wozniak, S., Cohen, A., Brauer, M. 2021. Ambient and household PM2.5 pollution and adverse perinatal outcomes: A meta-regression and analysis of attributable global burden for 204 countries and territories. PLOS Med. 18(9), e1003718. g https://doi.org/10.1371/journal.pmed.1003718.
Ghosh, R., Rankin, J., Pless-Mulloli, T., Glinianaia, S. 2007. Does the effect of air pollution on pregnancy outcomes differ by gender? A systematic review. Environ. Res. 105(3), 400-408. https://doi.org/10.1016/j.envres.2007.03.009.
Glinianaia, S. V., Rankin, J., Bell, R., Pless-Mulloli, T., Howel, D. 2004. Particulate air pollution and fetal health: a systematic review of the epidemiologic evidence. Epidemiol. 15(1), 36-45. https://doi.org/10.1097/01.ede.0000101023.41844.ac.
Gong, C., Wang, J., Bai, Z., Rich, D. Q., Zhang, Y. 2022. Maternal exposure to ambient PM2.5 and term birth weight: A systematic review and meta-analysis of effect estimates. Sci. Total Environ. 807, 150744. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.150744.
Gould, G. S., Havard, A., Lim, L. L., The Psanz Smoking In Pregnancy Expert, G., Kumar, R. 2020. Exposure to Tobacco, Environmental Tobacco Smoke and Nicotine in Pregnancy: A Pragmatic Overview of Reviews of Maternal and Child Outcomes, Effectiveness of Interventions and Barriers and Facilitators to Quitting. Int. J. Environ. Res. Public Health. 17(6). https://doi.org/10.3390/ijerph17062034
Grippo, A., Zhang, J., Chu, L., Guo, Y., Qiao, L., Zhang, J., et al. 2018. Air pollution exposure during pregnancy and spontaneous abortion and stillbirth. Rev. Environ. Health. 33(3), 247-264. https://doi.org/10.1515/reveh-2017-0033.

Han, C., Xu, R., Zhang, Y., Yu, W., Zhang, Z., Morawska, L., et al. 2021. Air pollution control efficacy and health impacts: A global observational study from 2000 to 2016. Environ. Pollut. 287, 117211. https://doi.org/https://doi.org/10.1016/j.envpol.2021.117211.

Hartling, L., Chisholm, A., Thomson, D., Dryden, D. M. 2012. A descriptive analysis of overviews of reviews published between 2000 and 2011. PLoS One, 7(11), e49667. https://doi.org/10.1371/journal.pone.0049667.

Heo, S., Fong, K. C., Bell, M. L. 2019. Risk of particulate matter on birth outcomes in relation to maternal socio-economic factors: a systematic review. Environ. Res. Lett. 14(12). https://doi.org/10.1088/1748-9326/ab4cd0.

Higgins, J. P. T. 2008. Commentary: Heterogeneity in meta-analysis should be expected and appropriately quantified. Int. J. Epidemiol. 37(5), 1158-1160. https://doi.org/10.1093/ije/dyn204.

Higgins, J. P. T., Thomas, J., Chandler, J., Cumpston, M., Li, T., Page, M. J., et al. (2021). Analysing data and undertaking meta-analyses. . In J. J. Deeks, J. P. T. Higgins, andD. G. Altman (Eds.), Cochrane Handbook for Systematic Reviews of Interventions version 6.2 (updated February 2021). Cochrane. Available at www.training.cochrane.org/handbook. Accessed October 3, 2021.

Hill, A. B. 2015. The environment and disease: association or causation? J. R. Soc. Med. 108(1), 32-37. https://doi.org/10.1177/0141076814562718.

Jackson, J. L., Kuriyama, A. 2019. How Often Do Systematic Reviews Exclude Articles Not Published in English? J. Gen. Intern. Med. 34(8), 1388-1389. https://doi.org/10.1007/s11606-019-04976-x.

Jacobs, M., Zhang, G., Chen, S., Mullins, B., Bell, M., Jin, L., et al. 2017. The association between ambient air pollution and selected adverse pregnancy outcomes in China: A systematic review. Sci. Total Environ. 579, 1179-1192. https://doi.org/10.1016/j.scitotenv.2016.11.100.

Ji, Y., Song, F., Xu, B., Zhu, Y., Lu, C., Xia, Y. 2017. Association between exposure to particulate matter during pregnancy and birthweight: a systematic review and a meta-analysis of birth cohort studies. J. Biomed Res. https://doi.org/10.7555/JBR.31.20170038.

Ju, L., Li, C., Yang, M., Sun, S., Zhang, Q., Cao, J., et al. 2021. Maternal air pollution exposure increases the risk of preterm birth: Evidence from the meta-analysis of cohort studies. Environ. Res. 202, 111654. https://doi.org/10.1016/j.envres.2021.111654.

Kannan, S., Misra, D. P., Dvonch, J. T., Krishnakumar, A. 2006. Exposures to airborne particulate matter and adverse perinatal outcomes: a biologically plausible mechanistic framework for exploring potential effect modification by nutrition. Environ. Health Perspect. 114(11), 1636-1642. https://doi.org/10.1289/ehp.9081.

Katoto, P., Byamungu, L., Brand, A. S., Mokaya, J., Strijdom, H., Goswami, N., et al. 2019. Ambient air pollution and health in Sub-Saharan Africa: Current evidence, perspectives and a call to action. Environ. Res. 173, 174-188. https://doi.org/10.1016/j.envres.2019.03.029.

Klepac, P., Locatelli, I., Korosec, S., Kunzli, N., Kukec, A. 2018. Ambient air pollution and pregnancy outcomes: A comprehensive review and identification of environmental public health challenges. Environ. Res. 167, 144-159. https://doi.org/10.1016/j.envres.2018.07.008.

Lamichhane, D. K., Leem, J. H., Lee, J. Y., Kim, H. C. 2015. A meta-analysis of exposure to particulate matter and adverse birth outcomes. Environ. Health Toxicol. 30, e2015011. https://doi.org/10.5620/eht.e2015011.

Lawn, J. E., Blencowe, H., Waiswa, P., Amouzou, A., Mathers, C., Hogan, D., et al. 2016. Stillbirths: rates, risk factors, and acceleration towards 2030. Lancet. 387(10018), 587-603. https://doi.org/https://doi.org/10.1016/S0140-6736(15)00837-5.

Lee, J. T. 2021. Review of epidemiological studies on air pollution and health effects in children. Clin. Exp. Pediatr. 64(1), 3-11. https://doi.org/10.3345/cep.2019.00843.

Li, C., Yang, M., Zhu, Z., Sun, S., Zhang, Q., Cao, J., et al. 2020. Maternal exposure to air pollution and the risk of low birth weight: A meta-analysis of cohort studies. Environ. Res. 190, 109970. PMID: 32763280. https://doi.org/10.1016/j.envres.2020.109970.
Li, X., Huang, S., Jiao, A., Yang, X., Yun, J., Wang, Y., et al. 2017. Association between ambient fine particulate matter and preterm birth or term low birth weight: An updated systematic review and meta-analysis. Environ. Pollut. 227, 596-605. https://doi.org/10.1016/j.envpol.2017.03.055.
Li, Z., Tang, Y., Song, X., Lazar, L., Li, Z., Zhao, J. 2019. Impact of ambient PM2.5 on adverse birth outcome and potential molecular mechanism. Ecotoxicol. Environ. Saf. 169, 248-254. https://doi.org/10.1016/j.ecoenv.2018.10.109.
Liu, C., Sun, J., Liu, Y., Liang, H., Wang, M., Wang, C., et al. 2017. Different exposure levels of fine particulate matter and preterm birth: a meta-analysis based on cohort studies. Environ. Sci. Pollut. Res. Int. 24(22), 17976-17984. https://doi.org/10.1007/s11356-017-9363-0
Liu, L., Ma, Y., Wang, N., Lin, W., Liu, Y., Wen, D. 2019. Maternal body mass index and risk of neonatal adverse outcomes in China: a systematic review and meta-analysis. BMC Pregnancy and Childbirth. 19(1), 105. https://doi.org/10.1186/s12884-019-2249-z.
Luo, D., Kuang, T., Chen, Y.-X., Huang, Y.-H., Zhang, H., Xia, Y.-Y. 2021. Air pollution and pregnancy outcomes based on exposure evaluation using a land use regression model: A systematic review. Taiwan J. Obstet. Gynecol. 60(2), 193-215. https://doi.org/https://doi.org/10.1016/j.tjog.2021.01.004.
Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E. 2020. Environmental and Health Impacts of Air Pollution: A Review [Review]. Front. Public Health. 8(14). https://doi.org/10.3389/fpubh.2020.00014.
Mannucci, P. M., Franchini, M. 2017. Health Effects of Ambient Air Pollution in Developing Countries. Int. J. Environ. Res. Public Health. 14(9), 1048. https://doi.org/10.3390/ijerph14091048.
Marczylo, E. L., Jacobs, M. N., Gant, T. W. 2016. Environmentally induced epigenetic toxicity: potential public health concerns. Crit. Rev. Toxicol. 46(8), 676-700. https://doi.org/10.1080/10408444.2016.1175417.
Martuzzi, M., Tickner, J. A. (2004). The precautionary principle: protecting public health, the environment and the future of our children. WHO Regional Office for Europe, Copenhagen, Denmark. Available at https://www.euro.who.int/__data/assets/pdf_file/0003/91173/E83079.pdf. Accesed May 19, 2021.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., The, P. G. 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLOS Med. 6(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097.
Mork, D., Wilson, A. 2021. Estimating perinatal critical windows of susceptibility to environmental mixtures via structured Bayesian regression tree pairs. Biometrics. n/a(n/a) https://doi.org/10.1111/biom.13568.
Morrison, A., Polisena, J., Husereau, D., Moulton, K., Clark, M., Fiander, M., et al. 2012. The effect of English-language restriction on systematic review-based meta-analyses: a systematic review of empirical studies. Int. J. Technol. Assess. Health Care. 28(2), 138-144. https://doi.org/10.1017/s0266462312000086.
Munn, Z., Aromataris, E., Tufanaru, C., Stern, C., Porritt, K., Farrow, J., et al. 2019. The development of software to support multiple systematic review types: the Joanna Briggs Institute System for the Unified Management, Assessment and Review of Information (JBI SUMARI). Int. J. Evid. Based Healthc. 17(1):36-43. Doi: 10.1097/XEB.0000000000000152.

Nieuwenhuijsen, M. J., Dadvand, P., Grellier, J., Martinez, D., Vrijheid, M. 2013. Environmental risk factors of pregnancy outcomes: a summary of recent meta-analyses of epidemiological studies. Environ Health, 12, 6. https://doi.org/10.1186/1476-069X-12-6.

Niyibizi, J., Zanré, N., Mayrand, M. H., Trottier, H. 2020. Association Between Maternal Human Papillomavirus Infection and Adverse Pregnancy Outcomes: Systematic Review and Meta-Analysis. J. Infect. Dis. 221(12), 1925-1937. https://doi.org/10.1093/infdis/jiaa054.

Nyadanu, S. D., Tessema, G. A., Mullins, B., Kumi-Boateng, B., Bell, M. L., Pereira, G. 2020. Ambient Air Pollution, Extreme Temperatures and Birth Outcomes: A Protocol for an Umbrella Review, Systematic Review and Meta-Analysis. Int. J. Environ. Res. Public Health. 17(22). https://doi.org/10.3390/ijerph17228658.

O'Donoghue, G., Kennedy, A., Puggina, A., Aleksovska, K., Buck, C., Burns, C., et al. 2018. Socio-economic determinants of physical activity across the life course: A "DEterminants of DIet and Physical ACtivity" (DEDIPAC) umbrella literature review. PLoS One, 13(1), e0190737. https://doi.org/10.1371/journal.pone.0190737.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 372, n71. https://doi.org/10.1136/bmj.n71.

Patra, J., Bakker, R., Irving, H., Jaddoe, V. W., Malini, S., Rehm, J. 2011. Dose-response relationship between alcohol consumption before and during pregnancy and the risks of low birthweight, preterm birth and small for gestational age (SGA)-a systematic review and meta-analyses. BJOG. 118(12), 1411-1421. https://doi.org/10.1111/j.1471-0528.2011.03050.x.

Pereira, G. 2021. Cut particulate air pollution, save lives. BMJ. 375, n2561. https://doi.org/10.1136/bmj.n2561.

Pereira, G., Bell, M. L., Honda, Y., Lee, J.-T., Morawska, L., Jalaludin, B. 2021. Energy transitions, air quality and health. Environ. Res. Lett. 16, 020202. https://doi.org/10.1088/1748-9326/abdaea.

Pereira, G., Bell, M. L., Lee, H. J., Koutrakis, P., Belanger, K. 2014. Sources of fine particulate matter and risk of preterm birth in Connecticut, 2000-2006: a longitudinal study. Environ. Health Perspect. 122(10), 1117-1122. https://doi.org/10.1289/ehp.1307741.

Pieper, D., Antoine, S. L., Mathes, T., Neugebauer, E. A., Eikermann, M. 2014. Systematic review finds overlapping reviews were not mentioned in every other overview. J. Clin. Epidemiol. 67(4), 368-375. https://doi.org/10.1016/j.jclinepi.2013.11.007.

Quinn, J. A., Munoz, F. M., Gonik, B., Frau, L., Cutland, C., Mallett-Moore, T., et al. 2016. Preterm birth: Case definition & guidelines for data collection, analysis, and presentation of immunisation safety data. Vaccine. 34(49), 6047-6056. https://doi.org/10.1016/j.vaccine.2016.03.045.

Rappazzo, K. M., Nichols, J. L., Rice, R. B., Luben, T. J. 2021. Ozone exposure during early pregnancy and preterm birth: A systematic review and meta-analysis. Environ. Res. 198, 111317. https://doi.org/10.1016/j.envres.2021.111317.

Rich, D. Q., Liu, K., Zhang, J., Thurston, S. W., Stevens, T. P., Pan, Y., et al. 2015. Differences in Birth Weight Associated with the 2008 Beijing Olympics Air Pollution Reduction: Results from a Natural Experiment. Environ. Health Perspect. 123(9), 880-887. https://doi.org/10.1289/ehp.1408795.

Rojas-Rueda, D., Morales-Zamora, E., Alsufyani, W. A., Herbst, C. H., AlBalawi, S. M., Alsukait, R., et al. 2021. Environmental Risk Factors and Health: An Umbrella Review of Meta-Analyses. Int. J. Environ. Res. Public Health. 18(2), 704. Doi:10.3390/ijerph18020704, https://www.mdpi.com/1660-4601/18/2/704.

Saenen, N. D., Martens, D. S., Neven, K. Y., Alfano, R., Bové, H., Janssen, B. G., et al. 2019. Air pollution-induced placental alterations: an interplay of oxidative stress, epigenetics, and the aging phenotype? Clin. Epigenetics. 11(1), 124. https://doi.org/10.1186/s13148-019-0688-z.

Sapkota, A., Chelikowsky, A. P., Nachman, K. E., Cohen, A. J., Ritz, B. 2010. Exposure to particulate matter and adverse birth outcomes: a comprehensive review and meta-analysis. Air Qual. Atmos. Health. 5(4), 369-381. https://doi.org/10.1007/s11869-010-0106-3.

Shaddick, G., Thomas, M. L., Mudu, P., Ruggeri, G., Gumy, S. 2020. Half the world's population are exposed to increasing air pollution. NPJ Clim. Atmos. Sci. 3(1), 23. https://doi.org/10.1038/s41612-020-0124-2.

Shah, P. S., Balkhair, T., Knowledge Synthesis Group on Determinants of Preterm, L. B. W. b. 2011. Air pollution and birth outcomes: a systematic review. Environ. Int. 37(2), 498-516. https://doi.org/10.1016/j.envint.2010.10.009.

Shea, B. J., Reeves, B. C., Wells, G., Thuku, M., Hamel, C., Moran, J., et al. 2017. AMSTAR 2: a critical appraisal tool for systematic reviews that include randomised or non-randomised studies of healthcare interventions, or both. BMJ. 358, j4008. https://doi.org/10.1136/bmj.j4008.

Siddika, N., Balogun, H. A., Amegah, A. K., Jaakkola, J. J. 2016. Prenatal ambient air pollution exposure and the risk of stillbirth: systematic review and meta-analysis of the empirical evidence. Occup. Environ. Med. 73(9), 573-581. https://doi.org/10.1136/oemed-2015-103086.

Simoncic, V., Enaux, C., Deguen, S., Kihal-Talantikite, W. 2020. Adverse Birth Outcomes Related to NO2 and PM Exposure: European Systematic Review and Meta-Analysis. Int. J. Environ. Res. Public Health. 17(21). https://doi.org/10.3390/ijerph17218116.

Slama, R., Darrow, L., Parker, J., Woodruff, T. J., Strickland, M., Nieuwenhuijsen, M., et al. 2008. Meeting report: atmospheric pollution and human reproduction. Environ. Health Perspect. 116(6), 791-798. https://doi.org/10.1289/ehp.11074.

Sleddens, E. F., Kroeze, W., Kohl, L. F., Bolten, L. M., Velema, E., Kaspers, P., et al. 2015a. Correlates of dietary behavior in adults: an umbrella review. Nutr. Rev. 73(8), 477-499. https://doi.org/10.1093/nutrit/nuv007.

Sleddens, E. F., Kroeze, W., Kohl, L. F., Bolten, L. M., Velema, E., Kaspers, P. J., et al. 2015b. Determinants of dietary behavior among youth: an umbrella review. Int. J. Behav. Nutr. Phys. Act. 12, 7. https://doi.org/10.1186/s12966-015-0164-x.

Steinle, S., Johnston, H. J., Loh, M., Mueller, W., Vardoulakis, S., Tantrakarnapa, K., et al. 2020. In Utero Exposure to Particulate Air Pollution during Pregnancy: Impact on Birth Weight and Health through the Life Course. Int. J. Environ. Res. Public Health. 17(23), 8948. Doi:10.3390/ijerph17238948, https://www.mdpi.com/1660-4601/17/23/8948.

Steinle, S., Reis, S., Sabel, C. E. 2013. Quantifying human exposure to air pollution—Moving from static monitoring to spatio-temporally resolved personal exposure assessment. Sci. Total Environ. 443, 184-193. https://doi.org/https://doi.org/10.1016/j.scitotenv.2012.10.098.

Stieb, D. M., Chen, L., Eshoul, M., Judek, S. 2012. Ambient air pollution, birth weight and preterm birth: a systematic review and meta-analysis. Environ. Res. 117, 100-111. https://doi.org/10.1016/j.envres.2012.05.007.

Stingone, J. A., Triantafillou, S., Larsen, A., Kitt, J. P., Shaw, G. M., Marsillach, J. 2021. Interdisciplinary data science to advance environmental health research and improve birth outcomes. Environ. Res. 197, 111019. https://doi.org/https://doi.org/10.1016/j.envres.2021.111019.

Stock, S., Zoega, H., Brockway, M., Mulholland, R., Miller, J., Been, J., et al. 2021. The international Perinatal Outcomes in the Pandemic (iPOP) study: protocol [version 1; peer review: 1 approved]. Wellcome Open Res. 6(21). https://doi.org/10.12688/wellcomeopenres.16507.1.

Stock, S. J., Bauld, L. 2020. Maternal smoking and preterm birth: An unresolved health challenge. PLoS Med. 17(9), e1003386. https://doi.org/10.1371/journal.pmed.1003386.

Street, M. E., Bernasconi, S. 2020. Endocrine-Disrupting Chemicals in Human Fetal Growth. Int. J. Mol. Sci. 21(4). https://doi.org/10.3390/ijms21041430.
Sun, X., Luo, X., Zhao, C., Chung Ng, R. W., Lim, C. E., Zhang, B., et al. 2015. The association between fine particulate matter exposure during pregnancy and preterm birth: a meta-analysis. BMC Pregnancy Childbirth. 15, 300. https://doi.org/10.1186/s12884-015-0738-2.
Sun, X., Luo, X., Zhao, C., Zhang, B., Tao, J., Yang, Z., et al. 2016. The associations between birth weight and exposure to fine particulate matter (PM2.5) and its chemical constituents during pregnancy: A meta-analysis. Environ. Pollut. 211, 38-47. https://doi.org/10.1016/j.envpol.2015.12.022.
Sun, Y., Ilango, S. D., Schwarz, L., Wang, Q., Chen, J.-C., Lawrence, J. M., et al. 2020. Examining the joint effects of heatwaves, air pollution, and green space on the risk of preterm birth in California. Environ. Res. Lett. 15(10), 104099. https://doi.org/10.1088/1748-9326/abb8a3.
Tanner, E., Lee, A., Colicino, E. 2020. Environmental mixtures and children's health: identifying appropriate statistical approaches. Curr. Opin. Pediatr. 32(2), 315-320. https://doi.org/10.1097/MOP.0000000000000877.
Thayamballi, N., Habiba, S., Laribi, O., Ebisu, K. 2020. Impact of Maternal Demographic and Socioeconomic Factors on the Association Between Particulate Matter and Adverse Birth Outcomes: a Systematic Review and Meta-analysis. J. Racial and Ethn. Health Disparities. https://doi.org/10.1007/s40615-020-00835-2.
Thompson, J. M., Eick, S. M., Dailey, C., Dale, A. P., Mehta, M., Nair, A., et al. 2019. Relationship Between Pregnancy-Associated Malaria and Adverse Pregnancy Outcomes: a Systematic Review and Meta-Analysis. J. Trop. Pediatr. 66(3), 327-338. https://doi.org/10.1093/tropej/fmz068.
Tsoli, S., Ploubidis, G. B., Kalantzi, O.-I. 2019. Particulate air pollution and birth weight: A systematic literature review. Atmos. Pollut. Res. 10(4), 1084-1122. https://doi.org/10.1016/j.apr.2019.01.016.
Tu, J., Tu, W., Tedders, S. H. 2016. Spatial variations in the associations of term birth weight with ambient air pollution in Georgia, USA. Environ. Int. 92-93, 146-156. https://doi.org/10.1016/j.envint.2016.04.005.
Uwak, I., Olson, N., Fuentes, A., Moriarty, M., Pulczinski, J., Lam, J., et al. 2021. Application of the navigation guide systematic review methodology to evaluate prenatal exposure to particulate matter air pollution and infant birth weight. Environ. Int. 148, 106378. https://doi.org/10.1016/j.envint.2021.106378.
Vervoort, D., Ma, X., Bookholane, H. 2021. Equitable Open Access Publishing: Changing the Financial Power Dynamics in Academia. Glob. Health: Sci. Pract. https://doi.org/10.9745/GHSP-D-21-00145.
Walter, C. M., Schneider-Futschik, E. K., Hall, N. L., Sly, P. D., Head, B. W., Knibbs, L. D. 2021. The health impacts of ambient air pollution in Australia: A systematic literature review. Intern. Med. J. https://doi.org/10.1111/imj.15415.
Wang, Y., Perera, F., Guo, J., Riley, K. W., Durham, T., Ross, Z., et al. 2021. A methodological pipeline to generate an epigenetic marker of prenatal exposure to air pollution indicators. Epigenetics. 1-9. https://doi.org/10.1080/15592294.2021.1872926.
Warren, J., Luben, T., Chang, H. H. 2020a. A spatially varying distributed lag model with application to an air pollution and term low birth weight study. J. R. Stat. Soc. Ser. C Appl. Stat. 69 3, 681-696. Doi: 10.1111/rssc.12407.
Warren, J. L., Kong, W., Luben, T. J., Chang, H. H. 2020b. Critical window variable selection: estimating the impact of air pollution on very preterm birth. Biostatistics. 21(4), 790-806. https://doi.org/10.1093/biostatistics/kxz006.
Wasserstein, R. L., Schirm, A. L., Lazar, N. A. 2019. Moving to a World Beyond “p < 0.05”. Am. Stat. 73(sup1), 1-19. https://doi.org/10.1080/00031305.2019.1583913.

Westergaard, N., Gehring, U., Slama, R., Pedersen, M. 2017. Ambient air pollution and low birth weight - are some women more vulnerable than others? Environ. Int. 104, 146-154. https://doi.org/10.1016/j.envint.2017.03.026
Whaley, P., Aiassa, E., Beausoleil, C., Beronius, A., Bilotta, G., Boobis, A., et al. 2020. Recommendations for the conduct of systematic reviews in toxicology and environmental health research (COSTER). Environ. Int. 143, 105926. https://doi.org/https://doi.org/10.1016/j.envint.2020.105926.
WHO, World Health Organization. (2006). WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide : global update 2005 : summary of risk assessment. https://apps.who.int/iris/handle/10665/69477. Accessed April 7, 2021.
WHO, World Health Organization. (2018). Air pollution and child health: prescribing clean air: summary. https://apps.who.int/iris/handle/10665/275545. Accessed April 7, 2021.
WHO, World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329. Accessed October 20, 2021.
Wilson, A., Chiu, Y. M., Hsu, H. L., Wright, R. O., Wright, R. J., Coull, B. A. 2017. Potential for Bias When Estimating Critical Windows for Air Pollution in Children's Health. Am. J. Epidemiol. 186(11), 1281-1289. https://doi.org/10.1093/aje/kwx184.
Wilson, A., Hsu, H.-H. L., Mathilda Chiu, Y.-H., Wright, R. O., Wright, R. J., Coull, B. A. (2019). Kernel Machine and Distributed Lag Models for Assessing Windows of Susceptibility to Environmental Mixtures in Children's Health Studies. arXiv:1904.12417. https://ui.adsabs.harvard.edu/abs/2019arXiv190412417W . Last revised September 22, 2021.
Woodruff, T. J., Sutton, P. 2014. The Navigation Guide systematic review methodology: a rigorous and transparent method for translating environmental health science into better health outcomes. Environ. Health Perspect. 122(10), 1007-1014. https://doi.org/10.1289/ehp.1307175.
Xie, G., Sun, L., Yang, W., Wang, R., Shang, L., Yang, L., et al. 2021. Maternal exposure to PM2.5 was linked to elevated risk of stillbirth. Chemosphere. 283, 131169. https://doi.org/10.1016/j.chemosphere.2021.131169.
Xue, T., Guan, T., Geng, G., Zhang, Q., Zhao, Y., Zhu, T. 2021. Estimation of pregnancy losses attributable to exposure to ambient fine particles in south Asia: an epidemiological case-control study. Lancet Planet. Health. 5(1), e15-e24. https://doi.org/10.1016/S2542-5196(20)30268-0.
Xue, T., Zhu, T., Geng, G., Zhang, Q. 2019. Association between pregnancy loss and ambient PM2·5 using survey data in Africa: a longitudinal case-control study, 1998-2016. Lancet Planet. Health. 3 5, e219-ee225. https://doi.org/10.1016/S2542-5196(19)30047-6.
Young, M. F., Ramakrishnan, U. 2020. Maternal Undernutrition before and during Pregnancy and Offspring Health and Development. Ann. Nutr. Metab. 76(suppl 3)(3), 41-53. https://doi.org/10.1159/000510595.
Yuan, L., Zhang, Y., Gao, Y., Tian, Y. 2019. Maternal fine particulate matter (PM2.5) exposure and adverse birth outcomes: an updated systematic review based on cohort studies. Environ. Sci. Pollut. Res. Int. 26(14), 13963-13983. https://doi.org/10.1007/s11356-019-04644-x.
Zeiher, J., Ombrellaro, K. J., Perumal, N., Keil, T., Mensink, G. B. M., Finger, J. D. 2019. Correlates and Determinants of Cardiorespiratory Fitness in Adults: a Systematic Review. Sports Med. - Open, 5(1), 39. https://doi.org/10.1186/s40798-019-0211-2.
Zhang, H., Zhang, X., Wang, Q., Xu, Y., Feng, Y., Yu, Z., et al. 2021. Ambient air pollution and stillbirth: An updated systematic review and meta-analysis of epidemiological studies. Environ. Pollut. 278, 116752. https://doi.org/10.1016/j.envpol.2021.116752.

Zhang, K., Lu, Y., Zhao, H., Guo, J., Gehendra, M., Qiu, H., et al. 2016. Association between atmospheric particulate matter and adverse pregnancy outcomes in the population. Int. J. Clin. Exp. Med. 9(11), 20594-20604.

Zhu, W., Zheng, H., Liu, J., Cai, J., Wang, G., Li, Y., et al. 2022. The correlation between chronic exposure to particulate matter and spontaneous abortion: A meta-analysis. Chemosphere. 286, 131802. https://doi.org/https://doi.org/10.1016/j.chemosphere.2021.131802.

Zhu, X., Liu, Y., Chen, Y., Yao, C., Che, Z., Cao, J. 2015. Maternal exposure to fine particulate matter (PM2.5) and pregnancy outcomes: a meta-analysis. Environ. Sci. Pollut. Res. Int. 22(5), 3383-3396. https://doi.org/10.1007/s11356-014-3458-7.

Tables

Table 1**.** Characteristics of systematic reviews without meta-analysis, ordered from most recent to earliest publication

First author, date [number of authors, countries]	**Exposure type and range or IQR**	**Outcome**	**Number of Databases, grey literature searched**	**Search date range and languages applied**	**No. of primary studies, study design, coverage**	**Publication year range**	**Total births**	**Risk of bias tool**	**Quality rating summary**	**Reporting guideline**	**Evidence of pre-specified review protocol**
1. Edwards (Edwards et al., 2022) 12/10/2021 [4; 3 UK and 1 Nepal]	$PM_{2.5}$, PM_{10}, NO_2, SO_2 Ranges: NA	LBW, SGA, PTB	Db =3 Grey =No	01/1989 - 10/2020. English	3 total: all cohort	2010-2019	663,255	Adapted the Navigation Guide tool	2 'probably low' and 1 'probably high'.	PRISMA	Open Science Foundation
2. Walter (Walter et al., 2021), 08/06/2021 [6; all Australia]	$PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3, CO. Ranges NA	LBW, BW, SGA, PTB	Db = 2 Grey = No	Inception - 01/07/2019. English	9 total: 8 cohort, 1 case-crossover. Australia	2006-2019	356382	NOS, Navigation Guide, and Mustafic's criteria	Moderate and high	PRISMA	No
3. Luo (Luo et al., 2021) 09/03/2021 [6; 5 China and 1 UK]	$PM_{2.5}$: 1.1-20.1 $\mu g/m^3$ PM_{10}: 3.3 - 39.2 $\mu g/m^3$ NO_2: 9.4 - 64.1 $\mu g/m^3$ NO: 2.7 - 39.5 ppb NO_x: 19.6 - 102.8 ppb	PTB, BW, LBW, SGA	Db= 6 Grey = No	Inception - 01/05/2019. English and Chinese.	39 total: 35 cohort, 4 case-control	2007-2019	10,533,974	NOS	7-9	No	No
4. Bekkar (Bekkar et al., 2020) 18/06/2020 [4; all USA]	$PM_{2.5}$:1.3 - 6.9 $\mu g/m^3$ O_3: 7.1 - 11.5 ppb	PTB, LBW, and SB	Db= 3 Grey =2	01/01/2007 - 30/04/2019. English	51 total: (43 retrospective cohort, 2 cross-sectional, 4 time series,	2007-2019	30,731,001	No	No	Arskey O'Malley PRISMA	No

					3 case-control. USA						
5. Heo (Heo et al., 2019) 12/11/2019 [3; All USA]	PM_{10}, $PM_{2.5}$ ($PM_{2.5-10}$, PM_1, $PM_{0.1}$) Ranges NA	PTB, LBW, SGA, and SB	Db=1 Grey = No	01/01/2000 - 07/07/2019. English	44 total: 35 case-control, 5 cohort, 1 case-control/cohort, 2 time-series, 1 ecologic. USA	1999-2019	41,793,876	No	No	STROBE, HEQAT, Cochrane.	No
6. Yuan (Yuan et al., 2019) 20/03/2019 [4; all China]	$PM_{2.5}$: 1.8 - 71.9 μg/m^3	BW, LBW, SGA, PTB	Db=1 Grey = No	01/2008 - 22/07/2017. English and Chinese.	42 total: 6 prospective, 35 retrospective cohort and 1 nested case-control. Global	2008-2017	33,419,565	No	No	No	No
7. Tsoli (Tsoli et al., 2019) 31/01/2019 [3; 2 Greece and 1 UK]	$PM_{2.5}$, PM_{10}, $PM_{2.5-10}$, PM_1, TSP Ranges NA	TBW, TLBW	Db=2 Grey = No	Inception - 08/2018. English	82 total:: 73 cohort, 6 ecological, 2 case-control, 1 cross-sectional. Global.	1997-2018	39,056,189	No	No	No	No#
8. Grippo (Grippo et al., 2018) 25/09/2018 [8; 3 USA and 5 China]	TSP, PM_{10}, $PM_{2.5}$, CO, SO_2, NO_2, O_3 Ranges NA	SAB (miscarriage) and SB	Db= 1 Grey = No	Inception - 03/2018. No language indicated	15 total: 3 each prospective cohort, retrospective cohort, and time-series, 4	1998-2018	4,432,632	No	No	No	No

					case-control and 1 each cross-sectional and ecological. Global						
9. Westergaard (Westergaard et al., 2017) 06/04/2017 [4; 2 Denmark, 1 Netherlands, and 1 France]	$PM_{2.5}$: 9.1 - 32.4 μg/m^3 NO_2: 13.4 ppb (one study) SO_2: NA O_3: NA SPM: NA	TLBW	Db=2 Grey= No	Inception – 21/08/2016. English	6 total: 1 prospective, 4 retrospective and 1 nationwide longitudinal survey. Global.	2013-2016	5,149,128 births	No	No	No	No
10. Jacobs (Jacobs et al., 2017) 01/02/2017 [9; 8 Australia and 1 USA]	$PM_{2.5}$: 61 μg/m^3 (one study) PM_{10}: 40 - 212 μg/m^3, NO_2: 24 - 61 μg/m^3, SO_2: 16 -102 μg/m^3 CO: 814 - 1730 μg/m^3 O_3: 61 μg/m^3 (one study)	BW, LBW, PTB, SB	Db= 5 Grey = No	1980 - 2015. English and Chinese	17 total: 2 prospective cohort, 4 retrospective cohort, 3 case-control, 1 case-crossover, 7 cross-sectional. China	1995-2015	505,734 births	Berman and Parker (2002) criteria	Stated but not reported	PRISMA	No
11. Shah (Shah et al., 2011) (26/11/2010) [2; both Canada]	PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, TSP. Ranges NA	LBW, PTB, SGA/IUGR, BW	Db=3 Grey = No	Inception - 15/10/2010. English	40 total: 30 cohorts, 4 case-control, 5 ecological Global.	1987-2011	7,476,326 births	Referred to their previous checklist	38/40 included studies had an overall moderate RoB, whereas 2 studies had a low RoB	MOOSE	No*

12. Bonzini (Bonzini et al., 2010) 09/2010 [6; All Italy]	$PM_{2.5}$: 5.1 - 25.4 μg/m^3 PM_{10}: 16.3 - 89.7 μg/m^3 NO_2: 10.4 - 117.9 μg/m^3 O_3: 33 - 91.4 μg/m^3 CO: 0.5-17.8 mg/m^3	PTB, LBW, SGA, BW	Db = 1 Grey = No	01/2004 - 12/2008. English.	18 total: 12 birth cohort, 1 matched case-control, 5 time-series.	2004-2008	1,987,093	No	No	No	No
13. Bosetti (Bosetti et al., 2010) 06/02/2010 [6; 5 Italy and 1 Spain]	$PM_{2.5}$: 5.3 - 21.9 μg/m^3 PM_{10}:3.2 - 889.7 μg/m^3 TSP: 68.5 - 375 μg/m^3	PTB, LBW, VLBW, SGA	Db= 1 Grey = No	1966 - 06/2009. English	30 total : 22 cross-sectional*, 4 time series, 3 case-control, 1 ecological Global	1995-2008	2,848,020	No	No	No	No
14. Ghosh (Ghosh et al., 2007) 09/05/2007 [4; all UK]	$PM_{2.5}$: 10.3 - 43.0 μg/m^3 PM_{10}: 31.5 - 85.9 μg/m^3 TSP: 5.93 μg/m^3 CO: 1.0 - 1.7 ppm SO_2: 3.8 -308 μg/m^3 NO_2: 12.1 - 43.5 ppb O_3: 18 - 27.23 ppb	BW, LBW, VLBW, PTB	Db=10 Grey = No	1966 -2005. English	5 total: 2 retrospective cohort, 1 prospective cohort, 2 case-control. Global	1997-2004	146,271	Developed a checklist from other guidelines	4 studies were rated 'fully meet the quality criteria' and 1 rated 'satisfactory'	Cochrane.	No
15. Glinianaia (Glinianaia et al., 2004) 09/01/2004 [5; all UK]	TSP, $TSPSO_2$, PM_{10}, $PM_{2.5}$ Ranges NA	LBW, VLBW, IUGR, PTB, and SB	Db=12 Grey =3	01/01/1996 – 31/12/2001. English	11 total: 8 cohorts, 1 case-control, 1 time-series, 1 ecological	1997-2001	Not provided for primary studies	No	No	CRD's Guidance and the U.K. National Health Service	No

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Note: NO_2, Nitrogen dioxide; NO_x, Nitrogen oxides; CO, Carbon monoxide; O_3, Ozone; SO_2, Sulphur dioxide; $PM_{2.5}$, particulate matter at aerodynamic diameter ≤ 2.5μm; $PM_{10,}$ particulate matter with aerodynamic diameter ≤ 10μm; TSP, total suspended particles; SPM, suspended particulate matter; $\mu g/m^3$, micrograms per cubic meter; ppm, parts per million; ppb, parts per billion; NA, not available; IQR, interquartile range; PTB, preterm birth; BW, birth weight; LBW, low birth weight; TLBW, term low birth weight; VLBW, very low birth weight; SGA, small-for-gestational age; IUGR, intrauterine growth retardation; SB, stillbirth; SAB, spontaneous abortion; Db, database; NOS, Newcastle- Ottawa scale; USA, United States of America; UK, United Kingdom; PRISMA, Preferred Reporting Items for Systematic reviews and Meta-Analyses; MOOSE, The Strengthening the Reporting of Observational Studies in Epidemiology; STROBE, Strengthening the reporting of observational studies in epidemiology; HEQAT, Health Evidence Quality Assessment Tool. Statement[#] “A review protocol reporting inclusion and exclusion criteria was available during the screening process to consolidate reviewers' judgement. The review protocol was not registered.” Statements[*] “The methods adopted by our group for systematically reviewing birth outcomes of various determinants have been described previously and are briefly outlined below (Shahand Zao, 2009; McDonald et al., 2010). A decision was made a priori to systematically review these data rather than to perform meta-analyses, as heterogeneities were identified in previous reviews”. *The cross-sectional used in this review included studies for birth cohorts classified in almost all reviews as retrospective cohort study design.

Table 2. Characteristics of systematic reviews with meta-analysis, ordered from recent to earliest.

First author, date [number of authors, countries]	Exposure type and range or IQR	Outcome	Number of databases (Db) and grey literature searched	Search date range and languages applied	No. of primary studies and study designs, coverage	Publication year range	Total births	RoB tool	Quality rating summary	Reporting guidelines	Evidence of pre-specified review protocol
1. Gong (Gong et al., 2022) 04/10/2021 [5; 4 China and 1 USA]	PM2.5: Range: 8.43 -66.09 μg/m^3	TBW (continuous outcome)	Db =6 Grey=No	Inception – 03/03/2021. English and Chinese.	31 total: all cohort.	2008-2021	24,824,520	NOS for quality assessment. GRADE handbook to grade certainty of evidence	22/31 studies had high NOS score (≥ 7; high quality) and 9 had medium scores. 'Very low' quality of the effect estimates in all meta-analysis due to high heterogeneity but moderate for the LUR-models subgroup.	PRISMA	No
2. *Zhu (Zhu et al., 2022) 03/08/2021 [11; all China]	$PM_{2.5}$, PM_{10} Range: NA	SAB	Db=3 Grey=No	Inception – 01/02/2021. English	6 total: 3 cohort, 3 case-control	2014-2021	735,719 natural pregnancies (65,726 SABs)	NOS for quality assessment. GRADE pro app to grade the certainty	All studies were "high quality" (NOS score ≥ 7). GRADE results of PM2.5 and PM10 were	PRISMA	No

								of evidence	both “moderate”		
3. Ju (Ju et al., 2021) 09/07/2021 [7; all China]	$PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3. Ranges: NA	PTB (including subtypes: moderate, very, and extremely PTB). 2.8 – 11.76%	Db=2 Grey=No	Inception - 10/2020. English	60 total: all cohort	1995-2020	21, 872,454 (1,499, 479; 6.86% PTB)	NOS	Included only studies with a total score of 7–9 (‘high quality’)	No	No
4. Xie (Xie et al., 2021) 13/06/2021 [10; 9 China and 1 USA]	$PM_{2.5}$: 11.8 – 70.6 μg/m^3	Stillbirth	Db=4 Grey=No	Inception – 18/10/2020 . English	7 total: 6 cohorts and 1 case-control. Global	2012-2020	4,342,251	Navigation Guide RoB criteria	“Low” or “Probably low” risk of bias	PRISMA	PROSPERO
5. Rappazzo (Rappazzo et al., 2021) 12/05/ 2021 [4; all USA]	O_3: 17 - 57 ppb	PTB	Db=2 Grey = 1	Inception - 31/01/2021 . English	20 total:17 cohort, 3 case-control Global	2005 - 2021	5,031,661	OHAT	One high, and 9 each ranked medium and low confidence overall	No	No
6. Zhang (Zhang et al., 2021) 22/02/2021 [7; All China]	$PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3 Ranges: NA	SB	Db=4 Grey=No	Inception – 11/12/2020 . No language indicated	14 total: 3 prospective and 5 retrospective cohorts, 2 case-control, 3 case-crossover, 1 time series. Global	2007-2020	7,227,534	NOS and OHAT tools	“Most included studies showed “low” or “probably low” risk, and “were of high quality.	PRISMA	No
7. Uwak (Uwak et al., 2021) 25/01/2021 [13, All USA]	$PM_{2.5}$, PM_{10}, and $PM_{2.5-10}$	BW	Db=3 Grey=No	Inception – 27/02/2020 . English	54 total: 43 retrospective , 9 prospective	2003-2020	57,960,152	Navigation Guide RoB	$PM_{2.5}$: 12/30 studies were rated overall as “low” or	Navigation guide systematic review	PROSPERO

	Ranges: NA				cohorts, 2 cross-sectional. Global.			criteria as	"probably low". PM_{10}: 10/29 studies were rated overall as "low" or "probably low" but high risk for all 5 studies on coarse PM.	methodology	
8. Simonici (Simoncic et al., 2020) 03/11/2020 [4, All France]	$PM_{2.5}$, PM_{10}, NO_2 Ranges: NA	BW/LBW, PTB, SGA	Db=1 Grey=No	Inception – 01/04/2020. English	30 total: 20 cohorts, 9 ecological time series, 1 spatial. Europe	2002-2019	3,466,265	Adapted from Croteau et al (2009) and Doi and Thalib (2008).	Minimum score was 0.806 out of 1.000	PRISMA	No
9. Thayamballi (Thayamballi et al., 2020) 08/09/2020 [4; all USA]	$PM_{2.5}$: 1.0-7.6 μg/m^3 PM_{10}: 2.7 - 7.4 μg/m^3	BW, LBW/TLBW, PTB, SGA, Stillbirth	Db=4 Grey=No	Inception – 30/06/2018. English	18 total. Unreported study design. USA	2007-2017	17,779,343	Unclear	Unclear	No	No
10. Li (Li et al., 2020) 04/08/2020 [7, all China]	$PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, and O_3 Ranges NA	LBW	Db=2 Grey=No	Inception – 06/2020.English	54 total: all cohort Global	1997-2020	27,087,009	NOS	High qualities: scores 7-9.	No	No
11. Ji (Ji et al., 2017) 30/05/2017 [6; All China]	$PM_{2.5}$ and PM_{10} Ranges NA	TLBW	Db = 5 Grey = No	Inception – 06/03/2017. English and Chinese	14 total: all cohort Global	2004-2016	933,272	NOS	7 high quality and 7 moderate quality	PRISMA	No

12. Liu (Liu et al., 2017) 15/06/2017 [7; all China]	$PM_{2.5}$: 5.1-70.8 μg/m^3	PTB	Db=5 Grey=No	No date indicated English and Chinese	11 total: 7 retrospective and 3 prospective cohorts, 1 nested case-control. Global	2007-2016	1,207,542	NOS	Average NOS score is 8	MOOSE	No
13. Li (Li et al., 2017) 28/04/2017 [17; all China]	$PM_{2.5}$: 1.8 - 22.1 μg/m^3	TLBW, PTB	Db=4 Grey=No	12/2015 - 07/2016 in English and Chinese	24 total : 19 retrospective cohort, 1 prospective cohort, 2 case-control, 1 and 1 cross-sectional. Global	2006-2016	14,600,860	NOS and AHRQ	Mean score ranged 6 to 8	MOOSE	No
14. Zhang (Zhang et al., 2016) 30/11/2016 [8; All China]	$PM_{2.5}$, PM_{10} Ranges: NA	SGA/IUGR, SGA, SB, SAB	Db=4 Grey=No	Inception - 31/12/2015 . English	17 studies: 14 retrospective cohort, 2 case-control, 1 cross-sectional. Global.	2005-2015	6,506,961	No	No	No	No
15. Siddika (Siddika et al., 2016) 24/05/2016 [4; 3 Finland and 1 Ghana]	PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3. Ranges: NA	SB	Db=3 Grey=No	Inception – 04/2015 "without any language restriction."	11 total :1 prospective cohort, 5 retrospective cohort, 1 case-control, 1 case-crossover, 1 daily time-series, 2 ecological. Global	1984-2015	4,467,963	NOS	Very high quality (3 studies), high quality (1 study).	No	No

16. Sun (Sun et al., 2016) 29/12/2015 [8, all China]	$PM_{2.5}$: 5.1-43.8 μg/m^3	LBW, BW	Db=5 Grey=No	Inception – 03/2015. English and Chinese	32 total: 4 prospective and 28 retrospective cohorts. Global	2004-2015	15,951,040	No	No	No	No
17. Sun (Sun et al., 2015) 18/11/2015 [7; 5 China and 2 Australia]	$PM_{2.5}$: 5.1-22.1 μg/m^3	PTB	Db=5 Grey=No	Inception – 12/2014. English and Chinese	19 total: 13 retrospective and 6 prospective cohort studies. Global	2005-2014	6,091,718	NOS	The average NOS quality score is 8	PRISMA	No
18. Lamichhane (Lamichhane et al., 2015) 03/11/2015 [4; All Incheon, Korea]	$PM_{2.5}$: 5.1 -21.9 μg/m^3 PM_{10}: 3.0 - 142.1 μg/m^3	PTB, BW.	Db= 2 Grey = No	01/1980 - 04/2015. English	44 total: 40 cohort, 4 case-control. Global	2000-2015	11,502,353	Downs and Black checklists	"14 studies were rated as relatively high quality (score≥15) and 13 rated as relatively low quality (score <15)."	MOOSE	No
19. Zhu (Zhu et al., 2015) 28/08/2014 [6, all China]	$PM_{2.5}$ Ranges: NA	BW, LBW, PTB, SGA, and stillbirth	Db= 3 Grey = 1	Inception – 01/03/2014. English	26 total: 25 cohort studies and 1 case-control. Global	2005-2014	10,719,453	No	No	No	No
20. Stieb (Stieb et al., 2012) 21/06/2012 [4, all Canada]	$PM_{2.5}$: 1.8 - 44.2 μg/m^3 PM_{10}: 3.3 - 89.7 μg/m^3 NO_2: 6.2 - 36.6 ppb SO_2: 1.1 - 12.2 ppb CO: 0.5 - 4.6 ppm	BW, LBW/VLBW (3.5 - 17.3%), PTB (3.3 - 10.3%), SGA/IUGR	Db = 8 Grey = No	01/01/1980 -01/2011 English	62 total: 54 cohort, 6 case-control, 2 ecological. Global	1987-2011	9,697,911	No	No	No	No

	O_3:13.4 - 34.1 ppb										
21. Sapkota (Sapkota et al., 2010) 23/11/2010 [5, all USA]	$PM_{2.5}$: 5.1 - 21.9 $\mu g/m^3$ PM_{10}: 11.8 - 71.1 $\mu g/m^3$	LBW/TLBW, PTB	Db= 2 Grey = No	Inception – 07/2009.No information on language	20 total: Unreported study designs. Global	2000-2009	3,134,406	No	No	No	No

*Zhu et al (2022) included 6 articles with 7 studies because one cohort study additionally reported separate results from case-crossover design.

Note: NO_2, Nitrogen dioxide; CO, Carbon monoxide; O_3, Ozone; SO_2, Sulphur dioxide; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5μm; $PM_{10,}$ particulate matter with aerodynamic diameter ≤ 10μm; $\mu g/m^3$, micrograms per cubic meter; ppm, parts per million; ppb, parts per billion; NA, not available; IQR, interquartile range; PTB, preterm birth; BW, birth weight; LBW, low birth weight; TLBW, term low birth weight; VLBW, very low birth weight; SGA, small-for-gestational age; IUGR, intrauterine growth retardation; SB, stillbirth; SAB, spontaneous abortion; Db, database; RoB, Risk of bias; USA, United States of America; UK, United Kingdom; PRISMA, Preferred Reporting Items for Systematic reviews and Meta-Analyses; MOOSE, The Strengthening the Reporting of Observational Studies in Epidemiology; NOS, Newcastle-Ottawa Scale; OHAT, Office of Health Assessment and Translation; AHRQ, Agency for Healthcare Research and Quality; PROSPERO, International prospective register of systematic reviews.

Table 3. Association between birth weight and ambient air pollution

Pollutant (incremental units)	Exposure period	Meta-analysis	Change in birthweight (g) (95% CI)	I^2 (%)	Primary studies (n)	Total births (N)	Consistency, confidence
$PM_{2.5}$ (10 µg/m^3)	Entire Pregnancy	Gong (2021)	-17 (-20, -13)	96	26	23,926,140	++, Pe
		Uwak (2021)	-28 (-48, -7)	94	15	15,424,198	
		Sun (2016)	-16 (-27, -5)	99	17	7,857,127	
		Lamichhane (2015)	-22 (-38, -6)	92	7	2,090,972	
		Zhu (2015)	-15 (-19, -10)	87	12	7,388,985	
		Stieb (2012)	-23 (-46, -1)	95	7	4,271,411	
	Trimester 1	Gong (2021)	-6 (-8, -3)	91	13	6,707,042	+, Pe
		Uwak (2021)	-7 (-15, 2)	87	11	3,547,223	
		Sun (2016)	-8 (-17, 0)	90	11	NA	
		Lamichhane (2015)	-6 (-20, 7)	88	5	1,261,503	
		Zhu (2015)	-7 (-14, 0)	82	7	5,153,167	
		Stieb (2012)	0 (-10, 9)	37	4	3,637,501	
	Trimester 2	Gong (2021)	-6 (-8, -4)	85	13	6,707,042	+, Pe
		Uwak (2021)	-6 (-11, -1)	68	11	3,547,223	
		Sun (2016)	-13 (-22, -3)	92	10	NA	
		Lamichhane (2015)	-11 (-19, -2)	82	4	1,257,650	
		Zhu (2015)	-8 (-15, -1)	85	5	4,742,687	
		Stieb (2012)	-15 (-34, 5)	75	4	3,634,129	
	Trimester 3	Gong (2021)	-5 (-8, -2)	94	20	10,361,367	+, Pe
		Uwak (2021)	-11 (-21, 0)	84	12	3,556,290	
		Sun (2016)	-10 (-17, -4)	86	13	NA	
		Lamichhane (2015)	-8 (-10, -5)	0	6	2,236,549	
		Zhu (2015)	-15 (-22, -8)	86	7	5,153,167	
		Stieb (2012)	-16 (-37, 1)	86	4	3,637,501	
PM_{10} (10 µg/m^3)	Entire Pregnancy	Uwak (2021)	-9 (-17, 0)	84	8	2,679,928	+, Pe
		Lamichhane (2015)	-10 (-14, -7)	0	5	477,123	
		Stieb (2012)	-8 (-10, -7)	16	7	3,932,746	

	Trimester 1	Uwak (2021)	3 (-3, 10)	14	6	757,843	+, Pe
		Lamichhane (2015)	-1 (-5, 2)	0	4	507,286	
		Stieb (2012)	-2 (-4, 1)	67	10	4,505,769	
	Trimester 2	Uwak (2021)	-3 (-8, 1)	0	6	757,843	+, Pe
		Lamichhane (2015)	-7 (-14, 1)	68	4	507286	
		Stieb (2012)	-2 (-4, 0)	41	10	4,505,769	
	Trimester 3	Uwak (2021)	-7 (-11, -2)	0	7	766,910	+, Pe
		Lamichhane (2015)	-5 (-8, -2)	0	5	913,913	
		Stieb (2012)	-2 (-7, 3)	93	10	4,505,769	
CO (100 ppb)	Entire Pregnancy	Stieb (2012)	-1 (-3, 1)	95	4	3,702,544	0, Pe
	Trimester 1	Stieb (2012)	0 (-1, 0)	95	8	4,576,045	0, Pe
	Trimester 2	Stieb (2012)	0 (0, 0)	0	7	4,299,282	0, Pe
	Trimester 3	Stieb (2012)	0 (-1, 1)	91	7	4,299,282	0, Pe
NO_2 (10 ppb)	Entire Pregnancy	Simonici (2020)	-3 (-12, 7)	28	6	86,680	+, Pe
		Stieb (2012)	-14 (-22, -6)	85	10	3,780,571	
	Trimester 1	Simonici (2020)	-27 (-56, 2)	36	4	3,435	+, Pe
		Stieb (2012)	-2 (-10, 5)	90	11	4,259,729	
	Trimester 2	Simonici (2020)	-17 (-46, 13)	26	4	3,435	0, Pe
		Stieb (2012)	0 (-1, 1)	0	9	3,979,113	
	Trimester 3	Simonici (2020)	-3 (-26, 19)	32	5	12,502	+, Pe
		Stieb (2012)	-4 (-15, 7)	94	10	3,982,966	
O_3 (10 ppb)	Entire Pregnancy	Stieb (2012)	-5 (-16, 6)	81	4	3,370,657	0, Pe
	Trimester 1	Stieb (2012)	1 (-3, 5)	81	8	4,325,899	0, Pe
	Trimester 2	Stieb (2012)	-5 (-9, -2)	77	8	4,325,899	+, Pe
	Trimester 3	Stieb (2012)	-1 (-4, 1)	80	8	4,325,899	0, Pe
SO_2 (10 ppb)	Entire Pregnancy	Stieb (2012)	15 (-15, 45)	80	3	3,718,863	0, Pe
	Trimester 1	Stieb (2012)	-15 (-42, 12)	95	6	4,098,747	0, Pe
	Trimester 2	Stieb (2012)	9 (-9, 28)	66	4	3,808,425	0, Pe
	Trimester 3	Stieb (2012)	15 (-5, 35)	93	5	3,883,096	0, Pe

Note: NO_2, Nitrogen dioxide; CO, Carbon monoxide; O_3, Ozone; SO_2, Sulphur dioxide; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5μm; PM_{10}, particulate matter with aerodynamic diameter ≤ 10μm; BW, birth weight; OR, odd ratio; CI, confidence intervals; ppb, parts per billion; NA, Not available; I^2, Heterogeneity; '++' represents more consistent positive association; '+' represents less consistent positive association; '0' represents contradictory/unclear direction; Pe, probable evidence of the observed direction of exposure effect.

Table 4. Association between low birth weight (LBW) and ambient air pollution

Pollutant (incremental units)	**Exposure period**	**Meta-analysis**	**OR (95% CI)**	**I^2 (%)**	**Primary studies (n)**	**Total births (N)**	**Consistency, confidence**
$PM_{2.5}$ (10 µg/m^3)	Entire Pregnancy	*Li (2020)	1.08 (1.04, 1.12)	86	29	536,218	+, Pe
		Ji (2017)	1.04 (0.99, 1.09)	67	6	594,626	
		Li (2017)	1.05 (0.98, 1.12)	85	4	8,226,866	
		Sun (2016)	1.09 (1.03, 1.15)	93	19	10,405,729	
		Zhu (2015)	1.05 (1.02, 1.07)	40	6	5,691,348	
		Stieb (2012)	1.05 (0.99, 1.12)	86	5	4,160,105	
		Sapkota (2010)	1.09 (0.90, 1.32)	57	4	831,042	
	Trimester 1	Li (2020)	1.03 (0.97, 1.09)	95	19	NA	+, Pe
		Ji (2017)	1.01 (0.98, 1.03)	0	3	436,799	
		Li (2017)	1.00 (0.91, 1.11)	90	3	1,163,751	
		Sun (2016)	1.03 (0.93, 1.13)	87	7	NA	
	Trimester 2	Li (2020)	1.03 (0.98, 1.08)	92	20	NA	+, Pe
		Ji (2017)	1.15 (0.96, 1.38)	66	3	436,799	
		Li (2017)	1.00 (0.96, 1.03)	81	4	1,587,470	
		Sun (2016)	1.04 (0.95, 1.13)	80	7	NA	
	Trimester 3	Li (2020)	1.05 (1.01, 1.10)	92	20	NA	+, Pe
		Ji (2017)	1.17 (0.94, 1.46)	79	3	436,799	
		Li (2017)	1.03 (0.98, 1.09)	55	3	1,163,751	
		Sun (2016)	1.23 (0.96, 1.59)	99	8	NA	
PM_{10} (10 µg/m^3)	Entire Pregnancy	Li (2020)	1.05 (1.03, 1.08)	70	23	286,188	+, Pe
		Ji (2017)	1.01 (0.96, 1.08)	68	9	326,518	
		Stieb (2012)	1.05 (1.02, 1.07)	68	14	4,419,929	
		Sapkota (2010)	1.02 (0.99, 1.05)	55	11	1,935,404	
	Trimester 1	Li (2020)	1.02 (1.00, 1.05)	72	13	NA	+, Pe
		Ji (2017)	1.06 (0.99, 1.12)	20	7	315,469	
		Stieb (2012)	1.01 (0.97, 1.05)	42	7	1,153,736	

		Sapkota (2010)	1.00 (0.97, 1.03)	NA	5	NA	
	Trimester 2	Li (2020)	1.01 (1.01, 1.02)	28	13	NA	+, Pe
		Ji (2017)	1.05 (0.99, 1.44)	23	6	313,955	
		Stieb (2012)	1.01 (0.98, 1.04)	23	7	1,153,736	
	Trimester 3	Li (2020)	1.00 (1.00, 1.01)	21	13	NA	0, Pe
		Ji (2017)	1.06 (0.97, 1.15)	50	7	315,469	
		Stieb (2012)	1.00 (0.98, 1.03)	13	7	1,153,736	
		Sapkota (2010)	1.00 (0.99, 1.01)	NA	7	NA	
CO (100 ppb)	Entire Pregnancy	Li (2020)	1.01 (1.00, 1.01)	53	8	112,239	+, Pe
		Stieb (2012)	1.01 (1.00, 1.01)	38	6	4,543,308	
	Trimester 1	Li (2020)	1.01 (1.00, 1.01)	12	5	NA	0, Pe
		Stieb (2012)	1.00 (1.00, 1.01)	0	5	1,129,363	
	Trimester 2	Li (2020)	1.01 (0.99, 1.02)	54	5	NA	+, Pe
		Stieb (2012)	1.01 (1.00, 1.01)	0	4	900,278	
	Trimester 3	Li (2020)	1.00 (0.98, 1.02)	68	5	NA	00, Pe
		Stieb (2012)	1.00 (0.99, 1.01)	86	5	1,129,363	
NO_2 (10 ppb)	Entire Pregnancy	Li (2020)	1.03 (1.01, 1.05)	90	23	509,997	+, Pe
		Stieb (2012)	1.02 (1.00, 1.04)	78	7	4,211,351	
	Trimester 1	Li (2020)	1.02 (1.01, 1.04)	11	12	NA	+, Pe
		Stieb (2012)	1.01 (0.99, 1.03)	0	5	1043794	
	Trimester 2	Li (2020)	1.01 (0.99, 1.04)	75	13	NA	+, Pe
		Stieb (2012)	1.02 (1.00, 1.04)	0	4	814,709	
	Trimester 3	Li (2020)	1.01 (0.97, 1.06)	78	13	NA	0, Pe
		Stieb (2012)	0.99 (0.93, 1.05)	70	5	1,043,794	
O_3 (10 ppb)	Entire Pregnancy	Li (2020)	1.05 (1.01, 1.09)	90	14	311,189	0, Pe
		Stieb (2012)	1.00 (0.91, 1.12)	25	3	3,377,984	
	Trimester 1	Li (2020)	1.00 (0.95, 1.05)	79	9	NA	0, Pe
		Stieb (2012)	0.99 (0.95, 1.04)	0	5	1,002,748	
	Trimester 2	Li (2020)	1.02 (0.95, 1.09)	87	8	NA	0, Pe

		Stieb (2012)	0.97 (0.89, 1.07)	34	3	496,900	
	Trimester 3	Li (2020)	1.09 (0.99, 1.20)	96	9	NA	+, Pe
		Stieb (2012)	1.01 (0.92, 1.12)	76	5	1,002,748	
SO_2 (10 ppb)	Entire Pregnancy	Li (2020)	1.12 (1.02, 1.24)	83	13	171,360	++, Pe
		Stieb (2012)	1.06 (1.04, 1.10)	0	7	4,400,175	
	Trimester 1	Li (2020)	1.05 (1.00, 1.12)	65	10	NA	+, Pe
		Stieb (2012)	1.04 (0.98, 1.08)	58	5	889,204	
	Trimester 2	Li (2020)	1.02 (0.99, 1.05)	20	10	NA	+, Pe
		Stieb (2012)	1.02 (0.96, 1.08)	41	4	660,119	
	Trimester 3	Li (2020)	0.98 (0.95, 1.01)	45	10	NA	-, Pe
		Stieb (2012)	0.98 (0.94, 1.04)	59	6	963,875	

Note: NO_2, Nitrogen dioxide; CO, Carbon monoxide; O_3, Ozone; SO_2, Sulphur dioxide; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5µm; $PM_{10,}$ particulate matter with aerodynamic diameter ≤ 10µm; LBW, low birth weight; OR, odd ratio; CI, confidence intervals; pp, parts per billion; NA, Not available; I^2, Heterogeneity; '++' represents more consistent positive association; '+' represents less consistent positive association; '0' represents contradictory/unclear direction; '-' represents less consistent negative association; Pe, probable evidence of the observed direction of exposure effect.
*Li (2020) reported number of LBW cases instead of total births for all exposures.

Table 5. Association between PTB and ambient air pollution

Pollutant (incremental units)	Exposure period	Meta-analysis	OR (95% CI)	I^2 (%)	Primary studies (n)	Total births (N)	Consistency, confidence
$PM_{2.5}$ (10 μg/m^3)	Entire Pregnancy	*Ju (2021)	1.07 (1.05, 1.10)	89	31	1,007,827	+, Pe
		Liu (2017)	1.15 (0.99, 1.33)	85	7	882,479	
		Li (2017)	1.02 (0.93, 1.12)	97	6	4,098,419	
		Sun (2015)	1.13 (1.03, 1.24)	91	13	3,089,186	
		Zhu (2015)	1.10 (1.03, 1.18)	52	8	1,764,632	
		Stieb (2012)	1.16 (1.07, 1.26)	17	4	197,980	
		Sapkota (2010)	1.15 (1.14, 1.16)	0	6	517,760	
	Trimester 1	Ju (2021)	0.98 (0.96, 1.01)	97	26	920,837	0, Pe
		Liu (2017)	1.15 (1.05, 1.24)	33	9	1,041,382	
		Li (2017)	1.03 (1.00, 1.06)	70	5	1,371,800	
		Sun (2015)	1.08 (0.92, 1.26)	91	10	1,668,004	
		Zhu (2015)	0.96 (0.77, 1.21)	87	6	743,647	
		Stieb (2012)	0.85 (0.60, 1.20)	94	4	589,100	
		Sapkota (2010)	1.04 (0.73, 1.34)	NA	4	NA	
	Trimester 2	Ju (2021)	1.03 (1.00, 1.07)	97	23	880542	+, Pe
		Li (2017)	1.01 (0.93, 1.10)	98	4	1,367,947	
		Sun (2015)	1.09 (0.82, 1.44)	99	5	1,340,807	
		Zhu (2015)	0.90 (0.79, 1.03)	0	3	598,606	
	Trimester 3	Ju (2021)	1.02 (1.00, 1.04)	93	23	923,545	+, Pe
		Li (2017)	1.02 (0.99, 1.04)	59	4	1,367,947	
		Sun (2015)	1.08 (0.99, 1.17)	92	9	2,208,883	
		Zhu (2015)	0.97 (0.89, 1.05)	31	6	1,240,212	
		Stieb (2012)	1.05 (0.98, 1.13)	33	4	589,100	
		Sapkota (2010)	1.07 (1.00, 1.15)	NA	3	NA	
PM_{10} (10 μg/m^3)	Entire Pregnancy	Ju (2021)	1.03 (1.01, 1.06)	92	15	210,850	+, Pe
		Lamichhane (2015)	1.24 (1.03, 1.45)	0	2	9,294	

		Stieb (2012)	1.16 (0.98, 1.38)	17	3	98,774	
		Sapkota (2010)	1.02 (0.99, 1.04)	73	8	1,047,489	
	Trimester 1	Ju (2021)	0.97 (0.94, 1.00)	97	16	263,928	-, Pe
		Lamichhane (2015)	0.99 (0.92, 1.07)	42	4	264,672	
		Stieb (2012)	0.98 (0.93, 1.03)	85	6	1,043,954	
		Sapkota (2010)	1.02 (0.97, 1.06)	NA	4	NA	
	Trimester 2	Ju (2021)	0.99 (0.96, 1.03)	98	14	257,476	-, Pe
		Lamichhane (2015)	0.97 (0.95, 0.99)	0	4	1,024,360	
		Stieb (2012)	0.97 (0.95, 0.99)	0	3	794,396	
	Trimester 3	Ju (2021)	1.01 (0.99, 1.02)	59	13	223,574	+, Pe
		Lamichhane (2015)	0.97 (0.86, 1.08)	58	3	229,967	
		Stieb (2012)	1.03 (1.01, 1.05)	20	6	1,043,954	
		Sapkota (2010)	1.02 (1.01, 1.03)	NA	5	NA	
CO (100 ppb)	Entire Pregnancy	Ju (2021)	1.04 (1.00, 1.08)	95	5	71,906	0, Pe
		Stieb (2012)	1.00 (0.99, 1.02)	0	2	112,941	
	Trimester 1	Ju (2021)	0.99 (0.96, 1.02)	95	3	70,680	0, Pe
		Stieb (2012)	1.00 (0.99, 1.00)	92	5	911,850	
	Trimester 2	Ju (2021)	1.04 (0.96, 1.12)	96	3	68,920	0, Pe
	Trimester 3	Ju (2021)	1.00 (0.99, 1.02)	78	4	71,049	00, Pe
		Stieb (2012)	1.00 (1.00, 1.01)	0	5	911,850	
O_3 (10 ppb)	Entire Pregnancy	Ju (2021)	1.07 (1.04, 1.10)	86	11	243,295	+, Pe
		Stieb (2012)	1.39 (0.62, 3.12)	89	2	98,449	
	Trimester 1	Ju (2021)	1.07 (1.04, 1.10)	91	11	304,353	+, Pe
		Rappazzo (2021)	1.06 (1.03, 1.10)	97	17	4,525,441	
		Stieb (2012)	1.10 (0.95, 1.28)	90	4	799,840	
	Trimester 2	Ju (2021)	1.04 (1.00, 1.08)	95	8	293,593	+, Pe
		Rappazzo (2021)	1.05 (1.02, 1.08)	97	15	4,713,201	
	Trimester 3	Ju (2021)	1.09 (1.03, 1.15)	96	8	201,663	0, Pe
		Stieb (2012)	0.98 (0.93, 1.05)	44	4	799,840	
NO_2		Ju (2021)	1.02 (0.98, 1.06)	88	20	343,203	+, Pe

(10 ppb)	Entire Pregnancy	Simonici (2020)	1.14 (0.81, 1.64)	72	4	80,458	
		Stieb (2012)	1.08 (0.91, 1.28)	53	5	162,815	
	Trimester 1	Ju (2021)	0.94 (0.90, 0.99)	69	21	398,229	-, Pe
		Stieb (2012)	0.93 (0.80, 1.08)	89	6	807,681	
	Trimester 2	Ju (2021)	1.00 (0.94, 1.07)	95	18	390,413	0, Pe
		Stieb (2012)	1.01 (0.88, 1.18)	22	2	422,703	
	Trimester 3	Ju (2021)	1.14 (1.06, 1.21)	92	15	331,248	+, Pe
		Stieb (2012)	1.03 (0.98, 1.09)	20	6	807,681	
SO_2 (10 ppb)	Entire Pregnancy	Ju (2021)	1.19 (0.95, 1.50)	83	8	158,735	0, Pe
	Trimester 1	Ju (2021)	0.95 (0.83, 1.09)	92	7	166,190	0, Pe
	Trimester 2	Ju (2021)	0.99 (0.89, 1.10)	85	6	160,122	0, Pe
	Trimester 3	Ju (2021)	0.97 (0.85, 1.10)	91	7	166,190	0, Pe

Note: NO_2, Nitrogen dioxide; CO, Carbon monoxide; O_3, Ozone; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5µm; PM_{10}, particulate matter with aerodynamic diameter ≤ 10µm; PTB, preterm birth; OR, odd ratio; CI, confidence intervals; pp, parts per billion; NA, Not available; I^2, Heterogeneity; '+' represents less consistent positive association; '0' represents contradictory/unclear direction; '-' represents less consistent negative association; Pe, probable evidence of the observed direction exposure effect; *Ju (2021) reported number of PTB cases instead of total births for all exposures.

Table 6. Association between stillbirth, spontaneous abortion (SAB) and ambient air pollution

Pollutant (incremental units)	**Exposure period**	**Meta-analysis**	**OR (95% CI)**	**I^2 (%)**	**Primary studies (n)**	**Total births (N)**	**Consistency, confidence**
$PM_{2.5}$ (10 µg/m^3)	Entire Pregnancy	Xie (2021)	1.15 (1.07, 1.25)	75	6	3,222,578	+, Pe
		Zhang (2021)	1.10 (1.07, 1.13)	62	7	4,647,479	
		Siddika (2016)	1.05 (0.99, 1.12)	0	2	3,745,243	
	Trimester 1	Xie (2021)	1.01 (0.90, 1.13)	87	6	3,892,183	0, Pe
		Zhang (2021)	0.96 (0.83, 1.09)	89	7	5,078,391	
		Siddika (2016)	1.11 (0.81, 1.51)	57	2	3,745,243	
	Trimester 2	Xie (2021)	1.06 (0.98, 1.14)	80	5	3,762,441	+, Pe
		Zhang (2021)	1.03 (0.94, 1.12)	82	6	4,855,016	
		Siddika (2016)	1.10 (0.86, 1.42)	48	2	3,745,243	
	Trimester 3	Xie (2021)	1.09 (1.01, 1.18)	79	4	3,180,667	0, Pe
		Zhang (2021)	1.09 (1.01, 1.18)	75	5	4,273,242	
		Siddika (2016)	1.00 (0.95, 1.05)	0	2	3,745,243	
PM_{10} (10 µg/m^3)	Entire Pregnancy	Zhang (2021)	1.01 (0.96, 1.05)	17	4	1,88,661	+, Pe
		Siddika (2016) and Zhang (2016)*	1.01 (0.95, 1.09)	85	2	104,089	
	Trimester 1	Zhang (2021)	0.94 (0.83, 1.04)	94	6	2,471,949	0, Pe
		Siddika (2016) and Zhang (2016)	1.00 (0.94, 1.06)	54	2	104089	
	Trimester 2	Zhang (2021)	0.99 (0.92, 1.05)	77	5	2248574	0, Pe
		Siddika (2016) and Zhang (2016)	1.01 (0.91, 1.12)	81	2	104,089	
	Trimester 3	Zhang (2021)	1.04 (0.97, 1.11)	89	4	1,666,800	+, Pe
		Siddika (2016) and Zhang (2016)	1.02 (0.92, 1.13)	91	2	104,089	
CO (100 ppb)	Entire Pregnancy	Zhang (2021)	1.00 (1.00, 1.00)	53	6	5,657,393	0, Pe
		Siddika (2016)	1.01 (1.00, 1.02)	21	3	3,847,818	
	Trimester 1	Zhang (2021)	1.00 (1.00, 1.00)	52	6	5,657,393	00, Pe
		Siddika (2016)	1.00 (0.99, 1.01)	32	3	3,847,818	

	Trimester 2	Zhang (2021)	1.00 (1.00, 1.00)	38	5	5,434,118	00, Pe
		Siddika (2016)	1.00 (0.99, 1.02)	64	3	3,847,818	
	Trimester 3	Zhang (2021)	1.00 (1.00, 1.00)	70	5	5,434,118	0, Pe
		Siddika (2016)	1.01 (0.99, 1.03)	80	3	3,847,818	
O_3 (10 ppb)	Entire Pregnancy	Zhang (2021)	1.02 (0.95, 1.09)	64	6	5,259,297	0, Pe
		Siddika(2016)	1.00 (0.97, 1.03)	20	2	3,128,844	
	Trimester 1	Zhang (2021)	1.06 (1.00, 1.11)	74	6	5,482,705	0, Pe
		Siddika(2016)	1.00 (0.98, 1.02)	0	2	3,128,844	
	Trimester 2	Zhang (2021)	1.02 (0.97, 1.08)	74	5	5,259,330	0, Pe
		Siddika (2016)	0.99 (0.94, 1.04)	69	2	3,128,844	
	Trimester 3	Zhang (2021)	0.96 (0.86, 1.06)	93	4	4,677,556	0, Pe
		Siddika (2016)	1.01 (0.97, 1.06)	63	2	3,128,844	
SO_2 (10 ppb)	Entire Pregnancy	Zhang (2021)	1.05 (0.96, 1.15)	7	6	5,657,493	+, Pe
		Siddika (2016)	1.08 (0.95, 1.22)	20	3	3,847,818	
	Trimester 1	Zhang (2021)	0.98 (0.83, 1.15)	73	6	5,657,493	0, Pe
		Siddika (2016)	1.14 (0.88, 1.48)	81	3	3,847,818	
	Trimester 2	Zhang (2021)	0.96 (0.80, 1.14)	73	5	5,434,118	0, Pe
		Siddika (2016)	1.01 (0.93, 1.10)	0	3	3,847,818	
	Trimester 3	Zhang (2021)	1.27 (0.98, 1.61)	89	5	5,434,118	+, Pe
		Siddika (2016)	1.15 (0.85, 1.56)	82	3	3,847,818	
NO_2 (10 ppb)	Entire Pregnancy	Zhang (2021)	1.05 (1.00, 1.11)	65	5	5,434,118	+, Pe
		Siddika (2016)	1.07 (0.97, 1.18)	80	3	3,847,818	
	Trimester 1	Zhang (2021)	1.01 (0.01, 1.06)	57	6	6,015,892	+, Pe
		Siddika (2016)	1.04 (0.98, 1.09)	55	3	3,847,818	
	Trimester 2	Zhang (2021)	0.99 (0.95, 1.04)	59	6	6,015,892	+, Pe
		Siddika (2016)	1.01 (0.95, 1.07)	66	3	3,847,818	
	Trimester 3	Zhang (2021)	1.04 (0.99, 1.10)	63	5	5,434,118	+, Pe
		Siddika (2016)	1.02 (0.98, 1.05)	0	3	3,847,818	

SAB-$PM_{2.5}$ (10 µg/m^3)	Trimester 1 or within 180 days of gestation	Zhu (2021)	1.20 (1.01, 1.40)	99	5	69,507	++, Pe
SAB-PM_{10} (10 µg/m^3)	Trimester 1 or within 180 days of gestation	Zhu (2021)	1.09 (1.02, 1.15)	79	5	12,741	++, Pe
		Zhang (2016)	1.34 (1.04, 1.72)	62	3	515,932	

*Two meta-analyses published in same year with complete duplicate and hence considered as one result.

Note: NO_2, Nitrogen dioxide; CO, Carbon monoxide; O_3, Ozone; SO_2, Sulphur dioxide; $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5µm; PM_{10}, particulate matter with aerodynamic diameter ≤ 10µm; SAB, spontaneous abortion; OR, odd ratio; CI, confidence intervals; ppb, parts per billion; NA, Not available; I^2, Heterogeneity; '+' represents less consistent positive association; '0' represents contradictory/unclear direction; '-' represents less consistent negative; Pe, probable evidence of the observed direction of exposure effect.

Figures

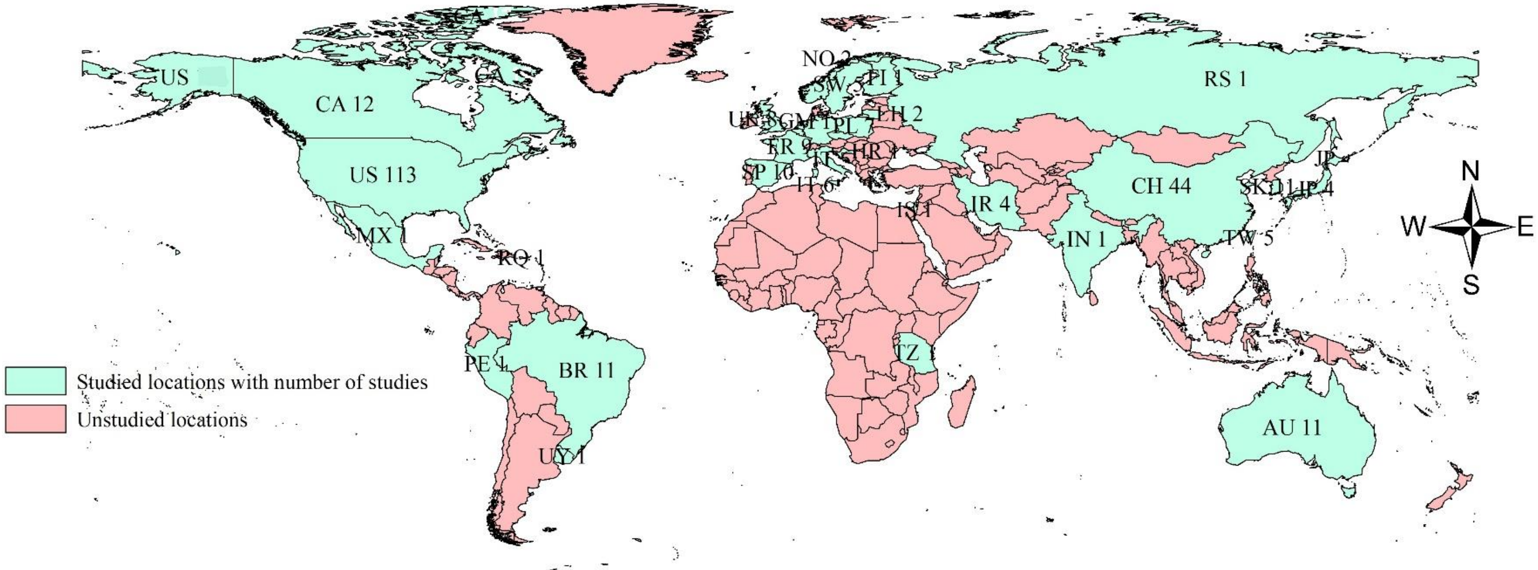

Figure 1. Spatial distribution of 287 country-specific primary studies from 31 countries included in the 36 systematic reviews and meta-analyses on ambient air pollution and adverse birth outcomes. Note: Number of studies for US, United States (113); CA, Canada (12); ME, Mexico (1); RQ, Puerto Rico (1); PE, Peru (1); BR, Brazil (11); UY, Uruguay (1); TZ, Tanzania (1); AU, Australia (11); IN, India (1); CH, China (44); TW, Taiwan (5); JP, Japan (4); SK, South Korea (11); RS, Russia (1); IR, Iran (4); IS, Israel (1); IT, Italy (5); SP, Spain (10); FR, France (9); BE, Belgium (3); GM, Germany (1); CZ, Czech Republic (5); HR, Croatia (1); NL, Netherlands (4); UK, United Kingdom (8); PL, Poland (7); LH, Lithuania (2); SW, Sweden (5); FI, Finland (1); NO, Norway (2).

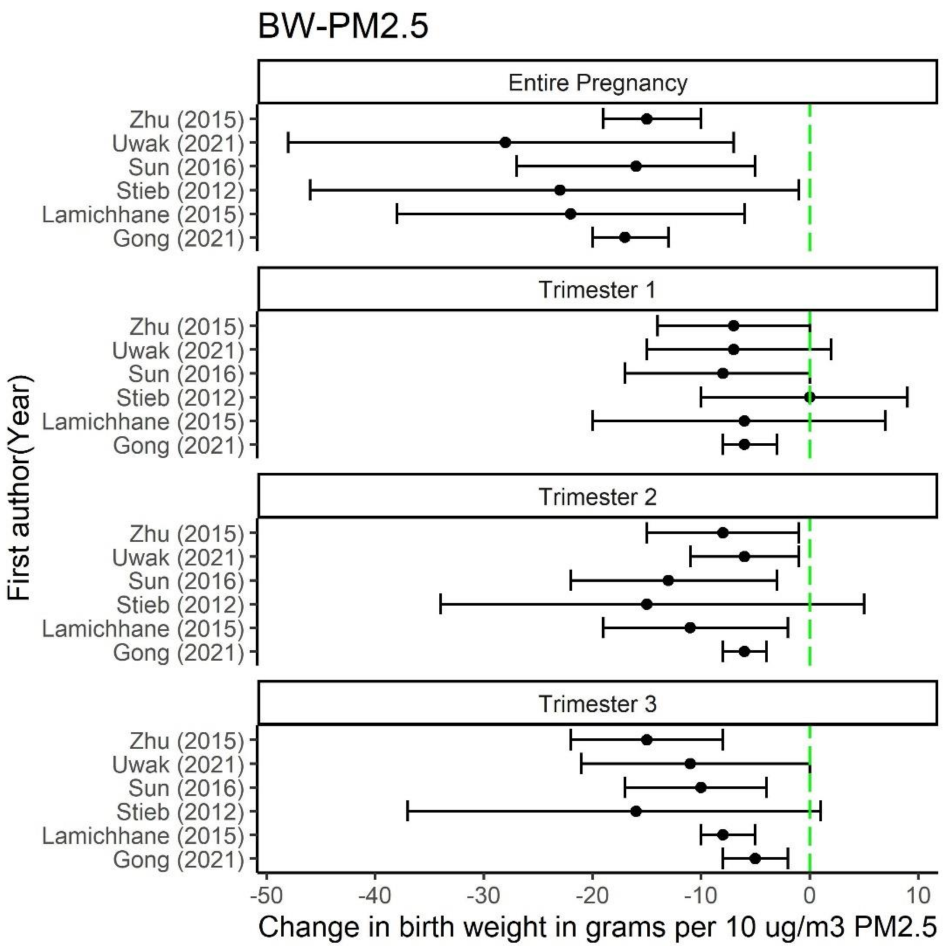

Figure 2. Forest plot of the association between change in birth weight (BW) per 10μg/m^3 $PM_{2.5}$ increase at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dashed line represents change in birth weight of 0 grams. Note: $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5μm.

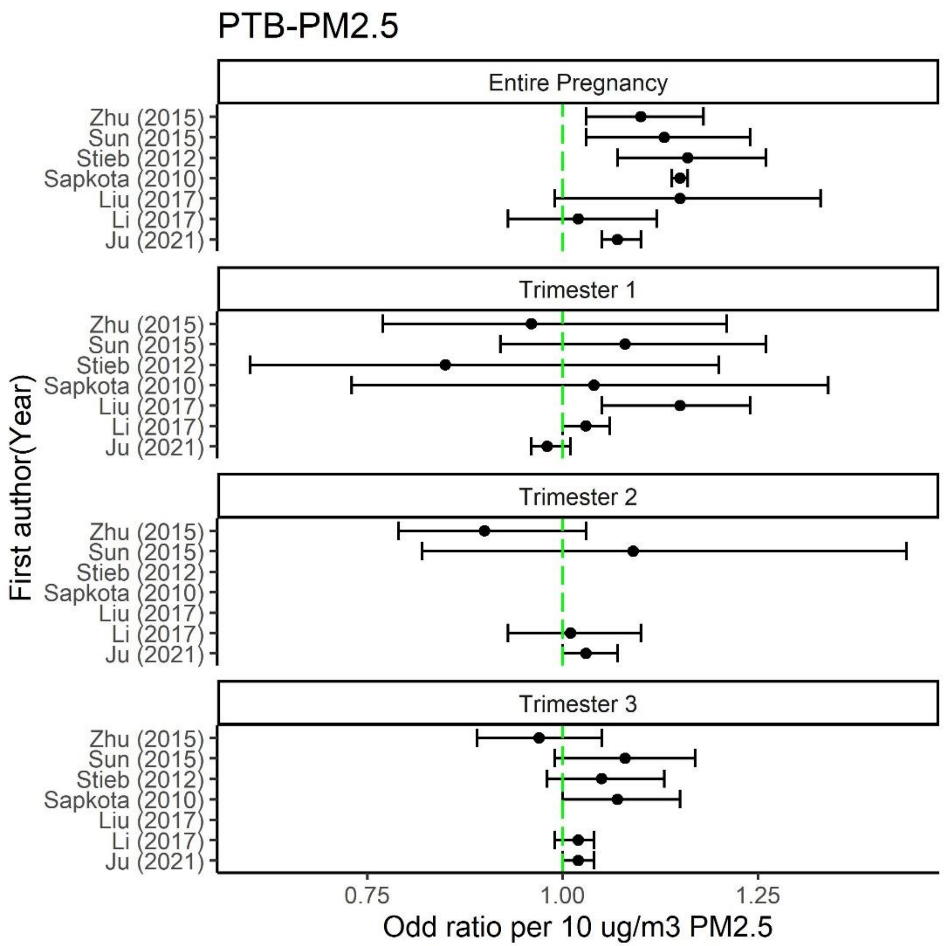

Figure 3. Forest plot of the association between preterm birth (PTB and fine particulate matter ($PM_{2.5}$) per 10µg/m^3 increment) during different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dashed line represents the reference for null association of 1. Note: $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5µm.

Prenatal Exposure to Ambient Air Pollution and Adverse Birth Outcomes: An Umbrella Review of 36 Systematic Reviews and Meta-analyses

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Supplementary Materials

Table S1: Search strategy for each database

I. PubMed

Set #	Advanced search within the title and abstract with the function ‘Title/Abstract’
1	"air pollut*"[Title/Abstract] OR "particulate matter*"[Title/Abstract] OR "carbon monoxide"[Title/Abstract] OR "sulfur dioxide"[Title/Abstract] OR "sulphur dioxide"[Title/Abstract] OR "nitrogen dioxide"[Title/Abstract] OR "nitrogen oxides"[Title/Abstract] OR "nitric oxide"[Title/Abstract] OR ozone[Title/Abstract] OR "gaseous pollut*"[Title/Abstract] OR "fine partic*"[Title/Abstract] OR "air qualit*"[Title/Abstract] OR "total suspended partic*"[Title/Abstract] OR "PM10"[Title/Abstract] OR "PM2.5"[Title/Abstract] OR "NO2"[Title/Abstract] OR "SO2"[Title/Abstract] OR "NOx"[Title/Abstract] OR "CO"[Title/Abstract] OR "O3"[Title/Abstract] OR "TSP"[Title/Abstract] OR "temperature*"[Title/Abstract] OR weather [Title/Abstract] OR heat*[Title/Abstract] OR cold*[Title/Abstract] OR climat*[Title/Abstract] OR "heat wave*"[Title/Abstract] OR heatwave*[Title/Abstract] OR "cold wave*"[Title/Abstract] OR coldwave*[Title/Abstract] OR "thermal stress"[Title/Abstract] ; Filters: English
2	"Pregnancy Outcome*"[Title/Abstract] OR "Birth Outcome*"[Title/Abstract] OR "Perinatal Outcome*"[Title/Abstract] OR "Obstetric Outcome*"[Title/Abstract] OR "Fetal Outcome*"[Title/Abstract] OR "Foetal Outcome*"[Title/Abstract] OR "Spontaneous Abortion"[Title/Abstract] OR "Premature Birth"[Title/Abstract] OR "Preterm Birth"[Title/Abstract] OR "Preterm Delivery"[Title/Abstract] OR "Premature Labo*"[Title/Abstract] OR Stillbirth[Title/Abstract] OR "Still birth"[Title/Abstract] OR "Fetal Death"[Title/Abstract] OR "Foetal Death"[Title/Abstract] OR "Pregnancy Loss"[Title/Abstract] OR Miscarriage[Title/Abstract] OR "Perinatal Death"[Title/Abstract] OR "Birth Weight"[Title/Abstract] OR "Birthweight"[Title/Abstract] OR "Fetal Weight"[Title/Abstract] OR "Foetal Weight"[Title/Abstract] OR "Fetal Growth"[Title/Abstract] OR "Foetal Growth"[Title/Abstract] OR "Gestational Age"[Title/Abstract] OR "Small-for-gestational age"[Title/Abstract] OR "intra-uterine growth retardation*"[Title/Abstract] OR "intrauterine growth retardation*"[Title/Abstract] OR "intrauterine growth restriction*"[Title/Abstract] OR "intra-uterine growth restriction*"[Title/Abstract] OR "PTB"[Title/Abstract] OR "PTD"[Title/Abstract] OR "LBW"[Title/Abstract] OR "TLBW"[Title/Abstract] OR "SGA"[Title/Abstract] OR "FGR"[Title/Abstract] OR "IUGR"[Title/Abstract] ; Filters-English
3	#1 AND #2
4	Review [Title/Abstract] OR "meta-analysis"[Title/Abstract]
5	#3 AND #4
6	#5 Filters applied, *English, Humans*

II. CINAHL

Search ID	Advanced search in the title and abstract with the function 'TI OR AB'
S1	TI ("air pollut*" OR "particulate matter*" OR "carbon monoxide" OR "sulfur dioxide" OR "sulphur dioxide" OR "nitrogen dioxide" OR "nitrogen oxides" OR "nitric oxide" OR ozone OR "gaseous pollut*" OR "fine partic*" OR "air qualit*" OR "total suspended partic*" OR "PM10" OR "PM2.5" OR "NO2" OR "SO2" OR "NOx" OR "CO" OR "O3" OR "TSP" OR "temperature*" OR weather OR heat* OR cold* OR climat* OR "heat wave*" OR heatwave* OR "cold wave*" OR coldwave* OR "thermal stress") OR AB ("air pollut*" OR "particulate matter*" OR "carbon monoxide" OR "sulfur dioxide" OR "sulphur dioxide" OR "nitrogen dioxide" OR "nitrogen oxides" OR "nitric oxide" OR ozone OR "gaseous pollut*" OR "fine partic*" OR "air qualit*" OR "total suspended partic*" OR "PM10" OR "PM2.5" OR "NO2" OR "SO2" OR "NOx" OR "CO" OR "O3" OR "TSP" OR "temperature*" OR weather OR heat* OR cold* OR climat* OR "heat wave*" OR heatwave* OR "cold wave*" OR coldwave* OR "thermal stress") ; Expanders - Apply equivalent subjects; Search modes - Boolean/Phrase
S2	TI ("Pregnancy Outcome*" OR "Birth Outcome*" OR "Perinatal Outcome*" OR "Obstetric Outcome*" OR "F#etal Outcome*" OR "Spontaneous Abortion" OR "Premature Birth" OR "Preterm Birth" OR "Preterm Delivery" OR "Premature Labo*" OR Stillbirth OR "Still birth" OR "F#etal Death" OR "Pregnancy Loss" OR Miscarriage OR "Perinatal Death" OR "Birth Weight" OR "Birthweight" OR "F#etal Weight" OR "F#etal Growth" OR "Gestational Age" OR "Small-for-gestational age" OR "intra-uterine growth retardation*" OR "intrauterine growth retardation*" OR "intrauterine growth restriction*" OR "intra-uterine growth restriction*" OR "PTB" OR "PTD" OR "LBW" OR "TLBW" OR "SGA" OR "FGR" OR "IUGR") OR AB ("Pregnancy Outcome*" OR "Birth Outcome*" OR "Perinatal Outcome*" OR "Obstetric Outcome*" OR "F#etal Outcome*" OR "Spontaneous Abortion" OR "Premature Birth" OR "Preterm Birth" OR "Preterm Delivery" OR "Premature Labo*" OR Stillbirth OR "Still birth" OR "F#etal Death" OR "Pregnancy Loss" OR Miscarriage OR "Perinatal Death" OR "Birth Weight" OR "Birthweight" OR "F#etal Weight" OR "F#etal Growth" OR "Gestational Age" OR "Small-for-gestational age" OR "intra-uterine growth retardation*" OR "intrauterine growth retardation*" OR "intrauterine growth restriction*" OR "intra-uterine growth restriction*" OR "PTB" OR "PTD" OR "LBW" OR "TLBW" OR "SGA" OR "FGR" OR "IUGR") ; Expanders – Apply equivalent subjects, Search modes – Boolean/Phrase
S3	S1 AND S2 Expanders – Apply equivalent subjects, Search modes – Boolean/Phrase
S4	TI ("review" OR "meta-analysis") OR AB ("review" OR "meta-analysis") Expanders – Apply equivalent subjects; Search modes – Boolean/Phrase
S5	S3 AND S4; Limiters – English Language; Human Expanders – Apply equivalent subjects; Search modes – Boolean/Phrase

III. Scopus

#	Advanced search in the title and abstract with the function ‘TITLE-ABS’
1	TITLE-ABS (“air pollut*” OR “particulate matter*” OR “carbon monoxide” OR “sulfur dioxide” OR “sulphur dioxide” OR “nitrogen dioxide” OR “nitrogen oxides” OR “nitric oxide” OR ozone OR “gaseous pollut*” OR “fine partic*” OR “air qualit*” OR “total suspended partic*” OR “PM10” OR “PM2.5” OR “NO2” OR “SO2” OR “NOx” OR “CO” OR “O3” OR “TSP” OR “temperature*” OR weather OR heat* OR c old* OR climat* OR “heat wave*” OR heatwave* OR “cold wave*” OR coldwave* OR “thermal stress”)
2	TITLE-ABS (“Pregnancy Outcome*” OR “Birth Outcome*” OR “Perinatal Outcome*” OR “Obstetric Outcome*” OR “F*etal Outcome*” OR “Spontaneous Abortion” OR “Premature Birth” OR “Preterm Birth” OR “Preterm Delivery” OR “Premature Labo*” OR Stillbirth OR “Still birth” OR “F*etal Death” OR “Pregnancy Loss” OR Miscarriage OR “Perinatal Death” OR “Birth Weight” OR “Birthweight” OR “F*etal Weight” OR “F*etal Growth” OR “Gestational Age” OR “Small-for-gestational age” OR “intra-uterine growth retardation*” OR “intrauterine growth retardation*” OR “intrauterine growth restriction*” OR “intra-uterine growth restriction*” OR “PTB” OR “PTD” OR “LBW” OR “TLBW” OR “SGA” OR “FGR” OR “IUGR”)
3	#1 AND # 2
4	TITLE-ABS (“review OR “meta-analysis”)
5	#3 AND #4 **AND** (LIMIT-TO (LANGUAGE,"English")) AND (LIMIT-TO (SRCTYPE,"j") OR LIMIT-TO (SRCTYPE,"d") OR LIMIT-TO (SRCTYPE,"Undefined")) AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"Undefined"))

IV. MEDLINE (Ovid) and
V. EMBASE (Ovid)

#	Advanced search within the title and abstract with the function ‘.ti,ab’
1	("air pollut*" or "particulate matter*" or "carbon monoxide" or "sulfur dioxide" or "sulphur dioxide" or "nitrogen dioxide" or "nitrogen oxides" or "nitric oxide" or ozone or "gaseous pollut*" or "fine partic*" or "air qualit*" or "total suspended partic*" or "PM10" or "PM2.5" or "NO2" or "SO2" or "NOx" or "CO" or "O3" or "TSP" or "temperature*" or weather or heat* or cold* or "climat*" or "heat wave*" or heatwave* or "cold wave*" or coldwave* or "thermal stress").ti,ab
2	limit #1 to (english language and humans)
3	("Pregnancy Outcome*" or "Birth Outcome*" or "Perinatal Outcome*" or "Obstetric Outcome*" or "F?etal Outcome*" or "Spontaneous Abortion" or "Premature Birth" or "Preterm Birth" or "Preterm Delivery" or "Premature Labo*" or Stillbirth or "Still birth" or "F?etal Death" or "Pregnancy Loss" or Miscarriage or "Perinatal Death" or "Birth Weight" or "Birthweight" or "F?etal Weight" or "F?etal Growth" or "Gestational Age" or "Small-for-gestational age" or "intra-uterine growth retardation*" or "intrauterine growth retardation*" or "intrauterine growth restriction*" or "intra-uterine growth restriction*" or "PTB" or "PTD" or "LBW" or "TLBW" or "SGA" or "FGR" or "IUGR").ti,ab
4	limit #3 to (english language and humans)
5	#2 AND #4
6	("review" or "meta-analysis").ti,ab.
7	limit #6 to (english language and humans)
8	#5 AND #7

VI. Web of Science Core Collection

#	Advanced search within the title, abstract and keywords with the function 'TS'
1	(TS=("air pollut*" OR "particulate matter*" OR "carbon monoxide" OR "sulfur dioxide" OR "sulphur dioxide" OR "nitrogen dioxide" OR "nitrogen oxides" OR "nitric oxide" OR ozone OR "gaseous pollut*" OR "fine partic*" OR "air qualit*" OR "total suspended partic*" OR "PM10" OR "PM2.5" OR "NO2" OR "SO2" OR "NOx" OR "CO" OR "O3" OR "TSP" OR "temperature*" OR weather OR heat* OR cold* OR climat* OR "heat wave*" OR heatwave* OR "cold wave*" OR coldwave* OR "thermal stress")) ; *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*
2	(TS=("Pregnancy Outcome*" OR "Birth Outcome*" OR "Perinatal Outcome*" OR "Obstetric Outcome*" OR "F$etal Outcome*" OR "Spontaneous Abortion" OR "Premature Birth" OR "Preterm Birth" OR "Preterm Delivery" OR "Premature Labo*" OR Stillbirth OR "Still birth" OR "F$etal Death" OR "Pregnancy Loss" OR Miscarriage OR "Perinatal Death" OR "Birth Weight" OR "Birthweight" OR "F$etal Weight" OR "F$etal Growth" OR "Gestational Age" OR "Small-for-gestational age" OR "intra-uterine growth retardation*" OR "intrauterine growth retardation*" OR "intrauterine growth restriction*" OR "intra-uterine growth restriction*" OR "PTB" OR "PTD" OR "LBW" OR "TLBW" OR "SGA" OR "FGR" OR "IUGR")) ; *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*
3	(#1 AND #2); *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*
4	(TS=("systematic review" OR "meta-analysis")) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*
5	#3 AND #4 *AND* **LANGUAGE:** (English) *Indexes=SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC Timespan=All years*

VII. Cochrane Database of Systematic Reviews

#	Advanced search within the title, abstract and keywords with the function 'Title Abstract Keyword'
1	("air pollut*" OR "particulate matter*" OR "carbon monoxide" OR "sulfur dioxide" OR "sulphur dioxide" OR "nitrogen dioxide" OR "nitrogen oxides" OR "nitric oxide" OR ozone OR "gaseous pollut*" OR "fine partic*" OR "air qualit*" OR "total suspended partic*" OR "PM10" OR "PM2.5" OR "NO2" OR "SO2" OR "NOx" OR "CO" OR "O3" OR "TSP" OR "temperature*" OR weather OR heat* OR cold* OR climat* OR "heat wave*" OR heatwave* OR "cold wave*" OR coldwave* OR "thermal stress") in Title Abstract Keyword - (Word variations have been searched)
2	("Pregnancy Outcome*" OR "Birth Outcome*" OR "Perinatal Outcome*" OR "Obstetric Outcome*" OR "Fetal Outcome*" OR "Foetal Outcome*" OR "Spontaneous Abortion" OR "Premature Birth" OR "Preterm Birth" OR "Preterm Delivery" OR "Premature Labo*" OR Stillbirth OR "Still birth" OR "Fetal Death" OR "Pregnancy Loss" OR Miscarriage OR "Perinatal Death" OR "Birth Weight" OR "Birthweight" OR "Fetal Weight" OR "Foetal Weight" OR "Fetal Growth" OR "Foetal Growth" OR "Gestational Age" OR "Small-for-gestational age" OR "intra-uterine growth retardation*" OR "intrauterine growth retardation*" OR "intrauterine growth restriction*" OR "intra-uterine growth restriction*" OR "PTB" OR "PTD" OR "LBW" OR "TLBW" OR "SGA" OR "FGR" OR "IUGR") in Title Abstract Keyword - (Word variations have been searched)
3	1 AND 2 in Title Abstract Keyword - in Cochrane Reviews (Word variations have been searched)

VIII. Joanna Briggs Institute EBP Database (Ovid)

#	Advanced search within the title and abstract with the function '.ti,ab.'
1	("air pollut*" or "particulate matter*" or "carbon monoxide" or "sulfur dioxide" or "sulphur dioxide" or "nitrogen dioxide" or "nitrogen oxides" or "nitric oxide" or ozone or "gaseous pollut*" or "fine partic*" or "air qualit*" or "total suspended partic*" or "PM10" or "PM2.5" or "NO2" or "SO2" or "NOx" or "CO" or "O3" or "TSP" or "temperature*" or weather or heat* or cold* or "climat*" or "heat wave*" or heatwave* or "cold wave*" or coldwave* or "thermal stress").ti,ab
2	("Pregnancy Outcome*" or "Birth Outcome*" or "Perinatal Outcome*" or "Obstetric Outcome*" or "F?etal Outcome*" or "Spontaneous Abortion" or "Premature Birth" or "Preterm Birth" or "Preterm Delivery" or "Premature Labo*" or Stillbirth or "Still birth" or "F?etal Death" or "Pregnancy Loss" or Miscarriage or "Perinatal Death" or "Birth Weight" or "Birthweight" or "F?etal Weight" or "F?etal Growth" or "Gestational Age" or "Small-for-gestational age" or "intra-uterine growth retardation*" or "intrauterine growth retardation*" or "intrauterine growth restriction*" or "intra-uterine growth restriction*" or "PTB" or "PTD" or "LBW" or "TLBW" or "SGA" or "FGR" or "IUGR").ti,ab.
3	#1 AND #2

IX. Epistemonikos Database (www.epistemonikos.org/)

#	Advanced search within the title and abstract with the function 'Title/Abstract'
1	Title/Abstract ("air pollut*" OR "particulate matter*" OR "carbon monoxide" OR "sulfur dioxide" OR "sulphur dioxide" OR "nitrogen dioxide" OR "nitrogen oxides" OR "nitric oxide" OR ozone OR "gaseous pollut*" OR "fine partic*" OR "air qualit*" OR "total suspended partic*" OR "PM10" OR "PM2.5" OR "NO2" OR "SO2" OR "NOx" OR "CO" OR "O3" OR "TSP" OR "temperature*" OR weather OR heat* OR cold* OR climat* OR "heat wave*" OR heatwave* OR "cold wave*" OR coldwave* OR "thermal stress")
2	Title/Abstract ("Pregnancy Outcome*" OR "Birth Outcome*" OR "Perinatal Outcome*" OR "Obstetric Outcome*" OR "Fetal Outcome*" OR "Foetal Outcome*" OR "Spontaneous Abortion" OR "Premature Birth" OR "Preterm Birth" OR "Preterm Delivery" OR "Premature Labo*" OR Stillbirth OR "Still birth" OR "Fetal Death" OR "Foetal Death" OR "Pregnancy Loss" OR Miscarriage OR "Perinatal Death" OR "Birth Weight" OR "Birthweight" OR "Fetal Weight" OR "Foetal Weight" OR "Fetal Growth" OR "Foetal Growth" OR "Gestational Age" OR "Small-for-gestational age" OR "intra-uterine growth retardation*" OR "intrauterine growth retardation*" OR "intrauterine growth restriction*" OR "intra-uterine growth restriction*" OR "PTB" OR "PTD" OR "LBW" OR "TLBW" OR "SGA" OR "FGR" OR "IUGR")
3	#1 AND #2; Publication type: systematic review

X. Grey literature sources and search strategy

Grey literature	Search straetgy
i. Google Scholar (first 200 hits) 21/10/2020	“air quality”|“air pollution”|“particulate matter”|“gaseous pollutants”|“total suspended particle”|“carbon monoxide”|“sulfur dioxide”|“sulphur dioxide”|“nitrogen dioxide”|“nitrogen oxides”|“nitricoxide”|ozone|temperature|weather|heat|cold|“climate change”|heatwave|coldwave|“thermal stress”|PM10|PM2.5|NO2|SO2|NOx|CO|O3|TSP AND (“Pregnancy outcomes”|“Birth Outcomes”|“Perinatal Outcomes”|“Obstetric Outcomes”|“Fetal Outcomes”|“Foetal Outcomes”|“Spontaneous Abortion”|“Premature Birth”|“Preterm Birth”|“Preterm Delivery”|“Premature Labor”|“spontaneous labour”|Stillbirth|“Still birth”|“Fetal Death”|“Foetal Death”|“Pregnancy Loss”|Miscarriage|“Perinatal Death”|“Birth Weight”|Birthweight|“Fetal Weight”|“Foetal Weight”|“Fetal Growth”|“Foetal Growth”|“Gestational Age”|“Small-for-gestational age”|“intra-uterine growth retardation”|“intrauterine growth retardation”|“intrauterine growth restriction”|“intra-uterine growth restriction”|PTB|PTD|LBW|TLBW|SGA|FGR|IUGR AND review|meta-analysis
ii. Google.com (screened first 200 hits where available) 21-22/10/2020	The following phrases were used: 1. systematic review and meta-analysis of air pollution and pregnancy and birth outcomes 2. systematic review and meta-analysis of air pollution and preterm birth 3. systematic review and meta-analysis of air pollution and low birth weight 4. systematic review and meta-analysis of air pollution and pregnancy loss, still birth, spontaneous abortion and miscarriage 5. systematic review and meta-analysis of air pollution and small for gestational age 6. systematic review and meta-analysis of climate change, temperature, heat and cold waves and pregnancy and birth outcomes 7. systematic review and meta-analysis of climate change, temperature, heat and cold waves and low birth weight 8. systematic review and meta-analysis of climate change, temperature, heat and cold waves and pregnancy loss, still birth, spontaneous abortion and miscarriage
iii. OpenGrey 24/10/2020	(“air pollut*” OR “particulate matter*” OR “carbon monoxide” OR “sulfur dioxide” OR “sulphur dioxide” OR “nitrogen dioxide” OR “nitrogen oxides” OR “nitric oxide” OR ozone OR “gaseous pollut*” OR “fine partic*” OR “air qualit*” OR “total suspended partic*” OR “PM10” OR “PM2.5” OR “NO2” OR “SO2” OR “NOx” OR “CO” OR “O3” OR “TSP” OR “temperature*” OR weather* OR heat* OR cold* OR “climat*” OR “heat wave*” OR heatwave* OR “cold wave*” OR coldwave* OR “thermal stress”) AND (“Pregnancy Outcome*” OR “Birth Outcome*” OR “Perinatal Outcome*” OR “Obstetric Outcome*” OR “F?etal Outcome*” OR “Spontaneous Abortion” OR “Premature Birth” OR “Preterm Birth” OR “Preterm Delivery” OR “Premature Labo*” OR Stillbirth OR “Still birth” OR “F?etal Death” OR “Pregnancy Loss” OR “Miscarriage” OR “Perinatal Death” OR “Birth Weight” OR “Birthweight” OR “F?etal Weight” OR “F?etal Growth” OR “Gestational Age” OR “Small-for-gestational age” OR “intra-uterine growth retardation*” OR “intrauterine growth retardation*” OR “intrauterine growth restriction*” OR “intra-uterine growth restriction*” OR “PTB” OR “PTD” OR “LBW” OR “TLBW” OR “SGA” OR “FGR” OR “IUGR”) AND (review OR meta-analysis)
iv. WorldWideScience.org 24/10/2020	Title: (“air pollut*” OR “particulate matter*” OR “carbon monoxide” OR “sulfur dioxide” OR “sulphur dioxide” OR “nitrogen dioxide” OR “nitrogen oxides” OR “nitric oxide” OR ozone OR “gaseous pollut*” OR “fine partic*” OR “air qualit*” OR “total

	suspended partic*" OR "PM10" OR "PM2.5" OR "NO2" OR "SO2" OR "NOx" OR "CO" OR "O3" OR "TSP" OR temperature* OR weather* OR heat* OR cold* OR climat* OR "heat wave*" OR heatwave* OR "cold wave*" OR coldwave* OR "thermal stress") AND ("Pregnancy Outcome*" OR "Birth Outcome*" OR "Perinatal Outcome*" OR "Obstetric Outcome*" OR "F*etal Outcome*" OR "Spontaneous Abortion" OR "Premature Birth" OR "Preterm Birth" OR "Preterm Delivery" OR "Premature Labo*" OR Stillbirth OR "Still birth" OR "F*etal Death" OR "Pregnancy Loss" OR "Miscarriage" OR "Perinatal Death" OR "Birth Weight" OR "Birthweight" OR "F*etal Weight" OR "F*etal Growth" OR "Gestational Age" OR "Small-for-gestational age" OR "intra-uterine growth retardation*" OR "intrauterine growth retardation*" OR "intrauterine growth restriction*" OR "intra-uterine growth restriction*" OR "PTB" OR "PTD" OR "LBW" OR "TLBW" OR "SGA" OR "FGR" OR "IUGR") AND (review OR meta-analysis); Filters; English language
v. World Health Organisation Global Health Medicus databases 24/10/2020	'Title, abstract, subject' search (tw:(air pollut* OR particulate matter* OR "carbon monoxide" OR "sulfur dioxide" OR "sulphur dioxide" OR "nitrogen dioxide" OR "nitrogen oxides" OR "nitric oxide" OR ozone OR gaseous pollut* OR fine partic* OR air qualit* OR total suspended partic* OR "PM10" OR "PM2.5" OR "NO2" OR "SO2" OR "NOx" OR "CO" OR "O3" OR "TSP" OR temperature* OR weather* OR heat* OR cold* OR climat* OR heat wave* OR heatwave* OR cold wave* OR coldwave* OR "thermal stress")) AND (tw:(Pregnancy Outcome* OR "Birth Outcome* OR Perinatal Outcome* OR Obstetric Outcome* OR F*etal Outcome* OR "Spontaneous Abortion" OR "Premature Birth" OR "Preterm Birth" OR "Preterm Delivery" OR Premature Labo* OR Stillbirth OR "Still birth" OR F*etal Death OR "Pregnancy Loss" OR "Miscarriage" OR "Perinatal Death" OR "Birth Weight" OR "Birthweight" OR F*etal Weight OR F*etal Growth OR "Gestational Age" OR "Small-for-gestational age" OR "intra-uterine growth retardation* OR intrauterine growth retardation* OR intrauterine growth restriction* OR intra-uterine growth restriction* OR "PTB" OR "PTD" OR "LBW" OR "TLBW" OR "SGA" OR "FGR" OR "IUGR")) AND (tw:(review OR meta-analysis))

Table S2. Lists of articles excluded after full-text screening stage with reasons per pre-specified eligibility criteria.

S/N	Article excluded	Reason(s)
1	Zhu et al, 2017	Full text in Chinese language
2	Feng et al 2017	Full text in Chinese language
3	de Toledo et al 2011	Full text in Portuguese language
4	Guo et al 2019	Retracted (Doi: 10.1631/jzus.B18r0122)
5	Nieuwenhuijsen et al, 2013	Summary of meta-analysis
6	Vrijheid et al 2016	A broad summary of the literature on systematic reviews and/or meta-analyses published between 2010 to 2015
7	Backes et al 2013	General literature review (not systematic review). No method section, no in/exclusion criteria, no specification of search terms and database searched.
8	Deepak et al 2016	General literature review (not systematic review). No method section, no in/exclusion criteria, no specification of search terms and database searched.
9	Heinrich et al 2007	General literature review (not systematic review). No method section, no in/exclusion criteria, no specification of search terms and databases searched.
10	Huang et al 2019	Unrelated outcomes of interest
11	Kloog 2019	General literature review (not systematic review). No method section, no in/exclusion criteria, no specification of search terms and database searched.
12	Koranteng et al 2007	Included only one related primary study
13	Lai 2013	Insufficient related studies of interest and lack required details on included studies.
14	Li et al 2019	General literature review, not systematic review
15	Maisonet et al 2004	Very scanty method without any clearly specified search strategy with search terms used for the literature search apart from the indication “We identified articles through Medline searches, bibliographies of individual articles, and reviews of scientific journals from 1966 through December 2001.”
16	Melody et al, 2019	Not exposure measurement of interest
17	Morakinyo et al 2016	Not outcomes of interest
18	Nandasena et al 2010	Not outcomes of interest
19	Proietti et al 2013	General literature review, not systematic review.
20	Stillerman et al 2008	General literature review, not a systematic review
21	Tan et al 2017	General literature review, not a systematic review
22	Triche et al 2007	General literature review, not a systematic review
23	Wang et al 2007	General literature review, not a systematic review
24	Windham et al 2008	General literature review, not a systematic review
25	Zheng et al 2016	General literature review, not a systematic review

26	Klepac et al, 2018	Study-specific details of the included studies (e.g., study design, sample size, effect estimates, location etc.) were not provided.
27	Ma et al 2020	Exposure-outcome of interest was not primary focus of the review but included 4 studies without any details on the included studies.
28	Srám et al 2005	Lack some of the required key details on the included primary studies: participants/sample size and the effect estimate (but provided effect estimates for only significant increased risks while providing 'NE, no effect' without the effect estimates for other results).
29	Vieira et al 2015	Exposure-outcome of interest was not the primary outcome of but included few related studies without required details on the included primary studies.
30	Khader et al 2016	Included 3 primary studies but lack exposure-outcome effect estimates for each listed criteria air pollutant.
31	Porpora et al, 2019	Included less than 3 primary studies on the exposure-outcome and with no details on included studies.
32	Lee et al 2020	General literature review (not systematic review) and summarised existing meta-analyse
33	Yu et al 2016	Full text in Chinese language
34	Polichetti et al 2013	General literature review with no in/exclusion criteria. Also, provided only yes/no for exposure-outcome association without any other results, information or details on the included primary studies.
35*	Steinle et al 2020	Overview of meta-analysis on particulate matter, birth weight and health through the life course
36	Gómez-Roig et al 2021	General literature review, not a systematic review
37	Ekland et al 2021	No details on included studies as systematic review and meta-analysis was not the main objective
38	Eeden et al 2021	General literature review, not a systematic review
39	Pereira, 2022	No systematic literature search, was a re-analysis of some studies included in Ju et al (2021).
40	Whaibeh et al 2022	General literature review, not a systematic review

*35-40 were from the prospective literature search and the updates.

Table S3. Additional information on systematic reviews without meta-analysis, ordered from recent to earliest.

First author, date [number of authors, countries]	Exposure(s)	Outcome(s)	Summary of results	Researchers' recommendations	Researchers' stated strengths and limitations
1. Edwards (Edwards et al., 2022) 12/10/2021 [4; 3 UK and 1 Nepal]	$PM_{2.5}$, PM_{10}, NO_2, SO_2 Ranges: NA	LBW, SGA, PTB	'No clear evidence of difference in the air pollution-pregnancy outcome relationship of those who did and did not move during pregnancy'. 'Three studies of relocation during pregnancy provided limited evidence to conclude an effect of relocation-related change in exposure on pregnancy outcome.'	'There would be value in expanding air pollution research that capitalizes on the advantages of relocation studies, but attention is needed to improve potential bias and confounder control in studies examining the effects of short-term relocations to environments of different air pollution levels.'	Strength This is the first literature review of the health effects of people who relocate from one environment to another of differing air pollution levels. Limitations 'Ambient pollutant levels were reported for the patients' entire pregnancies but pollutant levels before and after relocation were not explicitly reported in these studies.' 'The literature of relocation studies for studying the health effects of air pollution effects remains limited and very heterogenous in design and quality.'
2. Walter, 2021(Walter et al., 2021) 08/06/2021 [6; all Australia]	PM2.5,PM10,NO2,SO2,O3,CO	LBW, BW, SGA, PTB	'While some evidence indicated adverse birth outcomes, such as pre-term birth, and reduced intra-uterine growth, overall the birth outcomes were heterogeneous and it was not possible to draw firm conclusions.'	'There are apparent differences in the magnitude and range of health impacts across different pollutant sources, which may be beneficial in formulating preventative strategies aimed at reducing the health burden of outdoor air pollution in Australia.' 'Further research	**Strength** 'The screening of each database, study selection and quality assessment of studies was independently undertaken by two authors'. 'All included studies controlled for some potential confounders'.

				is required to characterise better the range of neo-natal impacts and identify specific exposure windows of heightened risk within the pregnancy.'	**Limitations** 'Over two thirds of the studies included in this review used fixed site monitors, and noted the limitations in capturing spatial variability of population exposure.' 'The included studies ranged in design and size, with one quarter being cohort design and of modest size by international comparison. The exclusion of proxy exposure measurements and subjective health measurements, such as questionnaires, resulted in the omission of several otherwise well conducted studies that were relevant to the remit of our review.'
3. Luo (Luo et al., 2021) 09/03/2021 [6; 5 China, 1 UK]	$PM_{2.5}$, PM_{10}, NO_2, NO_x,	PTB, BW, LBW, SGA	**Note:** Specific exposure-outcome with exposure periods not done for this review because the review article reported only key results of the included studies. Indicated below are key findings highlighted in the review. **PTB-NO_2** "A total of 16 studies explored the relationship between NO_2 and PTB. Only five studies obtained statistically significant results, and the rest studies did not find a significant association between prenatal exposure to NO_2 and PTB. Overall, the results are inconclusive." **SGA-NO_2**	From conclusion: "It is recommended that future studies should apply LUR models for individual exposure evaluation in China to better characterize the relationship between air pollution and adverse pregnancy outcomes." From abstract: "In addition, further research is required given that a lot of the associations looked at in the review were inconclusive"	Not reported

			"Twelve studies explored the relationship between NO2 exposure and SGA. Only four studies found statistical significance results. No significant association between NO_2 exposure and SGA was found in the rest studies. It is apparent that conclusions are inconsistent." **LBW/BW-NO_2** "Twenty-four studies explored the relationship between NO_2 and birth weight." Four studies "found that NO_2 exposure during pregnancy was associated with reduced birth weight (β range from -5.2 to - 43.6 g). Three studies found increased risk of term LBW. "However, two studies found exposure to NO_2 was associated with increased birth weight. "No substantive effects of NO_2 exposure on birth weight were evident in the rest of the studies. Overall, there is considerable heterogeneity in the effects of NO_2 exposure on birth weight, and therefore, results are inconclusive. " **PTB-PM2.5** "Among seven studies investigating the link between PM2.5 and PTB, only one study showed a statistically significant result. Overall, PM2.5 exposure during pregnancy is not associated with PTB." **SGA-PM2.5** "Six studies investigated the relationship between PM2.5 exposure during pregnancy and SGA, out of which three studies found that PM2.5 exposure was associated with an increased risk of SGA." In the other three studies, no significant association between PM2.5 and SGA was found. Results on association between exposure to PM2.5 during pregnancy and SGA were		

			not consistent." **BW/LBW-PM2.5** **"**Seventeen studies explored the relationship between PM2.5 and birth weight. Eight of the 17 studies found that PM2.5 exposure during pregnancy was associated with reduced birth weight.**"** **"**In addition, four studies concluded that PM2.5 exposure increased the risk of TLBW." **"**The rest of studies did not reach statistically significant conclusions. In general, the results show that PM2.5 exposure during pregnancy is associated with a decrease in birth weight**"** **BW-NOx :** "Six studies investigated the effect of NOx exposure on birth weight, however results were inconsistent." **"**The inconsistency of results shows that the relationship between NOx and birth weight is not well established. The effect of exposure to NOx on other pregnancy outcomes has been studied. Given the limited number of studies and mixed results, it is impossible to reach conclusions regarding the relationship between NOx exposure and adverse pregnancy outcomes.**"**		
4. Bekkar (Bekkar et al., 2020) 18/06/2020 [4, all USA]	$PM_{2.5}$, O_3	PTB, LBW, and SB	**PTB** **PM2.5**: (24 studies; 18 cohorts, 2 each time series, case-control and cross-sectional; 9,286,285 births). 16 reports on the whole pregnancy: 12 found significant increased risks, 3 non-significant increased risk and 1 with no association. 7 reports on 1st trimester; 5 found significant increased risks, 1 non-significant increased risk and 1 with no association. 8 reports on 2nd trimester; 6 found significant increased risks, 1 non-significant increased risk and 1 with no association. 6 reports on 3rd trimester; 2 found significant increased risks, 2 non-significant increased risk, 1 non-significant decreased risk, and 1 with no association.	The medical community at large and women's health clinicians in particular should take note of the emerging data and become facile in both communicating these risks with patients and integrating them into plans for care. Moreover, physicians can adopt a more active role as patient advocates to educate elected officials entrusted with public policy and insist	**Strengths:** The considerable sample size and the wide geographic range that includes every region of the US domestic population; focus on the US population makes the findings particularly relevant to pregnant women and health care clinicians in the US; the merit of tabulating the overall preponderance of observations from varying

			O3: (6 studies; 4 cohorts, 1each for case-control and cross-sectional; 1,868,257 births) 4 reports on the whole pregnancy period; 3 were significant increased risks and 1 no association. 2 reports on 2nd trimester; 1 each found significant increased risk and no association. 2 reports on 3rd trimester; 1 each found significant increased risk and no association. 1 report on 3rd trimester with no association. Varied weekly and week ranges of exposure periods reported with significant increased risks in early and late gestational weeks. **LBW** **PM2.5:** (17 studies; 15 cohorts and 1 each cross-sectional and case control; 11,729,145 births). 14 reports for entire pregnancy: 10 found significant increased risks and 4 non-significant increased risk. 4 for 1st trimester: 1 found significant increased risks and 3 non-significant increased risk 5 for 2nd trimester: 3 found significant increased risks and 2 non-significant increased risk 5 for 3rd trimester: 3 found significant increased risks and 2 non-significant increased risk **O3**: 8 studies (7 cohorts and 1 cross-sectional; 3,703,824 births). The cross-sectional study (222,259 births) examined and found significant increased risk of VLBW during birth month. 5 studies for whole pregnancy: 3 found significant increased risks and 2 non-significant increased risk 2 for 1st trimester: both found non-significant increased risk 3 for 2nd trimester: 2 found non-significant increased risk and 1 found significant decreased risk (protective effect). 1 for 3rd trimester and found non-significant increased risk **BW reduction** **PM2.5**: 12 studies (11 cohorts, 1 time series; 7,339,714 births).	on effective action to stop the climate crisis.	studies examining the same outcomes where pooled analysis across studies is not feasible. Limitations: this review covers only observational studies with heterogeneous sources of air pollution and heat exposure as well as diverse methods of measurement; different study designs may complicate direct comparison of the data even within a single study; limited number of studies on stillbirth.

			11 studies for entire pregnancy: 8 found significant increased risks and 3 non-significant increased risk 3 for 1st trimester: all found significant increased risks. 3 for 2nd trimester: all found significant increased risks. 4 for 3rd trimester: all found significant increased risks. **O3**; 4 cohort studies (4,463,021 births). 3 studies for entire pregnancy: all found significant increased risks. **SGA (and FGR)** **PM2.5**: 3 cohort studies (479, 889 births) of which one of them (122,203 births from Utah) examined FGR separately in addition to SGA. 1 study (122,203 births) reported for entire pregnancy and found non-significant for SGA and significant increased risks for FGR. 2 studies for 1st trimester: both found non-significant increased risks for SGA and 1 found significant increased risk for FGR. 1 study for 2nd trimester; found non-significant decreased risk for SGA and increased risk for FGR. 1 study for 3rd trimesters: significant for SGA but insignificant (for FGR) increased risks. **O3**: 4 cohort studies (644,794 births) of which one of them (122,203 births from Utah) examined FGR separately in addition to SGA. One study reported and found significant decreased risk (protective effect) for SGA and FGR for entire pregnancy. 1 study reported for entire pregnancy and found significant decreased risk (protective effect) for both SGA and FGR. 2 for 1st trimester for SGA with non-significant increased and decreased risks. The only study for FGR found significant decreased risk. 1 study for 2nd trimester; non-significant decreased risk for SGA and significant decreased risk for FGR. 3 for 3rd trimester; 2 significant increased and 1 significant decreased risk for SGA. The only study for FGR found significant decreased risk.		

			Three months pre-conception pollutant exposures were reported for one study (122,203 births from Utah, USA) found with significant increased risks for SGA/FGR. **Stillbirth** **PM2.5**: (5 studies; 4 cohorts and 1 nested case-control; 5,014,874 births). 4 reported for entire pregnancy; 1 found significant increased risk and 3 found non-significant increased risk. 1 reported for 1^{st}, 2^{nd}, and 3^{rd} trimester with non-significant increased risk for 1^{st} and 2^{nd} , and significant increased risk for 3^{rd}. I study reported and found non-significant risk for 2 days before delivery. **O3**: 3 studies (2 cohorts and one nested case-control; 4,410,761 births). 2 reported for entire pregnancy; 1 each found significant and non-significant increased risks. 1 reported and found significant increased risk for 3^{rd} trimester. 1 also found significant increased risk for the week before delivery. 'Specifically, significant PM2.5 and/or ozone association with PTB in 19/24 (79%) studies (all of these studies included PM2.5 and 7 also included ozone), from birth per study of mean (standard deviation) as 318 960 (393 272) with total births of 7.3 million; increased risk of median (range)% of 11.5 (2.0-19.0) for 11 studies on PM2.5. Significant ozone-PTB association in 2/4 (50%) studies for an increased risk from 3% to 9.6%; each measured the association by IQR, from 7.1 to 11.53 parts per billion (ppb) PM2.5 and/or ozone association with LBW was significant in 25/29 (86%) studies (all studies except 1 included PM2.5; 11 analyzed ozone in which 10 combined with PM2.5), from birth per study of mean (standard deviation) as 661 205 (878 074) with total births of 18.5 million, median (range) of 10.8 (2.0-36.0) for 8 studies on PM2.5 and 5/8 (62%) studies detected association of IQR		

			increases which ranged from 2.0 to 6.9 µg/m3. Three studies found association between ozone and LBW. PM2.5 and/or ozone association with SB was significant in 4/5 (80%) studies from birth per study of 1 020 975 (1 176 174) with total births of 5.1 million, median (range)% of 14.5 (6.0-23.0) for PM2.5.'		
5. Heo (Heo et al., 2019) 12/11/2019 [3; All USA]	PM_{10}, $PM_{2.5}$ ($PM_{2.5\text{-}10}$, PM_1, $PM_{0.1}$)	PTB, LBW, SGA, and SB	**Effects modification by race/ethnicity**: **PM-LBW**: Among 14 studies that focused on LBW and maternal race/ethnicity, 9 studies reported statistically significant risks with higher risk for infants of African American/black mothers compared to others. Two other studies found that risks for PM exposure (separately by racial/ethnic subgroups) were non- significant but higher in African American/ blacks. ***Suggestive evidence*** *that PM exposure risks for LBW are higher in infants of African-American/black mothers than in other racial/ethnical groups.* **PM-PTB** (18 studies): Among 17 studies based on PTB and race/ethnicity, 5 studies found statistically significant risks of PM exposure, with estimated risks generally higher for African American/blacks, whereas 1 study showed significant and higher risk for infants of white mothers. 5 other studies presented different magnitude of the risks but not statistically significant to clearly state the evidence of effect modification. The other 6 studies reported no significant evidence of effect modification of PTB by race/ethnicity. ***Suggestive evidence*** *that PM exposure risks for PTB are higher in infants of African-American/black mothers than in other racial/ethnical groups*. **PM-SGA (8 studies):** among the 8 studies based on SGA and race/ethnicity, 2 studies reported significant and higher risks in African American/blacks, whereas 2 studies showed insignificant risk differences in the relationship between PM and SGA for racial/ethnical subpopulations and 4 studies found no evidence of effect modification by race/ ethnicity. *We*	We suggest that more studies are required to understand potential effect modification of the risk of SGA and stillbirth due to maternal exposure to PM during pregnancy. Future studies are also needed for other socio-economic factors that can potentially play a role as effect modifiers such as income, job categories, occupation status, and access to prenatal care. Lastly, additional efforts to understand the interplay of race/ ethnicity and SES on vulnerability of birth outcomes to air pollution are needed to provide information for identifying vulnerable communities and populations and planning preventive measures.	**Limitations** Limitations of our study include the small number of relevant studies and geographically limited estimates for effect modification of the relationship between air pollution exposure and birth outcomes. Due to the small number of studies, it was not feasible to conduct a quantitative risk summarization; instead we provide a narrative summary of the evidence of effect modification based on the identified studies and our study should be interpreted in this context. **Strengths** A strength of this study is that we critically highlight research gaps for the evidence of effect modification by various maternal risk factors covering race/ ethnicity and SES. The differences in the PM-adverse birth outcome relationships among subpopulations

			*concluded that there existed **no current evidence** of effect modification by race/ethnicity for SGA*. **PM-Stillbirth (3 studies):** ***No evidence*** *was found for the effect modification by race/ethnicity for stillbirth,* although our conclusion is hindered by the small number of studies, while 1 study reported higher risks in white mothers for the relationship between PM and stillbirth with 2 other studies reporting no significant effect modification. **Effects modification by maternal educational attainment** **PM-LBW (6 studies):** 2 studies reported significantly higher PM risks in infants of mothers with less education, 1 study reported significantly higher PM risks in mothers with higher education, and 3 studies reported no difference in the PM risk by maternal education level. *Overall, **weak evidence of higher PM risk** for infants of mothers with less/high education existed for LBW*. **PM-PTB (8 studies):** 2 studies found that infants of mothers with less education had higher PM risk, whereas 6 studies did not find such evidence. *Overall, **weak evidence of higher PM risk** for infants of mothers with less/high education existed for PTB*. **PM-SGA (5 studies):** One study reported statistically significant results for the effect modification of PM risk for SGA by maternal education, whereas the 4 studies conducted in California did not find significant effect modification. *We concluded that there was **no evidence of higher risk** of SGA from PM exposure in mothers with less education*. **PM-SB (3 studies**): One study showed a tendency of higher risk by lower education level but the results were not statistically significant. Significant effect modification by maternal education was not found in the other 2 studies. Thus, *we concluded that there existed **no effect modification** by maternal education on the relationship between PM exposure and stillbirth*. **Effects modification by maternal income**		found in our review imply environmental injustice and provide important information relevant to decision-making for identifying and protecting vulnerable subpopulation.

			PM-LBW (4 studies): ***No evidence*** was found for effect modification as the studies reported no differences in PM risks by income level. **PM-PTB (7 studies):** ***No evidence*** was found for effect modification as the studies reported no differences in PM risks by income level. **PM-SGA (2 studies):** We concluded that there is ***no evidence*** of effect modification was concluded for SGA, which may relate to the small number of studies. **Effects modification by maternal occupation or un/employed during pregnancy** **PM-PTB (2 studies):** One study examined the relationship between PTB and PM exposure as modified by mothers' occupation, reporting higher risks in infants of farmers than other workers. The other study did not find risk differences between mothers who were employed and those who were unemployed during pregnancy. *We concluded **no evidence** of effect modification by occupation for the examined birth outcomes.* **Effect modification by area-level integrated socioeconomic status (**SES) levels. **PM-LBW (2 studies):** The 2 studies focusing on LBW reported significantly higher risks in regions with lower SES level. In conclusion, there existed ***no evidence*** for effect modification by area-level integrated SES levels for PM risk of LBW. **PM-PTB (3 studies):** In the 3 studies for PTB, the differences in the association between PM exposure and PTB were not statistically significant or the risk differences were not based on statistically comparable risk measurements. In conclusion, there existed ***no evidence*** for effect modification by area-level integrated SES levels for PM risk of PTB.		
6. Yuan (Yuan et al., 2019) 20/03/2019 [4, all China]	$PM_{2.5}$	BW, LBW, SGA, PTB	**PM2.5 and BW** (22 studies: 4 prospective and 18 retrospective cohort; 12,723,279 births). 23 results on entire pregnancy (one study reported twice for different exposure levels); 14 found significant increased risk of reduction in BW, 4 found non-significant	Relevant measures should be taken to reduce the exposure level of susceptible population and raise their awareness of health risks	**Strengths** Provide another subjective point of view to present varied effects of maternal exposure on multiple adverse outcomes through

			increased risk in BW reduction, 2 found significant decreased risk in BW (protective effect), 3 found non-significant decreased risk (protective effect). 7 studies reported for 1st trimester; 5 found significant increased risk and 2 found non-significant increased risk in BW reduction. 7 studies reported for 2nd trimester; 4 found significant increased risk and 2 found non-significant increased risk in BW reduction, and 1 found no association. 14 results from 12 studies reported for 3rd trimester; 6 found significant increased risk, 6 found non-significant increased risk in BW reduction, and 2 found non-significant decreased risk (protective effect). 2 studies reported for last month and both found increased risk which was significant in one and non-significant in the other. **PM2.5 and LBW/TLBW** (20 studies: 2 prospective and 18 retrospective cohorts; 24,577,804 births) 22 findings from 20 studies reported for entire pregnancy; 6 found significant increased risk, 8 found non-significant increased risk, 1 found significant decreased risk (protective effect), 4 found non- significant decreased risk (protective effect), and 3 found no association. 9 studies reported for 1st trimester; 2 found significant increased risk, 4 found non-significant increased risk, 2 found non-significant decreased risk (protective effect), and 1 found no association. 10 studies reported for 2nd trimester; 3 found significant increased risk, 4 found non-significant decreased risk, and 3 found no association. 10 studies reported for 3rd trimester; 2 found significant increased risk, 4 found non-significant increased risk, 2 found significant decreased risk (protective effect), and 1 found no association. **PM2.5 and PTB**	associated with PM2.5 exposure. Efforts should be made to implement more stringent air quality principles and improve ambient air quality.	this comprehensive summary; the evaluations included were fully adjusted instead of extraction to get similar covariates to ensure the quality of meta-analysis and reduce heterogeneity among different studies. Besides, we also exhibit estimations based on different exposure assessment, including traditional fixed monitoring data, remote sensing, and satellite data were also obtained from the literature.

			(18 studies: 1 prospective cohort, 16 retrospective cohort, 1 nested case-control; 10,593,350 births) 18 studies reported for entire pregnancy; 9 found significant increased risk, 2 found non-significant increased risk, 1 found significant decreased risk (protective), 5 found non-significant decreased risk, and 1 found no association. 11 studies reported for 1st trimester; 3 found significant increased risk, 1 found non-significant increased risk, 3 found non-significant decreased risk, and 4 found no association. 11 studies reported for 2nd trimester; 4 found significant increased risk, 1 found non-significant increased risk, 4 found non-significant decreased risk, and 2 found no association 11 studies reported for 3rd trimester; 3 found significant increased risk, 1 found non-significant increased risk, 6 found non-significant decreased risk, and 1 found no association 2 studies reported on last month where one found non-significant decreased risk and the other found no association. One study reported and found non-significant decreased risk for the last three months. **PM2.5 and SGA** (9 studies: 1 prospective and 8 retrospective cohorts; 5,562,394 births) 9 studies reported for entire pregnancy; 5 found significant increased risk, 2 found non-significant increased risk, 1 found significant decreased risk, and 1 found non-significant decreased risk. 6 studies reported for 1st trimester; 2 found significant increased risk, 2 found non-significant increased risk, 1 found significant decreased risk, and 1 found non-significant decreased risk. 6 studies reported for 2nd trimester; 3 found significant increased risk, 2 found non-significant increased risk, and 1 found significant decreased risk.		

			6 studies reported for 3rd trimester; 3 found significant increased risk, 1 found non-significant increased risk, and 2 found significant decreased risk.		
7. Tsoli (Tsoli et al., 2019) 31/01/2019 [3, 2 Greece, 1 London, UK]	$PM_{2.5}$, PM_{10}, $PM_{2.5-10}$, PM_1, TSP	TBW, TLBW	**PM2.5 and TBW change** 34 studies (31 cohort studies and 3 ecological;13,879,044 births with unreported for one study) 26 studies reported with 32 findings (site-specific results reported for some studies) for *entire pregnancy*: 15 found significant increased risk, 7 found non-significant increased risk, 5 found significant decreased risk (protective effect), 6 found non-significant decreased risk. 13 studies reported for *1st trimester*: 5 found significant increased risk, 2 found non-significant increased risk, 2 found significant decreased risk (protective effect), 4 found non-significant decreased risk. 14 studies reported for *2nd trimester*: 8 found significant increased risk, 2 found non-significant increased risk, 1 found significant decreased risk (protective effect), 2 found non-significant decreased risk, and 1 found no association. 17 studies reported for *3rd trimester*: 6 found significant increased risk, 6 found non-significant increased risk, 2 found significant decreased risk (protective effect), and 3 found non-significant decreased risk. One study reported and found no association in first month, 2 reported for last month with 1 significant and 1 non-significant increased risks, and another for last trimester found significant increased risk. **PM2.5 and TLBW change** 32 studies (29 cohort, 1 nested case-control, and 2 ecologic; 25,081,472 births) 49 findings (site-specific results reported for some studies) for *entire pregnancy*: 16 found significant increased risk, 15 found non-significant increased risk, 2 found significant decreased risk (protective effect), 15 found non-significant decreased risk. 15 studies reported (site-specific results reported for some studies) for *1st trimester*: 3 found significant increased risk,	"These findings underline the need for protective measures for exposure of pregnant women to particulate pollution. Future research needs to focus on understanding which chemical constituents and sources of PM are responsible for TLBWT and by which mechanisms, expanding our knowledge of the critical time windows of exposure, study characteristics that are responsible for differences in results, consider maternal occupational exposure, outdoor activities or indoor air exposure, and elucidating the biological pathways that underline the associations between maternal exposure, particulate air pollution and neonatal health. Future studies also need to take into consideration potential effect modification by characteristics of the built environment, such as proximity to traffic and green spaces. Establishing similar guidelines among studies, as the ones described in ICAPPO	**Limitations** 'Our search was restricted to English-only language publications and grey literature was not searched for eligible studies. Also, the review adopted a structured and independent screening process. The screening of the references of relevant reviews on the topic did not indicate additional papers for inclusion, thus we believe that all relevant publications were captured. In this review, results are presented using only single-pollutant models of PM.' **Strengths** 'To the best of our knowledge, this is the first systematic literature review summarizing all the available scientific literature on this topic up to October 2018, which can be used as valuable guide tool for future studies'

			4 found non-significant increased risk, 2 found significant decreased risk (protective effect), 5 found non-significant decreased risk, and 1 found no association. 16 studies reported (site-specific results reported for some studies) for *2nd trimester*: 1 found significant increased risk, 9 found non-significant increased risk, 1 found significant decreased risk (protective effect), 4 found non-significant decreased risk, and 1 found no association. 16 studies reported (site-specific results reported for some studies) for *3rd trimester*: 2 found significant increased risk, 6 found non-significant increased risk, 1 found significant decreased risk (protective effect), 6 found non-significant decreased risk, and 1 found no association. One study reported and found significant increased risk for 3rd month, another found non-significant decreased during preconception. One study reported monthly and found non-significant increased risk for almost all months. "The range of estimated change in BWT (in grams) was −0.51 (−1.58, 0.56) (Kumar, 2012) up to −3.1 (-5.1, −1.1) (Gehring et al., 2014) per 1 μg/m3 increase in PM2.5, −7 (−17.0, 2.0) (Pedersen et al., 2013) up to −16.0 (−29.0, −3.0) (Pedersen et al., 2015) per 5 μg/m3 increase in PM2.5 and −18.4 (SE 4.1) (Savitz et al., 2014) up to 11.00 (−3.0, 25.0) (Hannam et al., 2014) per 10 μg/m3 increase in PM2.5. An even more extreme reduction of BWT in grams was recorded compared with the previous, −48.4 (SE 7.1) (Hannam et al., 2014). **NB**: Review authors omitted results for some studies and only indicated 'TBWT results also available in the primary paper' , 'TLBWT results also available in the primary paper' or '…… results are also graphically available, "…results are also available for the different exposure metrics'. We considered only results included in the review article. **PM10 and TBW change**	(Woodruff et al., 2010), could be achieved through interdisciplinary collaborations that will expand our understanding and eliminate the differences employed among studies."	

			26 studies (24 cohort, 1 cross-sectional, and 1 ecologic; 5,894,513 births with unreported for one study) 18 results for *entire pregnancy*: 3 found significant increased risk, 13 found non-significant increased risk, 1 found significant decreased risk (protective effect), and 1 with no association. 13 studies for *1st trimester*: 3 found significant increased risk, 5 found non-significant increased risk, 1 found significant decreased risk (protective effect), 3 found non-significant decreased risk, and 1 with no association. 13 studies for *2nd trimester*: 3 found significant increased risk, 5 found non-significant increased risk, 5 found non-significant decreased risk. 16 studies for *3rd trimester*: 3 found significant increased risk, 7 found non-significant increased risk, 1 found non-significant decreased risk. First month, last month, last two months, and last trimester were also reported in 5 studies but none found significant in/decreased risk. "The range of estimated effects for LBWT (OR (95% CI)) was 1.01 (0.95, 1.08) (Brauer et al., 2008) up to 1.07 (1.01, 1.14) (Dibben and Clemens, 2015) per 1 μg/m3 increase in PM10 and 0.90 (0.60, 1.35) (Capobussi et al., 2016) up to 1.44 (0.62, 3.36) (Parker et al., 2011) per 10 μg/m3 increase in PM10. The range of estimated change in BWT (in grams) was −10.0 (−14.2, −5.7) (Gehring et al., 2014) up to 0.52 (0.19, 0.85) (Yang et al., 2003) per 1 μg/m3 increase in PM10 and -30.3 (−36.4, −24.2) (Parker et al., 2011) up to 47.0 (−10.5, 104.6) (Parker et al., 2011) per 10 μg/m3 increase in PM10" **NB**: Review authors omitted results for some studies and only indicated 'TBWT results also available in the primary paper', 'TLBWT results also available in the primary paper' or '…. graphically available in original paper', "…results are also available per trimester'. We considered only results included in the review article. **PM10 and TLBW change**		

			31 studies (27 cohort, 1 case-control, and 2 ecologic, 1 cross-sectional; 8,327,332 births) 29 findings (site-specific results reported for some studies) for *entire pregnancy*: 9 found significant increased risk, 13 found non-significant increased risk, 2 found significant decreased risk (protective effect), 4 found non-significant decreased risk, and 1 found no association. 11 studies for *1^{st} trimester*: 1 found significant increased risk, 5 found non-significant increased risk, 1 found significant decreased risk (protective effect), 3 found non-significant decreased risk, and 1 found no association. 11 studies for *2^{nd} trimester*: 8 found non-significant increased risk, and 3 found non-significant decreased risk. 13 studies for *$3^{rd\ t}$ trimester*: 2 found significant increased risk, 6 found non-significant increased risk, 4 found non-significant decreased risk, and 1 found no association. 1 finding each for preconception, last month and last 2 month with no significant in/decreased risk. **NB**: Review authors omitted results for some studies and only indicated 'TBWT results also available in the primary paper', 'TLBWT results also available in the primary paper' or '…. graphically available in original paper', "…results are also available per trimester'. We considered only results included in the review article. **PM2.5-10 and TBW:** 5 studies (4 cohort and 1 ecologic; 12,829,812 births) 5 studies (1 all regions' results) reported for entire pregnancy: 4 found significant and 1 non-significant increased risks. 2 reported for 1^{st} trimester; 1 each found significant and non-significant increased risks. 2 reported for 2^{nd} trimester and both found significant increased risk. 3 reported for 3^{rd} trimester; 2 found significant and 1 non-significant increased risks. 1 reported and found non-significant increased risk for 1^{st} month. **PM2.5-10 and TLBW**:		

			3 studies (2 cohort, 1 ecologic; 4,405,320 births) All reported for entire pregnancy; 2 found non-significant increased risk and 1 found no association. "The range of estimated change for TBWT (in grams) was −12.7 (−18.0, −7.5) (Parker and Woodruff, 2008) −9.4 (-12.8, −6.0) (MorelloFrosch et al., 2010) per 10 µg/m3 increase (95% CI) in PM2.5-10. The range of effects for TLBWT (OR (95% CI) was 0.88 (0.79, 0.98) (Kingsley et al., 2017) up to 1.17 (0.95, 1.39) (Pedersen et al., 2013) for black carbon and 0.99 (0.96, 1.02) (Morello-Frosch et al., 2010) up to 1.04 (0.99, 1.09) (Parker and Woodruff, 2008) for PM2.5-10." **Chemical components of PM** 11 studies for PM2.5, 2 studies each for PM10 and PM0.1 investigated effects of specific chemical constituents. 'Different chemical components of PM such as elemental carbon, nickel, zinc, potassium, iron and copper were associated with reductions in TBWT or increased risk of TLBWT.' **TSP and TBW/TLBW** 2 cohort studies; 351,434 TBW: 1 reported and found significant increased risk for 3rd trimester. TLBW: 1 reported and found non-significant increased risk for 1st trimester; 2 reported for 3rd trimester where 1 each found significant in/decreased risks. Others: PM0.1 (2 studies), PM1 (1 study) and PM7 (1 study).		
8. Grippo (Grippo et al., 2018) 25/09/2018 [8; 3 USA, 5 China]	TSP, PM_{10}, $PM_{2.5}$, CO, SO_2, NO_2, O_3	SAB (miscarriage) and SB	**SAB or miscarriage** **PM10**; Reported in 4 studies; 3 studies (1 prospective cohort for entire pregnancy, time-series study for cumulative lag0-14 days, and a case-control for < 14 weeks of gestation) found non-significant increased risk. Third study, a time-series, found significant increased risk within 180 days of gestation.	More evidence is needed.	**Limitations** The various definitions make it difficult to compare the results across the studies. Considering that women could be exposed to pollutants for only a short period during

			PM2.5; Reported in a prospective cohort that found significant increased risk. **CO**; Reported in 3 studies; a case-control study found significant increased risk for <14 weeks of gestation, no association in a prospective cohort study for entire pregnancy, and non-significant decreased risk in time-series for cumulative lag0-14 days. **NO**; Reported in a time-series study that found no association for cumulative lag0-14 days. **NO2**; Reported in 4 studies; case-control study found significant increased risk for <14 weeks of gestation, 2 studies (a prospective cohort for entire pregnancy, time-series study for cumulative lag0-14 days) found non-significant increased risk. The forth study, a time-series, found non-significant decreased risk within 180 days of gestation. **SO2**; Reported in 3 studies; a case-control study found significant increased risk for within 14 weeks of gestation, 2 studies (a prospective cohort for entire pregnancy and a time-series for cumulative lag0-14 days) found non-significant increased risk. **O3**; Reported in 4 studies; 3 studies (a prospective cohort for entire pregnancy, case-control for <14 weeks of gestation, and a time-series study for within 180 days of gestation) found significant increased risk. The forth study, a case-control study for cumulative lag0-14 days case-control study found no association. **TSP**; Reported in a case-control study that found significant increased risk within 14 weeks of gestation. **Stillbirth (SB)** *NB*: Included 2 time-series studies that **did not** examined entire or trimester periods; one examined cumulative lag0-14 days and found non-significant decreased risk for all included pollutants (PM10, SO2, NO, O3) but no association for NO2, the other examined daily rate ratio per increase on concurrent day and found significant increased risk for PM10 but no significant association for other included pollutants		third trimester; at least some stillbirths occurring during this period could be attributed to an acute exposure to these pollutants. Findings from studies on the associations between third trimester exposure to pollutants and stillbirths should be interpreted with caution because of the lack of specificity in quantifying the exposure period before the occurrence of stillbirth outcome. Many of the studies used air monitoring station data to represent individual air pollution exposure, without taking into account indoor air pollution and mobility of human activity. This limitation could result in misclassification bias. Many papers in this review reported results relating to various combinations of pollutants. Multiple pollutant models were used, and caution should be used when interpreting this data.

			(CO, NO2, SO2, O3) **PM10**; (6 studies; 2 each for prospective cohort and time series, and 1 each for retrospective cohort, and case-control). 2 studies reported for entire pregnancy period (> 20 or >23 or >28 gestational weeks); 1 each found non-significant increased and decreased risk. One study reported and found non-significant decreased risk in 1st trimester. One study reported and found non-significant increased risk in 2nd trimester. Two studies reported and both found significant increased risk in 3rd trimester. One study found generally no association. **PM2.5**; (7 studies; 3 retrospective cohort and 1 each for prospective cohort, and cross-sectional and 2 case-control). 5 studies reported for entire pregnancy period (>20 or >23 or >28 gestational weeks); 2 studies found significant increased risk and 3 found non-significant increased risk. One study reported and found non-significant decreased risk in the 1st and 2nd trimester. 4 studies reported for 3rd trimester and 2 each found significant and non-significant increased risk. One study found generally no association. **CO** (7 studies; 2 each for retrospective cohort and time-series, 1 each for prospective cohort, case-control, and cross-sectional). 3 studies reported for entire pregnancy period (or > 20 or >23 or >28 gestational weeks); 1 study found significant and 2 found non-significant increased risks. 3 studies reported for 3rd trimester; 1 study found significant increased risk and 2 studies found non-significant increased risk. 2 studies reported no association. **NO2** (8 studies; 2 each for retrospective cohort and time-series, 1 each for prospective cohort, case-control, cross-sectional, and ecological).		

			4 studies reported for entire pregnancy period (>20 or >23 or >28 gestational weeks); 2 studies found significant and 1 found increased risk, and 1 each found non-significant increased and decreased risk. 3 studies reported for 3rd trimester; 1 study found significant increased risk and 2 found non-significant increased risk. 1 study reported no association. **SO2**(8 studies; 2 each for retrospective cohort and time-series, 1 each for prospective cohort, case-control, cross-sectional, and ecological). 4 studies reported for entire pregnancy period (>20 or >23 or >28 gestational weeks); 3 studies found non-significant increased risk, and 1 found non-significant decreased risk. 3 studies reported for 3rd trimester; 2 found significant increased risk and 1 found non-significant decreased risk. 1 study reported no association. **O3**(6 studies; 2 each for retrospective cohort and time-series, 1 each for prospective cohort and case-control). 3 studies reported for entire pregnancy period (>20 or >23 or >28 gestational weeks); 1 each found significant increased, non-significant increased, and non-significant decreased risks. 1 study reported for 1st trimester and found significant increased risk. 1 study reported for 3rd trimester and found significant increased risk. 1 study reported no association. **TSP;**1 ecological reported and found non-significant decreased risk.		
9. Westergaard (Westergaard et al., 2017) 06/04/2017 [4; 2 Denmark, 1 Netherlands, 1 France]	$PM_{2.5}$, SPM, SO_2,NO_2, O_3	TLBW	**Effect modification of TLBW by smoking** **PM2.5**: a prospective cohort study of 74,178 births in 12 European countries; significant increased risk in both smokers (with higher OR) and non-smokers **SPM**: a nationwide population-based longitudinal survey in Japan of 44,109 births; non-significant decreased risk (protective effect) in smokers and significant increased risk in non-smokers.	'The limited evidence precludes for definitive conclusions and further studies are recommended'	'This commentary is not a complete review of all potential effect modifiers' The limited evidence precludes for definitive conclusions.

			SO_2: 1 study (44,109 births in the Japanese study); significant increased risk in both smokers (with higher OR) and non-smokers. **NO_2**: 1 study (44,109 births in the Japanese study); non-significant decreased risk in smokers and significant increased risk in non-smokers. **O_3**: 1 study (44,109 births in the Japanese study); non-significant decreased risk in smokers and non-significant increased risk in non-smokers. However, none of the interactions for smoking status reached statistical significance, $p>0.05$. (**NB**: review authors mistakenly exchanged the smoker/non-smoker CIs for NO2 and O3 as in the primary study, Yorifuji et al, 2015) **Effect modification of TLBW by maternal obesity.** **PM2.5;** 2 studies (retrospective and prospective cohorts; 1,035,123 births)**.** Higher OR in obese women compared to normal weight women in both studies. Also, significant decreased risk among underweights in the retrospective study but non-significant increased risk in the prospective study. **NO2 and O3:** 1 Californian retrospective cohort study (960,945 births); showed a marginally increased risk of TLBW for the obese mothers (BMI> 35 kg/m2) as compared with those of normal weight (BMI 20–24.9 kg/m2), non-significant increased (O3) and decreased (NO2) risks for underweight women with underweight (BMI ≤19 kg/m2) compared to normal weight women (BMI 20–24.9 kg/m2) **Effect modification by socioeconomic status (SES: education and income in 4 studies)** **PM2.5:** 3 studies (1prospective and 2 retrospective cohorts) In 2/3 studies (988,780 births), women with low education had significantly higher OR compared with women with high education. The third, a retrospective study (297,043 births) found non-significant difference between women with less or more than high school.		

			O3: a retrospective study (297,043 births) found significant increased risk in both women with less or more than high school (but with greater risk for > high school) **NO2:** A retrospective study (2,402,545 births) from Canada found non-significant decreased risk for women in the third tertile of the lowest income. **Effect modification of maternal asthma** One retrospective study (362,800 births) from Canada reported for PM2.5,NO2 and O3; found no significant difference between women with and without asthma. Decreased risk for PM2.5 and NO2 but significant increased risk in non-asthmatic and non-significant increased risk for asthmatic women.'		
10. Jacobs (Jacobs et al., 2017) 01/02/2017 [9; 8 Australia, 1 USA]	NO_2, SO_2, CO, PM_{10}, $PM_{2.5}$, O_3	BW, LBW, PTB, SB	**BW** **NO2** (3 studies); One study (cross-sectional) examined monthly association and found all non-significant increased risk in almost all months. The other 2 studies (both cross-sectional and) reported entire/trimester-specific (7 scenarios). One study reported entire pregnancy and found significant protective effect. 2 reported for 1st trimester and found significant and non-significant increased risks. 2 reported for 2nd trimester and both found significant increased risks. 2 reported 3rd trimester and significant increased risk and significant protective effect. **PM10** (3 studies); 1 retrospective cohort and 2 cross-sectional reported 11 entire/trimester-specific scenarios. 2 reported entire pregnancy and both found significant increased risk. 3 reported 1st trimester and 2 found significant increased risk and one found non-significant increased risk. 3 reported on 3rd trimester and one found non-significant increased risk while 2 found significant protective effect. **PM2.5**: One study (cross-sectional) examined monthly and found non-significant increased risk in all months. **SO2** (3 studies); 1 prospective cohort and 2 cross-sectional.	Further studies are needed to clarify associations for other outcomes and pollutants, particularly CO, PM2.5 and O3, for which there were relatively few studies.	**Strengths** An advantage of this study was that by including peer reviewed articles written in Chinese, we were able to include 14 additional studies on the topic that would not have been included had the review been limited to English language articles.

			One study (cross-sectional) examined monthly and found mixed of non-significant increased risks in and protective effects and with significant increased risk in the 8th month. The other cross-sectional study reported on the entire, 1st and 2nd trimesters and found significant increased risk for both entire and 1st and non-significant increased risk for 2nd. 2 reported on 3rd trimester where the prospective cohort found significant increased risk and the cross-sectional found non-significant protective effect. **CO:** One study (cross-sectional) examined monthly and found non-significant increased risk in almost all months and with significant increased risk in the 8th month. **LBW** **NO2**: 3 studies. A cross-sectional study reported and found no association for entire pregnancy. A retrospective cohort reported and found non-significant decreased risk for 1st trimester. 2 studies reported for 3rd trimester and one found significant decreased risk or protective effect (case-control study) and the non-significant decreased risk in the other (retrospective cohort). The retrospective cohort also reported non-significant decreased risk in 1st, 2nd, and 3rd months. **PM10**; 5 studies. One study (cross-sectional) reported for entire pregnancy and found non-significant increased risk. A retrospective cohort reported and found non-significant decreased risk for 1st trimester. 2 studies reported for 3rd trimester one found significant decreased risk or protective effect (case-control study) and the non-significant decreased risk in the other (retrospective cohort). Another retrospective study reported various monthly for VLBW and found non-significant decreased risk in most cases and a significant decreased risk or protective association for 7-9th months. **SO2**: 5 studies. One study (a cross-sectional) reported for entire pregnancy and found non-significant increased risk.		

			2 studies reported for 2nd trimester and found significant (case-control study) and non-significant (retrospective cohort) increased risks. 2 studies reported for 3rd trimester and one found significant increased risk (prospective cohort) but non-significant decreased risks in the other (retrospective cohort). Another retrospective study reported various monthly for LBW/VLBW and found mixed associations but with no statistical significance. **PTB** **PM10:** 8 studies; 2 each for retrospective cohort and case-control, 4 cross-sectional. 4 studies reported for entire pregnancy and one found significant increased risk and the other 3 found non-significant increased risk. 3 reported for 1st trimester where one found non-significant decreased risk and 2 found no association. 2 reported for 2nd trimester with non-significant increased risk in one and decreased risk in the other. 3 reported for 3rd trimester where 2 found non-significant increased risk and one found non-significant decreased risk. Several varied timeframes were examined in some studies and significant increased risk was found once for each of the following; 3 months before conception, 8 weeks, 2nd months, 3rd months, 4-6th months, 7-9th months, 2nd month before delivery. One case-control study (8969 births; 677 cases, 8292 controls), further classified the PTB as moderate PTB (32–36 weeks) or very PTB (<32 weeks) and then further as either medically indicated or spontaneous. For the sub-outcome medically-indicated PTB, significant increased odds were found for the entire pregnancy and 1st trimester. For very PTB, significant associations were observed in the last 4, 6, 8 weeks before delivery. **NO2**: 7 studies; 1 retrospective, 2 case-control, 4 cross-sectional. 3 reported on entire pregnancy and one found significant increased risk and the 2 found no association. 2 reported		

			on 1st trimester and both found non-significant decreased risk. 2 reported on 2nd trimester and both found decreased risk where one is significant. 3 reported for 3rd trimester and one found significant increased risk and 2 found non-significant decreased risk. Varied other timeframes were reported and one study found significant increased risk in 8th week before delivery. **SO2**: 7 studies; 2 each for retrospective cohort and case-control, 3 cross-sectional. 3 studies reported for entire pregnancy and all found significant increased risk. One reported for 1st trimester and found non-significant increased risk. 2 reported for 2nd trimester and both found non-significant increased risk. Varied other timeframes were reported a significant increased risk was reported once for each of the following: 3rd month, 1 month before delivery, 8th month before delivery. **O3**: One cross-sectional study reported for change in number of events in the 4,6, 8 weeks before delivery and found significant risk for 4 and 8weeks before delivery. **Stillbirth** Reported by one case-control study of 102,575 births (9325 cases, 93,250 controls). **CO**: no association for the entire pregnancy and all trimesters. **NO2**: no association for 1st trimester and non-significant decreased risk for the entire pregnancy, 2nd, and 3rd trimesters. **O3**: no association for 1st trimester and non-significant decreased risk for the entire pregnancy, 2nd, and 3rd trimesters. **PM10**: non-significant increased risk for 1st trimester and non-significant decreased risk for the entire pregnancy, 2nd, and 3rd trimesters. **SO2**: Non-significant increased risk for the entire pregnancy and 1st trimester but no association for the 2nd and 3rd trimesters.		

			Stillbirth was further reported by term and preterm births, and also several other timeframes with mixed findings. Significant decreased risk was found in 2nd trimester for **O3** and **PM10** among term births, significant increased risk for **SO2** in 1st trimester, and 1st, 2nd, and 3rd months among PTB stillbirth.		
11. Shah (Shah et al., 2011) (26/11/2010) [2; both Canada]	PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3, TSP	LBW, PTB, SGA/IUGR, BW	**LBW** **PM2.5;** 4 studies (3 cohort and 1 case-control; 3,971,602 births, 1 cohort had crude OR). 2 cohort studies reported on entire pregnancy where one found significant increased risk and the other found non-significant increased risk. 1 study several exposure levels for first month, last 2 weeks, and total gestation and found significant increased risks for 8 out of 9 scenarios. Another cohort reported average exposure during pregnancy for 3 different exposure levels and found non-significant decreased risk for all. **PM10:** 12 studies (9 cohort, 3 ecological; 5,074,520 births; 2 studies had crude OR) 5 studies reported for entire pregnancy; 3 found non-significant increased risk (including 1 crude OR), 1 found non-significant decreased risk and 1 found no association. 5 studies reported for 1st trimester; 1 found significant increased risk, 3 found non-significant increased risk (including 1 crude OR), and 1 found non-significant decreased risk. 5 studies reported for 2nd trimester; 1 found significant increased risk, 3 found non-significant increased risk (including 1 crude OR), and 1 found non-significant decreased risk. 6 studies reported for 3rd trimester; 2 found non-significant increased risk, 3 found non-significant decreased risk, and 1 found no association (crude OR). One study reported city-specific average exposure during pregnancy for 7 cities in Korea and found significant increased risk for 2 cities and non-significant increased risk for remaining cities.	*Implications for practice* The results of this systematic review reinforce the need for action to be taken to reduce exposure to environmental pollutants, especially during pregnancy. Clinicians should therefore encourage their pregnant patients to pay attention to local air quality index information and adjust their activities where a risk is identified. Regional, national and international efforts are needed to reduce air pollution, not only to improve birth outcomes, but also other health outcomes. Individual action by pregnant women, such as limiting time spent outside when the outdoor pollution level is higher, and reducing infiltration of outdoor pollution to indoor areas is needed.' *'Implications for research* The body of research needs to expand to augment our understanding of the biological mechanisms underlying the impact of	**Strengths** 'This is the first review to assess associations of birth outcomes using an exhaustive method that targets individual pollutants. Large number of studies, assessment of risk of biases in the included studies, and qualitative and quantitative analyses of exposure-outcome relationships are strengths of this review. **Limitations** We restricted our searches to English language publications. We did not include gray literature, abstracts, and proceedings, as the quality of such studies, particularly for the observational association type of studies, could not be assessed adequately.

			Another study reported average exposure during pregnancy for three different exposure levels and found non-significant decreased risk for two and significant decreased risk for the relatively highest exposure. **SO2**: 14 studies; 8 cohort, 2 case-control, 4 ecological studies; 5,379,951 births and unreported for 1 ecological study (3 cohort studies, 749,700 births included reported crude ORs). 5 studies reported for entire pregnancy where one each found significant and non-significant increased risk, 1 found no association, and 2 found non-significant decreased risk. 5 reported for 1st trimester where 1 found significant increased risk, 2 each found non-significant increased and decreased risks. 5 reported for 2nd trimester where 1 found significant increased risk, 3 found non-significant increased risk and 1 found non-significant decreased risk. 4 reported for 3rd trimester where 2 each found non-significant increased and decrease risks. Other exposure periods included during last month or trimester with different exposure levels with 2 finding significant increased risk and mixed finding in others, including non-significant increased/decreased risks. One case-control study (345 births) reported on VLBW and found significant increased risk. **NO2**: 11 studies; 9 cohort and 2 ecological; 5,228,442 births (one included cohort study with 388,105 births was a crude OR). 4 studies reported for entire pregnancy where 2 found significant increased risk, 1 each found non-significant increased and decreased risks. 4 reported for 1st trimester where 1 found significant increased risk and 2 each found non-significant increased and decreased risks.	various air pollutants, as well as the interactions between them. Key areas where research is needed to improve our understanding of the strength and magnitude of the association between air pollution and birth outcomes include (Slama et al., 2008): an improved method of detecting exposure at a large population level, development of an objective measure to assess duration and intensity of exposure of individuals, inclusion of entire populations or performance of carefully designed nested studies, complete assessment of outcomes throughout pregnancy, identification of considerations necessary to avoid residual confounding, and adjustment for residential mobility.’	

			5 studies reported for 2nd trimester where 1 found significant increased risk, and 2 each found non-significant increased and decreased risks. 4 studies reported for 3rd trimester where 2 each found non-significant increased and decreased risks. Other exposure periods include non-significant decreased risks for both 1st and last months reported in a cohort study (229,085 births). **NO**: 3 studies; 2 ecologic and 1 cohort; 165,470 births with unreported births in one ecologic (the included cohort had crude OR). A study reported on entire, 1st, 2nd and 3rd trimester and exposure above average at delivery; all found non-significant decreased risk in each instance. **CO**: 13 studies (9 cohorts, 2 case-control and 2 ecological studies; 5,367,034 births; one cohort study had crude OR). 4 studies reported for entire pregnancy and 2 found non-significant increased risk and another 2 (including 1 crude OR) found non-significant decreased risk. 4 studies reported for 1st trimester and 1 (crude OR) found significant increased risk while 3 found non-significant increased risk. 3 studies reported for 2nd trimester and 1 (crude OR) found significant increased risk while 2 found non-significant increased risk. 4 studies reported for 3rd trimester and 1 found significant increased risk, 2 found non-significant increased risk and one (crude OR) found significant decreased risk. Other exposure periods included 1st month, last 3 months, last month, during last trimester, total gestational exposure with several exposure categories; mixed findings, predominantly non-significant increased and decreased risk. **O3**: 7 studies (5 cohort and 2 ecological; 4,445,775 births) 2 studies reported for entire pregnancy and both found non-significant increased risk.		

			3 studies reported for 1st trimester where 1 found non-significant increased risk and 2 found non-significant decreased risk. 2 studies reported for 2nd trimester finding non-significant increased risk in one and decreased risk in the other. 3 studies reported for 3rd trimester where 1 found non-significant increased risk and 2 found non-significant decreased risk. A cohort study reported for 1st and last months and found non-significant increased risk for both exposure periods. **TSP**: 3 studies (2 cohort and 1 ecological; 351434 births with unreported birth for the ecological study). 1 study reported and found significant increased risk for entire pregnancy. 2 studies reported for 1st trimester; 1 found significant increased risk and the other found non-significant increased risk. 1 study reported and found non-significant increased risk for 2nd trimester. 2 studies reported for 3rd trimester; 1 found non-significant increased risk and the other found non-significant decreased risk. **BW (reduction)** **PM2.5:** 4 cohort studies; 3,929,272 births. 1 study reported and found significant increased risk for entire pregnancy 1 study reported and found significant increased risk for 1st trimester. 1 study reported and found non-significant increased risk for 2nd trimester. 1 study reported and found significant increased risk for 3rd trimester. A prospective study reported and find significant increased risk for 2 days in second trimester. Another study reported for three exposure levels for average exposure during pregnancy and found significant increased risk for one and non-significant increased risk for the other two exposure dosage		

			PM10: 4cohort studies; 393,2001 births. 2 studies reported for entire pregnancy; 1found significant increased risk and the other found non-significant increased risk. 1 study reported and found significant increased risk for 1st trimester. 1 study reported and found non-significant increased risk for 2nd trimester. 1 study reported and found non-significant increased risk for 3rd trimester. Another study reported for three exposure levels for average exposure during pregnancy and found significant increased risk for one and non-significant increased risk for the other two exposure dosage **NO2**: 7 cohort studies; 3941118 births. 5 studies reported for entire pregnancy; 1 found significant increased risk, 2 each found non-significant increased and decreased risks. 3 studies reported for 1st trimester; 2 found non-significant increased risk, 1 found non-significant decreased risk. 3 studies reported for 2nd trimester; 1 found non-significant increased risk, 2 found non-significant decreased risk. 3 studies reported for 3rd trimester; 1 found significant increased risk, 2 found non-significant decreased risk. **SO2**: 4 cohort studies; 3,917,781 births. 1 study reported and found non-significant increased risk for entire pregnancy. 2 studies reported for 1st trimester; 1 found non-significant increased risk and the other found non-significant decreased risk. 2 studies reported for 2nd trimester; 1 found non-significant increased risk and the other found non-significant decreased risk. 2 studies reported for 3rd trimester; 1 found non-significant increased risk and the other found non-significant decreased risk. 1 study reported and significant increased risk for the first 2 months. **CO**: 3 cohort studies; 3,906,772		

			2 studies reported for entire pregnancy; 1 found non-significant increased risk and the other found non-significant decreased risk. 1 reported and found non-significant increased risk for 1st trimester. 1 reported and found significant creased risk for 2nd trimester. decreased risk. 1 reported and found significant increased risk for 3rd trimester. **O3**: 2 cohort studies; 3,548,268 births. The first study (3,091 births) reported and found significant increased risk for entire pregnancy. The second study (3,545,177 births) reported for trimester-specific and found significant increased risk for 1st, 2nd, and 3rd trimesters. **PTB** **PM2.5:** 1 case-control; 2,543 births. Reported 1st trimester for two different exposure level and significant and non-significant increased risks. **SO2: 5 studies**; 4 cohort and 1 ecological studies; 5,97,922 births (2 included studies, a cohort and ecologic; 165,470 births reported crude ORs) 1 study each reported for each trimester and found significant increased risk for each trimester. A study each also reported and found nonsignificant decreased risk for 1st month, significant increased risk for last month and significant increased risk for at delivery. **PM10:** 2 cohort studies 285,515 births. 1 study (187,997 births) reported for entire pregnancy and found non-significant increased risk. The second study (97,518 births) reported and found non-significant increased risk for first month of pregnancy and significant increased risk for 6 weeks prior to delivery. **NO2**: 6 studies; 4 cohort and 1 each for case-control and ecological; 370,985 births (the included ecologic study with 126,752 births had crude OR).		

			3 studies reported for entire pregnancy where 2 found non-significant increased risk and 1 found non-significant decreased risk. 4 studies reported for 1st trimester where 2 found significant increased risk and 1 each found non-significant increased and decreased risks. 4 studies reported for 2nd trimester where 1 found significant increased risk, 2 found non-significant increased risk, and 1 found non-significant decreased risk. 4 studies reported for 3rd trimester where 3 found non-significant increased risk and 1 found non-significant decreased risk. One cohort study (229,085 births) reported for 1st and last months and found non-significant increased risk for both exposure periods. **NO**: 2 studies; a cohort and an ecologic; 165,470 births (both reported crude OR). The cohort study reported on 1st, finding significant increased risk, 2nd for non-significant increased risk, and 3rd trimester for significant increased risk. The ecological study reported for exposure above average at delivery and found non-significant increased risk. **CO**: 3 studies (2 cohort and 1 case-control; 329,146 births) 1 case-control (2,543 births) reported for and found non-significant decreased risk on entire pregnancy and non-significant increased risk for 1st trimester. The 2 cohort studies reported for 6weeks before delivery, first month, and last month with both non-significant increased/decreased risk, and a significant increased risk in last month. **O3**: 2 studies (1 each for case-control and cohort; 231,628 births). The cohort study (229,085 births) reported for first and last months and found non-significant decreased risk for both periods. The case-control study (2,543 births) reported different exposure categorised during 1st trimester finding both increased and decreased non-significant risks. **TSP**: 1 ecological study (unreported sample size)		

			Significant increased risk for 1st trimester. Non-significant increased risk for 2nd trimester. Significant increased risk for 3rd trimester. **SGA** **PM2.5:** 4 studies (all cohort; 183475 births). A cohort study (138,056 births) reported on and non-significant decreased risk for1st trimester, significant increased risk for 2nd, and non-significant decreased risk for 3rd trimester. Others reported for over duration of pregnancy or average exposure and for several exposure level categories and found significant risk for 2 scenarios and no/decreased risk for the rest. **PM10:** 6 cohort studies; 175,116 births. 2 studies reported for entire pregnancy; 1 found significant increased risk and the other found non-significant increased risk (crude OR)**.** 1 study reported and found no association for 1st trimester. 1 study reported and found significant increased risk for 2nd trimester. 1 study reported and found no association for 3rd trimester. 2 studies reported on and both found significant increased risk for first month of pregnancy. Another study reported for average exposure during pregnancy for three levels of exposure categories and found no association for relatively lowest level and non-significant decreased risk for the other two higher levels. **SO2**; 1 cohort study with 229,085 births. Reported for first month and found significant increased risk but no association for last month. **NO2**: 6 studies; all cohort studies; 404,008 (2 included studies; 3,876 births were unadjusted ORs, one each for entire and 2nd trimester). 2 studies reported for entire pregnancy and found non-significant increased and decreased risk. 2 studies reported for 1st trimester where one found no association and non-significant decreased risk in the other.		

			3 studies reported for 2nd trimester where one found no association and non-significant increased and decreased risk in the other two. 3 studies reported for 3rd trimester where one found non-significant increased risk and 2 found non-significant decreased risk. One study reported average exposure during pregnancy and found no association and non-significant decreased risk in two exposure levels. One cohort study (229,085 births) reported for first month and found significant increased risk but non-significant decreased risk for last month. **CO**; 4 studies (all cohort; 388,479 births; 1 had crude OR) 2 reported for entire pregnancy where 1 found non-significant increased risk and the other (crude OR) found no association. A study (138,056 births cohort) reported on and found non-significant decreased risk for both 1st and 2nd trimesters, and non-significant increased risk for 3rd trimester. Another study reported for 1st month with significant increased risk and non-significant decreased risk for last month. **O3**: 3 studies (all cohort; 370,232 births; 1 had crude OR). 2 studies reported on 1st trimester and both found no association. 2 studies reported for 2nd trimester and both found non-significant increased risk. 2 studies reported for 3rd trimester and both found no association. The third study reported for 1st and last months and found non-significant decreased risk for both periods.'		
12. Bonzini (Bonzini et al., 2010) 09/2010 [6, All Italy]	PM_{10}, CO, NO_2, O_3, $PM_{2.5}$	PTB, LBW, SGA, BW	**PTB (8 studies)** **PM10 (6 studies):** odds ratios for 14 pregnancy period-specific exposures standardized to an increase of 10 µg/m3 PM10 and 8/14 cases showed a significant increase in PTB risk with odds ratios ranging from 1.014 to 1.364.	'There is a need for large collaborative studies to validate the results, through comparison of different exposure assessment methods. These studies need to take time	Not stated for the review But general statements on studies. 'In the absence of an a priori clear hypothesis it's

			(**NB**: only 2 cases actually found significant association, both in 1st trimester where CI didn't include 1). Two of the eight (25%) studies reported statistically significant increases in PTB in the first trimester of pregnancy (13% for 52,113 births cohort study and 36% for 28,200 births time series study). **CO (5 studies)** 14 period-specific odds ratios (ORs) standardized for an increase of 1 mg/m3 in exposure was estimated and results from most of the cases were associated with an increased risk of approximately 1.0, with the exception of data from Leem et al. (South Korea), which produced a two-fold increased risk in the first trimester and 78% increased risk in the third trimester. Results from two studies (Wilhelm et al. and Ritz et al.) showed significant but smaller (ORs=1.178 and 1.333, respectively) increases in PTB in the first trimester in Californian women. (**Note**; 9/14 with 4/9 significant; 3 in 1st trimester from 3 cohort studies of 225,391births; 1 in 3rd trimester from a 52,113 births cohort study) **NO2 (4 studies)** The effect of NO2 The 4 studies gave 9 period-specific ORs and adjusted ORs for an increased exposure to 10 µg/m3 showed mild, yet statistically significant increases in risk of PTB in the first (2 cohort studies of 118,908 births) and third (1 cohort study of 52,113 births) trimesters. . **O3 (3 studies)** The 3 studies gave estimations of 7 period-specific ORs that ranged from 0.974 to 1.177 per an increase of 10 µg/m3. Two Australian studies (Hansen et al and Jalaludin et al) reported statistically significant increases for exposure during the first trimester respectively as 1.177 and 1.072. No significant increases in PTB risk were found associated with exposure in the second or third trimester of pregnancy. Two time series studies found significant association in 1st trimester, from 152,040 Australian births	activity-patterns, maternal characteristics and behaviour, and spatial confounders into account. Studies of prospective cohorts, with the use of biomarkers of exposure might be particularly forthcoming. Meanwhile, because of the extreme susceptibility of the fetus and the impact of perinatal adverse events on adult health, it may be prudent to continue to try and reduce exposure of pregnant women to air pollution throughout the world.'	also difficult to establish critical time windows of exposure for each outcome The variability across studies could reflect important differences in study design. Exposure assessment method is a crucial issue.'

			PM2.5 (4 studies) 10 period-specific ORs (5 of them >1.00) based on the 4 studies, standardized to an increase of 1 µg/m3 exposure and only 1/4 (25%) study reported significant risk of PTB in the first trimester. The case-control study showed a significant increase of risk during the first month of pregnancy, and the last two weeks of pregnancy, as well as the entire pregnancy, but did not provide trimester-specific risk estimates. (NB: 9 period-specific ORs; 1 significant association in 2nd week, 1st month and whole pregnancy by 1 matched case-control study of 42,692 births; 1st trimester by 1 cohort study of 667,795 births) **Term LBW** **PM10** (7 studies) The 7 studies gave a total of 17 period-specific ORs. 11/17 (65%) showed non-significant increased risks ranging from point estimates1.037 to 1.480, and two found borderline significant (one each for 1st in 74,284 births and 3rd trimesters in 136,134 births, both are cohort studies). One study reported no association consistently across each trimester. **CO** (5 cohort studies) 11 period-specific ORs No clear association in all studies except 1 cohort study of 136,134 births that found a significant 35% increase in risk for the 3rd trimester **NO2** (4 studies + 1 same study data) 10 period-specific ORs. 4 cases showed association but 2 were significant for the entire pregnancy period from 2 cohort studies of 428,753 births **O3** (3 studies) 9 period-specific ORs. 3 associated marginally but none showed significantly increased ORs **PM2.5** (2 studies)		

			Both studies studied entire pregnancy and 1(358,504 births cohort study) showed a small but statistically significant adverse exposure-related effect (OR=1.024;1.010 - 1.039) **SGA** **PM10 (4 studies)** 9 period-specific ORs 3 with increased ORs but none was significant **CO** (3 cohort studies) produced 9 period-specific ORs. One cohort study (386,202 births) showed statistically significant increased risks with exposure in each trimester (1.153 in the first trimester to 1.128 in the second trimester). Another 1 scenario found non-significant. **NO2** (3 cohort studies) 9 period-specific ORs. 5 associated with increased risk but 3 were significant (in each trimester from one cohort study of 386,202 births) **O3** (3 cohort studies) 8 period-specific ORs 1 showed non-significant increased risk in 1st trimester, 4 showed a decreased risk (2 in 3rd and 1 each in 1st and 2nd trimesters), the rest no association. **PM2.5** (3 cohort studies) 9 trimester-specific ORs 6 showed significant increased risk; 1 in 1st (cohort study of 386,202 births) 3 in 2nd (542,505 births of cohort studies) and 2 in 3rd trimesters (404,449 births) **BW** **PM10** (6 studies) 19 period-specific risk estimates. 14/19 risk estimates showed an association between exposure and lower birth weights (<25 g) when exposures were aligned to an increase of 10 µg/m3. The 6/14 had different levels of exposure (17 to 60 µg/m3), and all showed statistically significant decreases in birth weight (1 for whole preg in 358,504 births cohort, 1st trimester in 2 time series studies for 206,077 births, 2nd trimester and last month for 1 cohort of 138,056 births, 3rd trimester for 2 birth cohort studies of 362,405 births. One cohort study		

			of 1,514 births found significant increase of birth weight in 1st trimester. No consistency across studies was evident with regard to the period of pregnancy in which the effects were found. **CO** (5 studies) 18 period-specific estimates; 10 showing a decrease in birth weight). Significant adverse effects were observed in the 1st trimester in 3 cases (a time series of 179,460 births, 2 cohort studies of 362,405 births); both whole preg and 3rd trimester in a cohort study of 358,504 births. Significant in last month was found in a cohort study of 138,056 births. **NO2** (5 studies) 15 period-specific estimates, of which 10 suggested a decrease in birth weight but significant in 3 cases (1st and 3rd trimesters in a 138,056 births cohort study, whole preg in a 358,504 births cohort study). **O3** (4 studies) 14 period specific estimates. 4 showed statistically significant in-verse relationship between exposure and birth weight (2 in 2nd trimester from 2 cohort studies of 141,957 births, 1 each in 3rd trimester and whole preg period from 3,901births cohort study). Others showed non-significant adverse association. **PM2.5** (3 cohort studies) 11 period-specific estimates, most of the estimates showed small but statistically significant decreases in BW for increasing levels of exposure in each trimester and also in the entire pregnancy (1 in whole preg from 18,247 cohort births, 2 in 1st trimester from 376,751 cohort births, 2 in 2nd trimester from 156,303 cohort births, 2 in 3rd trimester from 376,751 cohort births), and a last month from 138,056 cohort births.		
13. Bosetti (Bosetti et al., 2010) 06/02/2010 [6; 5 Italy, 1 Spain]	TSP, PM_{10}, $PM_{2.5}$	PTB, LBW, VLBW, SGA	**PTB** **TSP** (2 studies)-a time series and cross-sectional; 103,518 births.	Further and better studies are needed to clarify whether there is a real effect of PM on these adverse pregnancy outcomes. The studies	NB: No statement on the limitations and strengths of the review. But highlighted the limitations of the included

			Significant for whole pregnancy period for the time series study. Associated for all trimesters but significant for 1st trimester for the cross-sectional study. **PM10** (9 studies)-3 time series and 6 cross-sectional;480,159 births and unreported for 2 studies. 5 studies examined 1st trimester and 2 found significant RR, 1 each non-significant increase and decrease RR and 1 no association. One found significant increased RR in first month and one found non-significant RR in whole preg. Only one reported 2nd trimester with no association. 3 reported 3rd trimester with non-significant increase RR. 3 reported last 6 week with one significant risk. **PM2.5** (4 studies)-all cross-sectional; 210,459 births and unreported in one study 2 out of 4 found significant for risk for 1st trimester. One found significant association for whole pregnancy. One each studied last 6 and 2 weeks and last 2 week was significant. No report on 3rd trimester. **LBW** 17 studies (2 case-control, 1 ecological, 14 cross-sectional) **TSP** (5 studies)- 3 cross-sectional, 1 case-control (for VLBW) and 1 ecological; 459,952 births excluding unreported births for the ecological study. 1 reported nonsignificant increased risk for LBW in whole preg the one case-control was significant for VLBW. 2 reported for 1st trimester and both showed significant increased risk. Only one reported for 2nd trimester and was significant risk. 3 reported for 3rd trimester and 2 showed significant risk. **PM10** (12 studies)- 11 cross-sectional on LBW and 1 case-control on VLBW; 1,259,186 births with one unreported size. 4 reported non-significant risk for whole preg	should include: better assessment of exposure using, for example geographic information system techniques, such as land use regression or air dispersion models, which take mobility into account; better information on confounders and analyze potential residual confounding; and measurement of biomarkers of exposure or personal exposure monitoring in order to validate exposure estimates. Other studies focused on better outcomes, such as ultrasound measurements during birth, may also help understand the effect of air pollution on adverse pregnancy outcomes.	primary studies (and summarised this in the conclusion and recommendations)

			6 reported 1st trimester where 4 showed non-significant risk, 1 no association and 1 decreased risk. 6 reported for 2nd trimester where 2 showed significant risk, 3 non-significant risk and 1 decreased risk. 7 reported 3rd trimester with none significant, 3 each non-significant increase and decrease risks, and one no association. **PM2.5** (3 studies)- all cross-sectional; 429,769 births. 2 reported whole preg where one showed significant increase risk and the other found decreased risk. One reported prevalence ratio which was significant in 3rd trimester. **SGA** **PM10** (3 studies)- all cross-sectional; 234,922 births. One did not report RR. One reported on whole preg and found non-significant RR. The other one reported no association prevalence ratio for 1st and 3rd trimesters but significant for 2nd trimester. **PM2.5** (3 studies)-all cross-sectional; 226,552 births. One reported on whole preg and found non-significant RR. 2 reported on 1st trimester where one found significant increased risk and the other found a decreased risk. Both found significant risk for 2nd trimester. One found significant risk for 3rd trimester and the other decreased risk.		
14. Ghosh (Ghosh et al., 2007) 09/05/2007 [4, UK]	TSP, PM_{10}, $PM_{2.5}$, CO, SO_2, NO_2, O_3	BW, LBW, VLBW, PTB	**LBW (3 studies)** A case-control study (36,305 births in USA) that examined gender differential with males as reference reported significant excess risk in females for LBW compared to males for exposures PM10, CO, O3. One cohort study in China (74671 births) reported higher but insignificant risk each for exposures SO2 and TSP in females. **VLBW** Another case-control (345 births in USA) also reported insignificant excess risk in females for combined TSPSO2 exposure. **BW (1 study)**	'Further investigation to ascertain interaction is required in high-powered datasets across different populations.'	'The interactive effects of air pollution, pregnancy outcomes and gender should be considered in light of known limitations such as exposure misclassification, bias and confounding. Studies that reported a gender based estimate were those that reported a positive association between air pollution and adverse

			A study from Poland, a prospective cohort of 362 births reported a significantly lower mean in females (212.80 g) for PM2.5 **PTB** NB: None examined exposure-outcome association with empirical measurement of the exposures. The review authors (Ghost et al, 2007) estimated unadjusted (except 2 adjusted) gender-specific effects between air pollutant and birth outcomes based on additional information from primary authors (4 studies); one study for each association. **LBW-SO2;** excess significant adjusted OR in males but insignificant in females. **LBW-TSP**; excess significant adjusted OR in males but insignificant in females. **LBW-PM10**; excess but insignificant unadjusted OR in both but higher in males than females. **LBW-NO2**; excess significant unadjusted OR in males but insignificant in females. **LBW-CO**; excess but insignificant unadjusted OR in both but lower in males than females. **LBW-O3**; reduced insignificant unadjusted OR in both but higher in males than females. **VLBW-TSPSO2**; excess but insignificant unadjusted OR in both but higher in males than females. **BW-PM2.5**; no evidence of significant difference between genders, unadjusted. **PTB-PM10**; excess but insignificant unadjusted OR in both but higher in males than females. **PTB-CO**; excess significant unadjusted OR in males but insignificant in females. **PTB-O3**; reduced significant unadjusted OR in both but lower in males than females. **PTB-NO2**; excess significant unadjusted OR in both but higher in males than females.		pregnancy outcomes. None of the studies that reported negative associations explored gender effects. Thus publication bias may be relevant here.'
15. Glinianaia (Glinianaia et al., 2004)	TSP, $TSPSO_2$, PM_{10}, $PM_{2.5}$	LBW, VLBW,	**LBW/BW** **TSP** (3 cohort studies); 6 trimester-specific cases; increased non-significant risk for 2 studies in 1st, 1 in 2nd	'Future research is needed to clarify whether there is a small adverse effect of	**Limitations** 'Publication bias, and the exclusion of papers not

09/01/2004 [5, UK]		IUGR, PTB, and SB	and 2 in 3rd trimesters of LBW. One found significant increased risk in 3rd trimester for LBW. 3 studies also reported significant reduction in mean BW (2 in 1st and 1 in 3rd trimesters). One ecological study with unadjusted OR also found increased non-significant OR of LBW. **PM10** (1 cohort); found decreased non-significant OR of LBW in each of the trimesters. **VLBW** Reported by one case-control study that found increased significant risk for TSPSO2. **IUGR** **TSP;** 1 cohort study found non-significant decreased OR in the 1st trimester and no association in other trimesters. **PM10**: 2 cohort studies each found significant increased adjusted OR in 1st month **PM2.5**; 1 cohort study found significant increased OR in 1st month. **PTB** **TSP**; 1 cohort study reported and found increased OR which was significant in 1st trimester but non-significant in 2nd and 3rd trimesters. Another cohort study found increased risk for 7-day lag and significant reduction in mean gestational age. **PM10**; 1 cohort reported and found increased risk which was non-significant in the 1st month but significant in 6 weeks before birth. **Stillbirth** **TSP**: Reported by an ecologic study with annual mean and found decreased non-significant adjusted rate. **PM10**: reported by one time-series study and found non-significant increased adjusted rate ratio of daily intrauterine deaths.	particulate air pollution on fetal health. Further ecologic studies are unlikely to add to the evidence. A time-series approach could be justified if the study examines the potential effect of short-term changes in air pollutant levels on acute events (eg, preterm birth, stillbirth), but it would not be useful when examining birthweight as an outcome variable. More refined methodologic designs are needed such as large population-based cohort or case-control studies using individual fetal outcome and covariate data and high-quality exposure data. Studies are more likely to find evidence for a small effect if they involve settings with wide variation of air pollution levels.'	published in English, could have decreased the number of results available for review. Most papers reported the results relating to various combinations of pollutant, exposure period, and outcome. The findings should be interpreted with caution in these circumstances because of the increased likelihood of a positive finding occurring by chance. All relevant comparisons should be reported, whatever the findings. Misclassification of exposure, which biases effect estimates toward the null. Studies exploring the health effects of PM are complex to summarize because the definitions and measurement techniques have varied over time. Differences in PM level, size, and composition could have affected the strength of association between PM and fetal growth in the different geographic settings. Most semi-individual studies in this review chose to control for key confounding factors (ie,

					gestational age, maternal age, infant sex) at an individual level. However, adjustments were made less often for other important individual risk factors such as smoking, socioeconomic status, and environmental exposures, including other air pollutants (eg, SO2,NO2)'

Note: NO_2, Nitrogen dioxide; NO_x, Nitrogen oxides; CO, Carbon monoxide; O3, Ozone; SO_2, Sulphur dioxide; $PM_{2.5}$, particulate matter at aerodynamic diameter ≤ 2.5μm; $PM_{10,}$ particulate matter at aerodynamic diameter ≤ 10μm; TSP, total suspended particles; SPM, suspended particulate matter; PTB, preterm birth; BW, birth weight; LBW, low birth weight; TLBW, term low birth weight; VLBW, very low birth weight; SGA, small-for-gestational age; IUGR, intrauterine growth retardation; FGR, foetal growth restriction; SB, stillbirth; SAB, spontaneous abortion; TBWT, term birth weight; OR, odd ratio; CI, confidence interval; SES. Socioeconomic status; BMI, body mass index.

Table S4. Results and additional information on systematic reviews with meta-analysis, ordered from recent to earliest.

First author, date [number of authors, countries]	**Exposure(s)**	**Outcome(s)**	**Main meta-analysis results and publication bias**	**Subgroups/Sensitivity**	**Researchers' recommendations**	**Researchers' stated strengths and limitations**
1. Gong (Gong et al., 2022) 04/10/2021 [5; 4 China, 1 USA]	$PM_{2.5}$	TBW (continuous outcome)	**Change in TBW per 10 μg/m^3** **Entire pregnancy** 26 cohort studies; 23,926,140 births RE model pooled beta= -16.54 (-20.07, -13.02) I^2= 95.6% 'No evidence of significant publication bias for any of the meta-analyses based on the Begg's test. However, a potential publication bias was observed in the overall meta-analyses during the entire pregnancy and the third trimester based on the Egger's test. There was no evidence of significant publication bias for the LUR-models subgroup based on the Begg's and Egger's test (p > 0.05)'.	**Change in TBW per 10μg/m^3** **By trimester**, *1st trimester* 13 cohort studies; 6,707,042 births RE model pooled beta= -5.81 (-8.39, -3.23) I^2= 91.3% *2nd trimester* 13 cohort studies; 6,707,042 births RE model pooled beta= -6.17 (-8.46, -3.87) I^2= 85.4% *3rd trimester* 20 cohort studies; 10,361,367 births RE model pooled beta= -5.02 (-8.22, -1.82) I^2= 93.7% **Entire pregnancy b**y exposure assessment methods. *Aerosol Optical depth-based method* 6 cohort studies; 2,163,255 births RE model pooled beta= -41.58 (-65.50, -17.67) I^2= 95.6% *From monitoring stations* 10 cohort studies; 12,792,286 births RE model pooled beta= -11.53 (-17.11, -5.947) I^2= 97.3% *Interpolation or dispersion models*	'More studies based on LUR models in this area are needed to verify our observation' 'With regard to exposure prediction, further improvements in the temporal resolution of LUR predictions could allow an assessment as to whether very short-term (e.g., even hourly) peak maternal exposures are more critical than steady long-term exposures in affecting birth outcomes. Improvements in the GIS database would likely improve performance of LUR models in generating fine-scale spatial	**Strengths** 'This is the first systematic review and meta-analysis of effects of PM2.5 on TBW.' **Limitations** 'The subgroup analyses included relatively few studies and needs more future studies to verify the findings. Second, the susceptible exposure time window has not yet been clarified.' 'Third, the I2 statistic, like other metrics, suffers from statistical power problems (Ioannidis, 2008).' 'Fourth, studies on non-linear concentration-response relationship were excluded because the results could not be inferred to relevant linear dose-response effect estimate and could not be pooled into the meta-analysis'.

				5 cohort studies; 5,888,150 births RE model pooled beta= -10.78 (-17.55, -4.01) I^2= 86.6% *LUR models* 5 cohort studies; 3,082,449 births RE model pooled beta= -16.77 (-22.51, -11.03) I^2= 18.3% **1st trimester by exposure assessment methods** *Aerosol Optical depth-based method* 5 cohort studies; 818581 births RE model pooled beta= -9.39 (-19.21, 0.44) I^2= 78.7% *From monitoring stations* 6 cohort studies; 3,194,424 births RE model pooled beta= -7.20 (-11.00, -3.41) I^2= 95.4% *Interpolation or Hierarchical Bayesian models* 4 cohort studies; 2,875,930 births RE model pooled beta= 2.00 (-6.39, -10.39) I^2= 92.8% *LUR models* 3 cohort studies; 3,012,531 births RE model pooled beta= -7.82 (-10.68, -4.97) I^2= 0.0% **2nd trimester by exposure assessment methods.** *Aerosol Optical depth-based method* 5 cohort studies; 818581 births RE model pooled beta= -13.38 (-30.38, 3.63)	predictions.' 'Enhancements to LUR models using spatio-temporal models that incorporate geostatistical smoothing (Keller et al., 2015), or that integrate other exposure predictions from satellite data or chemical transport models with LUR models (Lv et al., 2016; Friberg et al., 2016), may further reduce exposure measurement error and bias, as could use of biomarkers of exposure in pregnant women.' Application of models for generating exposure predictions for other pollutants may provide important insights into the components of the air pollutant mixture that are	

				I^2= 89.5% *From monitoring stations* 6 cohort studies; 3,194,424 births RE model pooled beta= -3.54 (-5.11, -1.96) I^2= 68.8% *Interpolation or Hierarchical Bayesian models* 4 cohort studies; 2,875,930 births RE model pooled beta= -3.32 (-5.96, -0.69) I^2= 6.6% *LUR models* 3 cohort studies; 3,012,531 births RE model pooled beta= -13.48 (-16.36, -10.61) I^2= 85.4% **3rd trimester by exposure assessment methods** *Aerosol Optical depth-based method* 6 cohort studies; 875,214 births RE model pooled beta= -8.78 (-13.17, -4.40) I^2= 33.6% *From monitoring stations* 6 cohort studies; 3,590,147 births RE model pooled beta= -2.44 (-6.66, -1.79) I^2= 96.3% *Interpolation or Hierarchical Bayesian models* 4 cohort studies; 2,875,930 births RE model pooled beta= 2.57 (-2.08, 7.21) I^2= 48.8% *LUR models* 4 cohort studies; 3,020,076 births RE model pooled beta= -14.94 (-17.87, -12.01)	more toxic in producing adverse birth outcomes. 'More accurate exposure assessment methods that incorporate indoor and outdoor pollutant exposures according to the time-activity pattern of pregnant women need to be developed.' 'Relatively standardized covariates are needed to be adjusted to increase the comparability among studies.' More studies based on the distributed lag model (DLM) or a distributed lag non-linear model (DLNM) need to be conducted to provide more precise susceptible exposure windows.'	

				I^2= 0.0% **Entire pregnancy by $PM_{2.5}$ concentration levels.** *Mean $PM_{2.5}$ exposure < 10 µg/m^3* 6 cohort studies; 3,868,577 births RE model pooled beta= -15.58 (-25.38, -5.79) I^2= 60.8% *Mean $PM_{2.5}$ exposure* > 10 µg/m^3 20 cohort studies; 20,057,563 births RE model pooled beta= -16.58 (-20.35, -12.81) I^2= 96.3% **Entire pregnancy by region** *Asia* 6 cohort studies; 3,033,587 births. RE model pooled beta= -6.37 (-11.20, -1.53) I^2= 77.9% *Europe* 3 cohort studies; 598,061 births. RE model pooled beta= -28.39 (-57.83, 1.04) I^2= 78.3% *North America* 17 cohort studies; 20,294,492 births. RE model pooled beta= -19.12 (-23.62, -14.62) I^2= 95.8% **Change in TBW per IQR µg/m^3** *Entire pregnancy* 21 cohort studies; 19,634,754 births. RE model pooled beta= -8.16 (-10.79, -5.54) I^2= 94.3% **Leave-one-out sensitivity analyses** For the overall meta-analysis and subgroup meta-analyses based on exposure assessment methods during the entire pregnancy there was 'no		

				meaningful impact on the pooled effect estimates or significance except for the interpolation/dispersion models subgroup.'		
2. Zhu (Zhu et al., 2022) 03/08/2021 [11; all China]	$PM_{2.5}$, PM_{10}	SAB	**SAB:** *$PM_{2.5}$ per 10 µg/m^3* 5 studies: (2 cohort, 2 case-control, 1 case crossover); 69,507 SABs RE model pooled RR= 1.20 (1.01, 1.40) I^2= 98.6% *PM_{10} per 10 µg/m^3* 5 studies: (2 cohort, 1 case-control, 1 case-crossover, 1 cross-sectional); 12,741 SABs RE model pooled RR= 1.09 (1.02, 1.15) I^2= 78.6%. Egger's regression and Begg's test; No publication bias for $PM_{2.5}$-SAB but PM_{10}-SAB showed possible publication bias.	**Leave-one-out sensitivity analysis** No substantial change	'Reducing pollution emissions should be listed as a vital public health strategy to prevent pregnancy complications and improve human reproductive health worldwide.' "Extra studies are warranted to investigate their specific dose-response effects and detailed molecular mechanisms or pathways, and explore the constituent-specific (e.g., the organic compounds, toxic metals) effects of particulate matter exposure on reproductive events. Furthermore, the association underlying ambient particulate matter	**Strengths** **'**The first systematic review and meta-analysis of epidemiological evidence regarding the effects of ambient PM2.5 on TBW**'.** **Limitations** Results were based on the study-specific effect estimates only. Results included only 'single-pollutant model and failed to evaluate the latent interactions among different pollutants.' 'The small number of the included studies precluded our ability to conduct subgroup analyses and explore extensively other potential sources of heterogeneity, and this present meta-analysis could not make further estimates of the exact dose- response relationship between PM2.5 or PM10 exposure levels and risks of SAB for

					and SAB risks with the synergistic effects of other factors (e.g., physical, genetic, immunological, meteorological factors) still needs to be fully discussed and elucidated.’	insufficient information.’
3. Ju (Ju et al., 2021) 09/07/2021 [7; all China]	$PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3. Ranges: NA	PTB (including subtypes: moderate, very, and extremely PTB).	**PTB:** **Entire pregnancy** *$PM_{2.5}$ per 10 µg/m^3* 31 cohort studies: 1,007,827 PTBs RE model pooled RR= 1.070 (1.046, 1.095) I^2= 88.9% *PM_{10} per 10 µg/m^3* 15 cohort studies: 210,850PTBs RE model pooled RR= 1.034 (1.009, 1.059) I^2= 91.6 % *NO_2 per 10 µg/m^3* 20 cohort studies: 343,203 PTBs RE model pooled RR= 1.010 (0.990, 1.030) I^2= 88.3% *SO_2 per 10 µg/m^3* 8 cohort studies: 158,735 PTBs	**PTB** **$PM_{2.5}$ per 10 µg/m^3** *1st trimester* 26 cohort studies: 920,837 PTBs RE model pooled RR= 0.982 (0.957, 1.007) I^2= 96.5% *2nd trimester* 23 cohort studies: 880,542 PTBs RE model pooled RR= 1.034 (1.001, 1.069) I^2=97.0 % *3rd trimester* 23 cohort studies: 923,545 PTBs RE model pooled RR= 1.018 (0.999, 1.037) I^2=93.2% *Last month* 5 cohort studies: RE model pooled RR= 0.997 (0.976, 1.018) I^2=0.0 % **PM_{10} per 10 µg/m^3** *1st trimester* 16 cohort studies: 263,928 PTBs	‘The results are not stable, there are few relevant literatures, and further investigation is needed, for CO and SO_2. The components of PM2.5 and PM10 should be evaluated in future studies to improve the comparability between studies. ‘In addition, although the heterogeneity was reduced to some extent by analytical method, it was still high in most cases in this study. Therefore, it is necessary to further study the sensitive Windows	**Strengths** ‘This meta-analysis covered a great number of high-quality cohort studies reporting associations between four different types of PTB and seven contaminants, and further sensitivity and subgroup analyses were performed to explore sources of heterogeneity and possible exposure-response relationships’. **Limitations** ‘High degree of heterogeneity was found between included studies and among different subgroups.’ “It is impossible to further explore the causes of

			RE model pooled RR= 1.072 (0.978, 1.175) I^2= 92.7% *O_3 per 10 µg/m^3* 11 cohort studies: 243,295 PTBs RE model pooled RR= 1.032 (1.018, 1.047) I^2= 86.3% Egger's and Begg's tests and the funnel plot did not show obvious publication bias. However, 'there was publication bias in exposure to O3 during a specific gestation period of PTB, PM2.5 during a specific gestation period of PTB and very PTB, and PM10 during a specific gestation period of PTB, very PTB and extremely PTB.' 'The trim and fill method, publication bias had little effect' but 'results of PM10 exposure to very PTB and O3 exposure to PTB during pregnancy showed that publication bias had a significant effect.'	RE model pooled RR=0.970 (0.937, 1.003) I^2= 97.4% *2nd trimester* 14 cohort studies: 257,476 PTBs RE model pooled RR=0.993 (0.960, 1.028) I^2= 97.8% *3rd trimester* 13 cohort studies: 223,574 PTBs RE model pooled RR=1.007 (0.992, 1.022) I^2= 58.7% *Last month* 3 cohort studies RE model pooled RR=0.987 (0.935, 1.042) I^2= 61.1% **NO_2 per 10 µg/m^3** *1st trimester* 21 cohort studies: 398,229 PTBs RE model pooled RR=0.972 (0.950, 0.994) I^2= 86.9% *2nd trimester* 18 cohort studies: 390,413 PTBs RE model pooled RR=1.002 (0.970, 1.034) I^2= 94.9% *3rd trimester* 15 cohort studies: 331,248 PTBs RE model pooled RR=1.066 (1.031, 1.102) I^2= 91.5% *Last month* 6 cohort studies RE model pooled RR= 1.033 (0.981, 1.087) I^2= 75.8%	of different air pollutants and their relationship with PTBs.' 'More longitudinal studies and experimental studies to further investigate the causes and underlying mechanisms'.	the country-differences without sufficient data from original studies.' 'There was publication bias in exposure to O3 during a specific gestation period of PTB, PM2.5 during a specific gestation period of PTB and very PTB, and PM10 during a specific gestation period of PTB, very PTB and extremely PTB.' 'This paper only studies the relationship between a single pollutant and PTBs, but does not discuss the interaction between multiple pollutants.'

				SO_2 per 10 μg/m^3 *1st trimester* 7 cohort studies: 166,190 PTBs RE model pooled RR=0.980 (0.930, 1.034) I^2= 91.5% *2nd trimester* 6 cohort studies: 160,122 PTBs RE model pooled RR=0.995 (0.954, 1.037) I^2= 84.8% *3rd trimester* 7 cohort studies: 166,190 PTBs RE model pooled RR=0.988 (0.939, 1.040) I^2= 90.5% *Last month* 2 cohort studies RE model pooled RR= 1.057 (0.997, 1.121) I^2= 0.0% **O_3 per 10 μg/m^3** *1st trimester* 11 cohort studies: 304,353 PTBs RE model pooled RR=1.035 (1.020, 1.051) I^2= 91.0% *2nd trimester* 8 cohort studies: 293,593 PTBs RE model pooled RR=1.020 (1.001, 1.040) I^2= 94.9% *3rd trimester* 8 cohort studies: 201,663 PTBs RE model pooled RR=1.043 (1.014, 1.072) I^2= 95.5% *Last month* 3 cohort studies		

				RE model pooled RR= 0.994 (0.959, 1.030) I^2= 75.4% **CO per 100 μg/m^3** *1st trimester* 3 cohort studies: 70,680 PTBs RE model pooled RR=0.991 (0.966, 1.017) I^2= 94.7% *2nd trimester* 3 cohort studies: 68,920 PTBs RE model pooled RR=1.031 (0.965, 1.101) I^2= 96.2% *3rd trimester* 4 cohort studies: 71,049 PTBs RE model pooled RR=1.002 (0.988, 1.017) I^2= 78.1% *Last month* 2 cohort studies RE model pooled RR= 1.002 (0.992, 1.012) I^2= 79.3% **NO_x per 20 μg/m^3** *1st trimester* 5 cohort studies: 61,828 PTBs RE model pooled RR=1.001 (0.959, 1.044) I^2= 80.4% *2nd trimester* 4 cohort studies: 59,728 PTBs RE model pooled RR=0.991 (0.948, 1.036) I^2= 85.6% *3rd trimester* 2 cohort studies: 26,016 PTBs RE model pooled RR=1.031 (0.996, 1.068)		

				I^2= 6.2% *Last month* 1 cohort study RR = 0.960 (0.930, 1.000) **By region for entire pregnancy** *$PM_{2.5}$ per 10 μg/m^3* Asian (8 cohort studies), RR = 1.061 (1.039, 1.084); North America (16 cohort studies), RR= 1.071 (1.012, 1.134); Oceania (2 cohort studies), RR= 1.400 (1.199, 1.634); European (4 cohort studies), RR= 1.071 (0.859, 1.335); South American (1 cohort study), RR= 0.978 (0.941, 1.017) *PM_{10} per 10 μg/m^3* Asian (6 cohort studies), RR= 1.049 (1.014, 1.085); North America (4 cohort studies), RR= 1.088 (1.005, 1.177); European (5 cohort studies), RR= 0.988 (0.939, 1.040) *NO_2 per 10 μg/m^3* Asian (7 cohort studies), RR= 1.103 (1.009, 1.206); North America (3 cohort studies), RR= 1.010 (0.968, 1.054); Oceania (2 cohort studies), RR= 1.085 (0.734, 1.605); European (8 cohort studies), RR= 1.003 (0.980, 1.028) *SO_2 per 10 μg/m^3* Asian (5 cohort studies), RR=1.009 (0.896, 1.136); North American (2 cohort) 0.982 (0.893, 1.080); Oceania (1 cohort) 2.737 (2.076, 3.609). *O_3 per 10 μg/m^3* Asian (4 cohort studies), RR= 1.071 (1.039, 1.103); North American (4 cohort studies), RR= 1.018 (1.004, 1.032); Oceania (1 cohort study), RR= 1.494 (1.190, 1.876);		

				European (2 cohort studies), RR= 1.010 (1.006, 1.014) *CO per 100 µg/m³* Asian (2 cohort studies), RR= 1.087 (0.976, 1.211); American (2 cohort studies), RR= 1.004 (0.979, 1.028); European (1 cohort study), RR= 0.898 (0.765, 1.054) *NO_x per 20 µg/m³* European (2 cohort studies), RR= 0.985 (0.919, 1.056) **Note**: There were trimester-specific results with very small number of studies per region. **By unit of increase for entire pregnancy** *$PM_{2.5}$:* per IQR µg/m³ (19 cohort studies), RR= 1.074 (1.013, 1.139); per 10 µg/m³ (8 cohort studies), RR= 1.054 (1.026, 1.082); per 5 µg/m³ (3 cohort studies), RR= 1.007 (0.889, 1.140); per 1 µg/m³ (2 cohort studies) 1.551 (1.038, 2.317) *PM_{10}:* per IQR µg/m³ (7 cohort studies), RR= 1.024 (0.984, 1.064); per 10 µg/m³ (4 cohort studies), RR=1.033 (0.985, 1.084); per 5 µg/m³ (2 cohort studies), RR= 1.205 (0.864, 1.679);		

				per 1 µg/m^3 (3 cohort studies), RR= 0.999 (0.942, 1.059); per SD µg/m^3 (1 cohort study), RR= 2.913 (0.801, 10.594) *NO_2:* Per IQR (11 cohort studies), RR= 1.010 (0.990, 1.029); Per 10 µg/m^3 (6 cohort studies), RR= 1.058 (0.982, 1.140); Per 3 µg/m3 (1 cohort study) 0.935 (0.888, 0.984); Per 1 µg/m3 (3 cohort studies), RR= 1.000 (0.982, 1.019); Per 5 ppb (1 cohort study), RR=0.936 (0.744, 1.177) *SO_2:* Per IQR (4 cohort studies), RR= 1.140 (0.987, 1.318); Per 10 µg/m3 (2 cohort studies), RR= 1.121 (0.848, 1.482); Per 3 µg/m3 (1 cohort study), RR= 0.903 (0.858, 0.950); Per 1 µg/m3 (1 cohort study), RR= 6.727 (1.103, 41.019) *O_3*: Per IQR (8 cohort studies), RR= 1.013 (1.005, 1.022); Per 10 µg/m3 (2 cohort studies), RR= 1.077 (1.013, 1.146); Per 1 µg/m3 (2 cohort studies), RR= 1.010 (1.006, 1.014); Per 10 ppb (1 cohort study), RR= 1.080 (1.062, 1.114). *CO*: Per IQR (3 cohort studies), RR= 1.001 (0.976, 1.026); Per 100 µg/m3 (2 cohort studies), RR= 1.087 (0.976, 1.211). NO_x		

				Per IQR (1 cohort study), RR= 0.960 (0.921, 1.001); Per 20 µg/m3 (1 cohort study), RR= 1.034 (0.945, 1.131) **Note**: There were trimester-specific results with small number of studies per unit of increase. **By effect estimate for entire pregnancy** *$PM_{2.5}$ per 10* µg/m^3 OR (21 cohort studies), 1.061 (1.005, 1.121); HR (7 cohort studies) 1.073 (1.043, 1.103); RR (3 cohort studies) 1.086 (1.022, 1.153). *PM_{10} per 10* µg/m^3 OR (10 cohort studies), 1.055 (1.012, 1.100); HR (4 cohort studies), 1.001 (0.968, 1.036); RR (1 cohort study), 1.085 (1.051, 1.120). *NO_2 per 10* µg/m^3 OR (13 cohort studies), 1.024 (0.991, 1.059); HR (5 cohort studies), 0.998 (0.973, 1.023); RR (2 cohort studies), 1.222 (0.674, 2.214). *SO_2 per 10* µg/m^3 OR (5 cohort studies), 0.995 (0.909, 1.089); HR (3 cohort studies), 1.357 (0.805, 2.287); *O_3 per 10* µg/m^3 OR (6 cohort studies), 1.031 (1.013, 1.050); HR (5 cohort studies), 1.037 (1.010, 1.065). CO *per 100* µg/m^3 OR (5 cohort studies), 1.034 (1.000, 1.069). *NO_x per 20* µg/m^3		

				OR (n = 2), 0.985 (0.919, 1.056). **Note**: There were trimester-specific results with small number of studies per effect estimate **Moderate PTB** *$PM_{2.5}$ per 10* µg/m^3 Entire pregnancy (8 cohort studies). RR=1.076 (1.039, 1.115) I^2= 61.3% 1st trimester (3 cohort studies) RR= 0.999 (0.986, 1.012) I^2= 0.0% 2nd trimester (3 cohort studies) RR=1.047 (1.034, 1.061) I^2= 36.2% 3rd trimester (3 cohort studies) RR=1.008 (0.967, 1.051) I^2= 80.9% *PM_{10} per 10* µg/m^3 Entire pregnancy (10 cohort studies) RR=1.081 (1.051, 1.111) I^2= 70.8% 1st trimester (3 cohort studies) RR= 1.012 (0.930, 1.100) I^2= 93.0% 2nd trimester (3 cohort studies) RR=1.045 (1.009, 1.082) I^2= 62.1% 3rd trimester (3 cohort studies) RR=1.018 (0.955, 1.085) I^2= 89.2% *NO_2 per 10* µg/m^3 Entire pregnancy (9 cohort studies) RR=1.066 (1.034, 1.099) I^2= 81.8% 1st trimester (1 cohort study) RR= 0.896 (0.841, 0.955) 2nd trimester (1 cohort study)		

				RR=1.153 (1.063, 1.251) 3rd trimester (1 cohort study) RR=1.010 (0.973, 1.048) *SO_2 per 10* µg/m^3 Entire pregnancy (2 cohort studies) RR=0.859 (0.805, 0.915) I^2= 45.2% 1st trimester (1 cohort study) RR=1.081 (0.820, 1.423) 2nd trimester (1 cohort study) RR=0.935 (0.785, 1.116) 3rd trimester (1 cohort study) RR=0.958 (0.841, 1.091) *O_3 per 10* µg/m^3 Entire pregnancy (6 cohort studies) RR=1.081 (1.060, 1.103) I^2= 60.3% 1st trimester (1 cohort study) RR=1.009 (0.989, 1.029) 2nd trimester (1 cohort study) RR=1.011 (0.981, 1.042) 3rd trimester (1 cohort study) RR=1.015 (0.998, 1.032) *O_3 per 100* µg/m^3 Entire pregnancy (3 cohort studies) RR=0.992 (0.966, 1.019) I^2= 87.0% **Very PTB** *$PM_{2.5}$ per 10* µg/m^3 Entire pregnancy (9 cohort studies). RR=1.169 (1.120, 1.221) I^2= 79.6% 1st trimester (6 cohort studies) RR=1.090 (1.042, 1.141) I^2= 92.7% 2nd trimester (6 cohort studies) RR=1.151 (1.084, 1.223) I^2= 96.3% 3rd trimester (6 cohort studies)		

				RR= 1.046 (0.981, 1.115) I^2= 96.5% *PM_{10} per 10* μg/m^3 Entire pregnancy (9 cohort studies). RR= 1.133 (1.061, 1.210) I^2= 82.3% 1st trimester (4 cohort studies) RR=1.061 (1.006, 1.119) I^2= 72.8% 2nd trimester (4 cohort studies) RR=1.022 (1.013, 1.032) I^2= 24.2% 3rd trimester (4 cohort studies) RR=1.053 (0.988, 1.121 I^2= 87.3% *NO_2 per 10* μg/m^3 Entire pregnancy (8 cohort studies). RR= 1.194 (1.111, 1.283) I^2= 77.0% 1st trimester (1 cohort study). RR= 0.939 (0.780, 1.131) 2nd trimester (1 cohort study) RR=1.370 (1.165, 1.612) 3rd trimester (1 cohort study) RR=1.109 (1.070, 1.149) *SO_2 per 10* μg/m^3 Entire pregnancy (1 cohort study). RR= 0.774 (0.374, 1.602) 1st trimester (1 cohort study) RR=0.928 (0.477, 1.805) 2nd trimester (1 cohort study) RR= 0.869 (0.652, 1.160) 3rd trimester (1 cohort study) RR= 0.960 (0.776, 1.187) *O_3 per 10* μg/m^3 Entire pregnancy (6 cohort studies). RR=1.119 (1.076, 1.164) I^2= 66.3%		

				1st trimester (2 cohort studies). RR=0.989 (0.892, 1.096) I^2= 83.8% 2nd trimester (2 cohort studies). RR=1.025 (0.974, 1.078) I^2=61.2% 3rd trimester (2 cohort studies) RR=0.993 (0.970, 1.017) I^2=0.0% *CO per 100* µg/m^3 Entire pregnancy (1 cohort study). RR= 0.991 (0.965, 1.017) **Extremely PTB** *$PM_{2.5}$ per 10* µg/m^3 Entire pregnancy (3 cohort studies). RR= 1.129 (1.019, 1.250) I^2= 78.0% 1st trimester (1 cohort study) RR= 1.140 (1.110, 1.180) 2nd trimester (1 cohort study) RR= 1.090 (1.060, 1.130) 3rd trimester (1 cohort study) RR= 1.000 (0.960, 1.040) *PM_{10} per 10* µg/m^3 Entire pregnancy (5 cohort studies). RR= 1.253 (1.133, 1.385) I^2= 88.8% 1st trimester (1 cohort study) RR= 1.090 (1.070, 1.120) 2nd trimester (1 cohort study) RR= 1.030 (1.010, 1.050) 3rd trimester (1 cohort study) RR= 0.990 (0.960, 1.020) *NO_2 per 10* µg/m^3 Entire pregnancy (4 cohort studies). RR= 1.228 (1.037, 1.454) I^2= 88.0% *O_3 per 10* µg/m^3 Entire pregnancy (2 cohort studies).		

				RR=1.259 (1.084, 1.463) I^2= 75.9% *CO per 100* µg/m^3 Entire pregnancy (2 cohort studies). RR= 0.930 (0.847, 1.022) I^2= 86.9% **Note**: As reported in overall PTB, there were subgroup results for the PTB subtypes but with very limited studies, predominantly 1 or 2 studies per subgroup (by study region, increment unit and study effect estimation model). **Leave-one-out sensitivity analysis** No substantial change.		
4. Xie (Xie et al., 2021) 13/06/2021 [10; 9 China, 1 USA]	$PM_{2.5}$	Stillbirth	**Stillbirth per 10 µg/m^3 PM2.5** ***Entire pregnancy*** 6 studies: 5 cohort and 1 case-control; 3,222,578 births. RE pooled OR; 1.15(1.07,1.25) I^2= 74.7% (high) with p= 0.001 No publication bias reported by Egger's test	**1st trimester** 6 cohort studies; 3,892,183 births. 1.01(0.90,1.13) I^2= 87.0%(high) with P<0.001 **2nd trimester** 5 cohort studies; 3,762,441 births 1.06 (0.98,1.14) I^2= 80.1%(high) with P<0.001 **3rd trimester** 4 cohort studies; 3,180,667 births 1.09 (1.01,1.18) I^2= 78.9%(high) with p=0.003	'Studies should use exposure assessment models (land use model, dispersion model, etc.) or satellite remote sensing technology to estimate individual exposure level, adopt identical outcome definition, and adjusted more comprehensive confounding factors.' 'Further pathophysiological researches and high quality population studies were still warranted'.	**Strengths** 'Included recently published studies, and included more studies and population, which enhanced the reliability of the results.' Second, a new risk of bias assessment instrument was applied to assess the risk of bias of the included studies. Compared with other tools, it was more suitable for the observational air pollution epidemiological studies on pregnant outcomes. Third, cumulative meta-analysis was conducted to reveal the effects of medical

					'It was beneficial to carry out corresponding measures to reduce the stillbirth rate, so as to mitigate the social and economic burdens caused by stillbirth.'	condition on the association between maternal exposure to PM2.5 and stillbirth.' **Limitations** ' First, most of the included studies appointed the concentration of PM2.5 of nearby monitoring stations to pregnant women, which might lead to potential exposure bias.' We just pooled the estimates of the single-pollutant model, failing to pool the multiple-pollutant model for few studies reported the results of it. There were high heterogeneity among the included studies'.
5. Rappazzo (Rappazzo et al., 2021) 12/05/ 2021 [4; all USA]	O_3	PTB	**Note**: The main analysis was the 1st and 2nd trimesters for O_3-PTB effect estimates for 10 ppb increases. **1st trimester** **(**17 studies: 14 cohort and 3 case-control; 4,525,441 births) RE pooled OR; 1.06 (1.03, 1.10) I^2= 97% (high) p <0.0001 with a prediction interval of 0.95–1.19. **2nd trimester**	**1st trimester** **Leave-one-out sensitivity analyses** Indicated that no single study had a substantial influence on the pooled estimate. **Continent-specific** Australia; 1.15 (1.09, 1.22) with I^2= 0.24% (low) Asia; 1.03 (1.01, 1.04) with I^2= 84.58% (high) Europe; 1.14 (1.08, 1.20) with I^2= 60.39% (moderate) North America; 1.01 (1.00, 1.02) with I^2= 3.74% (moderate).	'Further exploration in studies of ozone and PTB could address uncertainties, particularly with more complete consideration of other PTB risk factors, such as socioeconomic status, and race/racism.'	**Strengths** The incorporation of an evaluation of study quality to our methods. 'Inclusion of a larger number of studies compared to previous meta-analyses'. 'Able to focus on specific time windows within pregnancy, and perform several sensitivity analyses (e.g., trim and fill, leave one out, sub-

			(15 studies: 12 cohort and 3 case-control; 4,713,201 births) RE pooled OR; 1.05 (1.02, 1.08) with a prediction interval of 0.95–1.16. I^2= 97% (high) with p <0.001. **Overall confidence of evidence** Moderate **Publication bias** **1st trimester** funnel plot and Egger's test (p<0.001) indicated the presence of potential publication bias but a rank correlation test did not (p = 0.2). Trim-and-fill analyses estimated three missing studies and resulted in a pooled odds ratio 1.04 (1.00, 1.08) **2nd trimester** Funnel plot appeared balanced, the Egger's test (p<0.01) indicated evidence for potential publication bias but trim-and-fill analysis estimated no missing studies and rank correlation testing was non-statistically significant (p=0.55).	**Meta-regression** Indicated that a some of the variability in 1st trimester was explained by continent of study, **2nd trimester** Leave-one-out sensitivity analyses, indicated no single study had a substantial influence on the pooled estimate. **Meta-regression** No factors explained the observed heterogeneity in associations during the 2nd trimester.		group analyses) to examine robustness of the pooled effect estimates.' **Limitations** **"** The ability of the study quality analysis to identify specific influential components of the study quality scores is likely limited due to the large number of covariates adjusted for and other variability in the study designs and statistical analyses.**"** Study quality analysis did not directly consider statistical power. ' The inability to account for potential co-pollutant confounding is a limitation in the meta-analysis.' ' Information about the concentration-response relationship for ozone exposure and preterm birth is unavailable and an additional limitation.' 'Short-term ozone exposures may act on birth outcomes through different mechanistic pathways than long-

						term exposures, and thus were not included in this review.' No clear biological mechanism. 'Pooling estimates based on different averaging times likely contributes additional heterogeneity compared to analyses based on a consistent averaging time, and we did not adjust for effect measure in the meta-analysis'.
6. Zhang (Zhang et al., 2021) 22/02/2021 [7; All China]	PM2.5, PM10, SO2, NO2, CO, O3	Stillbirth	**Stillbirth with:** **PM2.5 per 10 µg/m3 increase** *Entire pregnancy* 7 studies (4 retrospective and 2 prospective cohorts and 1 case-control; 4,647,479 births) Pooled OR = 1.103 (1.074 to 1.131) I^2= 62.1%--moderate with p=0.015 **PM10 per 10 µg/m3 increase for** *Entire pregnancy* 4 studies (1 retrospective and 2 prospective cohorts and 1 case-control; 1,888,661 births) Pooled OR = 1.005 (0.961 to 1.049) I^2= 16.8%--low with p=0.307 **SO2 per 10 µg/m3 increase for e***ntire pregnancy*	**Stillbirth per 10 µg/m3 increase in PM2.5 b*y trimester*** *1st trimester* 7 studies (5 retrospective and 2 prospective cohorts; 5,078,391 births) Pooled OR = 0.962 (0.833 to 1.090) I^2= 88.7%--high with p=0.000 *2nd trimester* 6 studies (4 retrospective and 2prospective cohorts; 4,855,016 births) Pooled OR = 1.028 (0.939 to 1.116) I^2= 82.4%--high with p=0.000 *3rd trimester* 5 studies (3 retrospective and 2 prospective cohorts; 4,273,242 births) Pooled OR = 1.094 (1.008 to 1.180) I^2= 74.8%--moderate	'Prospective cohort studies, collecting maternal lifestyles and other exposures (e.g., green space) which may confound the air pollution-stillbirth relationship, with better study design and personal exposure strategies, are warranted in the future, especially in developing countries with severe air pollution. Furthermore, biological	**Strengths** "Our study used a large sample size and estimated a wide range of air pollutants, including airborne PM and gaseous pollutants. Second, we evaluated the quality and risk of bias of the included studies according to the widely accepted NOS and OHAT tools;all included studies were of high quality; with scores ranging from 7 to 8 for the NOS scale and from 3 to 5 for Mustafic's adapted scale (Mustafic et al., 2012)(Table S3), which makes our

			6 studies (3 retrospective and 2 prospective cohorts and 1 case-control; 5,657,493 births) Pooled OR = 1.020 (0.985 to 1.055) I^2= 7.3%--low with p=0.369 **NO2 per 10 µg/m3 increase for e***ntire pregnancy* 5 studies (2 retrospective and 2 prospective cohorts and 1 case-control; 5434118 births) Pooled OR = 1.026 (0.9996 to 1.057) I^2= 65.2%--low with p=0.022 **CO per 10 µg/m3 increase for e***ntire pregnancy* 6 studies (3 retrospective and 2 prospective cohorts and 1 case-control; 5,657,393 births) Pooled OR = 1.0007 (0.9991 to 1.0022) I^2= 52.8%--moderate with p=0.060 **O3 per 10 µg/m3 increase for e***ntire pregnancy* 6 studies (2 retrospective and 2 prospective cohorts, 1 case-control, and 1 case-crossover; 5,259,297 births) Pooled OR = 1.008 (0.974 to 1.043) I^2= 63.8%--moderate with p=0.017 **Publication bias** “Egger’s tests were used to assess for publication bias for	with p=0.003 **Stillbirth per 10 µg/m3 increase in PM10 by *trimester*** *1st trimester* 6 studies (2 retrospective and 3 prospective cohorts, and 1 case-control; 2,471,949 births) Pooled OR = 0.936 (0.830 to 1.042) I^2= 94.0%--high with p=0.000 **2nd** *trimester* 5 studies (1 retrospective and 3 prospective cohorts, and 1 case-control; 2,248,574 births) Pooled OR = 0.985 (0.916 to 1.053) I^2= 77.0%--high with p=0.002. **3rd** *trimester* 4 studies (3 prospective cohorts, and 1 case-control; 1,666,800 births) Pooled OR = 1.040 (0.970 to 1.110) I^2= 89.2%--high with p=0.000 **Stillbirth per 10 µg/m3 increase in SO2 by *trimester*** *1st trimester* 6 studies (3 retrospective and 2 prospective cohorts, and 1 case-control; 5,657,493 births) Pooled OR = 0.994 (0.933 to 1.055) I^2= 73.1%--moderate with p=0.002	mechanistic studies remain needed to clarify the potential pathways underlying the air pollution-stillbirth association countries. Research and aggressive policy interventions, such as developing clean energy aiming at reducing fossil fuel consumption to lower air pollutants emissions, should be on the top list of the world leaders’ agenda not only for the health of contemporary but also for future generations, which can help improve intergenerational inequity.’	findings reliable and valuable for public health professionals and policy makers. Third, we performed a meta-analysis of the effect estimates of long-term exposure by trimesters and found critical exposure windows for PM2.5, CO, and O3 exposure, which may help provide effective preventive measures for decreasing the risk of stillbirth, such as target policy interventions aimed at reducing the emission of PM2.5, CO, and O3.’ **Limitations** ‘First, the number of studies included is limited. Second, most of the included studies were performed in developed countries or areas with low levels of air pollution, which is not enough to represent the global population. Third, a possible correlation was observed among various air pollutants. Several studies have

			each pollutant during the short- and long-term exposure, and no substantial bias was detected."	*2nd trimester* 5 studies (2 retrospective and 2 prospective cohorts, and 1 case-control; 5,434,118 births) Pooled OR = 0.984 (0.918 to 1.050) I^2= 73.2%--moderate with p=0.005 *3rd trimester* 5 studies (2 retrospective and 2 prospective cohorts, and 1 case-control; 5,434,118 births) Pooled OR = 1.095 (0.993 to 1.197) I^2= 88.9%--moderate with p=0.000 **Stillbirth per 10 µg/m3 increase in NO2 by *trimester*** *1st trimester* 6 studies (3 retrospective and 2 prospective cohorts, and 1 case-control; 6,015,892 births) Pooled OR = 1.004 (0.980 to 1.029) I^2= 56.7%--moderate with p=0.041 *2nd trimester* 6 studies (3 retrospective and 2 prospective cohorts, and 1 case-control; 6,015,892 births) Pooled OR = 0.997 (0.972 to 1.022) I^2= 59.2%--moderate with p=0.032 *3rd trimester* 5 studies (2 retrospective and 2 prospective cohorts, and 1 case-control; 5,434,118 births) Pooled OR = 1.022		analyzed the correlation between different air pollutants and used the multipollutant model, while others did not. Therefore, some of the reported associations may be spurious. Due to the limited number of included studies, we did not consider the correlation between different air pollutants when conducting the meta-analysis. Fourth, we did not conduct a subgroup analysis to explore the source of heterogeneity due to the small number of studies included. High heterogeneity was observed concerning the air pollution-stillbirth association in some period; hence, we used random effect models to combine the effects. However, as typical limitations of random model, statistical errors may be underrated and overconfident conclusions can be yielded.'

				(0.995 to 1.050) I^2= 62.7%--moderate with p=0.030 **Stillbirth per 10 µg/m3 increase in CO by *trimester*** *1st trimester* 6 studies (3 retrospective and 2 prospective cohorts and 1 case-control; 5,657,393 births) Pooled OR = 1.0000 (0.9985 to 1.0014) I^2= 52.1%--moderate with p=0.064 *2nd trimester* 5 studies (2 retrospective and 2 prospective cohorts and 1 case-control; 5,434,118 births) Pooled OR = 1.0004 (0.9992 to 1.0015) I^2= 38.2%--moderate with p=0.166 *3rd trimester* 5 studies (2 retrospective and 2 prospective cohorts and 1 case-control; 5,434,118 births) Pooled OR = 1.0009 (1.0001 to 1.0017) I^2= 70.3%--moderate with p=0.009 **Stillbirth per 10 µg/m3 increase in O3 by *trimester*** *1st trimester* 6 studies (3 retrospective and 2 prospective cohorts and 1 case-control; 5,482,705 births) Pooled OR = 1.028 (1.001 to 1.055) I^2= 73.5%--moderate with p=0.002 *2nd trimester* 5 studies (2 retrospective and 2 prospective cohorts and 1 case-control; 5,259,330 births) Pooled OR = 1.012 (0.986 to 1.038) I^2= 74.1%--moderate with p=0.004		

				3rd trimester 4 studies (1 retrospective and 2 prospective cohorts and 1 case-control; 4,677,556 births) Pooled OR = 0.978 (0.927 to 1.029) I^2= 93.3%--moderate with p=0.000 **Short-term exposure of PM2.5 and stillbirth** *0 day* (event day) 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.000 (0.997 to 1.003) I^2= 0.0%--No with p=0.513 *1 day* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 0.997 (0.994 to 1.001) I^2= 0.0%--No with p=0.953 *2 days* 3 studies (one each retrospective, time series, and case-crossover; 261,175 births and unreported for the case-crossover study) Pooled OR = 1.001 (0.999 to 1.004) I^2= 0.0%--No with p=0.723 *3 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.001 (0.999 to 1.004) I^2= 45.7%--low with p=0.175 *4 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 0.999 (0.996 to 1.003) I^2= 0.0%--No with p=0.450 *5 days* 2 studies (1 retrospective and 1 time series; 261,175 births)		

				Pooled OR = 0.999 (0.996 to 1.002) I^2= 0.0%--No with p=0.8343 **6** *days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.023 (0.947 to 1.098) I^2= 64.9%--No with p=0.091 **Short-term exposure of PM10 and stillbirth** *0 day* (event day) 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.000 (0.998 to 1.001) I^2= 0.0%--No with p=0.681 *1 day* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 0.999 (0.998 to 1.001) I^2= 12.4%--Low with p=0.285 *2 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 0.999 (0.998 to 1.001) I^2= 45.2%--Low with p=0.177 *3 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.018 (0.966 to 1.070) I^2= 64.1%--Low with p=0.095 *4 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.000 (0.998 to 1.002) I^2= 0.0%--Low with p=0.644 *5 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 0.999 (0.997 to 1.001)		

				I^2= 0.0%--Low with p=0.404 *6 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 0.999 (0.997 to 1.001) I^2= 0.0%--Low with p=0.365 **Short-term exposure of SO2 and stillbirth** *0 day* (event day) 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 0.998 (0.990 to 1.006) I^2= 0.0%--No with p=0.838 *1 day* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.000 (0.992 to 1.008) I^2= 0.0%--No with p=1.000 *2 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.026 (0.976 to 1.076) I^2= 60.1%--Low with p=0.081 *3 days* 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 1.002 (0.994 to 1.010) I^2= 0.0%--No with p=0.610 *4 days* 3 studies (1 each retrospective cohort, time series and case-crossover; 261,175 births) with unreported for the case-crossover study Pooled OR = 1.003 (0.995 to 1.011) I^2= 47.6%--Low with p=0.148 **Short-term exposure of NO2 and stillbirth** *2 days*		

				2 studies (1 case-crossover with unreported birth and 1 time series with 37,800 births) Pooled OR = 1.004 (0.994 to 1.014) I^2= 0.0%--No with p=0.424 *4 days* 2 studies (1 case-crossover with unreported birth and 1 time series with 37,800 births) Pooled OR = 1.003 (0.996 to 1.009) I^2= 0.0%--No with p=0.445 **Short-term exposure of CO and stillbirth** *0 day (event day)* 2 studies (1 retrospective cohort and 1 time series with 261,175 births) Pooled OR = 0.9991 (0.9965 to 1.0017) I^2= 0.0%--No with p=0.524 *1 day* 2 studies (1 retrospective cohort and 1 time series with 261,175 births) Pooled OR = 0.9891 (0.9605 to 1.0177) I^2= 73.4%--moderate with p=0.053 *2 days* 3 studies (1 each retrospective cohort, time series and case-crossover: 261,175 births with unreported for the case-crossover study) Pooled OR = 0.9998 (0.9963 to 1.0033) I^2= 69.2%--moderate with p=0.039 *3 days* 2 studies (1 each retrospective cohort and time series: 261,175 births) Pooled OR = 0.9976 (0.9948 to 1.0003) I^2= 29.1%--Low with p=0.235 *4 days* 2 studies (1 each retrospective cohort and time series: 261,175 births)		

				Pooled OR = 1.0003 (0.9999 to 1.0008) I^2= 0.0%--No with p=0.574 *5 days* 2 studies (1 each retrospective cohort and time series: 261,175 births) Pooled OR = 0.9993 (0.9966 to 1.0019) I^2= 0.0%--No with p=0.639 *6 days* 2 studies (1 each retrospective cohort and time series: 261,175 births) Pooled OR = 1.0002 (0.9978 to 1.0026) I^2= 0.0%--No with p=0.461 **Short-term exposure of O3 and stillbirth** *0 day* (event day) 2 studies (1 retrospective and 1 time series; 261,175 births) Pooled OR = 0.999 (0.997 to 1.002) I^2= 45.8%--moderate with p=0.174 *1 day* 3 studies (1 each retrospective cohort, time series, and case-crossover; 619,541 births) Pooled OR = 0.999 (0.996 to 1.002) I^2= 0.0%--No with p=0.466 *2 day*s 3 studies (1 each retrospective cohort, time series, and case-crossover; 619,541 births) Pooled OR = 1.011 (0.982 to 1.039) I^2=53.5 %--moderate with p=0.116 *3 day*s 3 studies (1 each retrospective cohort, time series, and case-crossover; 619,541 births)		

				Pooled OR = 1.013 (0.987 to 1.040) I^2=50.1 %--moderate with p=0.136 *4 day*s 4 studies (1 each retrospective cohort and time series, and 2 case-crossover; 619,541 births and unreported for one study) Pooled OR = 1.002 (1.001 to 1.004) I^2=32.7 %--moderate with p=0.216 *5 day*s 3 studies (1 each retrospective cohort, time series, and case-crossover; 619,541 births) Pooled OR = 1.020 (0.976 to 1.064) I^2=77.5 %--moderate with p=0.012 *6 day*s 3 studies (1 each retrospective cohort, time series, and case-crossover; 619,541 births) Pooled OR = 1.010 (0.971 to 1.049) I^2=74.2 %--moderate with p=0.021 **Leave-out sensitivity analyses** Pooled estimates of long-term NO2 exposure and stillbirth were influenced by the findings of Hwang et al.'s study." Other sensitivity analyses did not substantially change the pooled estimates of long-term PM2.5, PM10, SO2, CO, and O3 exposure on the incidence of stillbirth.' For short-term exposure, "Sensitivity analyses showed that the pooled estimates of lag day 2 for CO exposure and stillbirth were influenced by the findings of Mendola et al.'s study" with no changes in pooled estimates for PM2.5,SO2, and O3 exposures.		

7. Uwak (Uwak et al., 2021) 25/01/2021 [13, All USA]	PM2.5, PM10, and PM2.5-10	BW	***IA. Only 'low' or 'probably low' RoB studies for PM2.5 and PM10. But PM2.5-10 has only 'high' or probably high' RoB studies.*** **BW change per 10 µg/m3 increase in PM2.5** *Entire pregnancy* 15 studies (13 retrospective and 2 prospective cohorts;15,424,198 births) RE pooled beta = −27.55 (-48.45 to −6.65) FE pooled beta =-15.58 (-16.07 to -15.09) I^2= 94%--high with p<0.01 **BW change per 10 µg/m3 increase in PM10** *Entire pregnancy* 8 studies (5 retrospective and 3 prospective cohorts; 2,679,928 births) RE pooled beta = −8.65 (-16.83 to −0.48) FE pooled beta =-7.34 (-9.46 to -5.23) I^2= 84%--high with p<0.01 **BW change per 10 µg/m3 increase in PM2.5-10 (coarse PM)** *Entire pregnancy* 5 studies (4 retrospective and 1 prospective cohorts; 12,829,812 births) RE pooled beta =	***IB. Only 'low' or 'probably low' RoB studies for PM2.5 and PM10. But PM2.5-10 has only 'high' or probably high' RoB studies.*** **BW change per 10 µg/m3 increase in PM2.5** ***By trimester*** *1st trimester* 11 retrospective cohort studies; 3,547,223 births) RE pooled beta = −6.50 (-15.07 to 2.07) FE pooled beta =-4.97 (-6.38 to -3.56) I^2= 87%--high with p<0.01 *2nd trimester* 11 retrospective cohort studies; 3,547,223 births) RE pooled beta = −5.69 (-10.58 to -0.79) FE pooled beta =-5.22 (-6.70 to -3.73) I^2= 68%--moderate with p<0.01 *3rd trimester* 12 studies (11 retrospective and 1 prospective cohort; 3,556,290 births) RE pooled beta = −10.67 (-20.91 to -0.43) FE pooled beta =-5.09 (-6.61 to -3.57) I^2= 84%--high with p<0.01	'Public health interventions to address infant birth weight suppression from PM may have a substantial impact on infant health, especially those at high risk for exposure. Future research and implementation strategies are recommended to help optimize interventions and policies to mitigate infant health effects.'	**Limitations** 'Reliance on expert evaluation in the process used for the risk of bias, quality and strength ratings. However, this limitation was overcome by creating a diverse team of experts from relevant fields to participate in this process The rating of the quality of evidence across studies was dependent on the available data. For instance, PM10 and PM2.5 are typically reported separately, but also likely occur in combination. Thus, models that consider multi-pollutant exposures may better represent gestational PM exposure. Most studies fail to consider secondary/co-exposures like ultrafine particulate matter, gas phase pollutants, or heat, which can also affect birth weight. Analyses did not include enough studies

			−8.81 (-10.32 to −7.31) FE pooled beta =-8.61 (-9.41 to -7.81) I^2= 0%--No with p=0.54 ***IIA. All studies despite RoB rating*** **BW change per 10 µg/m3 increase in PM2.5** *Entire pregnancy* 28 studies (25 retrospective and 3 prospective cohorts; 44,516,228 births) RE pooled beta = −23.47 (-44.25 to −2.69) FE pooled beta =-13.49 (-13.94 to -13.04) I^2= 98%--high with p<0.01 **BW change per 10 µg/m3 increase in PM10** *Entire pregnancy* 21 studies (15 retrospective and 6 prospective cohorts; 10,200,344 births) RE pooled beta = −5.20 (-10.95 to 0.55) FE pooled beta =-3.62 (-4.32 to -2.92) I^2= 95%--high with p<0.01 **Publication bias** **PM2.5, PM10:** Begg's and Egger's tests:	**BW change per 10 µg/m3 increase in PM10** ***By trimester*** *1st trimester* 6 studies (3 each retrospective and prospective cohorts; 757,843 births) RE pooled beta = 3.22 (-3.13 to 9.58) FE pooled beta =3.54 (-0.55 to 7.63) I^2= 14%--low with p=0.32 *2nd trimester* 6 studies (3 each retrospective and prospective cohorts; 757,843 births) RE pooled beta = -3.37 (-8.22 to 1.48) FE pooled beta =-3.37 (-7.96 to 1.23) I^2= 0%--No with p=0.66 *3rd trimester* 7 studies (3 retrospective and 4 prospective cohorts; 766,910 births) RE pooled beta = -6.57(-10.66 to -2.48) FE pooled beta =-5.74 (-9.68 to -1.80) I^2= 0%--No with p=0.68 **BW change per 10 µg/m3 increase in PM2.5-10** ***By trimester*** *1st trimester* 3 retrospective cohorts; 12,349,007 births)		to evaluate weekly exposure. There is also the potential for additional unmeasured confounding.' **Strengths** 'By publishing a pre-specified protocol and employing two independent reviewers for each study, our analysis includes a degree of transparency and robustness that is absent when using less structured approaches. A major strength of our study is the transparency and thoroughness of the Navigation Guide systematic review process, which incorporates the GRADE system for assessing the quality of synthesized human evidence in environmental health research in the absence of randomized clinical trials.'

			No evidence of publication bias (all p-values >0.05) was found as assessed using funnel plots and tests for asymmetry. **PM2.5-10:** Insufficient studies for publication test. **Quality of body of evidence according to Navigation guide methods** *PM2.5-BW* reduction (results from **'**low' or 'probably low' RoB studies) 1st trim: very low Entire pregnancy, 2nd and 3rd trimesters: low *PM10-BW* (results from **'**low' or 'probably low' RoB studies)**:** 1st and 2nd trimesters: low 3rd trimester and entire pregnancy: moderate *PM2.5-10/BW* 1st, 2nd, and 3rd trimesters: very low Entire pregnancy: low **Strength of evidence of adverse effect** *PM2.5-BW reduction:* "inadequate evidence" for all exposure windows. *PM10-BW reduction* 1st and 2nd trimesters: "inadequate evidence" 3rd trim and entire pregnancy: "limited evidence"	RE pooled beta = -2.70 (-3.90 to -1.49) FE pooled beta =-2.70 (-3.48 to -1.91) I^2= 0%--No with p=0.62 *2nd trimester* 3 retrospective cohorts; 12,349,007 births) RE pooled beta = -2.90 (-10.04 to 4.23) FE pooled beta =-2.80 (-3.64 to -1.96) I^2= 70%--moderate with p=0.03 *3rd trimester* 4 retrospective cohorts; 12,755,634 births) RE pooled beta = -4.93 (-10.82 to 0.96) FE pooled beta =-3.72 (-4.50 to -2.94) I^2= 76%--high with p<0.01 **IIB. All studies despite RoB rating BW change per 10 µg/m3 increase in PM2.5** ***By trimester*** *1st trimester* 18 retrospective cohorts; 28,587,814 births) RE pooled beta = -5.43 (-10.28 to -0.59) FE pooled beta =-3.75 (-4.53 to -2.97) I^2= 87%--high		

			PM2.5-10/BW reduction: “inadequate evidence” for all exposure windows.	with $p<0.01$ *2nd trimester* 18 retrospective cohorts; 28,869,530 births) RE pooled beta = -5.65 (-9.27 to -2.03) FE pooled beta =-3.67 (-4.49 to -2.84) I^2= 84%--high with $p<0.01$ *3rd trimester* 20 studies (19 retrospective and 1 prospective cohorts; 29,003,508 births) RE pooled beta = -7.52 (-13.54 to -1.51) FE pooled beta =-1.37 (-2.20 to -0.54) I^2= 92%--high with $p<0.01$ **BW change per 10 µg/m3 increase in PM10** ***By trimester*** *1st trimester* 21 (15 retrospective, 5 prospective cohorts, 1 cross-sectional; 5,822,040 births) RE pooled beta = -3.02 (-6.18 to 0.14) FE pooled beta =-2.98 (-3.68 to -2.29) I^2= 88%--high with $p<0.01$ *2nd trimester*		

				21 (15 retrospective, 5 prospective cohorts, 1 cross-sectional; 5,822,040 births) RE pooled beta = -3.48 (-6.23 to -0.73) FE pooled beta = -1.66 (-2.34 to -0.98) I^2= 88%--high with p<0.01 *3rd trimester* 24 (16 retrospective, 6 prospective cohorts, 2 cross-sectional; 6,259,325 births) RE pooled beta = -2.08 (-5.01 to -0.85) FE pooled beta = -1.27 (-1.95 to -0.59) I^2= 90%--high with p<0.01 **BW change per 10 µg/m3 increase in PM2.5 for entire pregnancy (all studies regardless of RoB) by *ethnicity*** *White* 7 studies (6 retrospective and 1 prospective cohorts;8,893,539 births) RE pooled beta = -32.00 (-60.03 to -3.98) FE pooled beta =-7.74 (-8.71 to -6.78) I^2= 95%--high with p<0.01 *Black* 5 retrospective studies; 8,867,779 births. RE pooled beta = -27.10 (-81.57 to 27.37) FE pooled beta		

				= -11.18 (-12.48 to -9.88) I^2= 93%--high with p<0.01 *Hispanic* 5 retrospective cohort studies; 8,525,968 births. RE pooled beta = -0.63 (-23.16 to 21.89) FE pooled beta = -6.88 (-7.67 to -6.09) I^2= 85%--high with p<0.01 **BW change per 10 µg/m3 increase in PM10 for entire pregnancy (all studies regardless of RoB) by *ethnicity*** *White* 4 studies (3 retrospective and 1 prospective cohorts; 5,461,652 births) RE pooled beta = -9.89 (-11.71 to -8.06) FE pooled beta = -9.89 (-11.11 to -8.66) I^2= 0%--No with p=0.47 *Black* 3 retrospective cohort studies ; 5,452,585 births) RE pooled beta = 3.47 (-64.74 to 71.67) FE pooled beta = -11.60 (-13.95 to -9.25) I^2= 97%--high with p<0.01 *Hispanic*		

				2 retrospective cohort studies; 5,094,081 births) RE pooled beta = -0.13 (-73.70 to 73.45) FE pooled beta = -4.96 (-6.12 to -3.80) I^2= 96%--high with p<0.01 **BW change per 10 μg/m3 increase in PM2.5 for entire pregnancy (all studies regardless of RoB)** ***By spatial scale of exposure assessment*** *Small (*(<5km proximity to monitor*)* 9 studies (6 retrospective and 3 prospective cohorts; 5,122,282 births) RE pooled beta = -20.3 (-34.87 to -5.18) FE pooled beta = -12.64 (-15.53 to –9.74) I^2= 83%--high with p<0.01 *Medium (*census tract, zip code, postal code, nearest monitor, <10 km and >/=5km) 9 retrospective cohort studies; 15,898,061 births) RE pooled beta = -45.07 (−113.16 to 23.02) FE pooled beta = -15.30 (-15.79 to –14.82) I^2= 98%--high with p<0.01 *Large (*(at the city or county level or >/= 10 km*)* 12 studies retrospective cohort studies; 27,441,062 births)		

				RE pooled beta = -9.69 (-24.98 to -5.60) FE pooled beta = -6.35 (-7.30 to –5.40) I^2= 97%--high with p<0.01 **NB**: Trimester specific results for spatial scales were also reported to explore heterogeneity and most had high heterogeneity. **BW change per 10 µg/m3 increase in PM10 for entire pregnancy (all studies regardless of RoB)** ***By spatial scale of exposure assessment*** *Small* 10 studies (4 retrospective and 6 prospective cohorts; 4,193,340 births) RE pooled beta = -10.23 (-17.96 to -2.51) FE pooled beta = -4.56 (-5.50 to –3.61) I^2= 96%--high with p<0.01 *Medium* 6 retrospective cohorts; 3,172,207 births) RE pooled beta = -0.43 (-17.88 to 17.03) FE pooled beta = -3.29 (-5.10 to –1.48) I^2= 96%--high with p<0.01 *Large* 8 studies (7 retrospective and 1 prospective cohort studies; 6,781,000 births). RE pooled beta = -4.25 (-10.53 to 2.04)		

				FE pooled beta = -6.11 (-6.69 to –5.54) I^2= 94%--high with p<0.01 **NB**: Trimester specific results for spatial scales were also reported to explore heterogeneity and most had high heterogeneity. **BW change per 10 µg/m3 increase in PM2.5 for entire pregnancy (all studies regardless of RoB)** ***By geographical settings*** *America* 20 retrospective cohort studies: 41,547,647 births) RE pooled beta = -27.36 (-56.98 to 2.26) FE pooled beta = -14.05 (-14.52 to –13.59) I^2= 98%--high with p<0.01 *Asia* 5 retrospective cohort studies: 2,884,855 births) RE pooled beta = -6.47 (-15.34 to 2.39) FE pooled beta = -5.09 (-6.87 to –3.30) I^2= 69%--moderate with p=0.01 *Europe* 3 prospective cohort studies: 83,726 births) RE pooled beta = -17.35 (-26.54 to -8.17) FE pooled beta		

				= -17.35 (-29.74 to –4.97) I^2= 0%-No with p=0.89 **NB**: Trimester specific results for geographical settings were also reported to explore heterogeneity and all had high heterogeneity. **BW change per 10 µg/m3 increase in PM10 for entire pregnancy (all studies regardless of RoB)** ***By geographical settings*** *America* 8 retrospective cohort studies: 6,718,959 births) RE pooled beta = -2.18 (-14.88 to 10.52) FE pooled beta = -4.69 (-5.83 to –3.54) I^2= 96%--high with p<0.01 *Europe* 8 studies (3 retrospective and 5 prospective cohort: 708,168 births) RE pooled beta = -14.55 (-23.52 to -5.58) FE pooled beta = -14.93 (-17.13 to –12.73) I^2= 89%--high with p<0.01 *Asia* 5 studies (4 retrospective and 1 prospective cohort: 2,773,217 births) RE pooled beta = -2.07 (-6.90 to 2.76) FE pooled beta		

				= -0.67 (-1.63 to 0.30) I^2= 88%--high with p<0.01 **NB**: Trimester specific results for geographical settings were also reported to explore heterogeneity and some had high heterogeneity. **Leave-one-out sensitivity analyses**. **PM2.5**: No significant difference but for the second trimester, heterogeneity is explained by a single study (Hyder et al. 2014) with a large effect size Omitting this study reduced I^2 from 68% to 40% and reduced the meta-estimate from − 5.69 g (−10.58, −0.79) to − 3.81 g (−7.88, 0.25)'. **PM10**: No significant difference instance but for the entire pregnancy, heterogeneity was explained largely by a single study (Geer et al. 2012) that reported a positive association, whereas all the other studies consistently showed an inverse association. Omitting this study reduced the I^2 from 84% to 0%, and changed the meta-estimate from − 8.65 g (−16.83 to −0.48) to − 11.22 g (−13.17 to −9.26). PM2.5-10: Heterogeneity was explained in 2[nd] and 3[rd] trimester by omitting single study but no difference for 1[st] trimester and entire pregnancy.		
8. Simonici (Simoncic et al., 2020) 03/11/2020 [4, All France]	PM2.5, PM10, NO2	BW/LBW, PTB, SGA	**PTB with** **PM2.5**: 2 cohort studies (74,061 births). 2 studies for whole pregnancy; no association in one and non-	**BW reduction per 10 µg/m3 increase in NO2** *1[st] trimester* 4 cohort studies; 3,435 births. FE pooled beta = -13.63 (-28.03 to 0.77)	'Our meta-analysis results provide pooled-risk for 5 combinations of air pollutant and	**Limitations** 'The features of the studies described above—such as study population, study design, sample size,

			significant increased risk in the other. 1 study (71493 births) reported for both 1st and 2nd trimesters and found non-significant decreased risk for both trimesters. **PM10**: 2 cohort studies (74,061 births) 2 for whole pregnancy; both found non-significant decreased risk. 1 study (71, 493 births) reported on both 1st and 2nd trimesters and found non-significant decreased risk for both trimesters. **NO2**: 4 cohort studies (80,458 births) examined whole pregnancy or trimester specific exposure periods. 4 reported for whole pregnancy; 1 found significant increased risk, 1 found non-significant increased risk, and 2 found non-significant decreased risk. 3 reported for 1st trimester; 1 each found significant increased risk, non-significant increased risk, and non-significant decreased risk. 3 reported for 2nd trimester; 2 found non-significant increased risk, and 1 found non-significant decreased risk. 2 reported for 3rd trimester; both found non-significant increased risk.	I^2= 35.8%-- low with p=0.197 *2nd trimester* 4 cohort studies; 3,435 births. FE pooled beta = -8.35 (-23.04 to 6.34) I^2= 25.8%- low with p=0.257 *3rd trimester* 5 cohort studies; 12,502 births. FE pooled beta = -1.73 (-12.83 to 9.36) I^2= 31.5%- low with p=0.212 **Leave-one-out sensitivity** The effect estimates of each 10 µg/m3 increase in NO2 exposure during the entire pregnancy on birth weight showed no significant change by removing one single study, suggesting that the combined results were relatively stable and reliable. This is except for the sensitivity analysis of the association between birth weight and NO2 exposure during the third trimester of pregnancy, where the omission of the study of Clemente et al. (2016) induced a reverse of the association that was hitherto negative; however, the result was still not statistically significant (beta = 2.5, 95% CI = (−9.18, 14.30)). Small variations were visible, and while point combined estimates were rather similar, the precision level of the confidence interval decreased.	birth weight and PTB, which may provide a coherent exposure–response function for environmental health risk assessments in European countries.’	the classification and definition of infant death, exposure assessment, difference between interquartile (IQR) used to assess the increase of exposure and confounding factors—could all, independently or in combination, affect the quality of each study itself and, also, their comparison in our systematic review. Some factors may overestimate while other one may underestimate the risk of birth outcome. Additionally the search could suffer from study selection biases. Non-English publications of relevant articles may have been ignored. Furthermore, we cannot exclude the possibility that our systematic review could be impacted by publication bias. Indeed, unpublished results (including grey literature and results not statistically significant, which are

			LBW **NO2**: 3 cohort studies (84,604 births) examined whole pregnancy or trimester-specific. 3 reported for whole pregnancy; all found significant increased risk. 2 for 1st trimester: 1 each found non-significant increased and decreased risks. 2 for 2nd trimester: 1 each found non-significant increased and decreased risks. 2 for 3rd trimester: both found non-significant increased risks. **PM2.5**: 2 cohort studies (80616 births). The 2 for whole pregnancy; 1 found significant increased and the other non-significant increased risks. 1 study (6,438 births) reported for all trimesters and found non-significant increased risk for 1st and 2nd but two-fold significant increased risk for 3rd trimester (2.00; CI: 1.10 to 3.62) **PM10**: 2 cohort studies (80616 births) 2 for whole pregnancy; both found non-significant increased risks. 1 study (6438 births) for all trimesters and found no			not available) may influence our meta-analysis findings towards the statistical significance of the risk estimates.'

			association, non-significant increased and significant increased risks for 1st, 2nd, 3rd trimesters respectively. **SGA** **NO2**: 2 cohort studies (1,291 births) examined both whole pregnancy and trimester-specific periods 2 for whole pregnancy; 1 each found non-significant increased and decreased risks. 2 for 1st trimester: 1 each found non-significant increased and decreased risks. 2 for 2nd trimester: 1 each found significant increased and non-significant decreased risks. 2 for 3rd trimester: 1 each found non-significant increased and decreased risks. Other several different indicators for daily exposures as lag days, weeks and months were also evaluated in some studies with diverse findings. "Among studies focusing on the 1st trimester of exposure the risk of adverse birth outcomes ranges from 0.78 to 1.67 with confidence interval range from 0.53 to 2.18. For the 2nd trimester of exposure results (OR) range from 0.83 to 1.67 with a confidence			

			interval range from 0.58 to 2.98. For the 3rd trimester of exposure results (OR) range from 0.88 to 2.00 with a confidence interval range from 0.62 to 3.62. These inconsistent results illustrate the lack of uniformity in the methods employed, difference between cross section, variability of variable's definition, and the lack of studies, particularly in Europe". 'Overall, the results reveal that the risk of adverse outcomes including: PTB, LBW, SGA was not found to be significantly associated with any of the pollutants. As for the other windows of exposure (each pregnancy trimester), results are very heterogeneous and there appears to be no clear trend regardless of the model used. For NO2 exposure results (OR) range from 0.81 to 1.28 with a confidence interval range from 0.91 to 1.74. For PM10 exposure results (OR) range from 0.97 to 1.46 with a confidence interval range from 0.74 to 2.24. And for PM2.5 exposures, results (OR) range from 0.92 to 1.98 with a confidence interval range from 0.72 to 4.19.'			

9. Thayamballi (Thayamballi et al., 2020) 08/09/2020 [4; all USA]	PM2.5, PM10 (and PM0.1)	BW, LBW/TLBW, PTB, SGA, Stillbirth	**Race/Ethnicity and PM2.5** **LBW**:2 studies (2,011,275 births) in California and found the most adverse effects among Blacks while the least were among Asians. **BW:** 7 studies with varied findings; 3 studies (4,954,011 births) identified Blacks as the most vulnerable. Another study (40,662 births) examined exposure during 3rd trimester and found Hispanics to be most vulnerable, followed by Blacks and then Whites. Another study (1,548,904) for entire pregnancy exposure found Whites to be most vulnerable, no association for Blacks and protective effects for Asians. Furthermore, 2 studies in California (339,674 births) found no strong influence of racial/ethnical effect modifications. **PTB**: 3 studies with varied results; higher risks in Blacks and Asians (231,637 births), Blacks and Hispanics (271,204), and no significant difference between Blacks and non-Blacks (3,389,450 births). **SGA**: Only one study in New Jersey (350,107 births) and found increased risk among the Blacks but not significance among the Hispanics and Whites.	**BW per 10µg/m3 of PM2.5 for race/ethnicity during entire pregnancy period** **Whites;** 5 retrospective cohort studies (6,484,085 births). Pooled effect = -15.7(-21.4 to -10.1) I^2= 68%-moderate with p= 0.01 **Hispanics:** 5 retrospective cohort studies (6,484,085 births). Pooled effect = -9.3 (-15.8 to -2.7) I^2= 92%-high with P< 0.01 **Blacks:** 4 retrospective cohort studies (6,467,392 births). Pooled effect = -21.9 (-32.0 to -11.7) I^2= 73%-moderate with P= 0.01 **Asians: 3** retrospective cohort studies (4,918,488 births). Pooled effect = -5.8 (-20.7 to 9.0) I^2= 95%-high with P< 0.01 **NB:** "Meta-analysis was conducted if three or more studies were available, which was only the case for race/ethnicity modification on the PM2.5-BW relationship in all race subgroups."	'For future studies, researchers are encouraged to conduct and present this type of effect modification analysis. More investigation is particularly expected for PTB, stillbirth, and birth defect outcomes, in order to draw more definitive conclusions about vulnerable subpopulations. Furthermore, other maternal factors, such as household income or medical health coverage, should also be considered as effect modifiers. Sociodemographic status and SES are a complicated measurement and difficult to capture by a single variable; therefore, investigating it from multiple angles is critical to understanding all implications.	**Limitations** "There are some inconsistencies across studies in terms of the definition of variables and selection of exposure windows'. 'The small number of studies limits our ability to make conclusive statements.' 'Meta-analysis for race/ethnicity modification on PM2.5-PTB, and PM10-PTB, and educational modification on PM2.5-BW, PM2.5-PTB, and PM10-PTB were not conducted because numerical results of effect modifications were not reported in some of the papers and could not be obtained from the authors.' 'Some of the studies included in this review were conducted in the same area, California. Therefore, our findings may be skewed toward California, which would limit its generalization to other parts of the U.S.' **Strengths**

			Stillbirth: Only one study in California (3,026,269 births) and found no support for effect modification. **Race/Ethnicity and PM10** **BW:** 4 studies; no significant difference between the Blacks and Whites in one study (358,504 Connecticut and Massachusetts births), Blacks most vulnerable, followed by Whites, Hispanics, and Asians (3,545,177 Californian births), Hispanics most vulnerable and Blacks less vulnerable during the 3rd trimester exposure (406,627 Atlanta births), and Whites most vulnerable while protective effects in Blacks and Hispanics (1,548,904 Texas births). **PTB:** 2 studies; non-Blacks were more vulnerable in full-gestational exposure (3,389,450 Georgian births), no influence of race/ethnicity in last month exposure (164,905 births in Detroit, Michigan) **SGA**: One study for last month pregnancy exposure (164,905 births in Detroit, Michigan) and found higher non-significant risk among Blacks than Whites. **Maternal Education and PM2.5**		Characterizing vulnerable subpopulations and quantifying their vulnerabilities are essential for addressing environmental justice since it can ultimately help regulatory agencies allocate resources and design policy interventions for communities that need it the most.'	'This is a comprehensive review of the literature that encompasses three types of PMs and various types of birth outcomes. To date, only two systematic reviews have been performed on this topic [22, 23], but none conducted a meta-analysis.' 'Limiting our study area to the U.S. enables us to better investigate the effect modification by maternal factors, which are unique to each country.' 'By attempting to perform a meta-analysis on the variables described above, this study revealed a major issue regarding the inconsistency of variable definitions and enlightens the need for a more consistent variable definition.

			LBW: 3 studies in California; 2 studies (2,011,275 births) found higher adverse risk among mothers with less than high school for full-gestational exposure. The 3rd study (72,632 births) had non-convergent model for high school but reported no modification for other educational levels. **BW**: 2 studies (1,373,311 Californian births) and found more risk of reduced BW among mothers with less than high school/college education. **PTB**: 2 studies with mixed findings; higher risk among mothers with higher education (college/advanced degree graduates) compared to those with less than high school (231,637 Californian births) and opposite (i.e., higher risk in less than high school educated mothers) in a Georgia study (3,389,450 births) but weak evidence of effect modification in both studies. **Stillbirth**: Only one study (3,026,269 Californian births) and found increased risk among mothers with higher education. **Maternal Education and PM10** **PTB**: 2 studies and found no influence of effect			

			modification; similar effects for with or more or less than high school (3389450 Georgian births), protective effect for mothers with less than 12 years education but not different from others (164,905 Michigan births). **SGA**: Only one study (164,905 births) in Detroit, Michigan and found non-significant increased risk among mothers with less than 12 years of education. **Publication bias** Not reported			
10. Li (Li et al., 2020) 04/08/2020 [7, all China]	PM2.5, PM10, NO2, SO2, CO, and O3	LBW	**LBW per 10µg/m3 of PM2.5** ***Entire pregnancy*** (29 cohort studies: 536,218 LBW births and unreported for one study). Pooled RR = 1.081 (95% CI: 1.043 to 1.120) I^2=86.0% - high, p=0.000, $\chi2$ =199.55 **LBW per 10µg/m3 of PM10** ***Entire pregnancy*** (23 cohort studies [**but** actually 17 studies because Seo et al 2010 for 7 cities in Korea was repeated 7 times for city-specific results]: 286,188 LBW births and unreported for one study). Pooled RR =1.05 (95% CI: 1.03 to 1.08), I^2=% 70.3-moderate, p=0.000,	***LBW per 10µg/m3 of PM2.5*** ***By trimester*** *1st trimester* (19 studies) RR =1.031(0.972 to 1.093) I^2=95.1% - high, p<0.001, $\chi2$ = 364.48 2nd *trimester* (20 studies) RR =1.031(0.982 to 1.08) I^2=91.5%-high, p<0.001, $\chi2$ = 223.43 *3rd trimester* (20 studies) RR = 1.053 (1.010 to 1.097) I^2= 92.0%-high, p<0.001, $\chi2$ = 237.35 **By the study region for entire pregnancy** *American countries* (18 studies) RR= 1.070 (1.019 to 1.124) *Asian countries* (7 studies) RR=1.044 (0.991 to 1.101) *European countries* (4 studies) RR=1.376 (1.187 to 1.594)	**NB**: No specific section on this. But from the conclusion. 'The exposure of SO2 or O3 was not significantly associated with increased LBW risk in none of the trimesters, despite the significant effects of the exposure during the entire pregnancy, which need to be further investigated.'	**Limitations** High degree of heterogeneity between the included studies were found in the study, as well as in various subgroups. Most of the exposure data were from the environmental protection agencies, which reflected the average concentration of air pollutants over a period of time, without considering the adverse effects of extreme environmental pollution. Almost all mothers and infants information was from public records, such as

			$\chi2$ =74.08 **NB**: RE for entire pregnancy and 1st trimester while FE for 2nd and 3rd trimester. **LBW per 10ppb of NO2** ***Overall risk for entire pregnancy*** (23 cohort studies; 509,997 LBW births). Pooled RR = 1.030 (1.008 to 1.053), I^2=% 89.5-high, p <0.001, $\chi2$ = 209.32 **Note**: RE was used for the entire pregnancy and 2nd and 3rd trimesters while FE for 1st trimester. **LBW per 100ppb of CO** ***for entire pregnancy*** (8 cohort studies; 112,239 LBW births) Pooled RR = 1.007 (1.001 to 1.014), I^2= 53.1% -moderate, p= 0.037, $\chi2$ = 14.92 **Note**: RE was used for the entire pregnancy and 2nd and 3rd trimesters while FE for 1st trimester. **LBW per 10ppb of SO2** ***for entire pregnancy*** (13 cohort studies); 171,360 LBW births	***By unit of increase of PM2.5 for entire pregnancy*** *Per 10 µg/m3 increase* (8 studies) RR=1.071 (1.025 to 1.119) *Per IQR* (15 studies) RR=1.037 (0.994 to 1.081) *Per 5 µg/m3* (3 studies) RR= 1.194 (0.919 to 1.551); *Per 1 µg/m3* (3 studies) RR= 1.211 (0.925 to 1.586). **By effect estimate model for entire pregnancy** *OR* (25 studies) RR=1.078 (1.039 to 1.119) *HR* (2 studies) RR=1.483 (1.149, 1.916) *RR* (2 studies) RR=1.050(0.904 to 1.220) **By the reporting of detailed birth weights (Yes/No*)* for entire pregnancy** *Yes* (16 studies) RR=1.066(1.029 to 1.105) *No* (13 studies) RR=1.103(1.029 to 1.182). ***Others trimesters*** Trimester-specific stratified analyses about the association of PM2.5- LBW in studies reporting the detailed birth weights, per 10 µg/m3 increase, and effect estimate model of OR and HR showed significant effects in the third trimester. **Leave-one-out sensitivity analyses** No significantly change after studies were sequentially excluded one by one. **LBW per 10µg/m3 of PM10** ***By trimester*** *1st trimester* (13 studies) RR = 1.022(0.998 to 1.047), I^2=71.5% -moderate, p<0.001, $\chi2$ = 42.06 *2nd trimester* (13 studies)		birth certificates, which limited the ability to control other important confounding factors. Only the relationship between single pollutant and LBW was investigated in this meta-analysis, while the interactions between multiple pollutants were not explored, due to the inherent limitations of meta-analysis. **Strengths** This meta-analysis covered a large number of high-quality cohort studies and performed various stratified analyses, which demonstrated the relationship between LBW and common air pollutants

			Pooled RR =1.12 (1.02 to 1.24) I^2=82.9%-high, p=0.000 χ2 = 70.34 **Note**: Random effect was used for the entire pregnancy and 1st trimester but fixed effect for 2nd and 3rd trimester. **LBW per 10ppb of O3** ***for entire pregnancy (overall risk)*** (14 cohort studies; 311,189 LBW births) Pooled RR = 1.045 (1.005 to 1.086), I^2= 90.3%-high, p <0.001, χ2 = 134.57 **N**: Random effect was used for the entire pregnancy and all trimesters. **Publication bias** **PM2.5** The funnel plot showed no evident publication bias, which was confirmed by the Egger' test (P > 0.05). **PM10** Significant publication bias was suggested in the entire pregnancy (P=0.031) but not the three trimesters (P > 0.05) **NO2** Significant publication bias were suggested in the entire pregnancy (P=0.004) but not the three trimesters (P > 0.05). **CO**	RR = 1.011 (1.005 to 1.017), I^2=28.2% - low, p=0.161, χ2 = 16.72 *3rd trimester* (13 studies) RR = 1.003 (0.995 to 1.011), I^2=20.6% - low, p=0.236, χ2 = 15.10 **By the study region for entire pregnancy** *American countries* (6 studies) RR= 1.018 (0.971 to 1.067) *Asian countries* (14 studies) RR= 1.050 (1.023 to 1.077) *European countries* (3 studies) RR= 1.105 (1.074 to 1.137) ***By unit of increase of PM10 for entire pregnancy*** *Per 10 μg/m3 increase* (5 studies) RR= 1.072 (0.998 to 1.151) *Per IQR* (17 studies) RR= 1.047 (1.022 to 1.072) *Per 1 μg/m3* (1 study) RR= 1.172 (0.855 to 1.606) **By effect estimate model for entire pregnancy** *OR* (21 studies) RR= 1.043 (1.021 to 1.066) *HR* (2 studies) RR= 1.063 (0.983 to 1.148) **By the reporting of detailed birth weights (Yes/No) for entire pregnancy** *Yes* (7 studies) RR= 1.016 (0.985 to 1.048) *No* (16 studies) RR= 1.078 (1.044 to 1.113) **Other trimesters for the subgroups** Trimester-specific stratified analysis in studies not reporting the detailed birth weights, per IQR increase, and in Asian		

			The funnel plot indicated no publication bias, which was confirmed by the Egger's test (P=0.05) **SO2** The funnel plot suggested no publication bias, which was confirmed by the Egger's test (P > 0.05) **O3** The funnel plot suggested no evident publication bias, which was confirmed by the Egger's test (P > 0.05)	countries showed significant effects in the second trimester. However, all such stratifications showed no significant effects in the first trimester or third trimester. **Leave-one-out sensitivity analyses** No significantly change after studies were omitted one after the other. **LBW per 10ppb of NO2** ***By trimester*** *1st trimester* (12 studies) RR = 1.022(1.009 to 1.035), I^2=10.6% - low, p= 0.243 $\chi2$ = 12.30 *2nd trimester* (13 studies) RR = 1.013 (0.988 to 1.038), I^2=74.9% - moderate, p<0.001, $\chi2$ =47.79 *3rd trimester* (13 studies) RR = 1.012 (0.969 to 1.058), I^2=78.1% - high, p<0.001, $\chi2$ =54.84 **By the study region for entire pregnancy** *American countries* (10 studies) RR= 1.009 (0.985 to 1.034) *Asian countries* (7 studies) RR= 1.040 (0.997 to 1.084) *European countries* (6 studies) RR= 1.115 (1.026 to 1.212) ***By unit of increase of NO2 for entire pregnancy*** *Per 10 µg/m3 increase* (6 studies) RR= 1.115 (1.026 to 1.212) *Per IQR* (13 studies) RR= 1.009 (0.989 to 1.030) *Per 1 pphm* (1 study) RR= 1.040 (1.030 to 1.050) *Per 1ppb (1 study)* RR= 1.051 (0.961 to 1.149) *Per 10ppb (2 studies)*		

				RR= 1.024 (0.977 to 1.075) **By effect estimate model for entire pregnancy** *OR* (21 studies) RR= 1.020 (0.999 to 1.042) *HR* (2 studies) RR= 1.331 (0.919 to 1.929 **By the reporting of detailed birth weights (Yes/No) for entire pregnancy** *Yes* (8 studies) RR= 1.023 (0.986 to 1.060) *No* (15 studies) RR= 1.035 (1.007 to 1.064) **Other trimesters for the subgroups** Trimester-specific stratified analysis in studies not reporting the detailed birth weights, per IQR increase, effect estimate model of OR, and at Asian countries showed significant effects in the first trimester. However, all such stratifications showed no significant effects in the second trimester or third trimester. **Leave-one-out sensitivity analyses** No significantly change after studies were omitted one by one, showing consistent with overall findings. **LBW per 100ppb of CO** ***By trimester*** *1^{st} trimester* (5 studies) RR = 1.008 (1.004 to 1.012), I^2=11.6% - low, p= 0.339 $\chi 2$ = 4.53 *2^{nd} trimester* (5 studies) RR = 1.005 (0.990 to 1.020) I^2= 54.2% - moderate, p= 0.068, $\chi 2$ = 8.73 *3^{rd} trimester* (5 studies)		

				RR =1.000 (0.984 to 1.016), I^2= 67.4% - moderate, p= 0.016, χ2 =12.26 **By the study region for entire pregnancy** *American countries* (3 studies) RR 1.006 (1.000 to 1.011) *Asian countries* (2 studies) RR= 1.045 (0.963 to 1.133) *European countries* (3 studies) RR= 1.006 (0.986 to 1.133) ***By unit of increase of CO for entire pregnancy*** *Per 100 µg/m3 increase* (1 study) RR= 1.023 (0.951 to 1.100) *Per IQR* (5 studies) RR= 1.005 (0.991 to 1.019) *Per 1 pphm* (1 study) RR= *Per 1ppm (1 study)* RR= 1.006 (1.003 to 1.009) *Per 1mg/m3 (1 study)* RR= 1.017 (1.003 to 1.032) **By effect estimate model for entire pregnancy** *OR* (8 studies) RR= 1.007 (1.001 to 1.014) **By the reporting of detailed birth weights (Yes/No) for entire pregnancy** *Yes* (4 studies) RR= 1.003 (0.995 to 1.011) *No* (4 studies) RR= 1.018 (1.001 to 1.036) **Other trimesters for the subgroups** Trimester-specific stratified analysis in studies not reporting the detailed birth weights, per IQR increase, per 1 mg/m3 increase, Asian countries and at European countries showed significant effects in the first trimester but no		

				significant effects in the 2nd or 3rd trimesters. **Leave-one-out sensitivity analyses** Results were not significantly altered after the studies were omitted one by one. **LBW per 10ppb of SO2** ***By trimester*** *1st trimester* (10 studies) RR = 1.054 (0.996 to 1.116), I^2=64.9% - moderate, p= 0.002 $\chi 2$ = 25.61 *2nd trimester* (10 studies) RR = 1.022 (0.994 to 1.052), I^2= 19.6% - low, p= 0.263, $\chi 2$ = 11.19 *3rd trimester* (10 studies) RR =0.981 (0.952 to 1.010), I^2= 44.5% - low, p=0.063, $\chi 2$ =12.26 **By the study region for entire pregnancy** *American countries* (4 studies) RR= 1.653 (0.982 to 2.783) *Asian countries* (7 studies) RR= 1.049 (0.968 to 1.138) *European countries* (2 studies) RR= 1.108 (0.691 to 1.775) ***By unit of increase of SO2 for entire pregnancy*** *Per 100 µg/m3 increase* (1 study) RR= 1.028 (1.016 to 1.041) *Per IQR* (7 studies) RR= 1.338 (1.048 to 1.709 *Per 1 ppb* (2 studies) RR= 1.102 (0.938 to 1.293) *Per 10oppb (1 study)* RR= 0.730 (0.438 to 1.216) *Per 1µg/m3 (2 studies)*		

				RR= 1.108 (0.691 to 1.775)) **By effect estimate model for entire pregnancy** *OR* (12 studies) RR= 1.082 (1.007 to 1.164) *HR* (1 study) RR= 13.951 (6.078 to 32.024) **By the reporting of detailed birth weights (Yes/No) for entire pregnancy** *Yes* (4 studies) RR= 1.028 (1.016 to 1.041) *No* (9 studies) RR= 1.251 (1.012 to 1.545) **Other trimesters for the subgroups** Trimester-specific stratified analysis in studies per IQR increase and at Asian countries showed significant effects in the 2nd trimester. All other such stratifications showed no significant effects in the 1st or 2nd trimesters. **Leave-one-out sensitivity analysis** No significant change, indicating that the results were in consistent with before excluding each study. **LBW per 10ppb of O3** ***By trimester*** *1st trimester* (9 studies) RR = 0.996 (0.947 to 1.046), I^2=78.5% - high, p<0.001 $\chi 2$ = 37.24 *2nd trimester* (8 studies) RR = 1.015 (0.948 to 1.087), I^2= 87.4% - high, p<0.001, $\chi 2$ = 55.36 *3rd trimester* (9 studies) RR =1.093 (0.992 to 1.204), I^2= 95.8% - high, p=0.063, $\chi 2$ <0.001 **By the study region for entire pregnancy**		

				American countries (10 studies) RR= 1.057 (1.013, 1.103) *Asian countries* (3 studies) RR= 1.051 (0.930 to 1.189) *European countries* (1 study) RR= 0.923 (0.859 to 0.992) ***By unit of increase of O3 for entire pregnancy*** *Per 10 µg/m3 increase* (1 study) RR= 0.923 (0.859 to 0.992) *Per IQR* (9 studies) RR= 1.066 (1.006 to 1.131) *Per 10ppb (1 study)* RR= 1.060 (0.942, 1.193) *Per 5ppb* (1 study) 1.173 (1.100 to 1.250) *Per 1 ppb* (1 study) RR= 1.038 (0.973 to 1.108) *Per pphm (1 study)* RR= 0.980 (0.965 to 0.995) **By effect estimate model for entire pregnancy** *OR* (13 studies) RR= 1.024 (0.991 to 1.059) *HR* (1 study) RR= 2.200 (1.751 to 2.765) **By the reporting of detailed birth weights (Yes/No) for entire pregnancy** *Yes* (5 studies) RR= 1.055 (0.987 to 1.127 *No* (9 studies) RR= 1.050 (0.988 to 1.117 **Other trimesters for the subgroups** Trimester-specific stratified analysis in studies per 10 ppb increase and effect estimate model of HR in the 1st trimester, effect estimate model of HR in the 2nd trimester, reporting the detailed birth weights and at Asian		

				countries in the 3rd trimester showed significant effects. **Leave-one-out sensitivity analyses** These indicated that the results were in consistent with before excluding each study. ***NB***: Unable to determine the sample sizes since forest plots were not provided to identify the specify studies.		
11. Ji (Ji et al., 2017) 30/05/2017 [6; All China]	PM2.5 and PM10	TLBW	***Entire pregnancy*** **LBW-PM2.5 per 10 μg/m³:** *Entire pregnancy* 6 cohort studies; 594,626 births OR= 1.04 (0.99,1.09); I^2= 67.4% (moderate) with p = 0.009 **LBW-PM10 per 10 μg/m³**: *Entire pregnancy* *(*9 cohort studies; 326,518 births*)* OR = 1.01 (0.96,1.08); I^2= 67.5% (moderate) with p = 0.002 ***Publication bias*** According to Egger's tests, except for the P-value (P = 0.025) of PM2.5 exposure in the 3rd trimester, no significant publication bias for the two pollutants can be seen.	***LBW risk By trimester*** **PM2.5 per 10 μg/m³** (3 cohort studies; 436,799 births for each trimester) *1st trimester* OR= 1.01 (0.98,1.03) I^2= 0.0% (low) p = 0.825 *2nd trimester:* 1.15 (0.96, 1.38) I^2= 65.8% (moderate) p = 0.054 *3rd trimester*: OR=1.17(0.94, 1.46) I^2= 79.4% (high) p = 0.008 **PM10** *1st trimester* (7 cohort studies; 315,469 births): OR= 1.06 (0.99,1.12); I^2= 20.3% (low) p = 0.275 *2nd trimester* (6 cohort studies; 313,955 births): OR= 1.05 (0.99, 1.44) I^2= 23.2% (low) p = 0.260 *3rd trimester* (7 cohort studies; 315,469 births): OR= 1.06 (0.97, 1.15).	Further studies are warranted to examine the origins of heterogeneity as more meaningful studies are conducted in the future.	**Strength** The in-depth evaluation of the evidence from birth cohorts is one of the main strengths of this review. **Limitations** 'Although less heterogeneity in some subgroups, high or moderate heterogeneities appeared in many of the subgroup analyses. These findings illustrated that the heterogeneity may also be affected by other factors. The socioeconomic status were not investigated due to the limitation in quantity of relevant studies.'

				I^2= 50.1% (low) p = 0.061 Other subgroups included study sample size, published year, study area, and exposure assessment method. **PM2.5 exposure with study sample size:** *Below 10,000* (OR = 1.20, 95% CI: 1.101-1.299, I^2 =0.0%, P = 0.554), *Above 10,000* (OR = 1.02, 95% CI: 1.00-1.042, I2=56.5% **Published year**: *Before to 2010* (OR = 1.03, 95% CI: 0.991-1.071, I2= 0.0%, P = 0.730), *After* 2010 (OR = 1.034, 95% CI: 1.007-1.061, I2= 61.8%, P = 0.001) **PM10 with study sample:** *Below 10,000* (OR = 1.08, 95% CI 1.00-1.15, I2 = 45.8%, P = 0.027), *Above 10,000* (OR = 1.02, 95% CI: 0.98-1.06, I2 = 54.3%, P = 0.008), **Published year** *before to 2010* (OR = 1.028, 95% CI: 0.99-1.067, I2 = 13.5%, P = 0.302), *After 2010* (OR = 1.047, 95% CI: 0.988-1.11, I2 = 68.1%, P< 0.001), **Study location at** *Europe and America* (OR = 1.05, 95% CI: 1.01-1.09, I2 = 54.2%, P = 0.003), at Asia (OR = 0.98, 95% CI: 0.90-1.07, I2 = 48.6%, P = 0.041), ***exposure measurement methods*** with *monitor* (OR = 1.03, 95% CI: 0.99-1.08, I2 = 32.7%, P = 0.079), *with model* (OR = 1.05, 95% CI: 0.99-1.11, I2 = 70.3%, P = 0.001).		

				Also collected articles which used *birth data directly from the national birth registry or hospital-birth records to explore the connection between PM exposure during pregnancy and LBW*: The pooled the estimate of PM10 for the entire pregnancy (OR = 1.07, 95%:1.02, 1.11) was larger than other trimesters, although no statistical significance of the three estimates can be obtained. Found that heterogeneity was lowest for the 3rd trimester and the highest for the 1st trimester.		
12. Liu (Liu et al., 2017) 15/06/2017 [7; all China]	PM2.5	PTB	**PTB per 10µg/m3 of PM2.5 for entire pregnancy** (7 studies; 5 retrospective and 2 prospective cohorts); 882,479 births. RE model OR= 1.15 (95% CI = 0.99 to 1.33) with p=0.07, I^2 =85%-high with p<0.00001, χ2 =40.53 **PTB per 10µg/m3 of PM2.5 *for 1st trimeste*r** (9 studies; 6 retrospective and 2 prospective cohorts and 1 nested case-control); 1,041,382 births. RE model OR= 1.15 (1.05 to 1.24) with p=0.001, I^2 =33%-moderate with p=0.15, χ2 =11.92 **Publication bias** The shape of the funnel plots seemed unsymmetrical in	**PTB per 10µg/m3 of PM2.5 for *entire pregnancy* by exposure level based on WHO IT-3** *high-level (≥15 µg/m3) exposure* (3 studies; 1 retrospective and 2 prospective cohorts); 303,326 births. FE model OR= 1.06 (1.04 to 1.08) with p<0.001, I^2 =0%-No with p=0.41, χ2 =1.76 *low-level (<15 µg/m3) exposure* (4 studies; 3 retrospective and 1 prospective cohorts); 579,153 births. RE model OR= 1.31 (1.06 to 1.63) with p=0.01, I^2 =47%-moderate with p=0.13, χ2 =5.68 **PTB per 10µg/m3 of PM2.5 for *1st trimester* by exposure level based on WHO IT-3** *high-level (≥15 µg/m3) exposure* (4 studies; 2 retrospective and 1 prospective cohorts, 1 nested case-control); 300,436 births. RE model OR= 1.11 (0.94 to 1.32) with p=0.21,	More prospected studies with clear exposure levels are still warranted in future.	**Strength** The studies included in this meta-analysis all employed cohort study design or nested case-control study design, which might prominently decrease heterogeneity between studies **Limitations** The results showed that although study designs, exposure levels, and main confounders partially explained the heterogeneity, moderate heterogeneities were still found in three of our analyses. Limited number of studies restricted us from conducting sensitivity analysis and subgroup

			high-level exposure group in the entire pregnancy, indicating the existence of publication bias. Beyond that, we did not find any statistically significant publication bias in other groups	I^2 =38%-moderate with p=0.18, $\chi2$ =4.83 *low-level (<15 µg/m3) exposure* (5 studies; 4 retrospective and 1 prospective cohorts); 740,946 births. RE model OR= 1.17 (1.04 to 1.30) with p=0.007, I^2 =44%-moderate with p=0.13, $\chi2$ =7.09 **sensitivity analysis** 'Since no significant heterogeneities were observed in these four meta-analyses and no group of study number is more than 5, sensitivity analysis is inappropriate for this meta-analysis'.		meta-analyses between studies based on different geographic areas and PM2.5 constituents. The restriction of languages (only studies published in English or Chinese were selected), and the exclusion of studies, results of which could not be transformed into OR and 95% CI, could be partly attributable to the publication bias.
13. Li (Li et al., 2017) 28/04/2017 [17; all China]	PM2.5	TLBW, PTB	**TLBW per 10µg/m3 of PM2.5 for entire pregnancy** (4 studies: 3 retrospective cohort and 1 cross-sectional); 8,226,866 births RE model; OR= 1.05 (0.98 to 1.12) with p=0.14 I^2 = 85%-high with p= 0.0001 **TLBW per IQR increases in PM2.5 for entire pregnancy** (7 studies: all retrospective cohort); 4,148,642 births FE model; OR= 1.03 (1.02 to 1.03) with p <0.00001 I^2= 22%-low with p= 0.26 **PTB per 10µg/m3 of PM2.5 for entire pregnancy**	**By trimester** **TLBW:** *1st trimester exposure (IQR)*- 3 retrospective cohort studies; 1,163,751 births OR= 1.00 (0.91 to 1.11) with p= 0.92 I^2 =90%- high with p <0.0001 *2nd trimester exposure (IQR)- 4 retrospective cohort studies*; 1,587,470 births. OR= 1.00 (0.96 to 1.03) with p=0.83 I^2 =81%- high with p= 0.001, *3rd trimester exposure (IQR)*-3 retrospective cohort studies; 1,163,751 births. OR= 1.03 (0.98 to 1.09) with p=0.28 I^2 =55%- moderate with p= 0.11, **PTB:** *1st trimester exposure (IQR)-5* studies (4 retrospective and 1 prospective cohorts; 1,371,800 births. OR= 1.03 (1.00 to 1.06) with p= 0.07 I^2 =70 moderate with p=0.009	'Future studies should employ individual direct exposure measurements to obtain more precise and accurate data.' 'More comprehensive and detailed birth records would help scientists control for such confounding variables.'	**Strengths** 'Our meta-analysis included all exposure models, including monitoring of network data, remote sensing data, or both, and we were inclined to choose exposure-estimate model, which used satellite data as exposure source.' **Limitations** 'The selection of study population, adjusted factors, air pollution data, and exposure estimation model varied among studies, and this is likely a source of heterogeneity.

			(6 studies; 3 retrospective cohort, 2 case-control, 1 cross-sectional); 4,098,419 births OR= 1.02 (0.93 to 1.12) with p=0.68 I^2 =97 %-high with p<0.00001 **PTB per IQR of PM2.5 for entire pregnancy** (8 studies; 7 retrospective cohort and 1 prospective cohort); 1,692,797 births OR= 1.03 (1.01 to 1.05) with p= 0.0002 I^2 = 63%-high, p= 0.008 **Publication bias** "We evaluated the possibility of a publication bias in the 23 studies, and the funnel plot illustrated a symmetrical distribution of the points, suggesting a lack of publication bias; furthermore, no publication bias was found by either Begg's test and Egger's test" P for Begg's test= 0.734	*2nd trimester exposure (IQR)-4* retrospective studies; 1,367,947 births. OR= 1.01 (0.93 to 1.10) with p= 0.83 I^2 =98- high with p<0.00001 *3rd trimester exposure (IQR)-4* retrospective studies; 1,367,947 births. OR= 1.02 (0.99 to 1.04) with p= 0.16 I^2 =59%- moderate with p=0.06		Furthermore, all of the studies' exposure estimation models used outdoor air pollution levels to calculate personal exposure. However, indoor air pollution varies and is vital to our discussion. Study region, the study design, and exposure assessment method could be sources of heterogeneity, we did not analyze them in this review owing to the restricted number of studies. Another variable is the fact that all of the included studies used different adjusting variables. Some vital variables, like smoking, were not included in the adjusted model. Due to our exclusion criteria, the number of included studies was limited. Furthermore, we only considered single pollutant models, because there was high heterogeneity between included studies in a subgroup analyses. Finally, a better understanding of the

						concentration-response association between air pollution and adverse birth outcome would be extremely valuable. We found there to be no publication bias based on an Egger's test, or a Begg's test. Nevertheless, owing to the limited sample size, we note that our study results should be interpreted with caution.’
14. Zhang (Zhang K, 2016) 30/11/2016 [8; All China]	PM2.5, PM10	SGA/IUGR, SGA, Stillbirth, SAB	**Stillbirth per 10µg/m3 of PM2.5 for entire pregnancy and trimesters** 4 studies **NB**: We excluded these meta-analytical results because results from a study (Pearce et al 2009) on black smoke levels, considered to be approximately equivalent to PM_4 were included to estimate the pooled OR. **Stillbirth per 10 µg/m3 of PM10 for entire pregnancy** 1 case-control study; 102,575 births OR = 0.98 (0.95 to 1.02) I^2= -- with p= -- **SGA per 10µg/m3 of PM2.5 for entire pregnancy**	**Stillbirth per 10µg/m3 of PM10 by trimester** *1st trimester* 2 studies (1 retrospective cohort and 1 case-control; 104,089 births) RE pooled OR = 1.00 (0.94 to 1.06) I^2= 54.1%- moderate p= 0.140 *2nd trimester* 2 studies (1 retrospective cohort and 1 case-control; 104,089 births) RE pooled OR = 1.00 (0.90 to 1.12) I^2= 81.1%- high p= 0.021 *3rd trimester* 2 studies (1 retrospective cohort and 1 case-control; 104,089 births) RE pooled OR = 1.02 (0.92 to 1.13) I^2= 90.9%- high p= 0.001 **SGA per 10µg/m3 of PM2.5 by trimester** *1st trimester*	More researches on such subjects are still needed.	**Limitations** ‘First, we found different degrees of heterogeneity across PM, which could be partly explained by differences in population demography, sample size, exposure assessment, compounds of particulate matters, etc. Secondly, we only described the impact of single pollutants without taking combined effects of multipollutants into account. Third, in this study, the term of intrauterine growth retardation (IUGR) was treated as the

			6 retrospective cohort studies (1,515,887 births) RE pooled OR = 1.15 (1.10 to 1.20) I^2= 0.0%- No p= 0.877 **SGA per 10µg/m3 of PM10** **NB**: 'However, none article revealed the relationship between PM10 and SGA, and that was why we did not perform meta-analysis between them' **SAB per 10µg/m3 of PM2.5** **NB**: 'No article revealing the risk of PM2.5 on SAB was found' **Publication bias** 'With all the value of P>0.05 in Egger's test, no publication bias was found in all analysis'	6 retrospective cohort studies; 1,740,763 births RE pooled OR = 1.07 (1.05 to 1.10) I^2= 5.0%- low p= 0.385 *2nd trimester* 5 retrospective cohort studies; 1,706,058 births RE pooled OR = 1.06 (1.02 to 1.10) I^2= 58.1%- moderate p= 0.049 *3rd trimester* 5 retrospective cohort studies; 1,706,058 births RE pooled OR = 1.06 (1.04 to 1.08) I^2= 13.4%- low p= 0.329 **SAB per 10µg/m3 of PM10 for 1st trimester** 3 studies (1 retrospective cohort, 1 case-control, and 1 cross-sectional; 515,932 births). RE pooled OR = 1.34 (1.04 to 1.72) I^2= 62.4%- moderate p= 0.070 **Sensitivity analysis** 'After removing each article sequentially, statistically steady results were obtained, suggesting our results of meta-analysis were robust.'		same as SGA, for most articles defined them in the same way. Finally, a limited number of literatures were included in our final analysis.'
15. Siddika (Siddika et al., 2016) 24/05/2016 [4; 3 Finland, 1 Ghana]	PM 10, PM2.5, NO2, SO2, CO, O3.	Stillbirth	NB: 4/11 studies were meta-analysed and the remaining synthesised narratively. **Stillbirth for entire-pregnancy period of exposure;** **PM2.5 per 4 µg/m3** (2 studies, both retrospective cohort, ranked high quality;	*By trimesters* **SO2** 1st *trimester* RE=1.040 (0.962 to 1.125) FE=0.997 (0.975 to 1.020) χ^2 = 10.34 p-value = 0.006 I^2 = 80.7% (high) *2nd trimester*	'Pregnant women should be aware of the potential adverse effects of ambient air pollution, although the prevention against exposure to air	**Strengths** 'We included all the studies identified in an extensive systematic search, so missing of important epidemiological studies is less likely to have happened.'

			3,745,243 births): RE = 1.021 (0.996 to 1.046), FE = 1.021 (0.996 to 1.046) χ^2 = 0.18 p-value = 0.669 I^2 = 00.0%(No) **PM10 per 10 μg/m3** (2 studies, each prospective cohort and case-control, both ranked high-quality studies; 104,089 births): RE = 1.014 (0.948 to 1.085), FE = 1.012 (0.986 to 1.039) χ^2 = 6.67 p-value = 0.010 I^2 =85.0% (high) **SO2 per 3 ppb increase** (3 studies; 2 retrospective cohort, 1 case-control, all 3 studies ranked very high quality =3,847,818 births), RE =1.022 (0.984 to 1.062), FE=1.019 (0.989 to 1.049) χ^2 =2.49 p-value = 0.288 I^2=19.6% (low) **NO2 per 10ppb** (same 3 studies as in SO2) RE= 1.066 (0.965 to 1.178), FE = 1.049 (1.012 to 1.088) χ^2 = 9.78 p-value = 0.008 I^2 =79.6% (high) **CO per 0.4ppm** (same 3 studies as in SO2) RE = 1.025 (0.985 to 1.066), FE = 1.022 (0.995 to 1.050) χ^2 = 2.52 p-value = 0.284	RE = 1.003 (0.977 to 1.030) FE = 1.003 (0.977 to 1.030) χ^2 = 1.79 p-value =0.408 I^2 = 0.0% (No) *3rd trimester* RE = 1.042 (0.951 to 1.142) FE = 0.996 (0.967 to 1.026) χ^2 = 11.26 p-value =0.004 I^2 = 82.2% (high) **NO2** 1st *trimester* RE= 1.035 (0.983 to 1.089) FE= 1.025 (0.996 to 1.054) χ^2 = 4.43 p-value =0.109 I^2 = 54.8% (high) *2nd trimester* RE =1.007 (0.948 to 1.071) FE =1.005 (0.977 to 1.034) χ^2 = 5.83 p-value =0.054 I^2 =65.7% (high) *3rd trimester* RE = 1.015 (0.980 to 1.051) FE =1.015 (0.980 to 1.051) χ^2 = 1.88 p-value =0.391 I^2 =0.0% (No) **CO** 1st *trimester* RE=1.011 (0.967 to 1.057) FE=1.002 (0.983 to 1.022) χ^2 = 2.92 p-value =0.232 I^2 =31.6% (moderate) *2nd trimester* RE =1.015 (0.948 to 1.087)	pollutants generally requires more action by the government than by the individual. The healthcare sector can create awareness and engage other sectors contributing to ambient air pollution (such as the housing sector, transportation sector, industries and the energy sector), to develop and implement policies such as control of vehicular emissions, fuel quality improvement and control of industrial waste emission, to reduce the risk of air pollutants. Future studies should integrate the use of personal monitoring methods and also consider the activity of mothers, change in	**Limitations** 'Even though our review contains eight more studies and much more information than the previous reviews, we found a very limited number of estimates for each of the pollutants, and only five studies made attempts to adjust for other air pollutants when presenting effect estimates of each air pollutant. Therefore, we could not include all of the studies in the meta-analyses, and the reliability on the summary effect estimate's is further compromised.'

			I^2 = 20.5%(low) **O3 per10 ppb** (2 studies; one each for case-control and retrospective cohort, both ranked high quality; 3,128,844 births); RE = 1.002 (0.971 to 1.034) FE = 1.005 (0.982 to 1.029) χ^2 = 1.24 p-value = 0.265 I^2 = 19.6%(low) **Publication bias** It was assessed by funnel plots, Begg's and Egger's tests results; 'There was no indication of publication bias present, although these results should be interpreted with caution because they were based on two or three study-specific effect estimates only' **Narrative synthesis** **SO2**; one each of case-crossover, time-series, and ecological studies found significant association with SB. A cross-sectional study and another ecological study found no significant association. **NO2**; significant association in case-crossover, time-series with various lag days, ecological.	FE =1.002 (0.979 to 1.025) χ^2 = 5.60 p-value =0.061 I^2 =64.3%(high) *3rd trimester* RE = 1.052 (0.973 to 1.138) FE =1.014 (0.992 to 1.038) χ^2 = 10.19 p-value =0.006 I^2 =80.4%(high) **PM10** 1st *trimester* RE=0.998 (0.936 to 1.064) FE=1.015 (0.991 to 1.039) χ^2 = 2.18 p-value =0.140 I^2 =54.1%(high) *2nd trimester* RE =1.005 (0.905 to 1.116) FE =0.968 (0.944 to 0.993) χ^2 = 5.31 p-value =0.021 I^2 =81.2%(high) *3rd trimester* RE = 1.021 (0.919 to 1.134) FE =0.995 (0.968 to 1.022) χ^2 = 10.96 p-value = 0.001 I^2 =90.9%(high) **PM2.5** 1st *trimester* RE=1.042 (0.920 to 1.180) FE= 1.002 (0.982 to 1.022) χ^2 = 2.35 p-value =0.126 I^2 =57.4%(high) *2nd trimester* RE =1.040 (0.940 to 1.152) FE =1.011 (0.996 to 1.026)	residence, air exchange, mother's occupation and outdoor activities of the mothers. The pregnant women should also be monitored if possible from the first month of pregnancy in order to ascertain the exact period of the effect.'	

			NO; Two studies that investigated this found no association. **NOx**; one study investigated this and found no association. **CO**; The findings of CO exposure with stillbirth were less consistent **PM2.5**; One time series found no significant association, one retrospective study found significant association only in the 3rd trimester. **O3**; The time series study found no association	χ^2 = 1.92 p-value =0.166 I^2=47.9% (moderate) *3rd trimester* RE = 1.00 (0.981 to 1.020) FE =1.00 (0.981 to 1.020) χ^2 = 0.23 p-value =0.631 I^2 =0.0% (No) **O3** 1st *trimester* RE=1.001 (0.983 to 1.020) FE=1.001 (0.983 to 1.020) χ^2 = 0.13 p-value =0.714 I^2 =0.0% (No) *2nd trimester* RE =0.991 (0.944 to 1.040) FE =1.004 (0.985 to 1.022) χ^2 = 3.18 p-value =0.074 I^2 =68.6%(high) *3rd trimester* RE = 1.012 (0.966 to 1.060) FE =1.025 (1.006 to 1.043) χ^2 = 2.72 p-value =0.099 I^2 =63.2%(high)		
16. Sun (Sun et al., 2016) 29/12/2015 [8, all China]	PM2.5 and chemical constituents	LBW, BW	**BW per 10μg/m3 of PM2.5 for entire pregnancy** 17 studies (1 prospective and 16 retrospective cohorts; 7,857,127 births) Pooled β= -15.9 (95% CI = -26.8 to -5.0) I^2 =98.5%-high with p <0.001	**Note**: Forest plots were not presented to enable us determine the study designs and sample sizes for the subgroup analyses. **BW per 10μg/m3 of PM2.5 by:** ***Trimesters*** *1st trimester* 11 studies Pooled β= -8.3 (-17.0 to 0.4) I^2 =89.8%-high with	'More studies in counties other than the USA are needed, especially in middle- or low-income counties with heavier air pollution. Further meta-analyses are necessary to	**Limitations** 'High or moderate heterogeneities in most of the subgroup meta-analyses, although less heterogeneity was found in some subgroups. These findings indicate that the heterogeneity

			LBW per 10µg/m3 of PM2.5 for entire pregnancy 19 studies (2 prospective and 17 retrospective cohorts; 10,405,729 births) Pooled OR= 1.090 (95% CI = 1.032 to 1.150) I^2 =92.6%-high with p <0.001 **Publication bias** 'The results of Egger's tests showed that there was no significant publication bias in most of the meta-analyses **except** for the BW-PM2.5 exposure analysis during the 2nd trimester and the LBW-PM2.5 analyses during the entire pregnancy as well as in the 3rd trimester.'	p <0.001 *2nd trimester* 10 studies Pooled β= -12.6 (-21.7 to -3.1) I^2 =92.2%-high with p <0.001 *3rd trimester* 13 studies Pooled β= -10.0 (-16.6 to -3.5) I^2 =85.8%-high with p <0.001 ***For entire pregnancy by study design*** *Prospective cohort* 2 studies Pooled β= -11.6 (-28.7 to 5.3) I^2 =0.0%-No with P=0.454 *Retrospective cohort* 15 studies Pooled β= -16.7(-28.7 to -4.8) I^2 =98.8%-high with p <0.001 ***For entire pregnancy by exposure assessment method*** *Individual level* 4 studies Pooled β= -15.7 (-42.1 to 10.6) I^2 =87.4%-high with p <0.001 *Semi-individual level* 8 studies Pooled β= -15.2 (-20.7 to -9.7) I^2 =76.3%-high with p =0.001 *Regional level* 6 studies	explore the sources of heterogeneity as more original studies are conducted in the future. It is crucial to reduce the ambient PM2.5 pollution and reduce maternal PM2.5 exposure during pregnancy to improve birth outcomes.'	among the included studies may also have been affected by other factors, such as socioeconomic status, that we did not consider in this study due to the limited number of relevant studies.'

				Pooled β= -17.3 (-43.4 to 8.8) I^2 =97.7%-high with p <0.001 ***For entire pregnancy by country*** *USA* 13 studies Pooled β= -18.8 (-31.4 to -6.3) I^2 =99.0%-high with p <0.001 *Others* 4 studies Pooled β= -1.8 (-12.2 to 8.7) I^2 =26.2%-low with p=0.401 **LBW per 10µg/m3 of PM2.5 by:** ***Trimesters*** *1st trimester* 7 studies Pooled OR= 1.026 (0.93 to 1.130) I^2 =86.9%-high with p <0.001 *2nd trimester* 7 studies Pooled OR= 1.035 (0.952 to 1.125) I^2 =79.8%-high with p <0.001 *3rd trimester* 8 studies Pooled OR= 1.233 (0.960 to 1.585) I^2 =98.7%-high with p <0.001 ***For entire pregnancy by* study design** *Prospective* 3 studies Pooled OR= 1.359 (1.102 to 1.676) I^2 =0.1%-low with		

				p =0.269 *Retrospective* 16 studies Pooled OR= 1.078 (1.022 to 1.137) I^2 =93.1%-high with P<0.001 ***For entire pregnancy by exposure assessment method*** *Individual level* 2 studies Pooled OR= 1.431 (1.149 to 1.783) I^2 =0.0%-No with p =0.570 *Semi-individual level* 10 studies Pooled OR= 1.008 (0.999 to 1.016) I^2 =40.5%-low with p =0.093 *Regional level* 8 studies Pooled OR= 1.145 (1.061 to 1.235) I^2 =73.6%-moderate with p<0.001 ***For entire pregnancy by* country** *USA* 14 studies Pooled OR= 1.079 (1.018 to 1.143) I^2 =94.3%-high with P<0.001 *Others* 5 studies Pooled OR= 1.141 (1.044 to 1.247) I^2 =36.1%-low with P=0.140 **Other subgroups** *Leave-out sensitivity analyses* Exclusion of single studies that had the largest and smallest effect size with regard to the		

				significance of the estimated associations had no effect except one study where exclusion of the study with the smallest effect size resulted in significant pooled effect of BW during first trimester. Also, to test the influence of 3 studies that considered preterm low birth weight (PLBW), exclusion of these studies found did not change the pooled estimate significantly *Meta-regression* The results of meta-regression analysis of showed similar modification effect patterns of the study characteristics, but none of the tests was statistically significant for BW-PM2.5 association but results of the meta-regression analyses of PM2.5 exposure on LBW was significantly impacted by the exposure assessment methods used (OR= 0.13, 95% CI: 0.06, 0.20) *PM2.5 chemical constituents* (7 studies in all; specifically, 2 to 4 studies for each and majority were 2 studies). Birth weight was negatively associated significantly with zinc, nickel, titanium, vanadium, organic carbon (OC), nitrate (NO^{-}_{3}); -all from 2 studies, and elemental carbon (EC) from 3 studies. For example, a 10 ng/m3 increase in Zn exposure was associated with a 7.5 g (95% CI: 5.0, 10.0) decrease in birth weight (from 2 studies). Similarly, the LBW risk was positively associated with potassium (3 studies), zinc (3 studies), nickel (4 studies), titanium (4 studies), elemental carbon (4		

				studies), silicon (3 studies), sulfur (2 studies) and ammonium ion (2 studies) levels. For instance, a 10 ng/m3 increase in Ti exposure was related to a 15.9% (95% CI: 0.7, 33.3) increase in the risk of LBW.		
17. Sun (Sun et al., 2015) 18/11/2015 [7; 5 China, 2 Australia]	PM2.5	PTB	**PTB per 10µg/m3 of PM2.5 for entire pregnancy** 13 studies (4 prospective, 9 retrospective cohort; 3,089,186 births Pooled OR= 1.13 (95% CI = 1.03 to 1.24) I^2 =91.4%-high with p <0.001 **Publication bias** Did not find any statistically significant publication bias in any of the meta-analyses	**PTB per 10µg/m3 of PM2.5 *for trimester*** *1st trimester* 10 studies (5 prospective and 5 retrospective cohorts; 1,668,004 births Pooled OR= 1.08 (0.92 to 1.26) I^2 =91.3%-high, with p<0.001 *2nd trimester* 5 studies (2 prospective and 3 retrospective cohorts; 1,340,807 births Pooled OR= 1.09 (0.82 to 1.44) I^2 =98.7%-high, with p<0.001 *3rd trimester* 9 studies (1 prospective and 8 retrospective cohorts; 2,208,883 births Pooled OR= 1.08 (0.99 to 1.17) I^2 =92.1%-high, with p<0.001 **PTB per 10µg/m3 of PM2.5 for *1st month of gestation*** 3 retrospective cohort studies; 342,423 births Pooled OR= 1.10 (0.92 to 1.30) I^2 =91.0%-high, with p<0.001 **PTB per 10µg/m3 of PM2.5 for *one month before birth*** 6 retrospective cohort studies; 3,556,199 births. Pooled OR= 1.01 (0.86 to 1.19) I^2 =96.8%-high, with p<0.001	"These results are important for policy makers and public health practitioners worldwide. More studies are needed in the future to explore which gestational windows are more susceptible to air pollution. More studies in countries other than the USA are needed, especially in middle or low income countries with higher levels of air pollution. More studies are needed in the future, especially studies assessing PM2.5 exposure at the individual level. Studies on the association between PM2.5 components and sources and preterm birth are	**Limitations** 'High heterogeneity between included studies. Heterogeneity across the included studies may also have been affected by other factors that we did not consider in this study, such as socioeconomic status and chemical constituents of PM2.5, due to the limited quantity of related studies.' **Strengths** No specific statement.

				PTB per 10µg/m3 of PM2.5 by exposure assessment methods *Assessed exposure at individual level* 3 studies (1 prospective and 2 retrospective cohort studies; 350,652 births Pooled OR= 1.11 (0.89 to 1.37) I^2 =61.3%-moderate, with p = 0.085 **NB**: Considered individual-level exposure as assessed using complicated dispersion models based on traffic, meteorology, roadway geometry, vehicle emission, air quality monitoring, and land use databases to estimate each subject's daily PM2.5 exposure level with high accuracy. *Assessed exposure at semi-individual level* 9 studies (3 prospective and 6 retrospective cohort studies; 2,353,605 births. Pooled OR= 1.14 (0.97 to 1.35) I^2 =93.0%-high, with p<0.001 **NB**: Semi-individual exposure was estimated using the daily PM2.5 concentration from the monitoring station nearest to the individual's residence. A*ssessed exposure at regional level* 4 retrospective cohort studies; 1,722,203 births. Pooled OR= 1.07 (0.94 to 1.23) I^2 =92.8%-high, with p<0.001 NB: Regional-level exposure was calculated using the average PM2.5 concentration in a region or a grid with low resolution. This method did not	still limited, and more studies are needed in the future. Improving the data quality of public records is one way to improve related studies. Future longitudinal studies that collect more detailed information at the individual level would be beneficial. Further studies are needed to explore the sources of heterogeneity in the future."	

				consider the variation in PM2.5 concentration within a region, and assumed that all subjects in this region had the same PM2.5 exposure concentration. **PTB per 10µg/m3 of PM2.5 by study design** *Retrospective cohort* 9 studies: 2,921,829 births. Pooled OR= 1.10 (1.01 to 1.21) I^2 =93.3%-high, with <0.001 *Prospective cohort* 4 studies: 167,357 births. Pooled OR= 1.42 (0.99 to 2.03) I^2 =39.5%-low, with p=0.201 **PTB per 10µg/m3 of PM2.5 by study setting/country** *USA* 8 studies (1 prospective and 7 retrospective cohort studies; 2,525,004 births. Pooled OR= 1.16 (1.04 to 1.29) I^2 =90.6%-high, with p <0.001 *Other countries* 5 studies (3 prospective and 2 retrospective cohort studies; 564,182 births. Pooled OR= 0.98 (0.95 to 1.01) I^2 =0.1%-low, with p=0.095. **Other subgroup analyses** Several meta regression analyses employed to further evaluate the impacts of study characteristics on the associations between PM2.5 exposure and preterm birth risks found similar results.		

				Leave-one-out sensitivity analyses In the meta-analysis that included studies assessing PM2.5 exposure at the semi-individual level, the estimate became significant after excluding a single study with the smallest effect size. All others after excluding a single study with the largest effect size, the smallest effect size, the largest standard error, or the smallest standard error did not yield any significant change.		
18. Lamichhane (Lamichhane et al., 2015) 03/11/2015 [4; All Incheon, Korea]	PM2.5, PM10	PTB, change in BW.	**Change in BW (g) per 10μg/m3 of PM2.5** ***Entire pregnancy*** ---- combined studies. (8 cohort studies; 5,493,944 births). Pooled ES = -13.88 g (95% CI, -15.70 to -12.06 g) I^2=47.5% moderate, p=0.064 ***Studies that adjusted for smoking*** *Entire pregnancy* (7 cohort studies; 2,090,972 births). pooled ES = -22.17 (-37.93 to -6.41) with I^2 =92.3% - high, p=0.000 (**NB**: Authors noted that meta-analysis for smoking-unadjusted was not conducted due to insufficient number of studies) **Change in BW (g) per 10μg/m3 of PM10** **(NB:** Separated by adjusted and unadjusted for smoking)	***By trimester*** **Change in BW (g) per 10μg/m3 of PM2.5** *1st trimester* (6 cohort studies; 4,565,337 births). pooled ES = -8.03(-14.54 to -1.53) with I^2=85.1% -high, p=0.000 *2nd trimester* (5 cohort studies; 4,561,484 births). pooled ES = -7.90 (-13.70 to -2.09) with I^2=88.0% -high, p=0.000 *3rd trimester* (7 cohort studies; 5,540,383 births). pooled ES = -6.04 (-7.69 to -4.39) with I^2 =14.6% - low p=0.318 ***Studies that adjusted for smoking*** *1st trimester* (5 cohort studies; 1,261,503 births). pooled ES = -6.20 (-19.51 to 7.12) with I^2 =87.8% - high	'Future large cohort studies with sufficient data and detailed information on timing of smoking during pregnancy and other potential confounding factors as well as reliable exposure data are required for a better understanding of the association between PM and the risk of adverse birth outcomes.' 'Considering the ubiquitous nature of particulate air pollution [72]. exposure, variation in effects by exposure period, especially time periods shorter than	**Strengths** 'One advantage of this review is that we appraised all individual studies included in the outcome specific analysis according to a structured and validated checklist, helping us to present quality assessment of methodological rigor of studies in a more organized and standardized way. The included studies allowed us to explore possible exposure-response relationship according to a critical exposure period, which offers another advantage of this meta-analysis.' **Limitations**

			Studies that adjusted for smoking: ***Entire pregnancy*** (5 cohort studies; 477,123 births). Pooled ES = - 10.31g (95% CI, - 13.57 to -7.05 g) I^2=0.0% low, p=0.947 **Studies that did not adjust for smoking:** ***Entire pregnancy*** (3 cohort studies; 3,788,093 births). Pooled ES = - 8.17g (95% CI, - 10.99 to -5.36g) I^2=35.2% low, p=0.214 **PTB per 10µg/m3 of PM2.5** **NB**: Ha et al (49) in the review article examined *PM10-PTB* and was described as such by the authors in Table 1 but Ha et al (2004; referenced wrongly in Table 1 and Figure S2 as '2014' but correctly referenced in reference list) was mistakenly included in estimating all the pooled ORs for *PM2.5-PTB* association. We therefore excluded the pooled ORs for the PM2.5-PTB association. The corresponding author was contacted twice but we did not receive any reply. **Adjusted for smoking;**	p=0.000 *2nd trimester* (4 cohort studies; 1,257,650 births). pooled ES = -10.57 (-18.95 to -2.20) with I^2 =82.0% - high p=0.001 *3rd trimester* (6 cohort studies; 2,236,549 births). pooled ES = -7.60 (-9.84 to -5.36) with I^2 =0.0% - low p=0.819 **Change in BW (g) per 10µg/m3 of PM10** **(NB:** Separated by adjusted and unadjusted for smoking; by low/high quality studies). ***Studies that adjusted for smoking:*** *1st trimester* (4 cohort studies; 507,286 births). Pooled ES = -1.43 (-4.77 to1.92) I^2=0.0% -low, p=0.964 *2nd trimester* (4 cohort studies; 507,286 births). Pooled ES = -6.50 (-13.85 to 0.85) I^2=68.2% -moderate, p=0.024 *3rd trimester* (5 cohort studies; 913,913 births). Pooled ES = -5.11 (-8.32 to -1.89) I^2=0.0% -low, p=0.704 ***Studies that did not adjust for smoking:***	trimester and sources of heterogeneity between studies and centers should be further explored. Our findings have substantial public health implications as reduced BW, although relatively small, is a risk factor for numerous adverse health effects early in life.'	"Although we realized that the countries where studies were conducted and the study design might also be sources of heterogeneity, they were not analyzed in the review due to the limited number of studies conducted in different countries. Though we recognized that several sensitivity analyses were conducted in relation to race or other factors, stratified analyses were not performed based on these categories due to the limited number of studies, particularly when divided by exposure period. We also aware that the use of effect estimates based on associations with ambient levels of pollutants as a surrogate for personal exposure levels may have resulted some exposure misclassification. Other limitation includes the fact that none of the included studies provided the

			PTB per 10µg/m3 of PM10 ***Entire pregnancy*** (2 studies: 1 each cohort and case-control; 9,294 births). Pooled OR = 1.24 (95% CI, 1.03 to1.45) I^2=0.0% -No, p=0.960 **Publication bias** "Did not detect a statistically significant publication bias based on the Egger's test (p=0.181 for PM10; p=0.241 for PM2.5) or by using contour-enhanced funnel plot. The funnel plot revealed that studies were missing in areas of higher statistical significance, suggesting that asymmetry may be more likely to be due to factors other than publication bias, such as variable study quality."	*1st trimester* (6 cohort studies; 3,836,556 births). Pooled ES = -3.31 (-6.45 to -0.18), I^2=81.1%-high, p=0.000 *2nd trimester* (6 cohort studies; 3,836,556 births). Pooled ES = -1.24 (-1.99 to -0.50), I^2=0.00% -low, p=0.603 *3rd trimester* (7 cohort studies; 40,149,12 births). Pooled ES = 1.36 (-4.90 to 7.63), I^2=94.1%-high, p=0.000 ***For relatively better-quality studies*** (NB: either un/adjusted smoking) *Entire pregnancy* (5 cohort studies; 630,250 births). Pooled ES = -10.59 (-13.24 to -7.94), I^2=0.0% -low, p=0.939. *1st trimester* (5 cohort studies; 686,746 births). Pooled ES = -2.16 (-5.40 to 1.09), I^2=0.0% No, p=0.500 *2nd trimester* (5 cohort studies; 686,746 births). Pooled ES = -5.95 (-12.19 to 0.29), I^2=57.8% -moderate, p=0.050 *3rd trimester* (6 cohort studies; 865102 births). Pooled ES = -5.23 (-10.35 to -0.12), I^2=49.5% -moderate, p=0.078 ***For relatively low-quality studies***		precise information on the timing of smoking during pregnancy."

				Entire pregnancy (4 cohort studies; 4,904,584 births). Pooled ES = -2.86 (-12.35 to 6.64), I^2=89.9% -high, p=0.000 *1st trimester* (5 cohort studies; 3,657,096 births). Pooled ES = -2.82 (-5.96 to 0.32), I^2=83.2% -high, p=0.000 *2nd trimester* (5 cohort studies; 3,657,096 births). Pooled ES = -1.24 (-1.98 to -0.49), I^2=0.0% -low, p=0.485 *3rd trimester* (6 cohort studies; 4,063,723 births). Pooled ES = 0.90 (-5.50 to 7.29), I^2=94.6% -high, p=0.000 **PTB per 10µg/m3 of PM10 (either un/adjusted for smoking)** *1st trimester* (8 cohort studies; 1,308,263 births). Pooled OR= 0.98 (0.94 to 1.03), I^2=72.6% -high p=0.001 *2nd trimester* (4 cohort studies; 1024360 births). Pooled OR= 0.97 (0.95 to 0.99), I^2=0.0% -No p=0.601 *3rd trimester* (7 cohort studies; 1,273,558 births). Pooled OR= 1.03 (1.01 to 1.05), I^2=27.1% -low p=0.221 **PTB per 10µg/m3 of PM10 (*Studies that adjusted for smoking)***		

				1st trimester (4 cohort studies; 264,672 births). Pooled OR = 0.99 (0.92 to 1.07), I^2=41.6% -moderate, p=0.162 *2nd trimester* (1 cohort study; 8,969 births). OR = 1.10 (0.65 to 1.56), I^2=NA p=NA *3rd trimester* (3 cohort studies; 229,967 births). Pooled OR =0.97 (0.86 to 1.08), I^2=57.9% -moderate, p=0.093 **PTB per 10µg/m3 of PM10 (*Studies that did not adjusted for smoking)*** *Entire pregnancy* (1 cohort study; 28,200 births). OR = 1.19 (95% CI, 0.80 to 1.58) I^2=NA, p=NA *1st trimester* (4 cohort studies; 1,043,591 births). Pooled OR =0.98 (0.91 to 1.05), I^2=74.4% -moderate, p=0.008 *2nd trimester* (3 cohort studies; 1,015,391 births) Pooled OR =0.97(0.95 to 0.99), I^2=0.0% -moderate, p=0.466 *3rd trimester* (4 cohort studies; 1,043,591births) Pooled OR =1.04(1.02 to 1.06), I^2=0.0% -moderate, p=0.449 **PTB per 10µg/m3 of PM10 by study quality** ***For relatively better-quality studies*** *Entire pregnancy* (1 case-control; 325births) OR =1.24 (1.02 to 1.46), I^2=NA, p=NA *Overall risk*		

				(6studies; 5 cohort and 1 case-control; 1,269,905 births) Pooled OR = 1.00 (0.97 to 1.02), I^2=77.6% -high p=0.000 *1st trimester* (5 cohort studies; 1,269,580 births) Pooled OR =0.98 (0.94 to 1.02), I^2=73.0% -moderate, p=0.005 *2nd trimester* (2 cohort studies; 1,013,877 births) Pooled OR =0.97 (0.94 to 0.99), I^2=0.0% -No, p=0.394 *3rd trimester* (4 cohort studies; 1,234,875 births). Pooled OR =1.03(1.00 to 1.06), I^2=57.2% -moderate, p=0.072 ***For relatively low-quality studies*** *Entire pregnancy* (2 cohort studies; 37,169 births). Pooled OR =1.20 (0.85 to 1.54), I^2=57.2% -moderate, p=0.072 *Overall risk* (4 cohort studies; 420,783 births). Pooled OR =1.00 (0.98 to 1.02), I^2=41.6% -low, p=0.057 *1st trimester* (4 cohort studies; 420,783 births). Pooled OR =1.01 (0.91 to 1.11), I^2=71.1% -moderate, p=0.015 *2nd trimester* (3 cohort studies; 392,583 births). Pooled OR =1.00 (0.98 to 1.01), I^2=0.0% -low, p=0.891 *3rd trimester* (4 cohort studies; 420,783 births). Pooled OR =1.02 (1.00 to 1.04), I^2=0.0% -low, p=0.566		

				3rd trimester or entire pregnancy by smoking status *Smoking adjusted* (4 studies: 3 cohort and 1 case-control; 230,292 births). Pooled OR =1.01 (0.90 to 1.13), I^2=64.4% -moderate, p=0.038 *Smoking unadjusted* (5 cohort studies; 1,557,554 births). Pooled OR =1.03 (1.01 to 1.05), I^2=33.3% -low, p=0.200 *Overall risk* (9 studies; 8 cohort and 1 case-control;1,655,983 births); 1.03 (1.01 to 1.05), I^2=44.6% -low, p=0.071 **Sensitivity Analyses** "With some noted exception, overall, we observed that meta-analysis estimates were stable, excluding a particular study did not change the summary point estimates much.		
19. Zhu (Zhu et al., 2015) 28/08/2014 [6, all China]	PM2.5	BW, LBW, PTB, SGA, and stillbirth	**BW reduction per 10µg/m3 of PM2.5 for entire pregnancy** 12 cohort studies; 7,388,985 births) RE pooled ES = -14.58 (-19.31 to -9.86) I^2= 86.8%- high p= 0.000 **LBW per 10µg/m3 of PM2.5 for entire pregnancy** 6 cohort studies; 5,691,348 births) FE pooled OR = 1.05 (1.02 to 1.07) I^2= 39.7%- low p= 0.141	**BW reduction per 10µg/m3 of PM2.5 for by trimester** *1st trimester* 7 cohort studies; 5,153,167 births. RE pooled ES = -6.63 (-13.65 to -0.39) I^2= 82.1%- high p= 0.000 *2nd trimester* 5 cohort studies; 4,742,687 births. RE pooled ES = -8.00(-14.52 to -1.48) I^2= 84.6%- high p= 0.000 *3rd trimester* 7 cohort studies; 5,153,167 births. RE pooled ES = -14.91 (-21.73 to -8.09) I^2= 86.3%- high	Extract from the discussion or conclusion: Socioeconomic status should be consistently adjusted in the future and other factors. Further explore the difference in effects by different exposure periods with consistency of study design methods, exposure assessment, and	**Limitations** 'We found a high or moderate degree of heterogeneity across some gestational exposure periods. We had not conceived the studies with other exposure periods (weeks and months, etc.) for the limited quantity of related studies. Our study was also confined to effect estimates on constituent of PM2.5'

			PTB per 10µg/m3 of PM2.5 for entire pregnancy 8 cohort studies; 1,764,632 births) RE pooled OR = 1.10 (1.03 to 1.18) I^2= 52.0%- moderate p= 0.042 **SGA per 10µg/m3 of PM2.5 for entire pregnancy** 6 cohort studies; 1,515,887 births. RE pooled OR = 1.15 (1.10 to 1.20) I^2= 0.0%- No p= 0.877 **Stillbirth per 10µg/m3 of PM2.5 for entire pregnancy** 1 cohort study by Faiz et al., 2012 (343,077 births in New Jersey, USA) OR= 1.18 (0.69 to 2.04) **Publication bias** No evidence of publication bias based on Begg's funnel plot and Egger's test, p>0.05	p= 0.000 **PTB per 10µg/m3 of PM2.5 by trimester** *1st trimester* 6 cohort studies; 743,647 births. RE pooled OR = 0.96 (0.77 to 1.21) I^2= 87.2%- high p= 0.000 *2nd trimester* 3 cohort studies; 598,606 births. RE pooled OR = 0.90 (0.79 to 1.03) I^2= 0.0%- No p= 0.700 *3rd trimester* 6 cohort studies; 1,240,212 births. RE pooled OR = 0.97 (0.89 to 1.05) I^2= 31.4%- low p= 0.200 **SGA per 10µg/m3 of PM2.5 for by trimester** *1st trimester* 6 cohort studies; 1,740,763 births. RE pooled OR = 1.07 (1.05 to 1.10) I^2= 5.0%- low p= 0.385 *2nd trimester* 5 cohort studies; 1,706,058 births. RE pooled OR = 1.06 (1.02 to 1.10) I^2= 58.1%- moderate p= 0.049 *3rd trimester* 5 cohort studies; 1,706,058 births. RE pooled OR = 1.06 (1.04 to 1.08) I^2= 13.4%- low p= 0.329 **Stillbirth per 10µg/m3 of PM2.5 by trimester** *1st trimester*	adjustment for factors. Further research studies are needed to evaluate pathophysiological mechanisms by considering alternative exposure metrics. Review of pooled effects of chemical constituents might be doable in near future. A lot of studies on different trimesters are also needed to explore the sensitive exposure window of the risk of SGA. Pregnant women need to take effective measures to reduce PM2.5 exposure.	

				1 cohort study by Faiz et al., 2012 (343,077 births in New Jersey, USA OR= 1.42 (0.90 to 2.20) *2nd trimester* 1 cohort study by Faiz et al., 2012 (343,077 births in New Jersey, USA OR= 1.39 (0.90 to 2.12) *3rd trimester* 1 cohort study by Faiz et al., 2012 (343,077 births in New Jersey, USA OR= 1.21 (0.55 to 2.66) **Sensitivity analysis** 'After removing each study sequentially, statistically similar results were obtained, indicating the stability of our meta-analysis.' **Meta-regression** Of the characteristics of the studies we evaluated, only meta-regression for study design method and exposure assessment showed significant heterogeneity between studies in the reported PM2.5-PTB associations. However, the sources of heterogeneity in the change of birth weight could partly be explained by adjusted or unadjusted of socioeconomic status because meta-regression for this showed significant heterogeneity		
20. Stieb (Stieb et al., 2012) 21/06/2012 [4, all Canada]	PM 10, PM2.5, NO2, SO2, CO, O3.	BW/LBW/VLBW, PTB, SGA/IUGR	**BW:** **BW per 10µg/m3 of PM2.5 for entire pregnancy** (7 cohort studies; 4,271,411 births) Pooled ES= -23.44 (95% CI = -45.50 to -1.38) I^2 =94.7%-high with p=0.000 **BW per 20µg/m3 of PM10**	**Trimester-specific** ***BW:*** ***BW per 10µg/m3 of PM2.5 for*** *1st trimester* (4 cohort studies; 3,637,501 births) Pooled ES= -0.30 (-9.85 to 9.25) I^2 =37.3%-low with p=0.188 *2nd trimester* (4 cohort studies; 3,634,129 births) Pooled ES= -14.66 (-34.01 to 4.70)	Variation in effects by exposure period and sources of heterogeneity between studies/centers should be further explored, potentially in coordinated multi-	**NB**: No specific section but extracts from the discussion. **Strengths** Included 'increased number of studies (62 compared to 9–41 in previous reviews).' 'Evaluated effects by gestational period,

			for entire pregnancy (7 cohort studies; 3,932,746 births) Pooled ES= -16.77 (95% CI = -20.23 to -13.31) I^2 =15.9%-low with p=0.308. **BW per 1ppm of CO for entire pregnancy** (4 cohort studies; 3,702,544 births) Pooled ES= -11.40 (95% CI = -29.70 to 6.90) I^2 =95.4%-high with p=0.000 **BW per 20ppb of NO2 for entire pregnancy** (10 studies: 9 cohort and 1 ecologic; 3,780,571 births) Pooled ES= -28.13 (95% CI = -44.81 to -11.45) I^2 =84.7%-high with p=0.000 **BW per 20ppb of O3 for entire pregnancy** (4 cohort studies: 3,370,657 births) Pooled ES= -10.01 (95% CI = -32.39 to 12.37) I^2 =80.9%-high with p=0.001 **BW per 5ppb of SO2 for entire pregnancy** (3 studies: 2 cohort and 1 ecologic; 3,718,863 births) Pooled ES= 7.30 (95% CI = -7.69 to 22.29) I^2 =79.5%-high with p=0.008 **LBW:**	I^2 =74.5%-moderate with p=0.008 *3rd trimester* (4 cohort studies; 3,637,501 births) Pooled ES= -16.05 (-37.43 to 1.34) I^2 =85.6%-low with p=0.000 ***BW per 20µg/m3 of PM10 f*or** *1st trimester* (10 cohort studies; 4,505,769 births.) Pooled ES= -3.92 (-8.97 to 1.13) I^2 =67.2%-moderate with p=0.001 *2nd trimester* (10 cohort studies; 4,505,769 births.) Pooled ES= -3.40 (-7.22 to 0.43) I^2 =41.2%-moderate with p=0.083 *3rd trimester* (10 cohort studies; 4,505,769 births.) Pooled ES= -4.20 (-14.27 to 5.86) I^2 =93.3%-high with p=0.000 **BW per 1ppm of CO for** *1st trimester* (8 cohort studies; 4,576,045 births) Pooled ES= -1.47 (-7.84 to 4.90) I^2 =94.5%-high with p=0.000 *2nd trimester* (7 cohort studies; 4,299,282 births) Pooled ES= 1.71 (0.76 to 2.67) I^2 =0.0%-No with p=0.445 ***3rd** trimester* (7 cohort studies; 4,299,282 births) Pooled ES= -0.90 (-7.85 to 6.04) I^2 =91.1%-high with p=0.000 **BW per 20ppb of NO2 for** *1st trimester* (11 cohort studies; 4,259,729 births) Pooled ES= -4.18 (-19.18 to 10.82)	center analyses. Future research priorities also include consideration of alternative exposure metrics and evaluation of critical exposure windows and pathophysiological mechanisms.	estimated continuous effects from categorical exposures, quantified heterogeneity and conducted meta-regression to examine the influence of certain study characteristics on effect sizes, as well as conducting numerous sensitivity analyses, for instance in relation to alternative methods of exposure classification.' **Limitations** Evidence of publication bias based on funnel plot asymmetry for PM10 and ozone and low birth weight despite obtaining additional unpublished results from study authors when possible. A high degree of heterogeneity for some exposure periods.

			LBW per 10µg/m3 of PM2.5 for entire pregnancy (6 studies: 5 cohort and 1 case-control; 4,160,105 births). Pooled OR= 1.05 (95% CI = 0.99 to1.12) I^2 =85.5%-high with p=0.000 **LBW per 20µg/m3 of PM10 for entire pregnancy** (14 cohort studies, one study with 7 city-specific estimates counted 7 times; 4,419,929 births) Pooled OR= 1.10 (95% CI = 1.05 to1.15) I^2 =68.4%-moderate with p=0.000 **LBW per 1ppm of CO for entire pregnancy** (6 cohort studies; 4,543,308 births) Pooled OR= 1.07 (95% CI = 1.02 to1.12) I^2 =38.2%-low with p=0.152 **LBW per 20ppb of NO2 for entire pregnancy** (10 studies; 7 cohort, 1 case-control, 1 ecological study with two results; 4,211,351 births) Pooled OR= 1.05 (95% CI = 1.00 to1.09) I^2 =78.4%-high with p=0.000	I^2 =90.0%-high with p=0.000 *2nd trimester* (9 cohort studies; 3,979,113 births) Pooled ES= 0.85 (-1.27 to 2.97) I^2 =0.0%-No with p=0.741 *3rd trimester* (10 cohort studies; 3,982,966 births) Pooled ES= -7.89 (-29.04 to 13.25) I^2 =93.5%-high with p=0.000 **BW per 20ppb of O3 for** *1st trimester* (8 cohort studies: 4,325,899 births) Pooled ES= 2.29 (-5.09 to 9.67) I^2 =80.6%-high with p=0.000 *2nd trimester* (8 cohort studies: 4,325,899 births) Pooled ES= -10.95 (-18.75 to -3.14) I^2 =77.2%-high with p=0.000 *3rd trimester* (8 cohort studies: 4,325,899 births) Pooled ES= -2.79 (-7.22 to 1.64) I^2 =80.0%-high with p=0.000. **BW per 5ppb of SO2 for** *1st trimester* (6 cohort studies; 4,098,747 births) Pooled ES= -7.57 (-21.09 to 5.95) I^2 =95.0%-high with p=0.000 *2nd trimester* (4 cohort studies; 3,808,425 births) Pooled ES= 4.64 (-4.59 to 13.87) I^2 =65.6%-moderate with p=0.033 *3rd trimester* (5 cohort studies; 3,883,096 births) Pooled ES= 7.61 (-2.38 to 17.59) I^2 =93.1%-high with p=0.000 **LBW:**		

			LBW per 20ppb of O3 for entire pregnancy (3 cohort studies; 3,377,984 births) Pooled OR= 1.01 (95% CI = 0.82 to1.25) I^2 =24.9%-low with p=0.264 **LBW per 5ppb of SO2 for entire pregnancy** (7 studies; 4 cohort, 2 ecological with two results from one of the ecological; 4,400,175 births) Pooled OR= 1.03 (95% CI = 1.02 to1.05) I^2 =0.0%-No with p=0.434 **PTB:** **PTB per 10µg/m3 of PM2.5 for entire pregnancy** (4 studies; 3 cohort and 1 case-control; 197,980 births) Pooled OR= 1.16 (95% CI = 1.07 to1.26) I^2 =17.0%-low with p=0.306 **PTB per 20µg/m3 of PM10 for entire pregnancy** (3 studies; 2 cohort and 1 case-control; 98,774 births) Pooled OR= 1.35 (95% CI = 0.97 to1.90) I^2 =16.9%-low with p=0.300 **PTB per 1ppm of CO for entire pregnancy** (2 studies; 1 cohort and I case-control; 112,941 births)	**LBW per 10µg/m3 of PM2.5 for** Trimester-specifics were not available. **LBW per 20µg/m3 of PM10 for** *1st trimester* (7 cohort studies; 1,153,736 births) Pooled OR= 1.03 (0.95 to1.11) I^2 =41.6%-low with p=0.114 *2nd trimester* (7 cohort studies; 1,153,736 births) Pooled OR= 1.02 (0.96 to1.09) I^2 =22.6%-low with p=0.256 *3rd trimester* (7 cohort studies; 1,153,736 births) Pooled OR= 1.01 (0.97 to1.06) I^2 =12.8%-low with p=0.332 **LBW per 1ppm of CO for** *1st trimester* (5 cohort studies; 1,129,363 births) Pooled OR= 1.05 (1.01 to1.09) I^2 =0.0%-No with p=0.644 *2nd trimester* (4 cohort studies; 900,278 births) Pooled OR= 1.07 (1.03 to1.12) I^2 =0.0%-No with p=0.666 *3rd trimester* (5 cohort studies; 1,129,363 births) Pooled OR= 1.01 (0.90 to1.14) I^2 =86.3%-high with p=0.000 **LBW per 20ppb of NO2 for** *1st trimester* (5 cohort studies; 1,043,794 births) Pooled OR= 1.03 (0.99 to1.06) I^2 =0.0%-No with p=0.905 *2nd trimester* (4 cohort studies; 814,709 births) Pooled OR= 1.04 (1.01 to1.08) I^2 =0.0%-No with p=0.863 *3rd trimester*		

			Pooled OR= 1.05 (95% CI = 0.95 to1.17) I^2 =0.0%-No with p=0.589 **PTB per 20ppb of NO2 for entire pregnancy** (5 studies; 4 cohort and 1 ecological; 162,815 births) Pooled OR= 1.16 (95% CI = 0.83 to1.63) I^2 =53.3%-moderate with p=0.073 **PTB per 20ppb of O3 for entire pregnancy** (2 cohort studies; 98,449 births) Pooled OR= 1.92 (95% CI = 0.38 to 9.76) I^2 =88.5%-high with p=0.003 **PTB per 5ppb of SO2** NB: No pooled estimates due to 2 or fewer estimates as stated by authors. **Publication bias** 'There was evidence of funnel plot asymmetry, indicative of publication bias, in the case of PM10 and ozone and LBW, for which there was a greater than expected number of positive than negative effect sizes among small, imprecise studies with larger standard errors. The Begg's test p-value was 0.04 for PM10 and the p-value on Egger's bias	(5 cohort studies; 1,043,794 births) Pooled OR= 0.98 (0.87 to1.10) I^2 =69.7%-moderate with p=0.010 **LBW per 20ppb of O3 for** *1st trimester* (5 cohort studies; 1,002,748 births) Pooled OR= 0.99 (0.91 to1.08) I^2 =0.0%- No with p=0.817 *2nd trimester* (3 cohort studies; 496,900 births) Pooled OR= 0.95 (0.79 to1.15) I^2 =33.5%-low with p=0.222 *3rd trimester* (5 cohort studies; 1,002,748 births) Pooled OR= 1.03 (0.84 to1.26) I^2 =75.6%-high with p=0.003 **LBW per 5ppb of SO2 for** *1st trimester* (5 cohort studies; 889,204 births) Pooled OR= 1.02 (0.99 to1.04) I^2 =58.3%-moderate with p=0.048 *2nd trimester* (4 cohort studies; 660,119 births) Pooled OR= 1.01 (0.98 to1.04) I^2 =40.6%-low with p=0.168 *3rd trimester* (6 cohort studies; 963,875 births) Pooled OR= 0.99 (0.97 to1.02) I^2 =59.3%-moderate with p=0.031 **PTB**: **PTB per 10µg/m3 of PM2.5 for** *1st trimester* (4 studies; 3 cohort and 1 case-control 589,100 births) Pooled OR= 0.85 (0.60 to1.20)		

			coefficient was 0.03 for ozone.'	I^2 =94.4%-high with p=0.000 *2nd trimester* (1 cohort study; 418,715 births) OR= 0.66 (0.57 to 0.77) I^2 = NA, p= NA *3rd trimester* (4 studies; 3 cohort and 1 case-control 589,100 births) Pooled OR= 1.05 (0.98 to1.13) I^2 =33.2%-low with p=0.213 **PTB per 20µg/m3 of PM10 for** *1st trimester* (6 cohort studies; 1,043,954 births) Pooled OR= 0.97 (0.87 to1.07) I^2 =85.3%-high with p=0.000 *2nd trimester* (3 cohort studies; 794,396 births) Pooled OR= 0.95 (0.91 to 0.99) I^2 =0.0%-No with p=0.461 *3rd trimester* (6 cohort studies; 1,043,954 births) Pooled OR= 1.06 (1.03 to 1.11) I^2 =20.1%-low with p=0.282 **PTB per 1ppm of CO for** *1st trimester* (5 studies; 4 cohort and 1 case-control; 911,850 births) Pooled OR= 0.96 (0.88 to1.05) I^2 =92.4%-high with p=0.000 *2nd trimester* (1 cohort study: 418,715 births) OR= 1.03 (0.99 to1.07) I^2 =NA, p=NA *3rd trimester* (5 studies; 4 cohort and 1 case-control; 911,850 births) Pooled OR= 1.04 (1.02 to1.06) I^2 =0.0%-No with p=0.569		

				PTB per 20ppb of NO2 for *1st trimester* (6 cohort studies; 807,681 births) Pooled OR= 0.87 (0.64 to1.17) I^2 =89.1%-high with p=0.000 *2nd trimester* (2 cohort studies; 422,703 births) Pooled OR= 1.03 (0.77 to1.39) I^2 =21.6%-low with p=0.259 *3rd trimester* (6 cohort studies; 807,681 births) Pooled OR= 1.06 (0.96 to1.18) I^2 =19.5%-low with p=0.286 **PTB per 20ppb of O3 for** *1st trimester* (4 cohort studies; 799,840 births) Pooled OR= 1.22 (0.91 to 1.64) I^2 =89.8%-high with p=0.000 *2nd trimester* (1 cohort study; 418,715 births) OR= 0.94 (0.88 to 1.00) I^2 =NA, p=NA *3rd trimester* (4 cohort studies; 799,840 births) Pooled OR= 0.97 (0.86 to 1.10) I^2 =44.2%-low with p=0.146 **Sensitivity analyses** Pooled estimates were generally insensitive to the inclusion of additional results based on term IUGR and SGA at term to studies of LBW. Pooled estimates were not sensitive to differences between actual and estimated odds ratios (using ratios and relative risks from one study (Wilhelm and Ritz, 2005) Assessed the validity of deriving effect estimates expressed in relation to		

				continuous pollutant concentrations from those based on discrete exposure categories and the results were not sensitive to inclusion of these additional values. Substituted effect estimates based on refined exposure classification in the place of base estimates; results were not sensitive to these substitutions. Conducted meta-regression of estimates of change in birth weight against explanatory variables for control for smoking, alcohol consumption, education, socioeconomic status, as well as mean pollutant concentration and whether studies were restricted to singleton or term pregnancies. Analyses were confined to birth weight effects based on entire pregnancy exposure for PM10, PM2.5 and NO2 due to sufficient number of effect (n=7, 8 and 10, respectively). Only term pregnancy was consistently associated with reduction of effect size for the three pollutants. Control for socioeconomic status was associated with reduced effect size in studies of PM10 only.		
21. Sapkota (Sapkota et al., 2010) 23/11/2010 [5, all USA]	PM2.5, PM10	LBW/TLBW, PTB	**LBW per 10μg/m3 of PM2.5 for entire pregnancy** (4 studies; 831,042 births.) OR= 1.09 (95% CI = 0.90 to 1.32) I^2 =57.4%-moderate with p=0.071 **LBW per 10μg/m3 of PM10 for entire pregnancy** (11 studies; 1,935,404 births). OR= 1.02 (95% CI = 0.99 to 1.05)	***By trimester*** **LBW per 10μg/m3 of PM2.5** NA due to insufficient study **LBW per 10μg/m3 of PM10** *1st trimester* (5 studies) OR=1.00 (0.97 to 1.03) *3rd trimester* (7 studies) OR=1.00 (0.99 to 1.01) **PTB per 10μg/m3 of PM2.5**	'Studies may need to assess outcome misclassification of gestational age and exposure at different developmental stages by matching or stratifying on gestational age and assessing exposures during	**Strength** 'First to present results from a systematic review of the literature and meta-analysis of studies published to date providing quantitative estimates of association between exposure to PM (PM10 and PM2.5) and two major adverse birth

			I^2 =54.5%-moderate with p=0.015 **PTB per 10µg/m3 of PM2.5 for entire pregnancy** (6 studies; 517,760 births) OR= 1.15 (1.14 to 1.16) I^2 =0.1%-low with p=0.416 **PTB per 10µg/m3 of PM10 for entire pregnancy** (8 studies; 1,047,489 births) OR= 1.02 (0.99 to 1.04) I^2 =73.0%-high with p=0.001 **NB**: Stated in method as RE and FE but no indication which was used for each in the forest plot or the tables. **Publication bias** 'There was no significant publication bias for both outcomes according to both tests (p>0.05 for both Begg's and Egger's test for bias).'	*1st trimester* (4 studies) OR=1.04 (0.73 to 1.34) *3rd trimester* (3 studies) OR=1.07 (1.00 to 1.15) **PTB per 10µg/m3 of PM10** *1st trimester* (4 studies) OR=1.02 (0.97 to 1.06) *3rd trimester* (5 studies) OR=1.02 (1.01 to 1.03) **NB**: I^2 not provided here. Forest plot unavailable to determine sample size. **Leave-one-out sensitivity analyses** Removing a particular study did not change the summary point estimates much with some noted exceptions. For PM10 exposure and LBW, removing the study by Maisonet et al. (2001) results in a statistically significant increase in risk. Likewise, for PM10 and PTB, when Ritz et al. (2000) was removed, the observed association was no longer formally statistically significant.	specific gestational windows (such as <25, 25–30, 30–35, and 35–37 weeks). Future studies need to also pay more attention to the likely multifactorial nature of these adverse birth events. Future epidemiological studies of air pollution and birth outcomes should consider mixture of chemical substances and geographical locations. It would be desirable to consider additional studies conducted in the low-resource countries in which levels of particulate pollution are much higher than those in the currently available studies when quantifying the burden of	outcomes: LBW and PTB.' **Limitations** 'While our meta-analysis further increased the statistical power to estimate even small increases in risk, this increased precision does, however, not exclude the possibility of greater residual confounding bias not reflected in our standard measures of uncertainty (CI) since birth record studies are typically limited to routinely recorded information and limits our ability to control for confounding by maternal or fetal risk factors.'

					disease related to particles and adverse birth outcome worldwide. However, such studies would require resources in routine air monitoring and health and risk factor surveillance that likely may not be available in low-resource countries for some time to come. Yet, this should not preclude inferences concerning health effects and implementing policies that may help to alleviate these important public health problems	

Note: NO_2, Nitrogen dioxide; CO, Carbon monoxide; O_3, Ozone; SO_2, Sulphur dioxide; $PM_{2.5}$, particulate matter at aerodynamic diameter ≤ 2.5μm; $PM_{10,}$ particulate matter at aerodynamic diameter ≤ 10μm; PTB, preterm birth; BW, birth weight; LBW, low birth weight; TLBW, term low birth weight; VLBW, very low birth weight; SGA, small-for-gestational age; IUGR, intrauterine growth retardation; SB, stillbirth; SAB, spontaneous abortion; Db, database; USA, United States of America; UK, United Kingdom; NOS, Newcastle-Ottawa Scale; OHAT, Office of Health Assessment and Translation; AHRQ, Agency for Healthcare Research and Quality; OR, odd ratio; CI, confidence interval; I^2, heterogeneity; FE, fixed effect; RE, random effect; RoB, risk of bias; IQR, interquartile range.

Table S5. Overlaps in the systematic reviews using Corrected Covered Area (CCA)

Review category	Number of times studies appeared in reviews (N)	Number of indexed primary studies (r)	Number of reviews (c)	CCA (%)	Overlap degree
SR	412	211	15	6.8	Moderate
SRMA	575	228	21	7.6	Moderate

Note: SR, systematic reviews without meta-analyses; SRMAs, systematic reviews with meta-analyses

$$CCA = \frac{N-r}{rc-r},$$

where *N* is the sum of the number of included primary studies (the total number of times studies appeared in the reviews) in the umbrella review, *r* is the total number of indexed primary studies *c* is the number of reviews. CCA score ≤ 5% implies slight overlap of primary studies, 6-10% moderate, 11-15% high and >15% very high degrees of overlaps (Pieper et al., 2014)

Table S6. Association between birth weight and particulate matters by race/ethnicity during the entire pregnancy period

Pollutant (incremental units)	**Exposure period**	**Meta-analysis**	**Change in birthweight (g) (95% CI)**	**I^2 (%)**	**Primary studies (n)**	**Total births (N)**	**Consistency, confidence**
$PM_{2.5}$ (10 µg/m^3)	Whites	Uwak (2021)	-32 (-60, -4)	95	7	8,893,539	++, Pe
		Thayamballi (2020)	-16 (-21, -10)	68	5	6,484,085	
	Hispanics	Uwak (2021)	-1 (-23, 22)	85	5	8,525,968	+, Pe
		Thayamballi (2020)	-9 (-16, -3)	92	5	6,484,085	
	Blacks	Uwak (2021)	-27 (-82, 27)	93	5	8,867,779	+, Pe
		Thayamballi (2020)	-22 (-32, -12)	73	4	6,467,392	
	Asians	Thayamballi (2020)	-6 (-21, 9)	95	3	4,918,488	0, Pe
PM_{10} (10 µg/m^3)	Whites	Uwak (2021)	-10 (-12, -8)	0	4	5,461,652	+, Pe
	Blacks	Uwak (2021)	3 (-65, 72)	97	3	5,452,585	0, Pe
	Hispanics	Uwak (2021)	0 (-74, 73)	96	2	5,094,081	0, Pe

Note: CI, Confidence interval; I^2, Heterogeneity; Beta represents change in birth weight in grams; '++' represents significant positive association ; '0' represents contradictory/unclear direction; Pe, probable evidence.

Table S7. Association between small-for-gestational age (SGA) and ambient air pollution

Pollutant (incremental units)	**Exposure period**	**Meta-analysis**	**OR (95% CI)**	**I^2 (%)**	**Primary studies (n)**	**Total births (N)**	**Consistency, confidence**
$PM_{2.5}$ (10 µg/m^3	Entire Pregnancy	Zhang (2016) and Zhu (2015)*	1.15 (1.10, 1.20)	0	6	1,515,887	+, Pe
	Trimester 1	Zhang (2016) and Zhu (2015)	1.07 (1.05, 1.10)	5	6	1,740,763	0, Pe
	Trimester 2	Zhang (2016) and Zhu (2015)	1.06 (1.02, 1.10)	58	5	1,706,058	+, Pe
	Trimester 3	Zhang (2016) and Zhu (2015)	1.06 (1.04, 1.08)	13	5	1,706,058	+, Pe

* Complete duplicated meta-analyses and hence considered as one. Note: OR, odd ratio; CI, confidence intervals; I^2, Heterogeneity; '+' represents less consistent positive association; '0' represents contradictory/unclear direction; Pe, probable evidence.

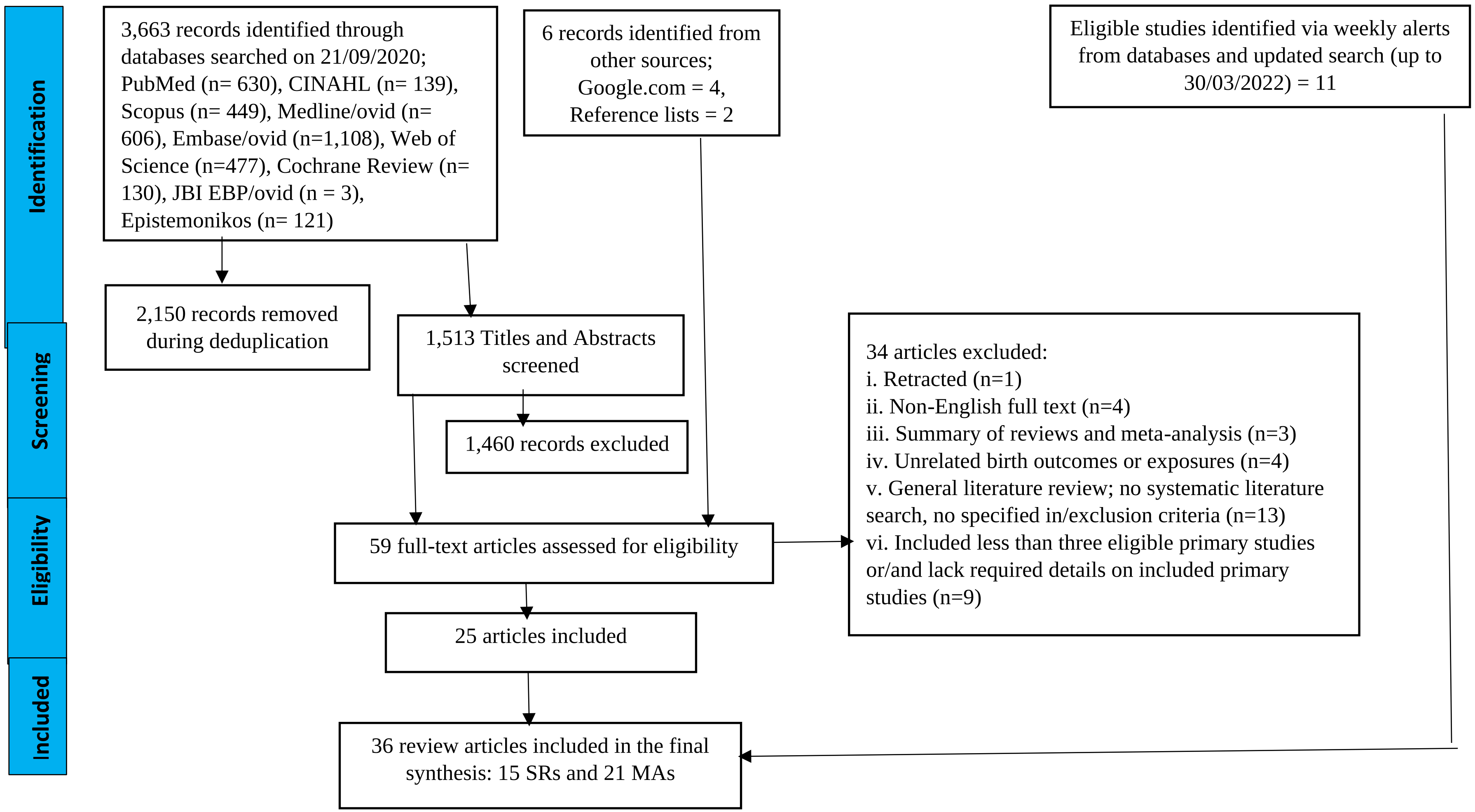

Figure S1. PRISMA flow chart showing the systematic literature search and processes involved in selecting the eligible studies for the umbrella review. Note: PRISMA, Preferred Reporting Items for Systematic reviews and Meta-Analyses; SRs, systematic reviews; MAs, meta-analyses.

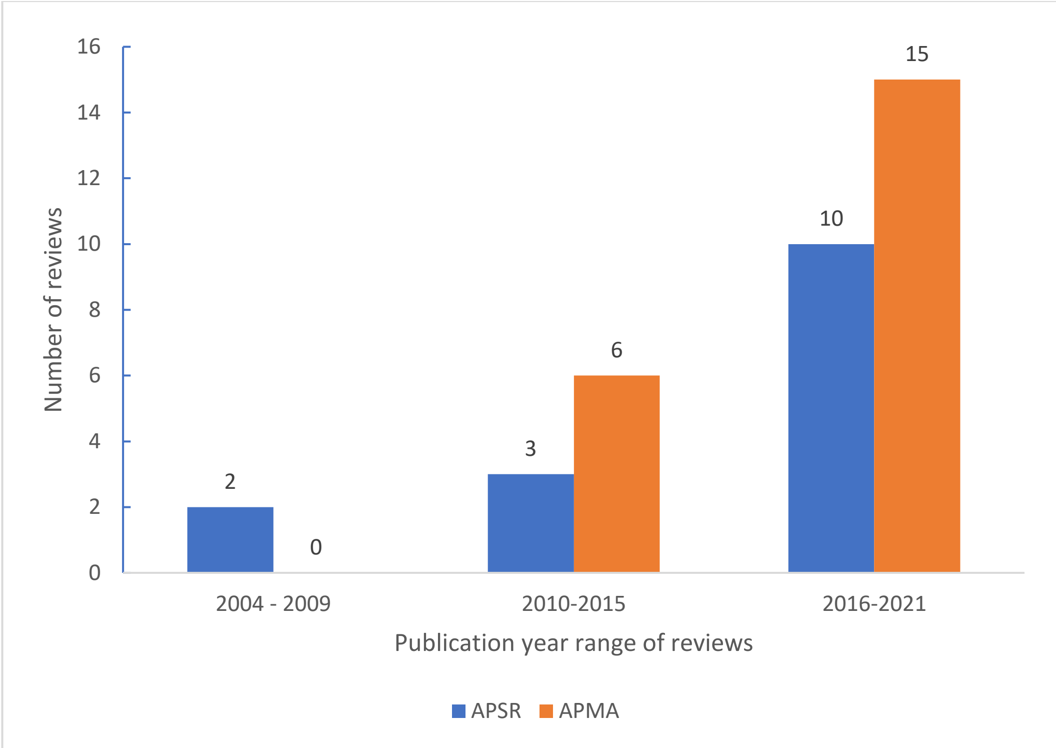

Figure S2. The number of systematic reviews on birth outcomes and air pollution without meta-analysis (APSR) and with meta-analysis (APMA) in five-year intervals.

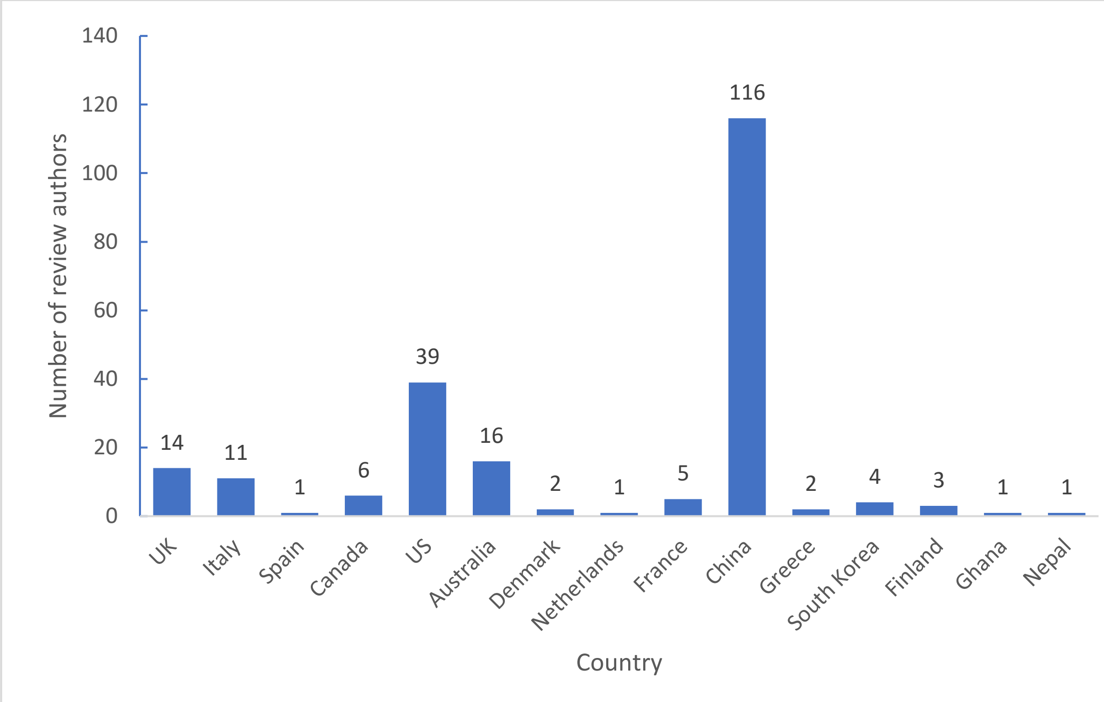

Figure S3. Country of affiliation and the number of reviews authors. A total of 222 authors were counted on the 36 included reviews. Note: Where there were multiple countries of affiliation for a review author on a given review paper, only the first affiliated country was considered, and review authors were counted per review without consideration to an author appearing in more than one review studies. UK, United Kingdom; US, United States.

First author, Year	1. Is the review question clearly and explicitly stated?	2. Were the inclusion criteria appropriate for the review question?	3. Was the search strategy appropriate?	4. Were the sources and resources used to search for studies adequate?[a]	5. Were the criteria for appraising studies appropriate?[b]	6. Was critical appraisal conducted by two or more reviewers independently?	7. Were there methods to minimize errors in data extraction?[c]	8. Were the methods used to combine studies appropriate?	9. Was the likelihood of publication bias assessed?	10. Were recommendations for policy and/or practice supported by the reported data?	11. Were the specific directives for new research appropriate?	Score (max=10)	Overall RoB
Edwards, 2021	Y	Y	Y	Y	Y	Y	Y	Y	NA	Y	Y	10	L
Walter, 2021	Y	Y	Y	Y	Y	Y	N	Y	NA	Y	Y	9	L
Luo, 2021	Y	Y	Y	Y	Y	N	N	Y	NA	Y	Y	8	M
Bekkar, 2020	Y	Y	Y	Y	N	N	N	Y	NA	Y	Y	7	M
Heo, 2019	Y	Y	Y	N	U	N	Y	Y	NA	Y	Y	7	M
Yuan, 2019	Y	Y	Y	N	N	N	N	Y	NA	Y	Y	6	M
Tsoli, 2019	Y	Y	Y	Y	N	N	N	Y	NA	Y	Y	7	M
Grippo, 2018	Y	Y	Y	N	N	N	N	Y	NA	Y	Y	6	M
Westergaard, 2017	Y	Y	Y	Y	N	N	N	Y	NA	Y	Y	7	M
Jacobs, 2017	Y	Y	Y	Y	U	N	N	Y	NA	Y	Y	7	M
Shah, 2011	Y	Y	Y	Y	Y	Y	Y	Y	NA	Y	Y	10	L
Bonzini,2010	Y	Y	Y	N	N	N	N	Y	NA	Y	Y	6	M
Bosetti, 2010	Y	Y	Y	N	N	N	N	Y	NA	Y	Y	6	M

Ghosh, 2007	Y	Y	Y	Y	U	N	N	Y	NA	Y	Y	7	M
Glinianaia, 2004	Y	Y	Y	Y	N	N	Y	Y	NA	Y	Y	8	M
Y	15	15	15	10	4	3	4	15		15	15	**Average score = 7.4**	Average overall RoB
U	0	0	0	0	3	0	0	0		0	0		M
N	0	0	0	5	8	12	11	0		0	0		

Figure S4. Summary of the risk of bias (RoB) assessment with Joanna Briggs Institute (JBI) critical appraisal checklist of the systematic reviews without meta-analysis for ambient air pollution and birth outcomes. (https://jbi-global-wiki.refined.site/space/MANUAL/3283910853/Appendix+10.1+JBI+Critical+Appraisal+Checklist+for+Systematic+reviews+and+Research+Syntheses)

[a]'Yes' if at least two electronic databases were searched

[b]'Yes' if standardised tools were used and results reported for each study, 'Unclear' if stated as done but results were not reported for each study.

[c]'Yes' if data extraction was performed by at least two reviewers independently

Yes (Y)	
Unclear(U)	
No (N)	
Not applicable (NA)	
High (H)	
Moderate (M)	
Low (L)	

First author, Year	1. Is the review question clearly and explicitly stated?	2. Were the inclusion criteria appropriate for the review question?	3. Was the search strategy appropriate?	4. Were the sources and resources used to search for studies adequate?[a]	5. Were the criteria for appraising studies appropriate?[b]	6. Was critical appraisal conducted by two or more reviewers independently?	7. Were there methods to minimize errors in data extraction?[c]	8. Were the methods used to combine studies appropriate?	9. Was the likelihood of publication bias assessed?	10. Were recommendations for policy and/or practice supported by the reported data?	11. Were the specific directives for new research appropriate?	Score (max=11)	Overall RoB
Gong, 2021	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Zhu, 2021	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	10	L
Ju, 2021	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Xie, 2021	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Rappazzo, 2021	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Zhang, 2021	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Uwak,2021	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Simonici, 2020	Y	Y	Y	N	Y	N	Y	Y	N	Y	Y	8	M
Thayamballi, 2020	Y	Y	Y	Y	U	Y	N	Y	N	Y	Y	8	M
Li, 2020	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Ji, 2017	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Liu, 2017	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Li, 2017	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Zhang, 2016	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9	L
Siddika, 2016	Y	Y	Y	Y	U	N	Y	Y	Y	Y	Y	9	L
Sun, 2016	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9	L

Sun, 2015	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Lamichhane, 2015	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	11	L
Zhu, 2015	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9	L
Stieb, 2012	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9	L
Sapkota, 2010	Y	Y	Y	Y	N	N	Y	Y	Y	Y	Y	9	L
Y	21	21	21	20	14	13	20	21	19	21`	21	**Average score = 10.1**	Average overall RoB
U	0	0	0	0	2	0	0	0	0	0	0		
N	0	0	0	1	5	8	1	0	2	0	0		

Figure S5. Summary of the risk of bias (RoB) assessment with Joanna Briggs Institute (JBI) critical appraisal checklist of the systematic reviews with meta-analysis for ambient air pollution and birth outcomes. (https://jbi-global-wiki.refined.site/space/MANUAL/3283910853/Appendix+10.1+JBI+Critical+Appraisal+Checklist+for+Systematic+reviews+and+Research+Syntheses)

[a]'Yes' if at least two electronic databases were searched

[b]'Yes' if standardised tools were used and results reported for each study, 'Unclear' if stated as done but results were not reported for each study.

[c]'Yes' if data extraction was performed by at least two reviewers independently

Yes (Y)	
Unclear(U)	
No (N)	
Not applicable (NA)	
High (H)	
Moderate (M)	
Low (L)	

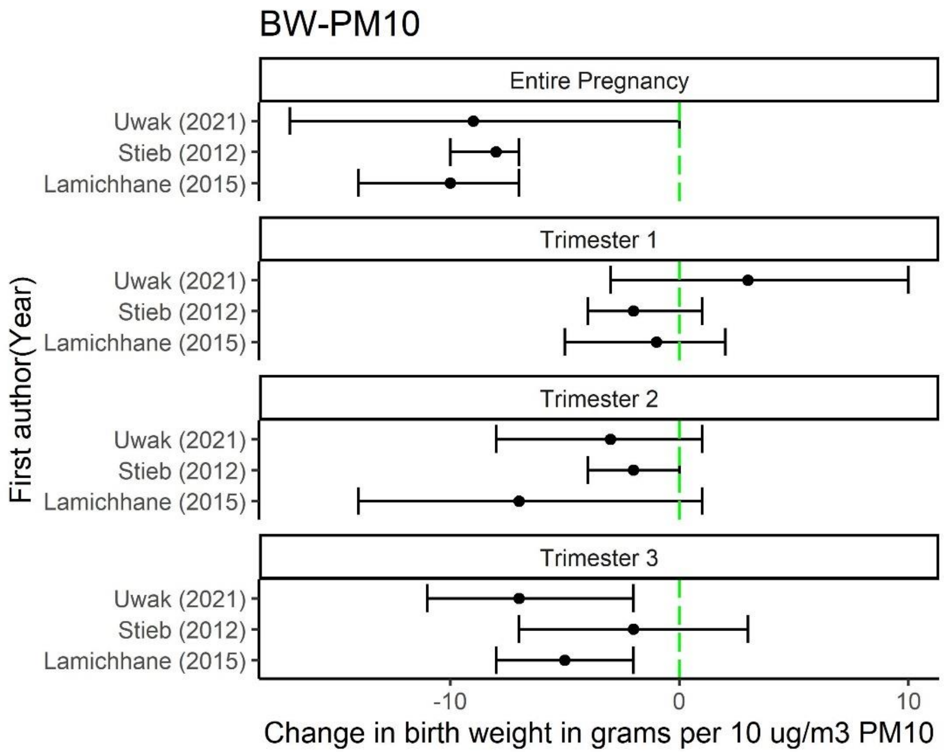

Figure S6. Association between change in birth weight (BW) in grams per 10μg/m^3 PM_{10} increase at different pregnancy periods. Solid points represent point estimates of the individual meta-analysis studies, and the whiskers represent 95% confidence intervals (CIs). The green dotted vertical line represents the reference for no change in birth weight of 0. Note: PM_{10}, particulate matter at aerodynamic diameter ≤ 10μm.

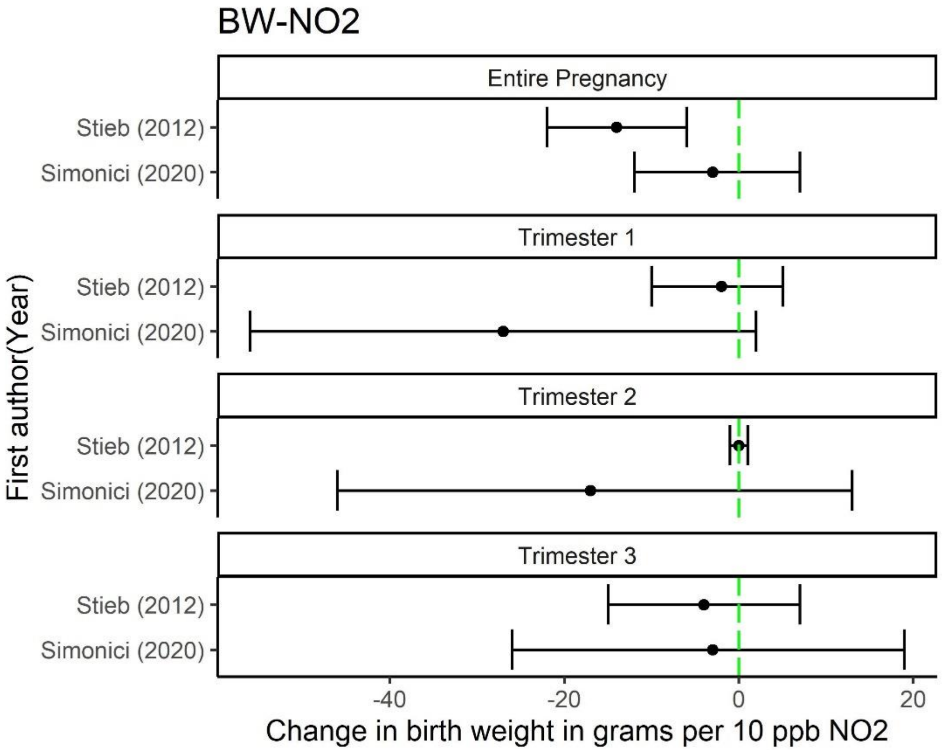

Figure S7. Forest plot of the association between change in birth weight (BW) in grams and Nitrogen dioxide (NO_2) per 10 parts per billion (ppb) increment in NO_2 at different pregnancy periods. Solid points represent point estimates of the meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for no change in birth weight of 0.

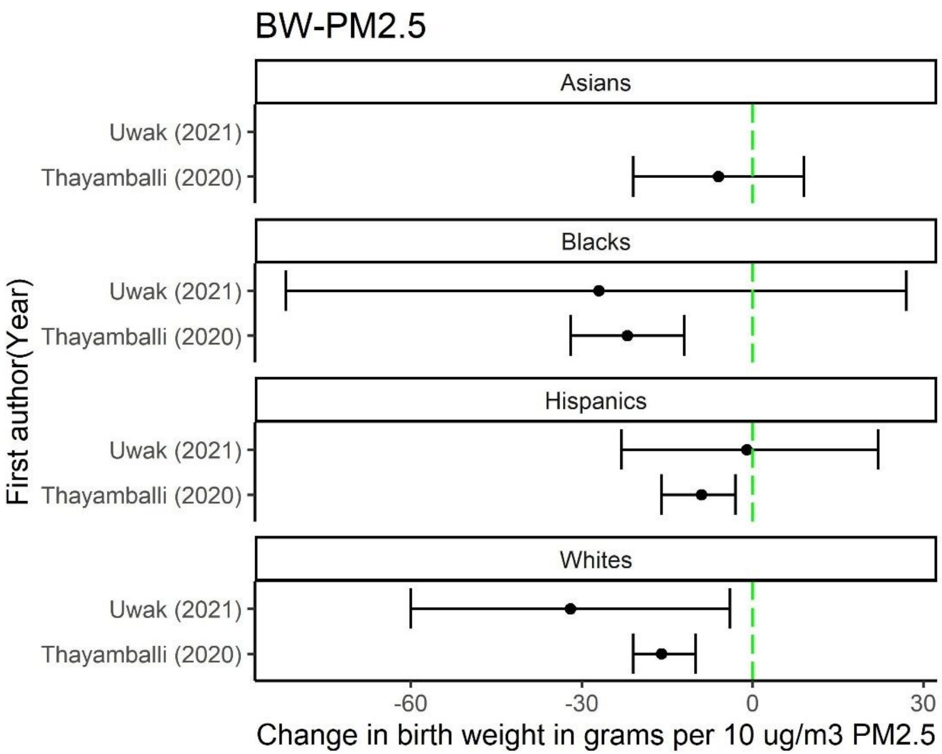

Figure S8. Forest plot of the association between $PM_{2.5}$ increase per 10µg/m^3 and change in birth weight in grams (BW) across entire pregnancy period by race/ethnicity. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for no change in birth weight of 0. Note: $PM_{2.5}$, particulate matter at aerodynamic diameter ≤ 2.5µm.

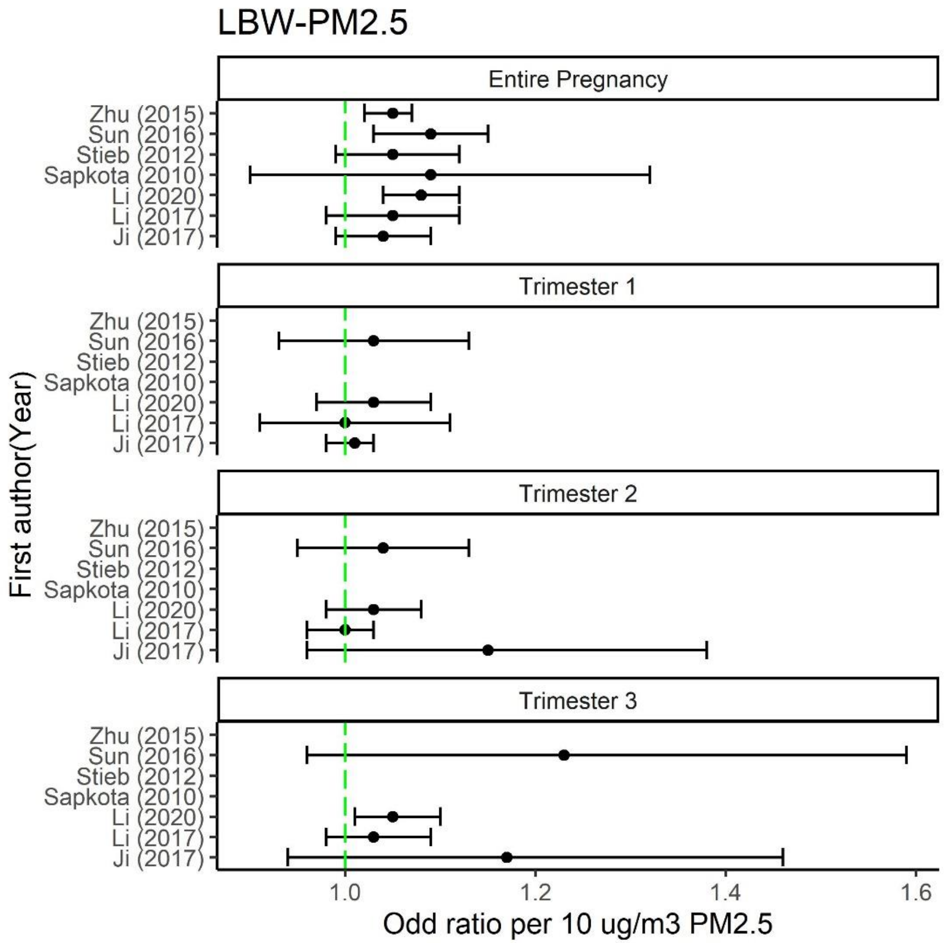

Figure S9. Forest plot of the association between low birth weight (LBW) per 10µg/m^3 $PM_{2.5}$ increase at different pregnancy periods) at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dashed line represents the reference for null association of 1. Note: $PM_{2.5}$, particulate matter with aerodynamic diameter ≤ 2.5µm.

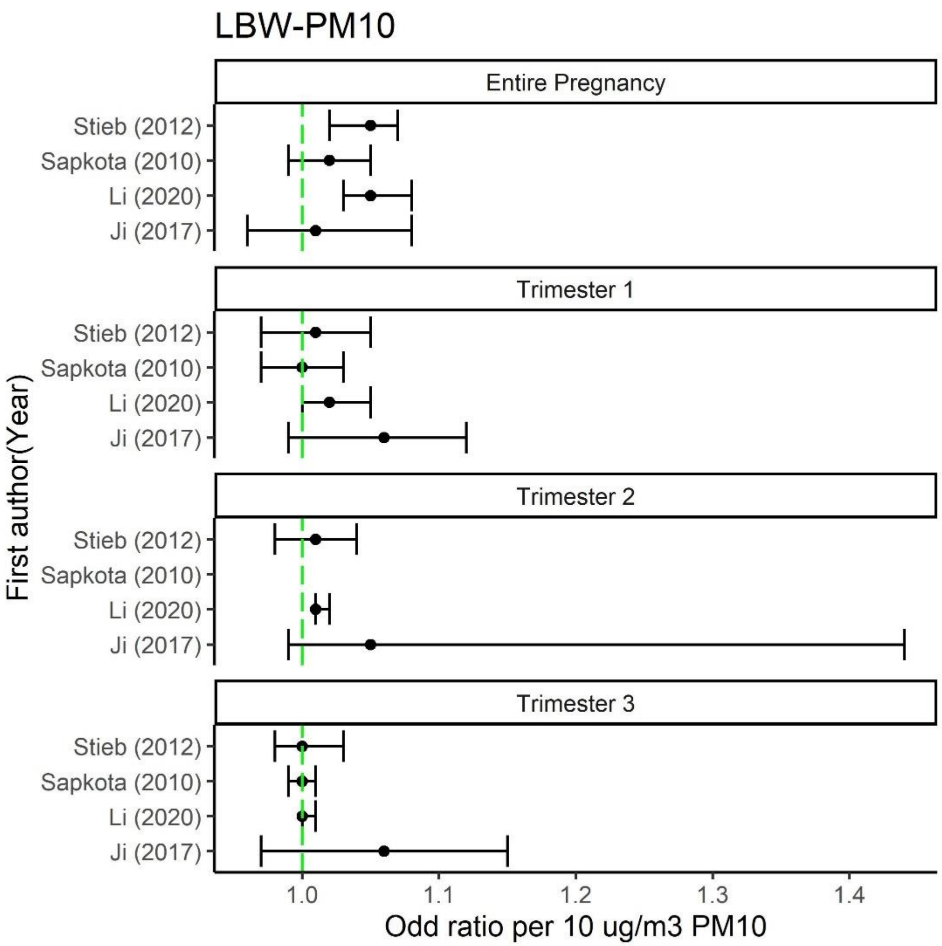

Figure S10. Forest plot of the association between low birth weight (LBW) per 10μg/m^3 PM_{10} increase at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1. Note: PM_{10}, particulate matter at aerodynamic diameter ≤ 10μm.

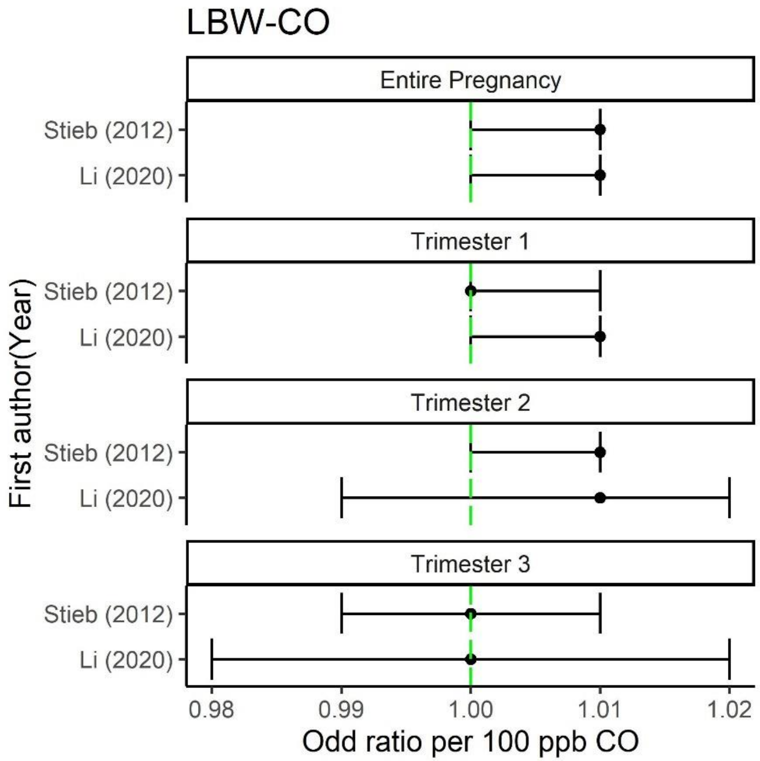

Figure S11. Forest plot of the association between low birth weight (LBW) and carbon monoxide (CO) per 100 parts per billion (ppb) increment in CO at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

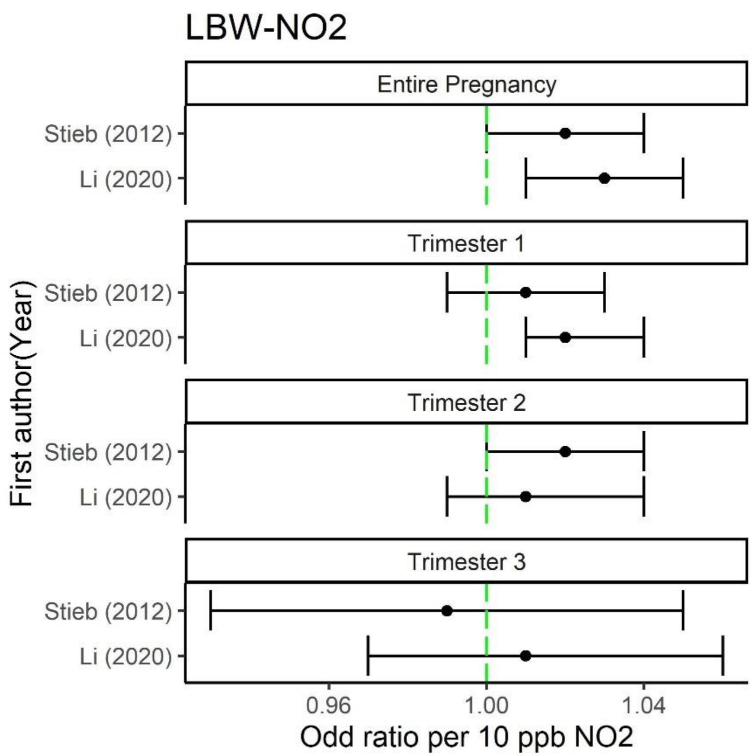

Figure S12. Forest plot of the association between low birth weight (LBW) and Nitrogen dioxide (NO_2) per 20 parts per billion (ppb) increment in NO_2 at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

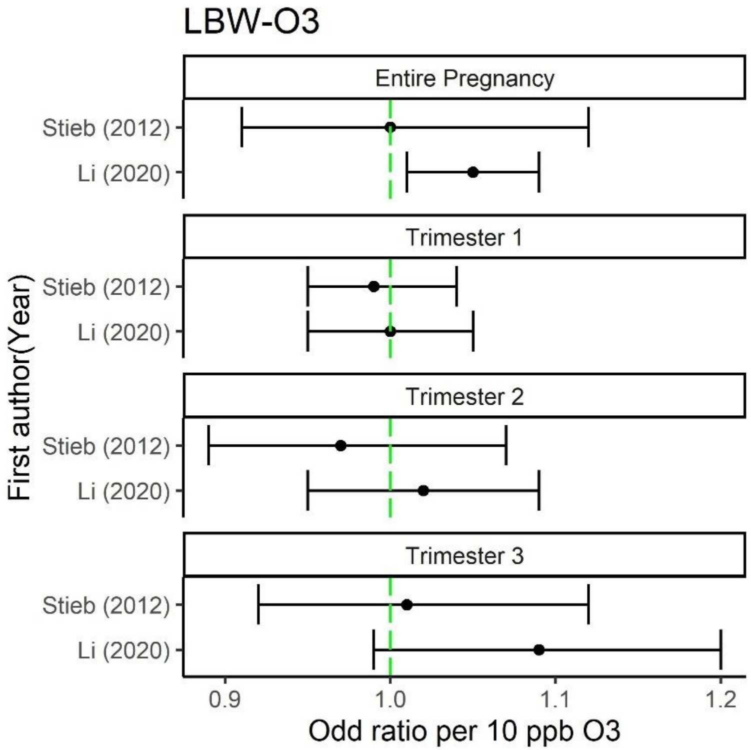

Figure S13. Forest plot of the association between low birth weight (LBW) and Ozone (O_3) per 10 parts per billion (ppb) increment in O_3 at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

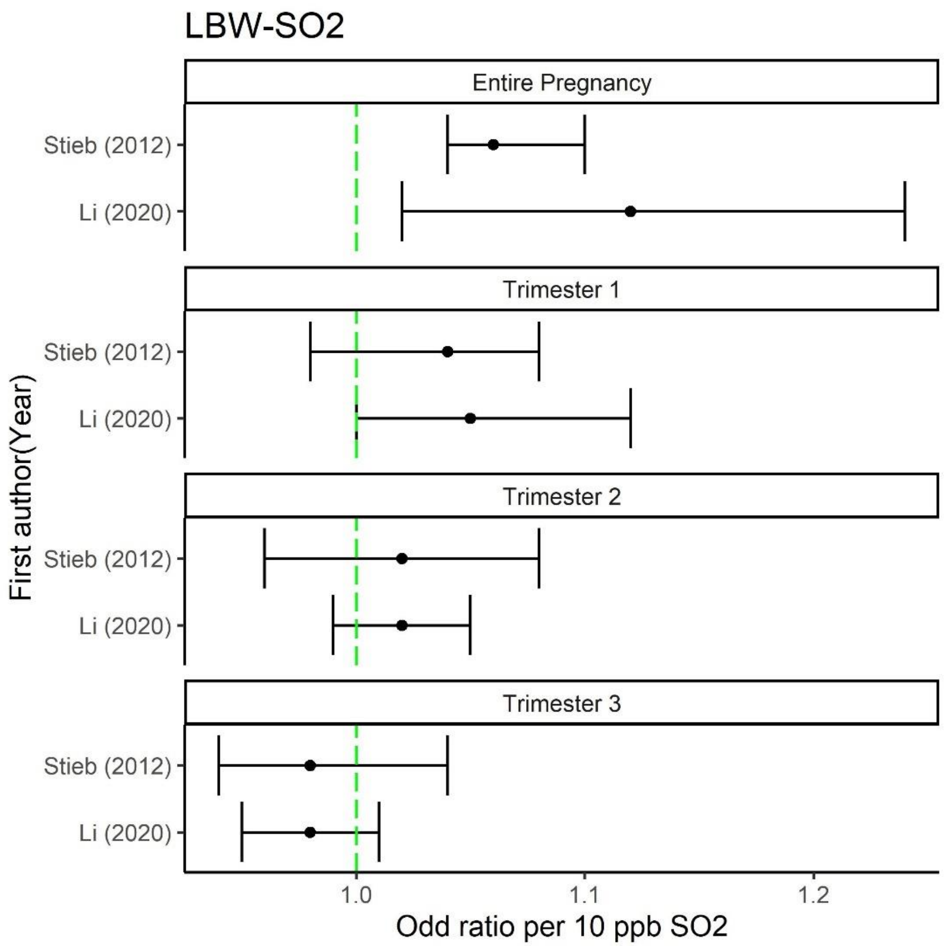

Figure S14. Forest plot of the association between low birth weight (LBW) and Sulphur dioxide (SO_2) per 10 parts per billion (ppb) increment in SO_2 at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

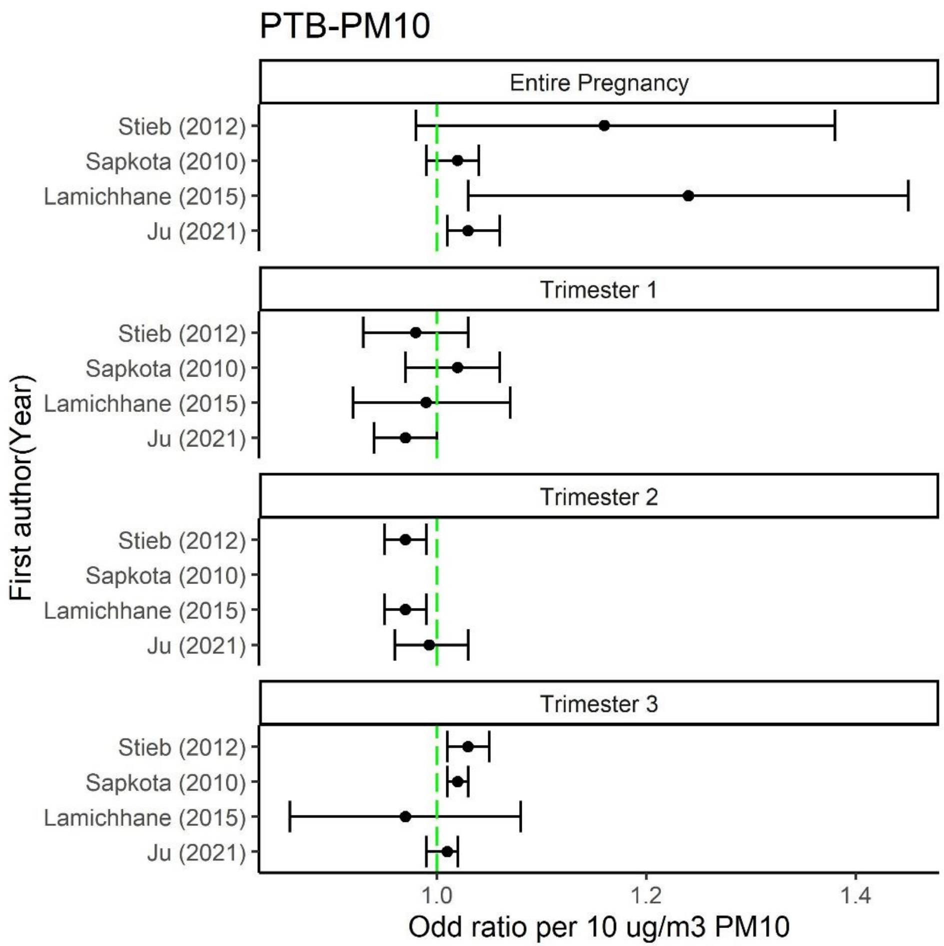

Figure S15. Forest plot of the association between preterm birth (PTB) per 10µg/m^3 PM_{10} increase at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents null association of 1. Note: PM_{10}, particulate matter at aerodynamic diameter ≤ 10µm.

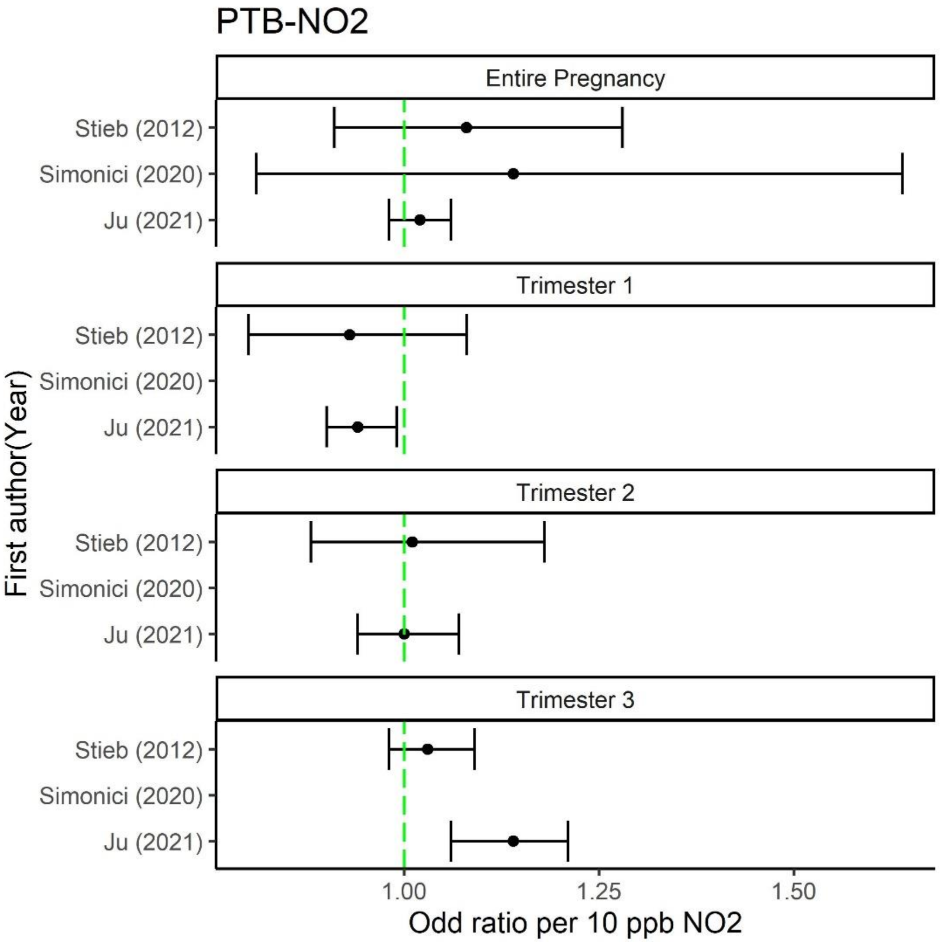

Figure S16. Forest plot of the association between preterm birth (PTB) and Nitrogen dioxide (NO_2) per 10 parts per billion (ppb) increment in NO_2 at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

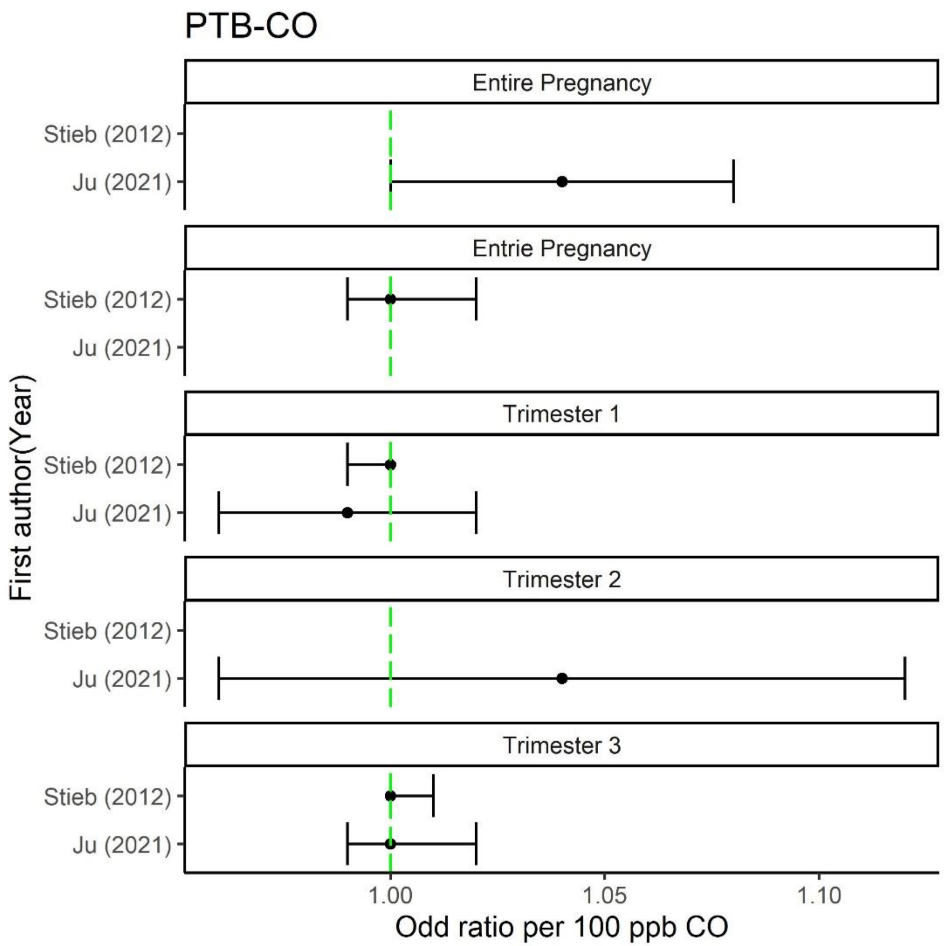

Figure S17. Forest plot of the association between preterm birth (PTB) and carbon monoxide (CO) per 100 parts per billion (ppb) increment in CO at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

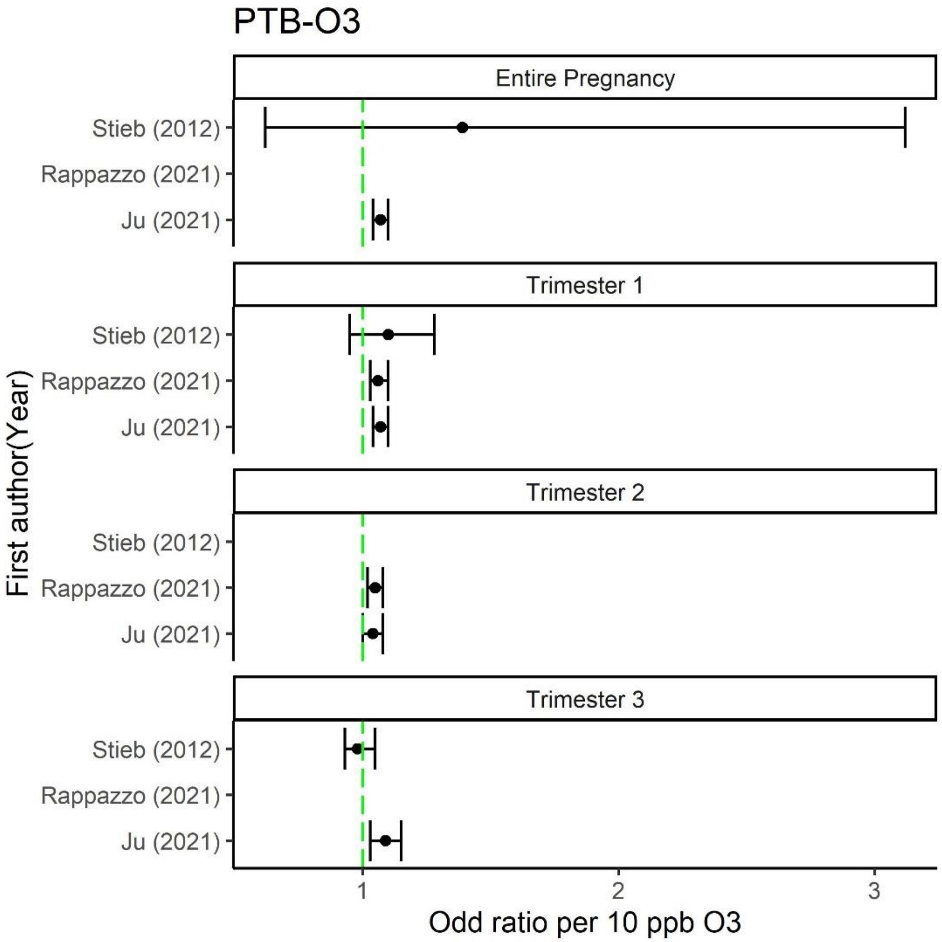

Figure S18. Forest plot of the association between preterm birth (PTB) and Ozone (O_3) per 10 parts per billion (ppb) increment in O_3 at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

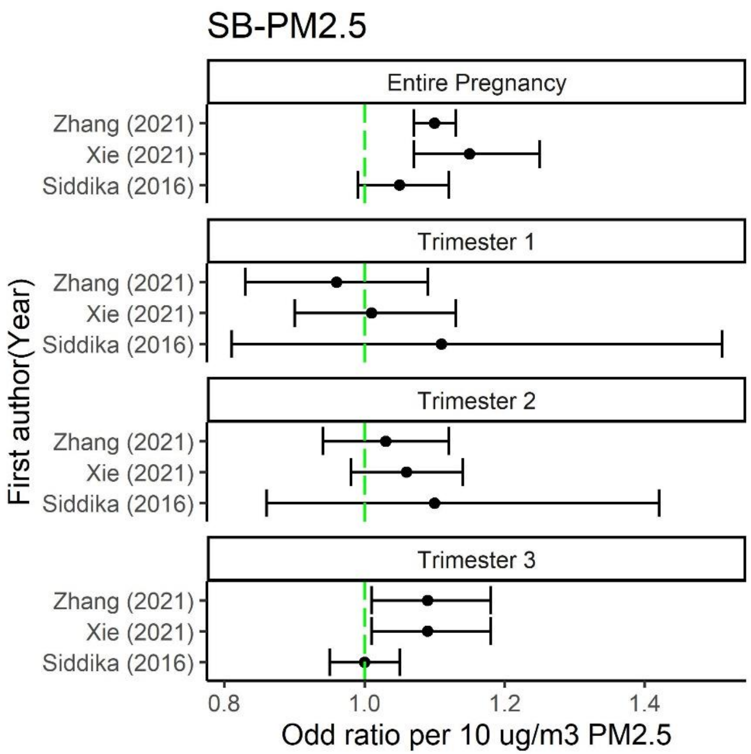

Figure S19. Forest plot of the association between stillbirth (SB) and fine particulate matter ($PM_{2.5}$) per 10μg/m^3 increment) during different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1. Note: $PM_{2.5}$, particulate matter at aerodynamic diameter ≤ 2.5μm.

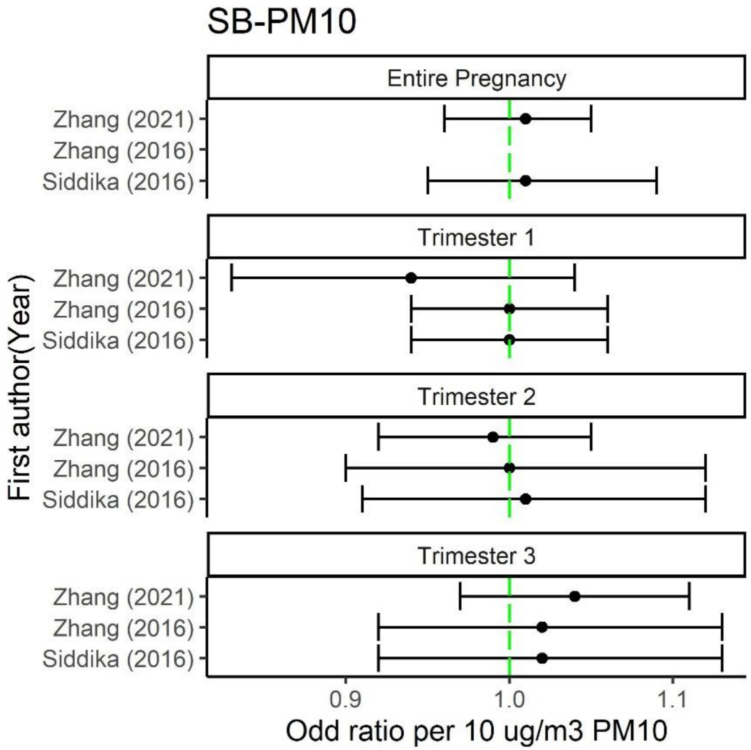

Figure S20. Forest plot of the association between stillbirth (SB) and fine particulate matter (PM_{10}) per 10μg/m^3 increment) during different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1. Note: PM_{10}, particulate matter at aerodynamic diameter ≤10μm.

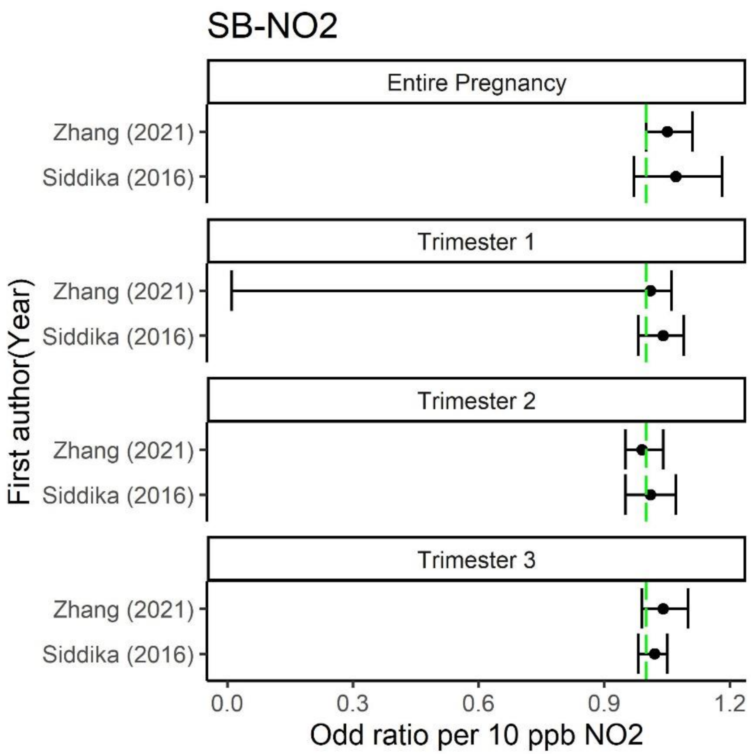

Figure S21. Forest plot of the association stillbirth (SB) and Nitrogen dioxide (NO_2) per 10 parts per billion (ppb) increment in NO_2 at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

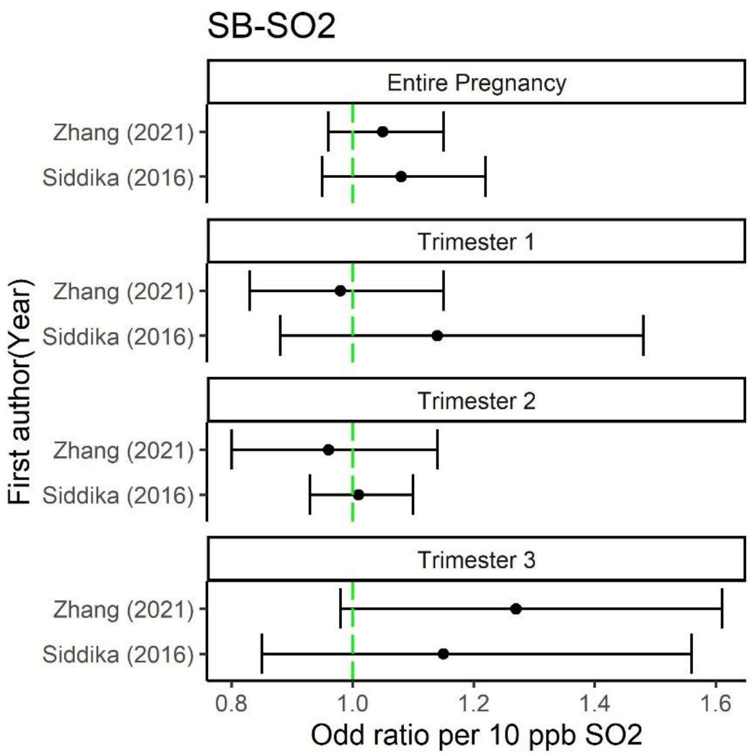

Figure S22. Forest plot of the association between stillbirth (SB) and Sulphur dioxide (SO_2) per 10 parts per billion (ppb) increment in SO_2 at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

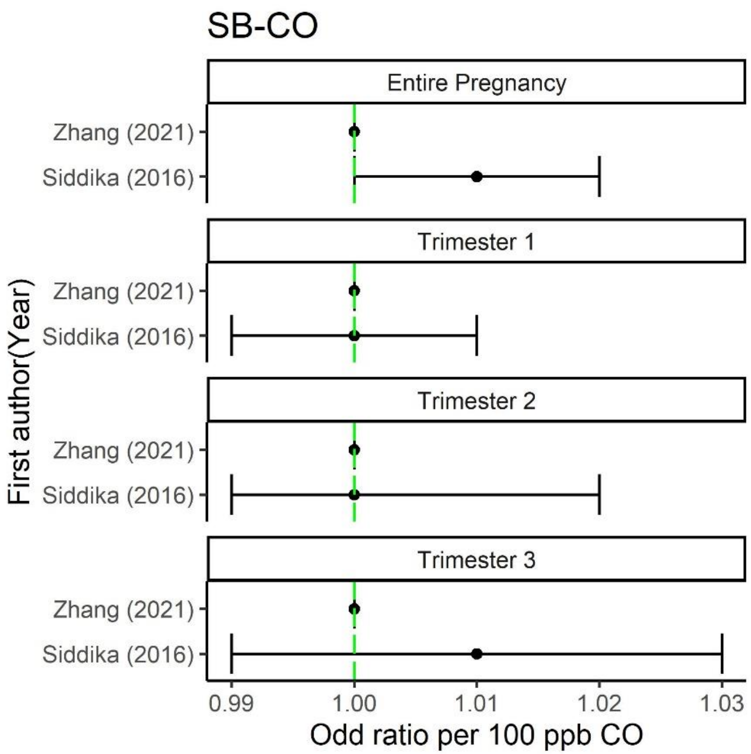

Figure S23. Forest plot of the association between stillbirth (SB) and carbon monoxide (CO) per 100 parts per billion (ppb) increment in CO at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

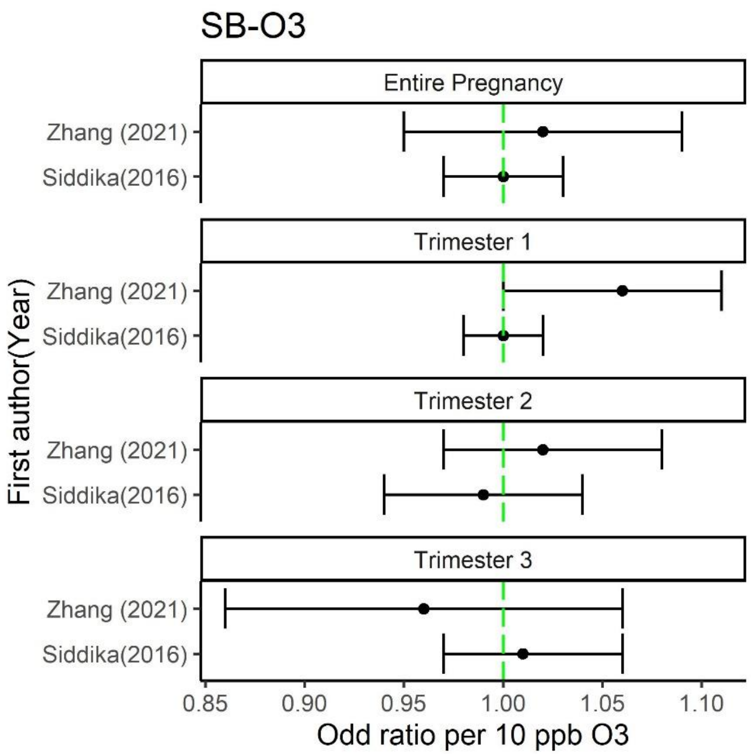

Figure S24. Forest plot of the association between stillbirth (SB) and ozone (O_3) per 10 parts per billion (ppb) increment in O_3 at different pregnancy periods. Solid points represent point estimates of the individual meta-analyses results, and the whiskers represent 95% confidence intervals (CIs). The vertical green dotted line represents the reference for null association of 1.

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	Page 1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	Page 2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	Page 3
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	Page 3-4
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	Page 4
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	Page 4
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	Supplemental Table S1
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	Page 4-5
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	Page 4-5
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.	Page 4-5
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	Page 4-5
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	Page 5
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	Page 6
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	Page 5-6
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	Page 5-6

Section and Topic	Item #	Checklist item	Location where item is reported
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	Page 5-6
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	Page 5-6
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NA
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NA
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	Page 5-6
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	Page 6
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	Supplemental Table S2
Study characteristics	17	Cite each included study and present its characteristics.	Table 1-2
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	Supplemental Figure S4-S5
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	Page 9-13, Table 3-6, Table S6-S7, Figure 2-3, Figure S6-24
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	Page 6-8
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	Page 9-13
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NA

Section and Topic	Item #	Checklist item	Location where item is reported
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	Page 9-13
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	Page 13-19
	23b	Discuss any limitations of the evidence included in the review.	Page 19-20
	23c	Discuss any limitations of the review processes used.	Page 19-20
	23d	Discuss implications of the results for practice, policy, and future research.	Page 20-21
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	Page 4
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	Page 4
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	Page 6
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	Page 22
Competing interests	26	Declare any competing interests of review authors.	Page 22
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	Supplemental material

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

References

Bekkar, B., Pacheco, S., Basu, R., DeNicola, N. 2020. Association of Air Pollution and Heat Exposure With Preterm Birth, Low Birth Weight, and Stillbirth in the US: A Systematic Review. JAMA Network Open. 3(6), e208243-e208243. https://doi.org/10.1001/jamanetworkopen.2020.8243

Bonzini, M., Carugno, M., Grillo, P., Mensi, C., Bertazzi, P. A., Pesatori, A. C. 2010. Impact of ambient air pollution on birth outcomes: systematic review of the current evidences. Med. Lav. 101(5), 341-363.

Bosetti, C., Nieuwenhuijsen, M. J., Gallus, S., Cipriani, S., La Vecchia, C., Parazzini, F. 2010. Ambient particulate matter and preterm birth or birth weight: a review of the literature. Arch. Toxico. 84(6), 447-460. https://doi.org/10.1007/s00204-010-0514-z.

Edwards, L., Wilkinson, P., Rutter, G., Milojevic, A. 2022. Health effects in people relocating between environments of differing ambient air pollution concentrations: A literature review. Environ. Pollut. 292, 118314. https://doi.org/https://doi.org/10.1016/j.envpol.2021.118314.

Ghosh, R., Rankin, J., Pless-Mulloli, T., Glinianaia, S. 2007. Does the effect of air pollution on pregnancy outcomes differ by gender? A systematic review. Environ. Res. 105(3), 400-408. https://doi.org/10.1016/j.envres.2007.03.009.

Glinianaia, S. V., Rankin, J., Bell, R., Pless-Mulloli, T., Howel, D. 2004. Particulate air pollution and fetal health: a systematic review of the epidemiologic evidence. Epidemiol. 15(1), 36-45. https://doi.org/10.1097/01.ede.0000101023.41844.ac

Gong, C., Wang, J., Bai, Z., Rich, D. Q., Zhang, Y. 2022. Maternal exposure to ambient PM2.5 and term birth weight: A systematic review and meta-analysis of effect estimates. Sci. Total Environ. 807, 150744. https://doi.org/https://doi.org/10.1016/j.scitotenv.2021.150744.

Grippo, A., Zhang, J., Chu, L., Guo, Y., Qiao, L., Zhang, J., et al. 2018. Air pollution exposure during pregnancy and spontaneous abortion and stillbirth. Rev. Environ. Health. 33(3), 247-264. https://doi.org/10.1515/reveh-2017-0033.

Heo, S., Fong, K. C., Bell, M. L. 2019. Risk of particulate matter on birth outcomes in relation to maternal socio-economic factors: a systematic review. Environ. Res. Lett. 14(12). https://doi.org/10.1088/1748-9326/ab4cd0.

Jacobs, M., Zhang, G., Chen, S., Mullins, B., Bell, M., Jin, L., et al. 2017. The association between ambient air pollution and selected adverse pregnancy outcomes in China: A systematic review. Sci. Total Environ. 579, 1179-1192. https://doi.org/10.1016/j.scitotenv.2016.11.100.

Ji, Y., Song, F., Xu, B., Zhu, Y., Lu, C., Xia, Y. 2017. Association between exposure to particulate matter during pregnancy and birthweight: a systematic review and a meta-analysis of birth cohort studies. J. Biomed Res. https://doi.org/10.7555/JBR.31.20170038.

Ju, L., Li, C., Yang, M., Sun, S., Zhang, Q., Cao, J., et al. 2021. Maternal air pollution exposure increases the risk of preterm birth: Evidence from the meta-analysis of cohort studies. Environ. Res. 202, 111654. https://doi.org/10.1016/j.envres.2021.111654.

Lamichhane, D. K., Leem, J. H., Lee, J. Y., Kim, H. C. 2015. A meta-analysis of exposure to particulate matter and adverse birth outcomes. Environ. Health Toxicol. 30, e2015011. https://doi.org/10.5620/eht.e2015011.

Li, C., Yang, M., Zhu, Z., Sun, S., Zhang, Q., Cao, J., et al. 2020. Maternal exposure to air pollution and the risk of low birth weight: A meta-analysis of cohort studies. Environ. Res. 190, 109970. https://doi.org/10.1016/j.envres.2020.109970.

Li, X., Huang, S., Jiao, A., Yang, X., Yun, J., Wang, Y., et al. 2017. Association between ambient fine particulate matter and preterm birth or term low birth weight: An updated systematic review and meta-analysis. Environ. Pollut. 227, 596-605. https://doi.org/10.1016/j.envpol.2017.03.055.

Liu, C., Sun, J., Liu, Y., Liang, H., Wang, M., Wang, C., et al. 2017. Different exposure levels of fine particulate matter and preterm birth: a meta-analysis based on cohort studies. Environ. Sci. Pollut. Res. Int. 24(22), 17976-17984. https://doi.org/10.1007/s11356-017-9363-0.

Luo, D., Kuang, T., Chen, Y.-X., Huang, Y.-H., Zhang, H., Xia, Y.-Y. 2021. Air pollution and pregnancy outcomes based on exposure evaluation using a land use regression model: A systematic review. Taiwan J. Obstet. Gynecol. 60(2), 193-215. https://doi.org/https://doi.org/10.1016/j.tjog.2021.01.004.

Pieper, D., Antoine, S. L., Mathes, T., Neugebauer, E. A., Eikermann, M. 2014. Systematic review finds overlapping reviews were not mentioned in every other overview. J. Clin. Epidemiol. 67(4), 368-375. https://doi.org/10.1016/j.jclinepi.2013.11.007.

Rappazzo, K. M., Nichols, J. L., Rice, R. B., Luben, T. J. 2021. Ozone exposure during early pregnancy and preterm birth: A systematic review and meta-analysis. Environ. Res. 198, 111317. https://doi.org/10.1016/j.envres.2021.111317.

Sapkota, A., Chelikowsky, A. P., Nachman, K. E., Cohen, A. J., Ritz, B. 2010. Exposure to particulate matter and adverse birth outcomes: a comprehensive review and meta-analysis. Air Qual. Atmos. Health. 5(4), 369-381. https://doi.org/10.1007/s11869-010-0106-3.

Shah, P. S., Balkhair, T., Knowledge Synthesis Group on Determinants of Preterm, L. B. W. b. 2011. Air pollution and birth outcomes: a systematic review. Environ. Int. 37(2), 498-516. https://doi.org/10.1016/j.envint.2010.10.009.

Siddika, N., Balogun, H. A., Amegah, A. K., Jaakkola, J. J. 2016. Prenatal ambient air pollution exposure and the risk of stillbirth: systematic review and meta-analysis of the empirical evidence. Occup. Environ. Med. 73(9), 573-581. https://doi.org/10.1136/oemed-2015-103086.

Simoncic, V., Enaux, C., Deguen, S., Kihal-Talantikite, W. 2020. Adverse Birth Outcomes Related to NO2 and PM Exposure: European Systematic Review and Meta-Analysis. Int. J. Environ. Res. Public Health. 17(21). https://doi.org/10.3390/ijerph17218116.

Stieb, D. M., Chen, L., Eshoul, M., Judek, S. 2012. Ambient air pollution, birth weight and preterm birth: a systematic review and meta-analysis. Environ. Res. 117, 100-111. https://doi.org/10.1016/j.envres.2012.05.007.

Sun, X., Luo, X., Zhao, C., Chung Ng, R. W., Lim, C. E., Zhang, B., et al. 2015. The association between fine particulate matter exposure during pregnancy and preterm birth: a meta-analysis. BMC Pregnancy Childbirth, 15, 300. https://doi.org/10.1186/s12884-015-0738-2.

Sun, X., Luo, X., Zhao, C., Zhang, B., Tao, J., Yang, Z., et al. 2016. The associations between birth weight and exposure to fine particulate matter (PM2.5) and its chemical constituents during pregnancy: A meta-analysis. Environ. Pollut. 211, 38-47. https://doi.org/10.1016/j.envpol.2015.12.022.

Thayamballi, N., Habiba, S., Laribi, O., Ebisu, K. 2020. Impact of Maternal Demographic and Socioeconomic Factors on the Association Between Particulate Matter and Adverse Birth Outcomes: a Systematic Review and Meta-analysis. J. Racial Ethn. Health Disparities. https://doi.org/10.1007/s40615-020-00835-2.

Tsoli, S., Ploubidis, G. B., Kalantzi, O.-I. 2019. Particulate air pollution and birth weight: A systematic literature review. Atmos. Pollut. Res. 10(4), 1084-1122. https://doi.org/10.1016/j.apr.2019.01.016.

Uwak, I., Olson, N., Fuentes, A., Moriarty, M., Pulczinski, J., Lam, J., et al. 2021. Application of the navigation guide systematic review methodology to evaluate prenatal exposure to particulate matter air pollution and infant birth weight. Environ. Int. 148, 106378. https://doi.org/10.1016/j.envint.2021.106378.

Walter, C. M., Schneider-Futschik, E. K., Hall, N. L., Sly, P. D., Head, B. W., Knibbs, L. D. 2021. The health impacts of ambient air pollution in Australia: A systematic literature review. Intern. Med. J. https://doi.org/10.1111/imj.15415.

Westergaard, N., Gehring, U., Slama, R., Pedersen, M. 2017. Ambient air pollution and low birth weight - are some women more vulnerable than others? Environ. Int. 104, 146-154. https://doi.org/10.1016/j.envint.2017.03.026

Xie, G., Sun, L., Yang, W., Wang, R., Shang, L., Yang, L., et al. 2021. Maternal exposure to PM2.5 was linked to elevated risk of stillbirth. Chemosphere. 283, 131169. https://doi.org/https://doi.org/10.1016/j.chemosphere.2021.131169.

Yuan, L., Zhang, Y., Gao, Y., Tian, Y. 2019. Maternal fine particulate matter (PM2.5) exposure and adverse birth outcomes: an updated systematic review based on cohort studies. Environ. Sci. Pollut. Res. Int. 26(14), 13963-13983. https://doi.org/10.1007/s11356-019-04644-x.

Zhang, H., Zhang, X., Wang, Q., Xu, Y., Feng, Y., Yu, Z., et al. 2021. Ambient air pollution and stillbirth: An updated systematic review and meta-analysis of epidemiological studies. Environ. Pollut. 278, 116752. https://doi.org/10.1016/j.envpol.2021.116752.

Zhang K, L. Y., Zhao H, Guo J, Gehendra M, Qiu H, Wu S, He D. 2016. Association between atmospheric particulate matter and adverse pregnancy outcomes in the population. Int. J. Clin. Exp. Med. 9(11), 20594-20604.

Zhu, W., Zheng, H., Liu, J., Cai, J., Wang, G., Li, Y., et al. 2022. The correlation between chronic exposure to particulate matter and spontaneous abortion: A meta-analysis. Chemosphere. 286, 131802. https://doi.org/https://doi.org/10.1016/j.chemosphere.2021.131802.

Zhu, X., Liu, Y., Chen, Y., Yao, C., Che, Z., Cao, J. 2015. Maternal exposure to fine particulate matter (PM2.5) and pregnancy outcomes: a meta-analysis. Environ. Sci. Pollut. Res. Int. 22(5), 3383-3396. https://doi.org/10.1007/s11356-014-3458-7.