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# THE EFFECTS OF AIR POLLUTION ON THE UPPER RESPIRATORY TRACT: A SYSTEMATIC REVIEW

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## INTRODUCTION

Air pollution now affects nearly every country in the world and has been described as a public health emergency, with ambient air pollution accounting for approximately 6.5 million deaths across the globe per year.[1] Air pollution is largely due to human activity and industrial growth over the past century and has had a significant impact on global air quality.[2,3]

### COMMON POLLUTANTS AND THEIR SOURCES

Air pollution consists of a complex mixture of particulate and gaseous components, which includes metals, organic chemicals (including volatile organic compounds [VOCs]) and biological materials that surround a carbon core.[4] Some of the most commonly studied air pollutants include particulate matter (PM), ozone, nitrogen oxide, carbon monoxide and sulphur dioxide.[5]

The size of inhaled PM is important for predicting its impact on human health. PM can be classified as: coarse PM, with a diameter between 2.5 µm and 10 µm ($PM_{10}$); fine PM, with a diameter between 0.1 µm and 2.5 µm ($PM_{2.5}$); or ultrafine PM, with a diameter less than 0.1 µm.[6]

Smaller particles (fine and ultrafine PM) have a greater capacity to penetrate further into the airways, reaching the distal regions of the lung.[4] Once in the lungs, water-soluble PM components may be able to enter the circulation by translocating through alveolar capillaries.[2] The sources of PM are varied. $PM_{10}$ largely consists of organic materials from natural sources, such as pollen, mould and re-suspended road dust, while combustion processes account for the majority of $PM_{2.5}$ and ultrafine PM. Ultrafine PM is highly unstable due to its small size and tends to aggregate with other particles a few hours after generation to form $PM_{2.5}$.[6]

## THE BURDEN OF AIR POLLUTION

Diesel exhaust particles have been estimated to account for up to 80% of human exposure to PM and most airborne PM in the world's largest cities.[2] However, there is also growing concern among researchers about the impact of air pollution in smaller cities and towns,[7] and of indoor air pollutants that may arise as a result of cooking indoors, combustion of solid fuels indoors, cleaning operations or emissions from construction materials and furnishings.[8-10] Household fuel combustion accounts for a quarter of global emissions of black carbon, which contributes significantly to climate change; other pollutants generated through household fuel combustion include carbon monoxide, methane, carcinogenic polycyclic aromatic hydrocarbons (PAHs) and VOCs.[9] Household air pollution is particularly concerning for women and children in low- and middle-income countries, owing to higher levels of exposure through increased domestic activity; it is estimated that this group accounted for over 60% of premature deaths from household air pollution in 2012.[9] Greenhouse gas emissions have played a significant role in the rise in global temperatures and, in turn, rising temperatures are expected to lead to a rise in the concentration and distribution of pollutants, such as ground-level ozone.[11] Climate change has also led to extended growing seasons for plants that produce allergenic pollen.[12,13] Prolonged and amplified exposure to allergens in a polluted environment may provide an explanation for the increased prevalence of allergic disease observed across the globe in recent years.[12,14,15]

## THE IMPACT OF AIR POLLUTION ON HUMAN HEALTH

Assessing the risk of air pollution to human health is difficult, since components are present in different combinations and concentrations in ambient air. The effects of air pollution on human health depend on the combination of pollutants, length of exposure and individual susceptibility.[3] Air pollution exposure is often assessed using data from local monitoring stations, but this may underestimate the true extent of exposure, as individuals are likely to encounter many different combinations and concentrations of pollutants as a result of daily activities.[11] Although the World Health Organization provides guideline values for daily and annual concentration of air pollutants, there is currently no evidence of a safe level of exposure or, more importantly, a threshold below which no adverse health effects occur.[10]

Air pollution has been linked to a diverse range of health effects and is seen as a key contributor to the global burden of disease.[16] Exposure to air pollution causes increased morbidity and mortality from respiratory and cardiovascular diseases, evidenced by numerous reports of increased hospital admissions for asthma, chronic obstructive pulmonary disease (COPD), pneumonia and upper respiratory tract infection in association with a range of air pollutants.[17–19] Exposure to air pollution during pregnancy can also affect the developing foetus and lead to low birth weight and lesions of the central nervous system.[3] Mortality is linked to exposure to high concentrations of $PM_{2.5}$ and ultrafine particulates;[16,20] particularly harmful components of PM include heavy metals, PAHs and organic compounds such as endotoxins.[3]

## THE UPPER RESPIRATORY TRACT AS THE FIRST LINE OF DEFENCE

The upper respiratory tract plays an important role in influencing the quality of inspired air and conditioning it before it reaches the lower respiratory tract.[5] When large foreign particles are inspired, they become trapped in the nasal mucus and are removed from the nasal cavity via mucociliary clearance.[5] Hair-like structures called cilia beat in a rhythmic motion to transport particles to the nasopharynx, where they are swallowed or expectorated.[21,22] Inspired particles over 3 µm are often deposited in the nasal valve area (the narrowest portion of the nasal passage), while those between 0.5 µm and 3 µm are trapped and filtered by the nasal mucosa.[23] Pollutants such as ozone may cause temporary defects in ciliary movement, known as secondary ciliary dyskinesia,[22] as well as an increase in the quantity and viscosity of mucus, which could lead to reduced clearance of foreign particles.[24] Dyspnoea (shortness of breath) has also been reported after exposure to air pollutants,[3] which can indicate reduced mucociliary clearance.[22]

Although the nose is able to filter larger particles (between 0.5 µm and 10 µm), those smaller than 0.5 µm are able to pass into the lower respiratory tract.[5,23] Gases of low solubility, such as nitrogen dioxide, are also able to evade the defensive properties of the respiratory tract mucosa and reach the bronchioles. In contrast, water-soluble particles, such as sulphur dioxide and aldehydes, generally have their greatest impact at the level of the upper respiratory tract, where they dissolve into the water around the nasal mucosa and initiate an inflammatory response.[5]

## OUR SYSTEMATIC REVIEW

Given the increasing burden of air pollution, we conducted a systematic review to outline the available evidence for the effects of air pollutants on the upper respiratory tract, and methods of prevention and relief of upper respiratory symptoms caused by air pollution.

# METHODS

Literature searches, guided by pre-specified keywords, were conducted in PubMed for English-language articles published between 2007 and 2017 (Table 1). Results were supplemented with Google Scholar searches to answer the following research questions.

1. What effects do air pollutants have on the respiratory tract, in particular nasal health?
2. What are the main upper respiratory symptoms associated with air pollution?
3. In areas of high air pollution, who is at greatest risk of experiencing allergies and upper respiratory tract symptoms?
4. What are the areas of unmet need in the relief of respiratory symptoms associated with air pollution?
5. Are there any data to support the use of barriers, such as masks or nasal applications, to reduce the symptoms of air pollution in the upper respiratory tract?

The titles and abstracts of all identified articles were screened, with studies conducted on animals, studies involving exposure to tobacco smoke, mould, damp and odorous chemicals, and studies focusing exclusively on lower respiratory disorders, such as asthma and COPD, excluded.

# RESULTS

A total of 680 research articles were identified from the initial PubMed and Google Scholar searches. Following screening, data were extracted from 73 papers (Figure 1). Additional relevant references were also included to supplement the available information.

### 1. What effects do air pollutants have on the respiratory tract, in particular nasal health?

#### OXIDATIVE STRESS

PM generally comprises carbon particles surrounded by reactive metals and organic chemicals, which, depending on the composition of these elements, can have diverse effects on cellular function.[3] Most of the identified articles suggest that pollutants exert their effects by inducing oxidative stress.[2,25,26] Oxidative stress involves the generation of free radicals (reactive oxygen and nitrogen species), which can cause damage to DNA and plasma membranes and lead to inflammation through activation of transcription factors involved in inflammatory pathways, such as nuclear factor kappa-light-chain-enhancer of activated B cells.[2,3]

Combustion-derived particulates can generate free radicals through their surface metals,[2] which may include iron, aluminium, sodium, magnesium, calcium and titanium.[4] Metals accumulate inside cells, where they can bind and inhibit enzymes in addition to affecting intracellular signalling pathways involved in cell proliferation and apoptosis.[3,27] After exposure to $PM_{2.5}$, human bronchial epithelial cells *in vitro* display dose-dependent increases in markers of oxidative damage and apoptosis.[26] Similar findings have been reported in a study of schoolchildren living in close proximity to an industrial estate. Nasal epithelium samples showed more than double the amount of average malondialdehyde–deoxyguanosine adducts, a marker of oxidative stress-induced DNA damage, in comparison to children living in a rural area.[25] $PM_{10}$, $PM_{2.5}$ and ultrafine PM were found to alter genes involved in the nuclear factor erythroid 2-related factor 2-mediated oxidative stress response in bronchial epithelial cells, a mechanism of defence against environmental toxicants.[6] In human nasal lavage samples, exposure to ozone combined with heat has also been associated with the presence of CC16, an anti-inflammatory protein used as a marker of nasal epithelial damage.[28]

## IMMUNE ACTIVATION

Air pollutants can also influence immune function. Two *in vitro* studies indicated that PM exposure can lead to increased expression of pro-inflammatory cytokines in the airway epithelium, including interleukin (IL)-1β, IL-6 and IL-8.[4,29] After exposure to ozone and sulphur dioxide, nasal biopsies taken from healthy individuals displayed evidence of neutrophil infiltration;[30] in allergic individuals, the frequency of eosinophils present in nasal scrapings appeared to be influenced by the presence of pollutants in the external environment.[31]

It has been speculated that air pollution could be responsible for exacerbation and increased prevalence of allergic disease.[2,12] Traditional allergens, such as pollen, induce an allergic response in the airway through presentation of allergenic proteins to the immune system, leading to a $Th_2$-dominant immune response and production of immunoglobulin E antibodies. This can result in inflammation and airway remodelling, leading to asthma and allergic rhinitis in individuals with a genetic predisposition.[2,5] A combination of pollen and air pollutants may elicit a greater immune response than pollen alone, with one review suggesting that nitration of pollen by air pollutants may lead to an increase in its allergenic potential.[32] However, it is not known how often such events occur and some studies have failed to find a link between air pollution and the development of allergic sensitisation.[33–35] In a meta-analysis of five European birth cohorts, no association was found between traffic-related air pollutants and development of allergic disease.[34]

Elevated levels of PM have also been associated with hospital visits for upper respiratory tract infection,[36] which may be due to the effects of pollutants on immune function. Air pollution particulates could lead to an aberrant immune response to infection, with one *in vitro* study reporting that human type II alveolar cells displayed fewer antimicrobial peptides in response to *Mycobacterium tuberculosis* after exposure to both $PM_{10}$ and $PM_{2.5}$.[29]

## EFFECTS ON THE UPPER RESPIRATORY SYSTEM

Structural changes in nasal cells have been documented after exposure to air pollutants. Nasal biopsies taken from humans experimentally exposed to ozone or sulphur dioxide displayed fragmented tight junctions and a disorganised strand network in comparison to biopsies from non-exposed individuals,[30] suggesting that air pollutants may lead to disruption of the epithelial barrier. Drying of the vocal folds has also been reported to increase vulnerability to the effects of air pollution, with sustained insults from environmental sources disrupting the structure of the vocal fold epithelial barrier.[24]

Airborne chemicals can trigger activation of chemoreceptors in the nasal cavity and cause induction of respiratory reflexes, including rhinorrhoea, sneezing, coughing and laryngospasm. Activation of receptors on afferent nerve fibres may also trigger symptoms of irritation.[5]

In addition, nasal function may be affected by air pollutants. In a study of road runners, nasal resistance (measured by anterior rhinometry) was found to be significantly reduced when running inside the city in comparison to outside the city, despite nasal transport time remaining the same in both locations.[37] A decrease in resistance could reduce the ability of the nose to filter particles and, therefore, increase the chance of particles entering into the lower respiratory tract.

### 2. What are the main upper respiratory symptoms associated with air pollution?

The upper respiratory tract is the initial point of contact for inhaled pollutants, yet the majority of studies have focused on the effects of air pollution on the lower respiratory tract and the exacerbation of pre-existing diseases, such as asthma and COPD. However, some common upper respiratory complaints associated with air pollution have been documented in the literature.

**NOSE AND THROAT SYMPTOMS**

There is evidence that the prevalence of allergic rhinitis is increasing worldwide, accompanied by a high prevalence of non-allergic rhinitis caused by air pollution exposure.[15,21,38] In a global study of 2778 allergic rhinitis patients, 51.2% identified air pollution as a potential cause of their symptoms.[38] Allergic rhinitis is caused by activation of the adaptive immune response after exposure to inhaled allergens, and symptoms include nasal and palatal itching, nasal congestion and sneezing.[21] Symptoms of allergic rhinitis and other allergic diseases may be exacerbated when combined with exposure to pollutants, although the exact mechanism by which this occurs is unclear.[2,5] Non-allergic rhinitis is associated with exposure to PM, dust, cleaning solvents and strong odours, and is exacerbated by temperature and humidity changes.[21] Symptoms of non-allergic rhinitis include runny nose, nasal congestion and nasal mucosal erythema (reddening of the skin/mucosa).[21] In a study of air pollution-related symptoms among 3025 individuals living in Thailand, the most frequently reported upper respiratory symptoms were stuffy nose and runny nose, reported by 34.8% and 28.7% of participants, respectively.[39] Studies examining the effects of indoor air pollution on office workers have reported that upper respiratory symptoms, such as upper respiratory tract irritation and infection, are common complaints in buildings with high levels of airborne particles.[40,41] More specifically, building-related symptoms can include nose itching, runny nose, nasal congestion and sneezing, and are linked to indoor carbon dioxide levels.[41]

Inhalation of pollutants can also cause throat symptoms. In office workers, dry throat is reported to be associated with exposure to carbon dioxide and indoor VOCs.[41] In addition, a time-series study in Thailand identified an association between nitrogen dioxide exposure and laryngeal symptoms or dry cough.[39] Furthermore, cough and dry cough have been found to be associated with exposure to nitrogen dioxide and $PM_{2.5}$ in the first year of life.[42,43]

**INFECTIONS**

A number of studies have suggested that air pollutants increase susceptibility to upper respiratory tract infection. In a study of children in Taipei, higher concentrations of nitrogen dioxide and ozone were found to be related to an elevated risk of attending an outpatient clinic due to acute upper respiratory tract infection, including acute pharyngitis, acute laryngitis and influenza.[36] Similarly, elevated rates of paediatric emergency room visits for upper and lower respiratory tract infection were documented after reductions in air quality due to a volcanic eruption in Ecuador.[44] Similar patterns have also been observed in the general population. A study of house calls made by doctors in Paris over a 3-year period identified a correlation between ambient PM and house calls for both upper and lower respiratory disease.[45] An increase of 10 $\mu g/m^3$ in mean $PM_{10}$ levels was estimated to result in a 4.9% increase in relative risk of house calls for upper respiratory disease, with effects appearing to persist for approximately 4 days following exposure to pollutants.[45]

### 3. In areas of high air pollution, who is at greatest risk of experiencing allergies and upper respiratory tract symptoms?

**VULNERABLE GROUPS**

Studies suggest that children and elderly individuals are among the vulnerable groups who are particularly susceptible to the effects of air pollution. Children are especially vulnerable for a number of reasons: a child's immune and antioxidant defence mechanisms are still developing; a faster breathing rate results in inhalation of higher doses of pollutants compared to adults; and they generally spend more time playing outside, where they may be exposed to pollutants.[46] In a study of children in Cordoba, Argentina, those living near industrial areas of the city were at higher risk of suffering upper respiratory tract infections (including common cold, laryngitis, pharyngitis and sinusitis) in comparison to those living further away from industrial sites. These infections were associated with increases in estimated exposure to $PM_{10}$.[47] Elderly residents exposed to air pollution from nearby mine dumps in South Africa were found to have an increased likelihood of chronic respiratory illness, including asthma and bronchitis, in addition to a high prevalence of chronic cough symptoms compared to those who were not exposed.[48]

**PRE-EXISTING ILLNESS**

Individuals with pre-existing illnesses are at increased risk of adverse symptoms following exposure to pollutants. In Milan, incremental increases in ozone concentration were associated with a 78% increase in emergency room admissions for asthma,[19] while in a Taiwanese study, presence of a co-morbid upper respiratory tract infection was found to increase the risk of hospital admission for pneumonia associated with elevated levels of ambient air pollution.[17] Studies in older individuals with congestive heart failure have reported reduced oxygen saturation and increased diastolic blood pressure associated with indoor and outdoor $PM_{2.5}$,[49] as well as poor self-reported health in association with elevated ozone.[50]

A number of cohort studies have investigated a link between air pollution and the development of allergic disease among children, yet there is still no conclusive evidence to confirm an association.[34,35,51] However, air pollution does appear to exacerbate pre-existing respiratory allergies. In a Norwegian study, sufferers of allergic rhinitis were more likely to have poor perceptions of indoor air quality in comparison to individuals with other allergies.[52] Asthmatic individuals are also among susceptible groups who are likely to experience discomfort as a result of indoor air pollution.[53]

**LIFESTYLE EXPOSURE**

Several studies in the literature highlight the importance of lifestyle factors in relation to exposure to air pollutants. Individuals commuting in cities are differentially exposed to PM depending on their chosen mode of transport. The highest PM exposures in London are encountered when commuting via the underground, closely followed by buses,[54] and, in Indonesia, exposure to PM is higher in motorcycle users compared to car users.[55] Five studies investigating the effects of indoor air pollution in city office buildings were also identified.[40,41,53,56,57] Office workers in high-rise buildings may be exposed to ozone, which enters through open windows and doors. This exposure may lead to building-related symptoms, with individuals with allergies or tobacco sensitivity at higher risk.[40,53,56] One study identified that people with nasal histamine hyper-reactivity had a time-dependent increase in mucous membrane irritation compared to atopic individuals, who had a low and stable rate of irritation.[58] This implies that allergy is not the only cause of increased susceptibility to nasal irritants and further investigations are required to determine how individuals respond to nasal irritation caused by air pollution.

## 4. What are the areas of unmet need in the relief of respiratory symptoms associated with air pollution?

Few of the identified articles suggested avenues for prevention and relief of symptoms caused by air pollution, with most proposing avoidance as the best strategy. However, existing treatments for allergic and non-allergic rhinitis may provide relief of nasal irritation, while dietary supplements could enhance the body's own natural defence mechanisms against pollutants.

### AVOIDANCE

The majority of suggestions for relief of respiratory symptoms are focused around avoidance or removal of the source of air pollution. In a survey of allergic rhinitis sufferers, 93.4% of patients were advised by physicians to avoid exposure to irritants and allergens.[38] Although it may not be possible for families based in cities to move to less polluted areas, this strategy has been shown to be effective. Asthmatic children from a polluted city in Italy experienced a four-fold decrease in nasal eosinophil concentration (a marker of nasal inflammation) after spending a week living in a rural environment.[31]

### TREATING EXISTING SYMPTOMS

Few studies recommend specific treatments for relieving the effects of air pollution. Therefore, treatment must be guided by the individual symptoms that arise as a result of pollutant exposure. Nasal irrigation and nasal sprays (often available as over-the-counter [OTC] medications) are two approaches used to treat the symptoms of non-allergic rhinitis associated with air pollution, including nasal congestion and runny nose. For relieving nasal irritation and removing excess mucus, a nasal saline rinse can be considered for both non-allergic and allergic forms of rhinitis.[21,59] The mechanical cleansing action of saline irrigation may help to directly remove irritants from the nose and improve mucociliary clearance via hydration of the nasal mucous membranes and reduction of mucus viscosity.[60] Nasal steroid sprays are an established treatment for allergic rhinitis via the reduction of mast cells, which are the cause of allergic symptoms and inflammation.[21,38] Fluticasone propionate is also indicated for non-allergic rhinitis in the USA;[61] however, more studies are needed to determine its efficacy for relieving symptoms associated with air pollution. In one study examining its efficacy in the relief of non-allergic rhinitis symptoms associated with air pollution (rhinorrhoea and nasal congestion), fluticasone was found to provide similar improvements when compared to placebo, which the authors suggest could be due to low levels of air pollution during the study or a lack of inflammation among the participants, who had low baseline eosinophil counts, indicating a non-inflammatory rhinitis phenotype.[62]

Among allergic rhinitis sufferers, nasal congestion is one of the most bothersome symptoms.[38] Intermittent use of nasal decongestants is recommended for short-term relief, yet no specific studies examining the use of decongestants for symptoms of air pollution were identified in this review. Use of topical nasal decongestants for longer than 5 consecutive days can lead to rebound nasal congestion (rhinitis medicamentosa) and so alternative methods should be implemented for chronic symptoms.[61] Intranasal and oral antihistamines may provide relief from symptoms of itching and sneezing, while anticholinergics can help prevent runny nose.[21]

No specific studies evaluating treatments for relief of cough or throat symptoms caused by air pollution were identified in the literature; however, options are available to treat cough of a variety of origins. Traditional OTC treatments include cough suppressants, decongestants and expectorants.[63] Cough suppressants help relieve coughing attacks, decongestant medications and nasal rinses reduce cough symptoms by increasing mucociliary clearance and reducing post-nasal drip, and expectorants improve the effectiveness of a cough in eliminating purulent substances by increasing the volume of airway water or secretions.[60,63,64] A dry throat may also be relieved using a throat spray or lozenges that directly coat, moisten or deposit active ingredient in the mouth and throat.[65] Specific evidence is needed to support the use of the aforementioned treatments for managing cough and throat symptoms induced by air pollution.

### DIETARY CHANGES

Dietary supplements may help reduce and prevent the effects of air pollution.[42] Children given formula supplemented with the polyunsaturated fatty acids docosahexaenoic acid and arachidonic acid in the first year of life were found to have a lower incidence of upper respiratory tract infection, wheezing, asthma and allergy at 3 years of age compared to those fed non-supplemented formula.[66] Other studies have suggested that dietary antioxidants could represent a potential treatment option to reduce oxidative stress caused by air pollution and attenuate the inflammatory response in asthma.[3,46] Human xenobiotic metabolising enzymes that naturally detoxify foreign compounds could be induced by dietary supplementation,[46] while nutrients with natural chelating properties, such as antioxidants, herbs, minerals and amino acids, could facilitate detoxification after exposure to PM and heavy metals.[3] In addition, a diet rich in plant-based foods containing polyphenols may help to detoxify environmental carcinogens.[3]

## 5. Are there any data to support the use of barriers, such as masks or nasal applications, to reduce the symptoms of air pollution in the upper respiratory tract?

Avoiding exposure to air pollution is difficult, especially for inhabitants of large cities. For many individuals, protective barriers may be the next best option for minimising exposure to air pollution. However, the efficacy of masks and nasal filters can vary substantially depending on the material from which they are made and their fit around the face.

### NASAL FILTERS

Two papers investigated the use of nasal filters for the prevention of upper respiratory tract symptoms due to air pollution. One review of evidence from five clinical studies suggested that nasal filters are effective in reducing symptoms of allergic rhinitis and may be a viable alternative to masks for use in polluted areas.[67] An open clinical study of allergic rhinitis sufferers found a significant reduction in runny nose, nasal congestion, nasal pruritus and sneezing in those who used silicone nasal filters for 4 hours a day versus controls. Moreover, those in the treatment group also reported a reduction in antihistamine use.[68] Challenges exist in the development of nasal filters that allow for differences in the shape and size of individual nostrils, are comfortable to wear, aesthetically acceptable and effective in filtering smaller particles while maintaining airflow resistance. However, recent advances in 3D printing technology may provide an opportunity for development of custom-made nasal filters to help resolve these issues.[67]

### MASKS

Masks are recommended for protection against environmental pollutants, especially for people commuting on roads.[7,55] An Indonesian study compared three types of mask (surgical masks, bandanas and motorcycle masks) in road users and found that surgical masks were able to reduce exposure to $PM_{10}$ and $PM_{2.5}$ by 71% and 30%, respectively. Conversely, both motorcycle masks and bandanas reduced $PM_{10}$ but led to an increase in $PM_{2.5}$. The reason for this was undetermined, though it may relate to accumulation of particles inside the mask or a high level of particle penetration through fabric bandanas.[55] In general, masks and fabrics are more efficacious at preventing entry of larger particles, with fabrics reported to only provide a filtration efficiency of up to 33% for particles of 1 µm.[69] Masks and fabrics must be sealed around the edge of the face to provide optimal protection; PM may leak through the top, bottom and sides of masks that do not fit properly[67,70] and, therefore, masks must be specially designed if they are to be used by young children, who are especially vulnerable to the effects of air pollution. A basic N95 respirator mask may provide superior protection in comparison to a surgical mask, and can provide protection against both $PM_{10}$ and $PM_{2.5}$.[67,70]

## CONCLUSIONS

Air pollution comprises a mixture of PM and gaseous components, which can lead to a variety of upper respiratory symptoms, including runny nose, sneezing and cough, in exposed individuals. Air pollution can also exacerbate pre-existing respiratory illness and allergy, and increase the likelihood of contracting an upper respiratory tract infection. Current treatments for allergic and non-allergic rhinitis are effective and well tolerated; however, more evidence is needed to support the efficacy of such treatments for relief of air pollution-related symptoms. Nasal filters and masks are efficacious at reducing exposure to common pollutants and allergens, and may represent a good alternative when avoidance of air pollution is not possible. A plant-based diet, supplemented with dietary antioxidants, may help harness an individual's own antioxidant defences and provide a novel way of preventing and reducing the effects of air pollution.

Further characterisation of the effects of individual air pollutants at the cellular level is needed to fully delineate the relationship between air pollutants and respiratory function. In addition, in order to develop effective treatments for relieving symptoms caused by air pollution, those symptoms must be better characterised and distinguished from general symptoms of infection and allergy. A greater understanding of the relationship between allergy and air pollutants will also help explain the relationship between air pollution and the increasing prevalence of allergic respiratory diseases.

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## TABLES AND FIGURES

### TABLE 1: SEARCH STRINGS FOR PUBMED LITERATURE SEARCHES.

| RESEARCH QUESTION | SEARCH STRING |
|---|---|
| 1 | "Nose"[MeSH] OR "Pharynx"[MeSH] OR "Larynx" OR "Respiratory Mucosa"[MeSH] OR "Upper Respiratory" AND "Air Pollution"[MeSH] |
| 2 | "Nose"[MeSH] OR "Pharynx"[MeSH] OR "Larynx" OR "Respiratory Mucosa"[MeSH] OR "Upper Respiratory" AND "Air Pollution"[MeSH] AND "Symptoms" OR "Signs and Symptoms, Respiratory"[MeSH] |
| 3 | "Nose"[MeSH] OR "Pharynx"[MeSH] OR "Larynx" OR "Respiratory Mucosa"[MeSH] OR "Upper Respiratory" AND "Air Pollution"[MeSH] AND "Symptoms" or "Signs and Symptoms, Respiratory"[MeSH] AND "Persons"[MeSH] |
| 4 | "Signs and Symptoms, Respiratory"[MeSH] AND "Air Pollution"[MeSH] AND "Therapeutics"[MeSH]<br><br>"Nose"[MeSH] OR "Pharynx"[MeSH] OR "Larynx" OR "Respiratory Mucosa"[MeSH] OR "Upper Respiratory" AND "Air Pollution"[MeSH] AND "Symptoms" or "Signs and Symptoms, Respiratory"[MeSH] AND "Therapeutics"[MeSH] |
| 5 | "Nose"[MeSH] OR "Pharynx"[MeSH] OR "Larynx" OR "Respiratory Mucosa"[MeSH] OR "Upper Respiratory" AND "Air Pollution"[MeSH] AND "Symptoms" or "Signs and Symptoms, Respiratory"[MeSH] AND "Prevention" OR "Barrier" OR "Masks"[MeSH] OR "Filters" OR "Nasal Filter" |

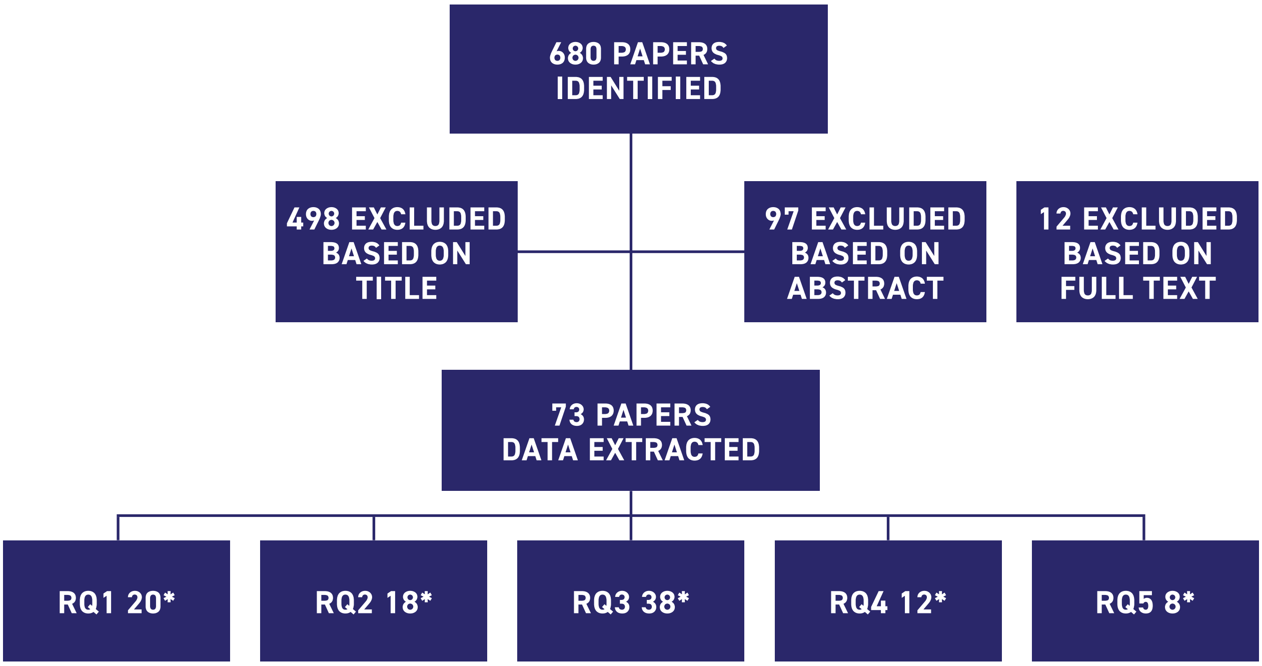


**FIGURE 1: FLOW DIAGRAM OF ARTICLES IDENTIFIED FOR INCLUSION.**

*Some articles deemed relevant for more than one research question.
RQ, research question.