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Effects of Long-term Exposure to Air Pollution on Maternal and Child Health

Preety Chaudhary[1], Dr Jatinder Verma[2]

[1]MA in Environmental and Occupational Health, PG Diploma in Clinical Research, BSc. Biotechnology, Freelancer (Environment, Health), New Delhi, India,
[2]Ayurvedic Medical Officer, Panchakarma specialist, Department of AYUSH, Haryana, India,

Abstract
Air pollution is a critical environmental factor that poses significant risks to maternal and child health. Pregnant women are exposed to multiple air pollutants, including particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO), which can enter the bloodstream and affect both maternal well-being and fetal development. Epidemiological studies have linked long-term exposure to these pollutants with adverse pregnancy outcomes, including preterm birth, low birth weight, gestational hypertension, and complications such as preeclampsia. We reviewed epidemiological literature on air pollution exposure during pregnancy and its impact on maternal and child health, increasing risks of neurodevelopment disorders, respiratory diseases, and immune system dysfunction in children. Research on air pollution shows decreased lung function, asthma, pneumonia, acute lower respiratory tract infection in children. Studies reveal strong evidence against air pollution which comes with large number of health issues in offspring due to exposure of particulate matter.

Keywords: air pollution, particulate matter, maternal health, child health, respiratory diseases

1. Introduction

Air pollution is one of the most pressing environmental health challenges globally, affecting millions of people, particularly vulnerable groups such as pregnant women and infants/child. Rapid industrialization, urbanization, and increased vehicular emissions have significantly contributed to rising air pollution levels, exposing populations to harmful pollutants such as particulate matter (PM), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and heavy metals [1][11], and significantly affects human health, particularly the cardiovascular system linked to an increased risk of heart disease, high blood pressure, and stroke [2]. Exposure to these pollutants, especially over the long term, can cause inflammation, oxidative stress, and dysfunction in blood vessels, leading to conditions such as atherosclerosis, heart attacks, and heart failure [3]. Particulate matter (PM), which is released from industrial activities, vehicular emissions, and burning fossil fuels, is one of the most harmful air pollutants. These tiny particles can enter the bloodstream through the lungs and trigger an immune response, leading to chronic inflammation and damage to the blood vessels [4]. Studies have shown that exposure to PM 2.5 is strongly associated with an increased risk of cardiovascular diseases, with a 10 $\mu g/m^3$ rise in PM 2.5 concentration linked to an 11% increase in cardiovascular mortality [2]. In addition to PM 2.5, gaseous pollutants such as NO_2 and SO_2 contribute to vascular dysfunction and elevate the risk of heart-related conditions [3].The biological mechanisms behind these health effects involve

several pathways. First, exposure to pollutants leads to oxidative stress, which damages cells and promotes inflammation in blood vessels [4]. This inflammation contributes to the narrowing and hardening of arteries, increasing the likelihood of heart attacks and strokes. Second, air pollution can disrupt the autonomic nervous system, leading to irregular heart rhythms and an increased risk of sudden cardiac death [2]. In addition, pollutants can activate blood clotting pathways, increasing the chances of thrombosis and other cardiovascular complications [3].

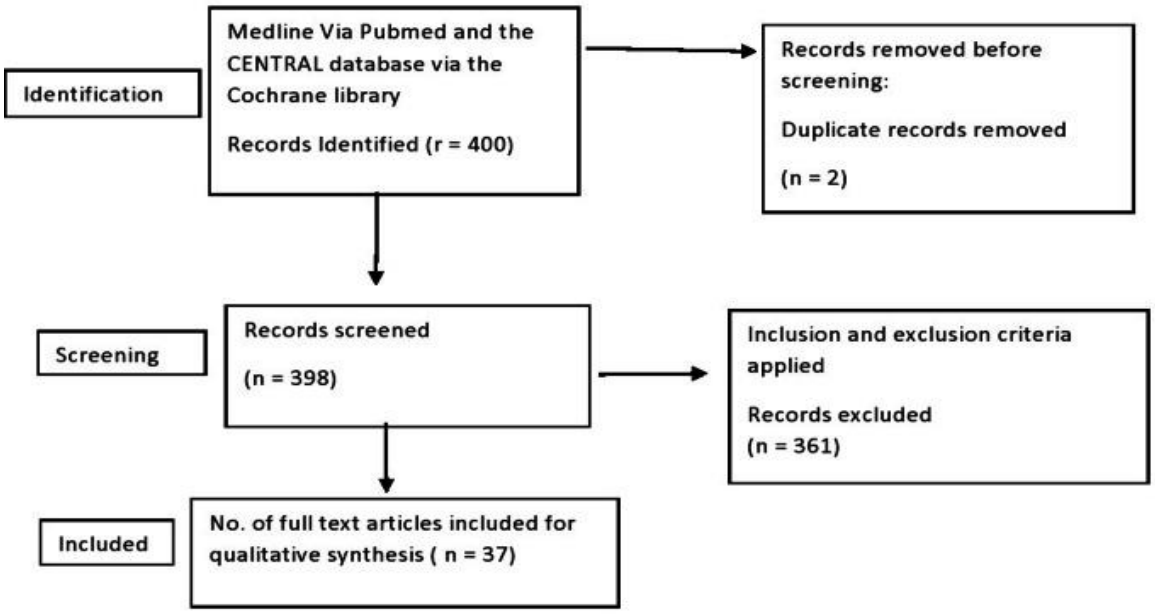
Moreover, long-term exposure to these pollutants has been associated with serious health risks, particularly for maternal and child health. Pregnant women exposed to high levels of air pollution face an increased risk of complications such as preterm birth, low birth weight (LBW), gestational hypertension, and preeclampsia [16][12]. These adverse effects can have lifelong consequences for infants, affecting their growth, cognitive development, and overall well-being [13]. Moreover, children exposed to polluted environments in early life experience a higher prevalence of respiratory infections, asthma, impaired lung function, and neurodevelopmental disorders [17]. Studies have also linked prenatal and postnatal exposure to air pollution with long-term metabolic and cardiovascular issues [18][14].The underlying biological mechanisms that contribute to these adverse health outcomes include oxidative stress, systemic inflammation, epigenetic modifications, and placental dysfunction [5][15]. Pollutants can cross the placental barrier, directly affecting fetal development, while maternal inflammatory responses can further exacerbate negative outcomes [6][13]. This review aims to comprehensively examine the impact of long-term exposure to air pollution on maternal and child health, and discuss the epidemiological studies involved.

2. Methodology

A thorough search was done using different academic sources, including PubMed, ScienceDirect, ResearchGate, and Google Scholar. In addition, reports from trusted organizations like the World Health Organization (WHO) and the European Environment Agency (EEA) were also reviewed to gather relevant information. We find more than 100 epidemiological studies on the impact of long-term air pollution exposure on maternal and child health. Research has shown that pregnant women exposed to high levels of air pollution, particularly PM 2.5, NO_2, and CO, have a 10–15% higher risk of preterm birth and a 20–25% increased risk of low birth weight. A study involving over 100,000 births across multiple countries found that mothers living in highly polluted areas were more likely to develop gestational hypertension and diabetes. In addition, air pollution exposure has been linked to a 30% higher risk of respiratory illnesses and asthma in children, with prenatal exposure affecting lung function and neurodevelopment. Long-term studies also suggest that children exposed to pollution in early life have a higher likelihood of developing cognitive and behavioural disorders.

Also, we used the Cochrane Library and PubMed to search the Central database and Medline. The following search method was specifically designed for each database: Effects of pollution on pregnancy and infants. To find new studies, we also looked through the references list of potentially relevant papers. Studies returned from these computerized searches and pertinent sources listed in those studies' bibliographies were examined (Figure 1) [19].

Fig. 1: Identification of Search Strategies for Qualitative Review Synthesis Databases and Registers on the Effects of Pollution on Pregnancy and Infants.



3. Overview of impact of air pollution on maternal and child health

Air pollution poses serious risks to maternal and child health, increasing the likelihood of pregnancy complications such as preterm birth, low birth weight, and gestational hypertension [11]. Women may be more vulnerable to pollution due to biological and hormonal factors [15]. Infants exposed to pollutants face higher risks of respiratory illnesses, weakened immunity, and neurodevelopmental delays [13]. Pollution also contributes to maternal health conditions, highlighting the need for preventive actions [14]. For instance, India has some of the worst air pollution levels in the world, with 14 out of the 15 most polluted cities globally being located in the country shown in table 1 [20] whereas, table 2 shows air pollution affects children's respiratory health in India. Biomass smoke, crop residue burning, and indoor pollution contribute to asthma and lung issues. Traffic pollution and parental smoking worsen respiratory conditions, while industrial exposure can lead to severe lung diseases [22][23][24][25][26].

Table 1: List of The Top 14 Most Polluted Indian Cities [20].

RANK	CITY	$PM_{2.5}$ LEVEL (Annual Mean, µg/m^3)
1	Kanpur	173
2	Faridabad	172
3	Varanasi	151

RANK	CITY	$PM_{2.5}$ LEVEL (Annual Mean, µg/m^3)
4	Gaya	149
5	Patna	144
6	Delhi	143
7	Lucknow	138
8	Agra	131
9	Muzaffarpur	120
10	Srinagar	113
11	Gurgaon	113
12	Jaipur	105
13	Patiala	101
14	Jodhpur	98

PM: Particulate matter (Diameter of ≤2.5 µm).

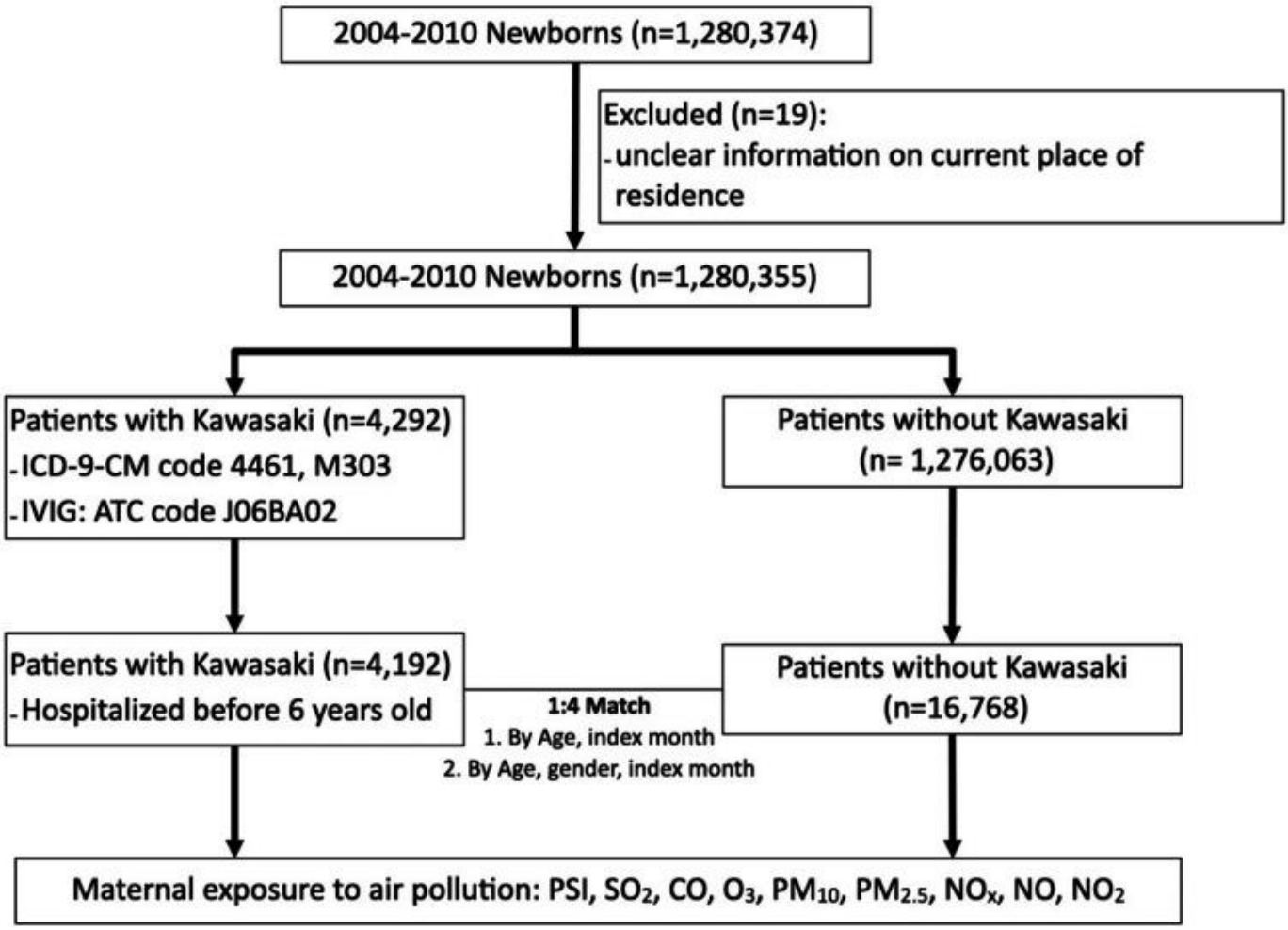
Table 2: List of Studies on Air Pollution That Have Been Carried Out In an Indian Population.

S. No.	Author	Study Design	Sample Size	Exposure	Parameter Studied	Comments and Association
1.	Padhy et al., 2009 [21]	Case-control	Control (105) Biomass user (115)	Biomass smoke	Respiratory symptoms Oxidative stress Haematological changes	Exposure to biomass smoke significantly associated with respiratory diseases, oxidative stress, and haematological changes
2.	Awasthi et al., 2010 [22]	Cohort	23 children (10–13 years of age)	Agriculture crop residue burning (ACRB)	Pulmonary function	Decrease in pulmonary function with an increase in air pollutant levels due to ACRB
3.	Kumar et al., 2015 [23]	Cohort	3104 children	Indoor suspended particulate matter (SPM)	Asthma	Indoor SPM level was significantly higher in asthmatic children's houses
4.	Singh et	Cross-	44,928 (6–7	Traffic	Asthma	Traffic pollution and

S. No.	Author	Study Design	Sample Size	Exposure	Parameter Studied	Comments and Association
	al., 2015 [24]	sectional, multicenter	year age group); 48,088 (13–14 year age group)	pollution, maternal and paternal smoking		maternal and paternal smoking is associated with increased prevalence of asthma
5.	Murlidhar et al., 2015 [25]	Case-report	11-year-old boy, malnourished	Secondary exposure to sandstone mining	Silico-tuberculosis	Mother started working in the mines soon after her marriage and the family lives close to the mines
6.	Rumchev et al., 2017 [26]	Cohort	170 children between 1 and 15 years	Indoor exposure to $PM_{2.5}$	Respiratory symptoms	No significant association between PM-exposure and respiratory symptoms even though odds are high

Exposure to air pollution during pregnancy has been linked to various adverse maternal health outcomes. Studies have shown that pregnant women exposed to high levels of air pollutants, such as fine particulate matter (PM2.5), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), are at an increased risk of developing complications like gestational hypertension and preeclampsia [27]. These conditions can lead to serious health issues for both the mother and the developing fetus. In addition, air pollution has been associated with systemic inflammation and oxidative stress in pregnant women, which may contribute to impaired placental function and reduced nutrient and oxygen delivery to the fetus. This can result in adverse birth outcomes, including low birth weight and preterm birth [28]. In recent research, suggested a link between prenatal and early-life exposure to air pollution and the incidence of Kawasaki disease, a condition that causes inflammation in blood vessels, primarily in children. Exposure to pollutants such as fine particulate matter (PM 2.5) and nitrogen dioxide (NO_2) during pregnancy and infancy may contribute to the development of this disease by triggering systemic inflammation and immune system dysregulation [29]. These findings are growing evidence of air pollution's impact on both maternal and child health, databases are shown in figure 2.

Fig. 2: Prenatal and Early Exposure to Air Pollution and the Incidence of Kawasaki Disease.



Source: [29]. ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification; IVIG, intravenous immune globulin; ATC code, Anatomical Therapeutic Chemical code; PSI, Pollutant Standards Index; SO_2, sulphur dioxide; CO, carbon monoxide; O_3, ozone; PM, particulate matter; NO, nitric oxide; NO_2, nitrogen dioxide

Air pollution causes severe respiratory infections, especially in children and vulnerable populations. Indoor air pollution, primarily from biomass combustion, significantly increases the risk of pneumonia in children under five in low- and middle-income countries [30]. Short-term exposure to fine particulate matter (PM2.5) has been associated with acute respiratory infections in children, leading to increased hospital visits [31]. In addition, exposure to ozone and fine particulate matter has been linked to emergency respiratory visits across different age groups, further emphasizing the harmful impact of air pollution on lung health [32]. Short-term spikes in PM 2.5 levels have been shown to increase cases of lower respiratory infections, including pneumonia and bronchitis [33][34]. Furthermore, studies suggest that air pollution worsened the severity of COVID-19, as regions with higher pollution levels reported increased mortality rates [35]. Air pollution is also known to weaken the immune system, making individuals more susceptible to respiratory infections [36]. Vitamin D deficiency, combined with pollution exposure, may further increase vulnerability to respiratory illnesses, including COVID-19, by suppressing the body's natural immune defences [37]. Also, air pollution is a major factor in worsening respiratory diseases, particularly asthma and chronic obstructive pulmonary disease (COPD). Studies

have shown that exposure to outdoor air pollutants like PM10 and NO2 can trigger asthma attacks and COPD exacerbations, as seen in metropolitan areas such as Berlin [38]. Children with asthma or asthma-like symptoms are especially vulnerable to short-term exposure to these pollutants, leading to increased respiratory distress and hospital visits [39]. Poor air quality has been linked to negative health outcomes in children, affecting their lung development and increasing the risk of chronic respiratory conditions [40]. In cities like London, higher pollution levels have been associated with increased respiratory-related doctor visits and a higher demand for inhaler prescriptions, demonstrating the immediate impact of air pollution on respiratory health [41]. Similarly, in Taiwan, short-term exposure to ambient air pollutants has been directly linked to more hospitalizations for childhood asthma [42]. Hospital stays for children with asthma have also been found to be longer in areas with high air pollution, as observed in South Texas [43]. Furthermore, traffic-related air pollution has been identified as a significant risk factor for the development of childhood asthma, with long-term exposure increasing the likelihood of disease onset [44]. High concentrations of fine particulate matter (PM 2.5) not only increase asthma incidence but also contribute to more severe respiratory conditions in children [45].

4. Conclusion

Long-term exposure to air pollution poses serious risks to maternal and child health. It increases the chances of pregnancy complications, preterm birth, low birth weight, and developmental disorders in children. Infants and young children exposed to polluted air are more likely to suffer from respiratory problems, weakened immunity, and cognitive issues. This issue requires stricter pollution control policies, better healthcare access, and increased awareness among pregnant women. Simple steps like using air purifiers, avoiding high-pollution areas, and promoting clean energy can help reduce exposure. Protecting maternal and child health from air pollution is essential for ensuring a healthier future generation.

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