

Health Effects of Sulfur and Nitrogen Oxides Along with Particulate Matter and Phthalate On Women and Children: An Investigation On Air Pollutants

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Abstract: *Clean air is one of the basic requirements of human health. However, during the process of economic development, pollution is found to be a significant health hazard worldwide. Pollution is the introduction of harmful materials into the environment, which causes diseases and premature death. One of the major causative materials for pollution is pollutants. A pollutant is a substance introduced into the environment that has undesired effects. Among the different kinds of pollutants, air pollutants are easily spreadable. Air pollutants refer to naturally occurring substances, such as particulate matter, ozone, sulfur oxide, nitrogen oxides, phthalate, and volatile organic compounds. Household combustion devices, motor vehicles, burning of fossil fuels, industrial facilities, and forest fires are common sources of air pollutants. Thus, these air pollutant substances affect the health of children and women. Also, Air pollutants cause mortality as well as specific diseases, such as stroke, ischaemic heart disease, chronic obstructive pulmonary disease, and pneumonia in women and children. Therefore, the current review paper's objective is to explain air pollutants, such as sulfur and nitrogen oxides, particulate matter, and phthalate along with their health effects. Also, this review explains the air pollutants, their types, and their health effects on women and children.*

Keywords: air pollutants, sulfur dioxide, particulate matter (PM), phthalate, harmful materials, health effects, and nitrogen oxide.

INTRODUCTION

In the past 20 years, pollution has become one of the largest environmental destruction. Pollution restricts economic growth, worsens poverty and inequality in both urban and rural areas, and significantly contributes to climate change [1]. Pollution is the largest environmental cause of disease and early death around the world. The three major types of pollution are air pollution, water

pollution, and land pollution. Air pollution is contamination of the indoor or outdoor environment. Also, water pollution occurs when harmful substances are often mixed with the water bodies. Finally, land pollution refers to the deterioration of the earth's land surfaces above and below the ground level. Among the types, the majority of deaths occur because of the easily spreadable character of air pollution. Some of the harmful substance that causes air pollution are hydrogen chloride, benzene, toluene, and metals [2]. These harmful materials are called pollutants. This can also be created by human activity, such as trash or runoff produced by factories. Pollutant causes environmental risks and health effects, leading to 7 million early deaths each year [3]. Pollutants are classified as primary or secondary. Air pollutants come under the primary pollutant. The air pollutant is a substance in the air that can have many effects on humans and the ecosystem.

The air pollutants can be solid particles, liquid droplets, or gases. It may be in the form of an aerosol also [4]. When polluted air is inhaled, the pollutants enter in bloodstream and contribute to coughing or itchy eyes and worsen leading to even early death. Some of the important air pollutants that cause health impacts are particulate matter (PM), Ozone (O₃), Nitrogen dioxide (NO₂), Carbon monoxide (CO), Sulfur oxide (SO), and phthalate [5]. Figure 1 explains the health impacts of air pollution with pollutant materials.

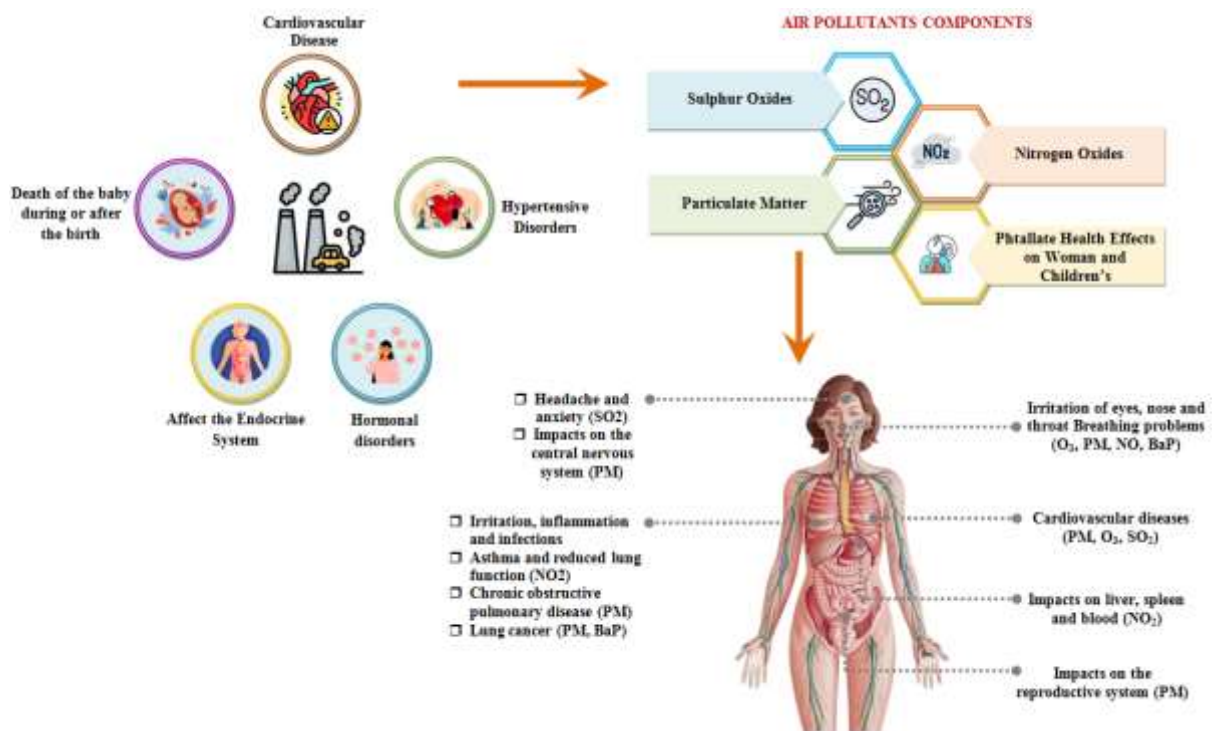


Figure 1: Health impacts of air pollution with the pollutant materials

The air pollutants and their effect on health are explained below,

- ▶ **Particulate matter (PM)** - The mixture of solid particles and liquid droplets found in the air causes irritation of the eyes, nose, and throat and shortness of breath.
- ▶ **Sulfur oxides (SO)** - The SO is the pollutant that contributes particulate pollution. This irritates the respiratory tract and increases the risk of tract infections [6].
- ▶ **Nitrogen oxides (NO)** - The oxides of nitrogen are a mixture of gases. This causes irritation in the lungs, possibly causing cough and experience shortness of breath, tiredness, and nausea.
- ▶ **Phthalate (C₈H₄O₄₋₂)** - C₈H₄O₄₋₂ is a common contaminant. The high exposure to phthalates is linked to asthma and rhinitis [7].



Figure 2: Section of the paper

RESEARCH QUESTIONS AND ARTICLE SELECTION STRATEGY

A research question is the main question that the study is seeking to answer. A clear research question guides the review paper on exactly what should be found out. Thus, by clearly focusing on the research question, the objective of the review is mainly concentrated.

Research questions

The RQs formed in the articles mainly concentrate on the objective. Therefore, the RQs are classified into 5 types, namely Q1, Q2, Q3, Q4 and Q5. Figure 3 explains the RQs.

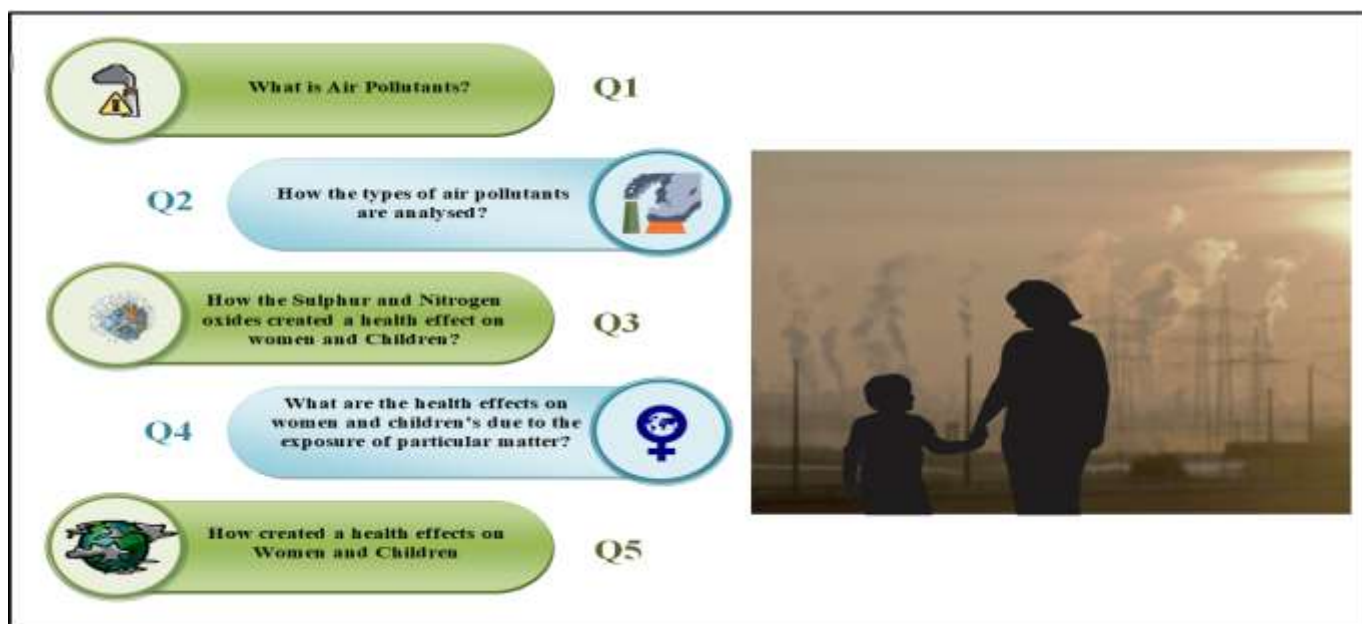


Figure 3: Outline of the RQs

2.2. Article selection strategy

Article selection means that the correct article should be chosen for the appropriate review. The articles are picked based on the requirements and appropriate keywords of the particular review paper. By selecting the correct article for the review, the objective of the review is mainly concentrated effectively.

Inclusion Criteria

- The study that concentrates on the research studies published between 2015 and 2024 is included.
- Papers related to the health effects of air pollutants like sulfur and nitrogen oxides, particulate matter, and phthalate on women and children are included in the study.

Exclusion Criteria

- The article only associated with other pollutants, such as water and land pollutants, is omitted.
- The articles published before 2015 are excluded.
- The articles related to the pollutant materials other than the keywords are excluded.

Resources of Search

The main objective of the resource search is to select the correct search and identify the important proof for the search and presented research. Search resources focus on the areas of the search and the selection of correct relevant articles using the online platform.

Sources: The related studies are taken from academic search engines, such as IEEE Xplore, Elsevier, Springer, and Google Scholar. Thus, the data correlate with the objective of the research. The search concentrates on research materials related to “health effects of sulfur and nitrogen oxides along with particulate matter and phthalate on women and children” within the time frame from 2015 to 2024.

Databases: Important databases, including Scopus, Science Citation Index Expanded (SCIE), and Web of Science (WOS), are used to identify the papers.

Database Insights: Scopus is found to be distinct from other important databases. Scientific journals and conference proceedings are available in the Scopus database; so, it is the best resource for researchers.

Paper selection: In paper selection, 80 papers are selected for this review. Based on the given criteria, the papers are selected and identified. After analyzing the details of the search, the search outcome of this literature survey is described briefly in Figure 4.

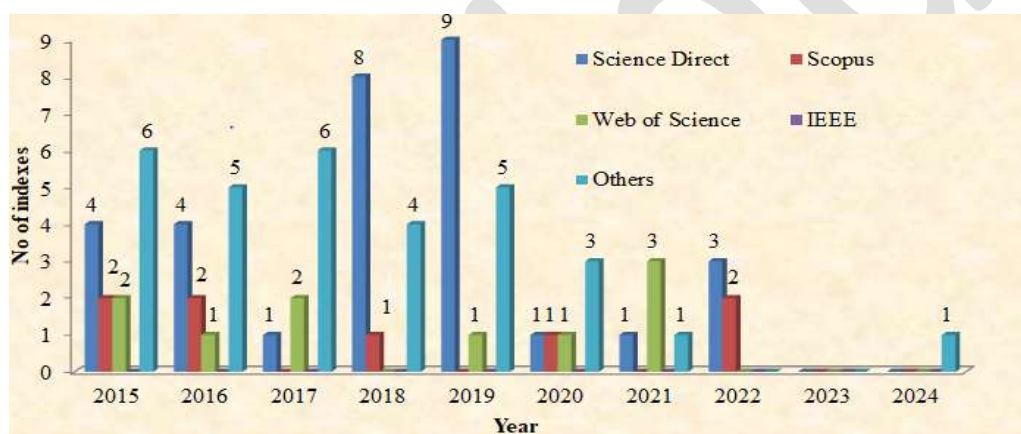


Figure 4: Search results

LITERATURE SURVEY ON HEALTH EFFECTS OF SULFUR AND NITROGEN OXIDES ALONG WITH PARTICULATE MATTER AND PHTHALATE ON WOMEN AND CHILDREN

Exposure to air pollutants increases the risk of respiratory tract infections by the interaction of pollutants with the immune system. Thus, the types of air pollutants contribute to respiratory symptoms in both healthy patients and those with underlying pulmonary disease.

Thus, this paper is introduced to identify the air pollutant, analysis of the types of air pollutants, and health effects of sulfur oxides, nitrogen oxide, particular matter, and phthalate on women and children.

OUTLINE OF COMMON AIR POLLUTANTS

Pollutants are the major cause of the pollution. The air pollutants refer to solid particles that appear as a result of mixing the droplets [11]. From smog hanging over cities to smoke inside homes, air pollution poses a major threat to health and climate [12]. Some of the air pollutants are particulate matter, ground-level ozone, carbon monoxide, sulfur oxide, nitrogen dioxide, and lead [13]. These harmful substances cause serious effects on human health, which affects children and women a lot [14]. The effect can cause serious health effects like breathing and lung disease [15].

ANALYSIS OF THE TYPES OF AIR POLLUTANTS

The articles related to the components and their types, which cause air pollutants are explained in below Table 1.

Table 1: Articles related to the components and the types of air pollutants

Author Name	Objective	Types of air pollutants	Outcome	Limitation
Bobo, et al. [26]	The main objective was to investigate the emission characteristics of sulfur trioxide (SO ₃) simultaneously through ammonia-based limestone wet flue gas desulfurization.	Sulfur trioxide (SO ₃) [One of the types of SO]	From the analysis, SO ₃ under typical ULE technical routes was in the range of 74.33–167.83 and 48.76–86.30 g/ (t of coal).	The field measurements in the real operation of CFPPs were still limited.
Kathrin, et al. [27]	The major goal was to measure the campaign for developing Land Use Regression (LUR) models to predict the spatial variability in several other air pollutants in the Augsburg region.	Particulate matter-(PM _{2.5})	The analysis depicted that the particulate matter was highly correlated with nitrogen oxides.	Augsburg region resulted in a smaller and much denser monitoring network.
Kayes, et al. [28]	The objective was to examine the relationship between meteorological parameters, such as daily mean temperature, relative humidity (%), and the concentration of criteria air pollutants.	Particulate matter-(PM _{2.5} and PM ₁₀)	The regression analysis showed that both the multiple non-linear and linear models performed similarly in predicting concentrations of particulate matter.	(PM _{2.5} and PM ₁₀) exceeded the optimum limit during the dry season. It also had a slightly lower optimum limit during monsoon.

SULFUR OXIDE AND THEIR HEALTH EFFECTS ON WOMEN AND CHILDREN

The chemical component (SO) is one of the major causative factors of the air pollutant [36]. The SO component creates major health problems in women and children, thus leading to respiratory problems, such as bronchitis that can irritate the nose, throat, and lungs [37]. Some of the articles related to the SO and their health effects on women and children are given below in Table 2.

Table 2: Articles related to the SO and their health effects on women and children

Researcher Name	Aim	Health Effects of the SO		Result
		Women	Children	
Qiannan, et al. [38]	The study aimed to examine the association between short-term exposure to SO ₂ and childhood Hand, Foot, and Mouth Disease (HFMD) in Hefei, China.	*	During the cold season, the observed significant association of SO ₂ affected female children aged between 5–14 years old.	In total cases, The Relative Risk (RR) at lag0 was 1.038 (95% confidence interval (CI): 1.018–1.057).
Shuang, et al. [39]	The aim was to evaluate maternal exposure to SO ₂ before and after conception association during the 3 months and the first trimester.	The pregnant women who were exposed to SO ₂ had major effects on the children, with birth defects and premature babies.	The fetus was affected by immature development in the mother's womb.	From the results, the SO ₂ exposure during the 3 months before conception was significantly associated with the risk of hypospadias (highest tertile: OR = 7.40, 95% CI: 3.54–15.62).
Wang, et al. [40]	The aim was to describe the associations between occupational exposures and age at natural menopause in Jinchuan cohort.	The women (naturally exposed to the SO ₂) were found to be affected by early menopause at particular small ages.	*	From the results, the blue-collar workers who were exposed to SO ₂ for 21 – 25 years had the earliest mean ANM.
Xin, et al. [41]	The study aimed to explore the association of SO ₂ in Anhui province and 16 prefecture-level cities from 2015 to 2020.	*	The children who were exposed to SO ₂ had health effects and affected by tuberculosis.	The results showed that SO ₂ exposure had an impact on the risk of outpatient visits for children and students.

*Indicates the data was unavailable

NITROGEN OXIDE AND THEIR HEALTH EFFECTS ON WOMEN AND CHILDREN

The term nitrogen oxide (NO) usually consists of two gases-nitric oxide (NO), which is a colourless and odourless gas, and nitrogen dioxide (NO₂), which is a reddish-brown gas with a pungent odour [46]. Elevated levels of nitrogen dioxide can cause damage to the human respiratory tract and increase a person's vulnerability to the severity of respiratory infections and asthma [47]. Long-term exposure to high levels of nitrogen dioxide can cause chronic lung disease [48]. Some of the articles related to Nitrogen oxide and their health effects on women and children are given below in Table 3.

Table 3: Articles related to Nitrogen oxide (NO) and their health effects on women and children

Authors Name	Aim	Effects of the NO		Result
		Women	Children	
Audrius, et al. [49]	The aim was to assess individual maternal exposure to NO ₂ during pregnancy and to examine the association between the exposure and pregnancy outcomes.	The effect of NO in women with pregnancy was Low. Birth Weight (LBW), Term Low Birth Weight (TLBW), Small for Gestational Age (SGA), and Preterm Birth (PB).	*	The results of the logistic regression analysis showed that LBW risk was increased significantly with increased exposure to NO ₂ .
Benjamin, et al. [50]	The aim was to investigate the exposure to higher amounts of air pollutants, including NO ₂ , associated with increased risk of development and progression of kidney disease.	The women who were exposed to NO ₂ had major health problems like kidney failure.	*	Spline Analysis depicted that the monotonic increased the association between NO ₂ , concentrations, and the risk of kidney outcomes.
Luke, et al. [51]	The aim was to identify the NO ₂ exposure (last 12 months) using monitors near each Child's school.	*	The NO ₂ exposure to air pollutants affected the children's respiratory health.	The increased NO ₂ exposure was significantly associated with predicted FEV ₁ (−1.35 percentage points [95% CI: −2.21, −0.49]) and FVC (−1.19 percentage points [95% CI: −2.04, −0.3]).

* Indicates the data was unavailable

Yu, et al. [54] described the association of wheeze during the first 18 months of life with indoor nitrogen dioxide, formaldehyde, and a family history of asthma. This study was conducted from 1 November 2009 to 30 April 2011 in Local Hong Kong infants born children who were exposed to NO₂. The results provided a possible causal relationship between domestic exposure to formaldehyde and the induction of asthma in children. The study had a lack of full compliance with air sampling.

Jonathan, et al. [55] explained the nitrogen dioxide exposure in school classrooms of inner-city children with asthma. The classroom NO₂ was collected by passive sampling for 1 week periods, twice per year coinciding with lung function testing. From the analysis, the NO₂ attained mean values at about 11.1ppb (range 4.3 – 29.7ppb). The data was limited in the ability to tease apart NO₂ from other co-pollutants.

PARTICULAR MATTER AND THEIR HEALTH EFFECTS ON WOMEN AND CHILDREN

PM is a mixture of solid particles and liquid droplets found in the air [56]. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough that are to be seen with the naked eye [57]. The PM particles had several types like PM_{0.1}, PM_{0.2}, and PM₁₀ [58]. The types of PM particles created air pollutants and caused adverse health effects in women and children [59]. The health problems of PM are heart disease, asthma, and low birth weight. Unhealthy levels can also reduce visibility and cause the air to appear hazy [60]. Some of the articles related to PM and their health effects on women and children are mentioned in Table 4.

Table 4: Articles related to PM and its health effects on women and children

Author Name	Aim	PM study Location	Outcome	Health effects	
				Women	Children
Kalpana, et al. [61]	The aim was to examine the PM _{2.5} exposures during pregnancy associated with birth weight in an integrated rural-urban, mother-child cohort in the state of Tamil Nadu, India.	Tamil Nadu, India	From the analysis, PM _{2.5} exposures associated with 4 g (95% CI: 1.08 g, 6.76 g) decreased the birth weight.	The women were affected by PM particles had complications during pregnancy.	*
Rebecca, et al. [62]	The aim was to investigate the association between maternal exposure to PM _{2.5} and IUI in the Boston Birth Cohort.	Boston (City in Massachusetts)	Comparing the highest PM _{2.5} with exposure quartiles, the multi-adjusted association with IUI was significant for all exposure periods.	*	The foetus was affected with health complications due to the exposure to PM.
Jiu, et al. [63]	The aim was to examine the putative adverse effects of ambient fine particulate matter (PM _{2.5}) on brain volumes in older women.	*	From the analysis, older women with greater PM _{2.5} exposures had significantly smaller white matter.	The effects of PM in older women created a brain disorder.	*
Ly, et al. [64]	The aim of the study was to examine the short-term effects of PM ₁₀ , PM _{2.5} , and PM ₁ on respiratory admissions among young children in Hanoi.	Hanoi, Vietnam	The study demonstrated that children in Hanoi were at increased risk of respiratory problems due to the high level of airborne particles.	*	The effect of PM had a high risk of respiratory problems in children.

PHTHALATES HEALTH EFFECTS ON WOMEN AND CHILDREN

Exposure to higher levels of phthalates has been associated with menstruation disturbances, ovulation abnormalities, and a higher risk of endometriosis [69, 70]. Some of the articles related to phthalates and their studies on the particular location along with the health effects on women and children are given in Table 5

Table 5: Articles related to the phthalates and their studies on the particular location with the health effects on women and children

Researchers Name	Aim	Phthalates study location	Outcome	Effects of Phthalates	
				Women	Children
Mercede, et al. [71]	The aim of the study was to assess the Phthalate exposure and its determinants among children at the age of 7 years from the Polish Mother and Child.	Poland	The phthalates were found to be lower in the most affluent social class, showing statistically significant results ($p < 0.05$).	*	Children who were exposed to Phthalates had skin diseases often.
Daniela, et al. [73]	To evaluate the association between prenatal and childhood phthalate exposure and atopic disease in children at the age of 9 years.	Thailand	The higher urine concentration of mono-2-ethyl-5-oxohexyl phthalate increased the risk of food allergy in children at the age of 9 years.	*	Children were more affected by urinary infections
Wei, et al. [74]	The study aimed to assess Phthalate metabolite levels and explore the factors influencing exposure in children.	Netherlands	From the results, the potential strategies reduced exposure to phthalates, avoiding plastic food containers and chemical fragrances.	*	Children aged 6-12 were mostly affected by the urinary tract infection.

COMPARISON EFFECTS OF SULFUR OXIDES NITROGEN OXIDE PARTICULAR MATTER IN WOMEN AND CHILDREN

When comparing the effects of SO, NO_x, and PM on women and children, it's important to recognize that all these pollutants can have significant health impacts. Respiratory problems like asthma and bronchitis occur because of SO. Children are particularly vulnerable due to their higher breathing rates and developing lungs. Women, especially if pregnant, can also experience exacerbated respiratory conditions. NO exposure can lead to respiratory diseases, such as asthma and chronic bronchitis.

Greenberg, *et al* [76] explained the modelling of long-term effects attributed to NO₂ and SO₂ exposure on asthma morbidity in a nationwide cohort of women and children in Israel. Arithmetic Mean Level (AM), Average Peak Concentration (APC), and total number of air pollution Exposure Episodes (NEP) were used. According to the data, exposure response was better connected with NO₂ peak concentration than with average exposure concentration in asthmatic participants. In all models, SO₂ showed a reduced but still significant exposure-response relationship.

Jian, *et al* [78] explained the association of air pollution with pubertal development with the evidence from Hong Kong Children. PM₁₀ exposure in utero and infancy was negatively linked with pubertal stage and breast development in 1,938 girls, but SO and NO exposures in gestation, during infancy and childhood, were negatively associated with a pubertal stage in 2,136 males.

SUMMARY OF THE REVIEW

In review, the health effects of sulfur and nitrogen oxides along with particulate matter and phthalate on women and children were analyzed. The main purpose of this review was to analyze the effects of these air pollutants on women and children. The health effects along with the overview of the pollutants were explained in the review. The studies associated with the objective also analyzed the air pollutants, types of air pollutants, and the health effects of sulfur and nitrogen oxides along with particulate matter and phthalate on women and children. To make the review paper more innovative, the research questions were categorized into A, B, C, D, and E.

Studies associated with what are air pollutants (A): This question aims to understand the studies associated with air pollutants and is illustrated in section 3.1.

Studies associated with how the types of air pollutants are analyzed (B): This question's objective is to explain the types of air pollutants, which are explained in Section 3.2.

Studies associated with how the SO₂ and NO created a health effect on women and children (C): This question seeks how the SO₂ and NO created a health effect on women and children and is explained in Sections 3.3 and 3.4.

Studies associated with what are the health effects on women and children due to the exposure of particular matter (D): The studies associated with what are the health effects on women and children due to the exposure of particular matter are mentioned in section 3.5.

Studies associated with how phthalates created a health effect on women and children (E): The studies associated with how phthalates created a health effect on women and children are mentioned in section 3.6.

Therefore, this review gives a clear explanation of the air pollutants, their types, and their components, such as sulfur oxide, nitrogen oxides, particulate matter, and phthalates associated with the health effects, and their concentration on the effects are clearly explained.

CONCLUSION

From the detailed literature review, it was noted that the health effects of air pollutants, such as sulfur and nitrogen oxides, particulate matter, and phthalates presented important considerations for both women and children. These pollutants were constantly associated with a wide range of adverse health results from respiratory and cardiovascular issues to developmental and reproductive impairments. In the analyzed research articles, it was found that women experienced unique health effects because of distinct physiological and hormonal factors. Also, children were specifically at risk because of their developing systems and better rates of air intake associated with body size. It was also noted that SO and NO contributed to respiratory diseases and might influence the growth of chronic conditions. Phthalates that were regularly found in various consumer products had been associated with endocrine disruption and potentially affect reproductive health and developmental processes in children. However, the limitation was that evaluating health results connected to air pollution could be difficult because of the occurrence of numerous influencing factors. So, future researchers should consider this limitation and find methods to evaluate the health outcomes of air pollution in an easier way. Providing protection for women and children via targeted policies can help to avoid the health effects and promote a healthier environment for future generations.

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