

Outdoor environment

Introduction



Key points

- A large proportion of the European population lives in areas with unhealthy outdoor air quality, and is thus unable to avoid exposure to the harmful effects of pollution.
- The health effects of outdoor air pollution are the result of a mixture of gaseous and particulate pollutants, acting independently and in concert.
- The acute and chronic effects of outdoor air pollution are distinct from each other and must be studied independently.
- Daily variations in outdoor air pollution cause daily variations in mortality and respiratory symptoms.
- In the long term, outdoor air pollution can reduce life expectancy, affect lung development, increase asthma incidence and lead to other chronic respiratory diseases.

Like tobacco smoke, ambient air pollution is a well-established cause of morbidity and mortality. However, unlike smoking, air pollution is not a lifestyle choice but a ubiquitous involuntary environmental exposure, which can affect 100% of the population from the womb to death. Large parts of the European population continue to live in areas with unhealthy air quality. For some pollutants and in some regions, this situation is not improving and is even deteriorating. Changes in combustion and fuel technologies, industrial production, movement of goods and urban planning affect the constituents, and thus possibly the toxicity, of air pollution, in addition to the degree of exposure.

Pollution: composition/sources

Air pollution results from a complex mixture of thousands of pollutants. This mixture may include solid and liquid particles suspended in the air (particulate matter (PM)), and various gases such as ozone (O₃), nitrogen oxides (NO₂ or NO_x), volatile organic compounds (VOCs), and carbon monoxide (CO). The mixture varies with geographical location and the sources of the emissions. Particles vary in number, size, shape, surface area and chemical composition, while both particles and gases may vary in solubility and toxicity. The most important processes causing air pollution relate to the combustion of fossil fuels used in cars and

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trucks, aeroplanes, vessels or other engines, as well as in industries, power plants or household heating systems. Due to the close proximity of people to emissions, transport-related activities, particularly the use of cars and trucks, are an important source of air pollutants.

Traditionally, studies of the health effects of air pollution have measured some marker of air pollution, *e.g.* size-specific PM fractions, such as particles with an aerodynamic diameter of $<10\ \mu\text{m}$ (PM₁₀) or $<2.5\ \mu\text{m}$ (PM_{2.5}), respectively, or NO₂. Commonly used indirect markers of traffic-related pollutants are traffic density at the nearest road or residential distance from busy roads.

Pathophysiological effects of air pollutants

While experimental studies have shown a range of effects related to single pollutants, it should be emphasised that the effects of ambient air pollution cannot be assigned to a single pollutant in the mixture. As in the case of tobacco smoke, many pollutants act together in a series of partly interrelated mechanisms, which result in the observed associations between levels of air pollution and a range of health outcomes. Oxidative stress and both local and systemic inflammation are suggested to be the main harmful mechanisms set in train following the inhalation of these pollutants. A first step may be the generation of reactive oxygen species in the lung cells (*e.g.* from contact with the carbon core of inhaled particles where toxic substances such as sulfates, nitrates and metals are adsorbed). PM of various sizes and highly oxidative gases (*e.g.* O₃ or NO_x) have been shown to induce local pulmonary reactions related to oxidative stress. Both local and systemic inflammatory reactions, mediated through cytokines and chemokines, have been found in experimental studies in cellular systems and in animals, as well as in exposure-chamber studies with human subjects.

Claims that one specific aspect or constituent of ambient air pollution is 'more important' than others need to be interpreted with great caution. Such comparisons are inherently difficult to make, as the effect also depends on the health outcomes under study, the timescale (*e.g.* acute *versus* long-term effects) being considered, the underlying susceptibilities of the exposed individuals, and possibly the nature and concentrations of the co-pollutants.

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Marker of air pollution	Questionnaire-based respiratory health data	Objective respiratory markers	Biomarkers of effect	Health system use	Acute effects on mortality	Long-term effects on mortality/ life expectancy
Particulate matter	Respiratory symptoms	Diminished lung function, impaired growth of lung function	Airway inflammation, chronic lung disease	Emergency admissions for respiratory diseases, asthma	Increase in daily mortality	Increased mortality from cardiopulmonary diseases
Ozone	Respiratory symptoms	Diminished lung function	Airway inflammation	Emergency admissions for asthma	Increase in daily mortality	Suggestive for respiratory death
Nitrogen oxides	Respiratory symptoms	Increased bronchial reactivity, impaired growth of lung function	Airway inflammation, alteration in lung immune defences	Emergency admissions for respiratory diseases	Increase in daily mortality	Increased long-term mortality from cardiopulmonary diseases

Table 1 – Examples of established associations between frequently used markers of ambient air pollution and various respiratory health outcomes. Markers of air pollution are often correlated with each other and the health effects are often nonspecific. While urban air pollution is considered a cause of these adverse health effects, specific effects cannot be assigned to single pollutants.

Respiratory health effects

The respiratory tract is the portal of entry of air pollutants, and thus the lung is the first organ affected. The range of respiratory diseases that can be caused by air pollution exposure is large. Studies on the health impacts of air pollution differentiate between acute and chronic effects. The acute effects of pollution may be apparent within hours or days of exposure, but other health effects of air pollution result from long-term exposure, leading to chronic disease. While the acute and chronic effects of air pollution are partly interrelated, the distinction is important when planning and interpreting epidemiological studies as well as for policy making. Table 1 summarises the most important respiratory health effects of air pollution and how they can be measured.

Short-term respiratory effects of air pollution

Daily mortality


Several epidemiological studies have shown that the daily number of deaths, mainly from cardiovascular and respiratory diseases, tracks daily fluctuations in air pollution. A seminal European multi-city time-series analysis, APHEA (Air Pollution and Health: A European Approach), carried out in 29 study centres, found an increase of deaths from illness of 0.6% per 10 $\mu\text{g}\cdot\text{m}^{-3}$ increase in daily PM₁₀ concentration, and data from hundreds of cities around the world have shown similar results. Studies on short-term mortality show that in general the air pollution-related relative risk is higher for respiratory outcomes than for cardiovascular ones, but since more people die from cardiovascular diseases, the absolute number of cardiovascular deaths related to air pollution is as large as, or larger than, the number of respiratory deaths attributable to air pollution.

Daily respiratory exacerbations

The daily variation in disease burden due to urban pollution is also shown by increases in the number of emergency hospital visits and admissions due to respiratory diseases, including asthma. The APHEA study reported increases per 10 $\mu\text{g}\cdot\text{m}^{-3}$ change in daily PM₁₀ concentration of: 1.2% for asthma in children; 1.1% for asthma in adults aged up to 64 years; and 0.9% for all respiratory diseases (including chronic obstructive pulmonary disease (COPD), asthma and other respiratory diseases) in the elderly.

Patients with asthma, especially children who are not receiving anti-inflammatory or bronchodilator therapy, suffer more on or after days with higher pollution levels. Because of the large individual day-to-day variation in, and the many concomitant factors that influence, asthma symptoms, effects in asthmatic patients are not easily demonstrable without strict adherence to the study protocol and individualised exposure assessment. However, panel studies (longitudinal studies in which participants repeatedly provide information over some period of time) on asthmatic patients employing such rigorous methods have noted increased wheezing, cough and attacks of breathlessness, accompanied by poorer lung function and the need for additional medication, associated with daily variations in PM, NO₂ and/or O₃.

Weather influences the daily variation of pollutant concentrations considerably, with both unduly high (such as heatwaves) and low temperatures having consequences for health. Therefore, all studies on the short-term effects of air pollution need to take account of the effects of weather and other factors that vary over time. Modern



epidemiological methods enable the effects of such covarying factors to be disentangled from those attributable to the pollutants.

Long-term consequences

Long-term or lifetime exposure to ambient pollutants may also have pathological effects that eventually result in chronic ailments. The investigation of these effects usually requires large studies and, ideally, follow-up investigations over many years; consequently, fewer studies have investigated these types of effects. However, in the past 10 years, several studies have also confirmed the existence of chronic adverse effects of ambient air pollution.

Mortality and life expectancy

Mortality and life expectancy are important markers of lifetime morbidity and therefore play an important role in air pollution research. Studies conducted in Europe, the USA and Canada have confirmed that the overall effects of pollution on mortality are far larger than the fraction attributed to acute exposures. In general, respiratory disease is less often the cause of death than cardiovascular disease, and the two are often combined in the category of cardiopulmonary mortality. Cardiopulmonary mortality was associated with long-term differences in PM and sulfate concentrations between cities in the Harvard Six Cities Study and in the American Cancer Society (ACS) study. Comparison of community-level concentrations of fine PM with death rates 16 years later among more than 500 000 participants in the ACS study showed a 6% increase in cardiopulmonary deaths per $10 \mu\text{g}\cdot\text{m}^{-3}$ of PM_{2.5} in models taking a range of other factors into account. In a further analysis of the data from the Los Angeles (USA) area after 18 years of follow-up, modelled PM_{2.5} concentrations were assigned to each residence. This more accurate assignment of exposure resulted in larger mortality estimates, with cardiopulmonary mortality increasing by 20% per $10 \mu\text{g}\cdot\text{m}^{-3}$ increase in concentration of PM_{2.5}. While traffic-related pollutants continue to play a dominant role in Europe, other sources of air pollution – including biomass burning or PM during Saharan dust episodes – also result in adverse effects.

Cohort studies in Europe have been able to confirm the relationship between cardiopulmonary death risk and pollution (figure 1). In three European studies, it was possible to analyse the data for respiratory and cardiovascular mortality separately. The results showed that urban air pollution, assessed individually for all participants by modelling traffic emissions of NO_x, was associated with overall mortality,

mortality from ischaemic heart diseases, respiratory mortality, lung cancer mortality and (weakly) with cerebrovascular mortality. A Dutch cohort study with 20 years of exposure data observed weak associations of traffic density on the nearest main road with cardiopulmonary death. Respiratory deaths were related to NO_2 , black smoke, traffic density within a radius of 100 m, and living near a main street.

Chronic respiratory disease in children

Children are more active and engage in more outdoor activities than adults. They breathe more rapidly and their metabolic rate is higher. Children's immune systems are not fully developed, so the incidence of respiratory infections is high. Their lungs are still growing and any deficit in growth will have an impact for the whole of the child's life. Moreover, possible confounding or modifying factors, such as active smoking, occupational exposure to dust and smoke or medical treatment, are largely absent, making the interpretation of epidemiological results more straightforward. Investigations into the development of lung function in children and the incidence of asthma – the most important chronic disease in children – are particularly relevant and interesting.

Symptoms

As early as the 1980s, several cross-sectional studies from Germany, Switzerland, France and the USA showed that school-age or pre-school children in communities exposed to higher levels of dust, sulfur dioxide (SO_2) and NO_2 suffered more from cough and acute bronchitis than children in less polluted regions. This phenomenon has been confirmed in recent studies.

Lung function (spirometry)

More recently, many cross-sectional studies have reported lower lung volumes in children living in more polluted areas. Of outstanding importance is the largest and most detailed long-term study ever conducted on air pollution and lung development in children, namely the University of Southern California (USC) Children's Health Study from the greater Los Angeles area. Several cohorts recruited during elementary or middle school and followed into adulthood confirm that ambient air pollution jeopardises the development of children's lungs, resulting in lower lung volumes and maximum expiratory flows at 18 years of age.

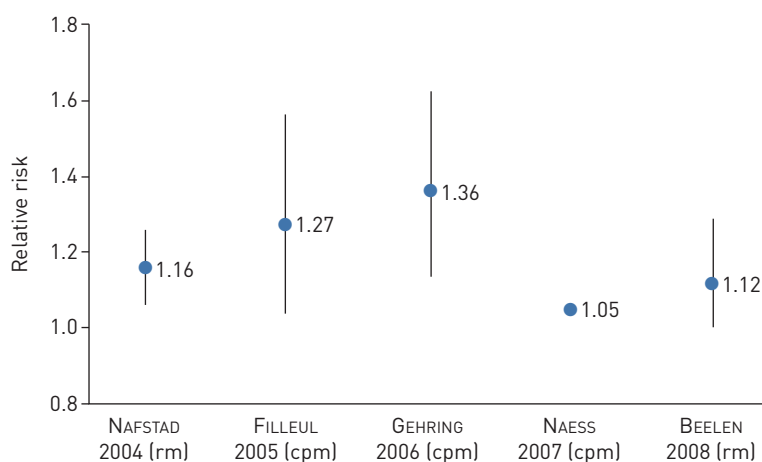


Figure 1 – Relative risks (RR) for respiratory (rm) or cardiopulmonary (cpm) mortality with 95% confidence intervals from European cohort studies on air pollution expressed per $10 \mu\text{g}\cdot\text{m}^{-3}$ increase in NO_2 or NO_x .



Childhood asthma

While exacerbations of asthma clearly correlate with air quality, geographical comparisons of the prevalence of asthma or allergies do not follow differences in urban background levels of pollutants, such as PM_{2.5} or PM₁₀. Novel approaches now integrate local measurements of traffic-related pollutants, geographic information systems, information about land use and spatial modelling techniques to characterise the local distribution of traffic-related pollutants within communities. People living alongside busy roads experience several-fold higher exposures to traffic-related primary pollutants than people living some 50–100 m further away. Epidemiological studies investigating the prevalence of childhood asthma as a function of proximity to traffic strongly suggest that living close to a busy road increases the risk of developing asthma in childhood, even with confounding factors taken into account. Despite rather different urban structures, traffic patterns and car fleets, this finding has now been confirmed in seminal cohort studies both in the USA (e.g. the USC Children's Health Study) and Europe. Most importantly, a European birth cohort, with children followed up to 8 years of age, has confirmed a higher incidence of asthma related to ambient air pollution. The results of the USC study are strongly suggestive that there is an interaction between genetic factors and exposure to traffic-related pollutants.

The contrasting lack of association between asthma onset and urban background pollution, and the strong associations between proximity to traffic arteries and asthma incidence – controlling for socioeconomic differences – suggests that those pollutants occurring at very high concentrations along street corridors (e.g. ultrafine particles, black carbon, particle-bound metals) play a key role in the genesis of asthma. Indeed, several recent reviews have concluded that near-road traffic-related air pollutants are causally related to the development of asthma in childhood. Urban planning decisions may therefore have major public health implications. The results place diesel cars, trucks and buses that emit particularly high concentrations of soot and large numbers of very toxic substances loaded on particles from exhaust, abrasion, and suspension, at the centre of the policy debate. While some believe that the impact of traffic-related air pollution on asthma prevalence is small, several health impact assessment studies have now confirmed that the public health burden of living close to a busy road is substantial. This is particularly the case in Europe, where a large proportion of urban citizens live along heavily trafficked street canyons.

Chronic respiratory disease in adults

The most important risk factor for chronic respiratory diseases in adults is smoking, and the health effects of

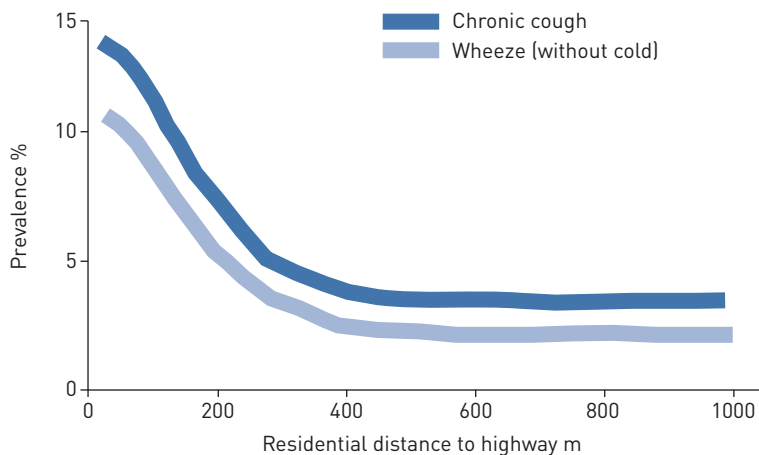


Figure 2 – Frequency of cough and wheeze is highest in Swiss adults living close to the highway. The spatial distribution of symptoms follows the spatial distribution of near-road traffic-related pollutants such as ultrafine particles, diesel soot, carbon monoxide and other primary pollutants. Associations are adjusted for other risk factors. Adapted from HAZENKAMP-VON ARX *et al.*, 2011.

smoking and ambient air pollution have much in common. Studies evaluating the impact of outdoor air pollution on diseases such as COPD and asthma in adults need to take into account the inter-correlation of these factors, in addition to individual traits such as age, sex and genetic factors. Results based on people who have never smoked are particularly valuable.

Symptoms

Chronic cough and phlegm have been associated with long-term ambient PM exposure in several repeated cross-sectional studies in the USA and Europe. The Swiss study on Air Pollution and Lung Disease in Adults (SAPALDIA) confirmed that the prevalence of chronic symptoms declined as individually assigned home outdoor air quality improved. Some studies have shown that respiratory symptoms are more prevalent among participants living close to main streets, independently of background pollutant concentrations. As mentioned in the introduction to this chapter, air pollution is a complex mixture of constituents and such findings may indicate the independent role of some pollutants (or clusters of pollutants) in causing the same or similar health responses. Figure 2 shows the distribution of the prevalence of cough and wheeze among Swiss adults as a function of their residential distance from the highway. This cross-Alpine transit route is the dominant source of primary traffic-related pollutants in this rural valley. In contrast to more homogeneously distributed fine particles, the distributions of traffic-related primary pollutants – such as ultrafine particles, diesel soot, CO, NO or metal-rich resuspended particles – follow the very same spatial patterns.

Lung function and COPD

Many studies (mostly cross-sectional, *i.e.* at a single time-point) have reported associations between lung function and air pollution, and there is a degree of inconsistency in the results, possibly for methodological reasons. Most importantly, reduction in exposure to pollutants has been shown to reduce age-related decline in lung function – a highly relevant finding observed in the SAPALDIA study where exposure to ambient air pollution was estimated at the individual level, taking full account of changes in residence during the 11-year follow-up. While a few studies support the notion that air pollution may also contribute to the development of COPD, further investigations are needed. Major difficulties with this assessment relate to more general challenges and uncertainties in COPD research. While air pollution is clearly

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associated with impaired development of lung function in children (as discussed previously), the way in which poor lung function in early life relates to later development of COPD is not clearly defined or understood. Moreover, air pollution triggers respiratory symptoms and enhances infections, but it is not known how these findings relate to the development of COPD, though cohort studies confirm that people with chronic symptoms and repeated infections are at higher risk of developing COPD. Last but not least, it is not well established whether COPD in nonsmokers and smokers can be considered as the same phenotype of disease.

Adult asthma incidence

As in children, asthma in adults is not correlated with urban background levels of pollution such as PM_{2.5}. However, the few studies investigating the contribution of local traffic-related air pollution to asthma onset in adults have produced similar findings to those looking at childhood asthma incidence. More research is needed to clarify these results and the interaction with atopy, genetics and other host factors.

Lung cancer

In nonsmokers, lung cancer is a relatively rare disease with a long latent period. The time from diagnosis to death is often short, and treatment has limited success. To look at lung cancer in population-based studies, the population sample needs to be large and the follow-up time long. Therefore, despite the coherence between experimental information, occupational studies and many results in population studies, not all long-term epidemiological studies have shown a link between ambient air pollution and lung cancer mortality. In the ACS cohort study, lung cancer incidence increased by 8% per 10 $\mu\text{g}\cdot\text{m}^{-3}$ increase in PM_{2.5} levels, measured as between-city difference; in a Danish cohort study, lung cancer incidence increased by 3.7% per 10 $\mu\text{g}\cdot\text{m}^{-3}$ increase in NO_x, used as a marker of exposure to traffic-related pollutants. Most importantly, particles – in particular those from diesel engines – are loaded with carcinogens. The Californian Environmental Protection Agency as well as the International Agency for Research on Cancer list diesel exhaust as an established carcinogen.

The large-scale European Study of Cohorts for Air Pollution (ESCAPE) will add to the evidence of long-term effects of air pollution on chronic diseases, including a range of respiratory ailments, such as the incidence of asthma and COPD and the symptoms of bronchitis, as well as the development of lung function and lung cancer (www.escapeproject.eu). Rigorous and standardised assessment of the exposure of European citizens to traffic-related pollution will highlight future policy requirements to tackle air quality along busy roads and highways.

The importance of susceptibility

To understand and interpret the observed respiratory health effects, it is crucial to acknowledge the relevance of susceptibility (or protective) factors that modulate individual reactions to exposure to ambient pollutants. The identification of susceptibility factors is subject to intense research. Given the relevance of the pathophysiological mechanisms mentioned previously, it is not surprising that an increasing number of studies report stronger effects of air pollutants in subjects with limited capacity to defend against oxidative stress and to balance inflammatory responses. Such modulating factors may relate to sex, age, underlying diseases and pro- and anti-oxidant intake, as well as a range of genetic characteristics. For example, a controlled trial in Mexican children not only confirmed the association between O₃ and respiratory health, but also revealed interactions related to oxidative stress pathways: children with anti-oxidant treatment were far less affected by O₃ than the placebo groups; and children with functional variants of the *GSTM* gene were protected against the adverse respiratory effects of ozone.

Relevance and outlook

Just as medicine should be based on evidence, public health action and policy should be grounded in science. Despite many unanswered questions, the evidence is sufficient to advocate sustained improvements of air quality across Europe. Thus, current scientific knowledge must reach policymakers in a comprehensible way. This is particularly urgent in the European Union, where air-quality standards are less stringent than in many individual member states and other areas of the world, and in conflict with research findings and the guidelines proposed by the World Health Organization (WHO). As with tobacco smoke, the voice of health professionals is instrumental in shaping the opinions of the public and policymakers. European research findings make a strong case for sustained improvements in air quality to support public health. In fact, the early tri-national European health impact assessment of air pollution emphasised what several local and trans-European analyses have since confirmed: the public health impact of air pollution is very substantial, thus, the benefits of a reduction in air pollution will be large, in terms of both cost-relevant morbidity and the summary health indicator of life expectancy. As shown in recent assessments on childhood asthma and air pollution, the benefits of clean air have, if anything, been substantially underestimated in the past.

Further reading



Reviews and risk assessments

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