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Effects of atmospheric pollution on human health*

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Abstract. Most air pollutants do not lead to specific diseases. Depending on the pollutant, the concentration and the duration of exposure, some organs are more affected than others. The most frequent disorders are those caused by irritant gases and particulates on the mucous membranes and respiratory organs. The consequences are eye, nose and throat inflammations, diminished lung function, increased susceptability to respiratory infection and a higher incidence of chronic bronchitis. These disorders and diseases are, of course, influenced by other factors as well, such as immune deficiency, allergies, occupational exposure to pollutants, and particularly smoking. The effects of air pollutants are, therefore, multifactorially conditioned and nonspecific disorders are placed in the foreground. Evidence for an association of air pollution with adverse effects on human health is drawn from three sources: animal experiments, experimental human exposures, and epidemiologic studies of exposed human populations. The burden of atmospheric pollution must be reduced to protect human health by an adequate safety margin. In particular, the increased sensitivity of sick and aged people as well as children should be taken into account. In defining the maximum emmission levels, preventive aspects should have priority so as to keep the risk of damage to health and the harmful influences on the environment to a minimum.
Key words. Air pollutants; health effects; epidemiological studies; experimental studies; air quality standards.

Methods for proving health effects

Today we have relevant scientific methods by which the influence of diverse factors can be investigated and considered. With these we can make statements about the effects of air pollution on human beings and the environment. For a comprehensive evaluation, however, multiple investigations using different types of field equipment and posing different types of questions are always necessary. The two most important study methods for proving the effects of air pollution on health are epidemiological investigations and experimental studies[13].

Epidermiological studies are investigations for establishing the effects of the actual air pollution load on a particular population group. We differentiate between 'cross-sectional studies', in which the frequency of particular health problems in areas with different air pollution levels are compared, and 'longitudinal studies', where comparative observations are made of the same population groups while under exposure to lower and higher air pollution levels. (For example before, during and after smog episodes.) The meaningfulness of such studies depends on the size of the investigated group, the size of the sought or observed difference concerning health effects, and the level of pollution. The distribution in relation to age, sex, general health and social status must be comparable between the investigated groups. Furthermore, we must take into account the influence of intervening factors such as smoking habits, occupational exposure and climate.

Experimental studies establish the effects of individual pollutants or mixtures of pollutants depending on the dosage, time of exposure, the physical activity, temperature and the air humidity. These studies are conducted with voluntary subjects by standardized methods and under precisely controlled conditions. The results are valid for the investigated group under the controlled experimental conditions. They have only limited generality to conditions in the real environment where there are different mixtures of pollutants and changing climatic conditions.

The following results of investigations have shown a correlation between the frequency of chronic respiratory diseases and respiratory symptoms in healthy persons (adults and children) with the extent of air pollution over extended periods of time.

Examples of 'cross-sectional studies'

Chapman et al.[8] made cross-sectional investigations in four cities which had different levels of pollution in Utah, in the USA. They interviewed in total 5623 mothers and fathers of school children. They established the long-term effect of relatively low concentrations of sulphur dioxide on the frequency of chronic coughs and expectoration. In the most heavily exposed city (Magna) the average 5-year values of sulphur dioxide concentrations were 115 micrograms per cubic meter and of sulfates 14 micrograms per cubic meter ($\mu g/m^3$). In the other cities the respective values lay between 11 and 36, respectively 5 and 8 $\mu g/m^3$. The prevalence of chronic coughs and expectoration in Magna for the non-smoking mothers was 4.2% and for the non-smoking fathers 7.8% on average. For the smoking mothers the prevalence was 21.8% and for the smoking fathers 22.2% on average. In the other cities the respective prevalences were significantly lower, on average 2% or 17% respectively. No significant difference was found between the cities with low pollution levels.

Mostardi et al.[12] investigated lung function values and the frequency of respiratory symptoms among 146 children in the age group 10 to 11 in an area with heavy pollution and also 153 children in the same age group in an area of low pollution. The frequency of respiratory symptoms (coughing, runny noses, hoarseness, colds, irritation of the eyes) was established by a questionnaire filled in by the parents. Lung functions were measured by means of a spirometer at school. At the school with the higher pollution load the mean daily values during the school year for sulphur dioxide were 77 and for nitrogen dioxide 54 $\mu g/m^3$. Individual symptoms per day were about twice as frequent than in the school with less pollution (sulphur dioxide 21 and nitrogen dioxide 37 $\mu g/m^3$). Furthermore the lung function values during acute respiratory tract infections showed a larger degree of disorder.

Braun-Fahrländer et al.[3] investigated the association between air pollution and respiratory symptoms in a diary study on a random sample of 1063 Swiss children aged from 0 to 5 years in four different areas of Switzerland (two urban, a suburban and a rural area). Passive samplers inside and outside the home measured nitrogen dioxide concentration over 6 weeks. During this time diaries were filled out by parents. 20% of them were validated with the attending pediatrician's case notes and were in good agreement. The frequency of respiratory symptoms per child per day was found to increase with increasing levels of nitrogen dioxide measured outdoors. The relationship was more significant for the non-smoking families with Swiss children. Possible other factors were accounted for by multiple regression analysis; the variables 'season' and 'child's susceptibility to colds' also showed a significant association with respiratory symptoms. But the relationship between nitrogen dioxide outdoors and respiratory symptoms per child per day remained statistically significant. The result indicates that air pollution is a contributory factor in the development of respiratory symptoms in children.

Euler et al.[9,10] investigated the effect on the frequency of chronic obstructive airways disease from long term exposure to airborne dust pollution and sulphur dioxide, using a questionnaire from the National Heart, Lung and Blood Institute. Their subjects were a group of healthy adults. The relative risk, 1.18, under a concentration of sulphur dioxide of more than 105 $\mu g/m^3$ over 500 h per year, was significantly increased. With a concentration of airborne dust particles of more than 150 $\mu g/m^3$ (2500 h per year) a relative risk of 1.32 was also found. The same test group was exposed to oxidants at a concentration of more than 200 $\mu g/m^3$ over 750 h per year and the relative risk for chronic respiratory diseases (1.20) was higher than over an exposure time of 250 h per year (1.07). With a concentration of more than 300 $\mu g/m^3$ the relative risk increased with the time of exposure. Exposure to nitrogen dioxide did not show a significant correlation whereby only a small part of the population group under investigation was exposed to values over 100 $\mu g/m^3$. Passive smoking at work increased the prevalence of bronchitis significantly.

Example of a 'longitudinal study'

Wichmann et al.[14] made measurements of lung function during smog periods in 1981 using different population groups. 111 healthy workers from the areas of Cologne and Dusseldorf who were not occupationally exposed, showed increased airway resistance during the smog period in comparison to the control period. Additionally, 59 patients with slight obstructive airway disease who came from diverse regions of Germany showed a worsening of their conditions. In comparison to the control period, airway resistance was increased and the spirometric parameters were decreased. Mean values of sulphur dioxide for the investigated periods were 250 $\mu g/m^3$. The investigastions have shown that, even during relatively low emission loads, small but consistent changes in suitable measuring values regarding lung functioning are identifiable.

Example of an experimental study

Linder et al.[11] investigated the effects of ozone on physical activity. They tested twelve healthy women and twelve healthy men on an exercise bicycle until exhaustion in a climatic chamber at ozone levels of less than 8 $\mu g/m^3$ (the control), 120 to 140 and 245 to 260 $\mu g/m^3$. Ozone levels as high as 200 $\mu g/m^3$ are often reached during the summer months in rural as well as urban areas. Under high ozone, a clear decrease of performance was seen at maximal effort as well as a shift of the anaerobic threshold to somewhat lower performance values. These changes are probably caused by increasingly difficult breathing. At high ozone concentrations, further symptoms were recognized: itching of the throat and neck, thirst, fatigue and itching eyes. In addition, comparable levels of exercise were judged as more strenuous.

Effects of air pollutants

In total, all investigations to date have shown that the effects of air pollutants are multifactorially determined and often very nonspecific disorders are in the foreground. There is also no specific 'air pollution disease'. The complex effects cannot be traced back to simple correlations, whereby every detectable effect has a particular sole cause. A further difficulty is that the ensuing disorders and diseases in many cases run their course slowly and so to speak in a hidden fashion. The purpose is, however, to recognize damaging processes at an early stage, before these speed up and reach a critical stage. That's why it is necessary to think in multifactorial correlations and to remove ourselves from the old linear way of thinking which only copes with monocausal relationships.

Detrimental effects of air pollution on health are[2]: annoyance from odors; eye, nose and throat irritations; impairment of lung function; impairment of physical performance; increased susceptibility to respiratory diseases; increased incidence of chronic bronchitis and asthma; increased risk of cardiovascular diseases.

The influence of 'air pollution factors', under the listed effects, depends on the type, concentration and duration of exposure to the pollutant.

The most important air pollutants contributing to the development and to the course of health deterioration and diseases are the irritants sulfur dioxide, nitrogen dioxide and ozone, but also suspended particulates and acid aerosols. Also in keyword fashion, here are the health effects of the individual pollutants as we know them today[4–7]. These effects are always dependent on the concentration and the time of exposure, and on their combination with other pollutants.

Sulfur dioxide

Sulfur dioxide is an irritant of the upper respiratory tract. At higher concentrations during deep breathing it is also active in the lower airways. It causes a narrowing of the bronchial tubes, an increase in the flow resistance of the respiratory paths, an impairment of lung capacity, impairment of the function of the ciliated epithelium and an increase in mucous secretion.

The acute effects are – especially in combination with suspended particulates – an impairment of lung function and for asthmatics an increased frequency of their attacks.

Chronic effects are more frequent respiratory symptoms, impairment of lung function and an increase in chronic bronchitis.

Nitrogen dioxide

Nitrogen dioxide is an irritant of the respiratory tract. Acute exposure causes an increased air flow resistance in the respiratory tract.

With long term exposure, an increase in the frequency of chronic bronchitis, coughing and expectoration along with disorders of lung functioning can be observed, particularly in combination with suspended particulates and sulfur dioxide.

Ozone

Ozone is an irritant of the eyes and respiratory tract. Because of its low water solubility it can easily penetrate into the small airways.

During experimental investigations the following effects have been observed, depending on the type of exposure: irritation reactions of the tissues with biochemical and morphological changes (alveolar, epithelial and ciliated epithelial), triggering of inflammatory processes, damage of macrophages which are important for resistance to infections, as well as functional disorders of the lung. Acute effects are – depending on the concentration and duration of exposure – irritation of the eyes and respiratory tract and a decrease of lung function. The effects are increased by other photochemical oxidants (eg. peroxyacetyl nitrate and nitric acid) and in combination with other pollutants. There are great differences in susceptibility among healthy adults and also children as well as people suffering from other lung diseases. With strenuous physical exercise the occurrence of irritations is increased and the physical performance level (for example in endurance sports) can be decreased.

Frequently repeated ozone exposure can have an influence on the development and the course of respiratory disorders. In areas with high ozone concentrations a greater frequency of respiratory symptoms and a decrease of lung function can be observed in the population.

Suspended particulates

Suspended particulates can be carriers of sulfates, nitrates, heavy metals, polycyclic hydrocarbons and the emissions from diesel vehicles.

From a health point of view the percentages of the respirable fractions are of importance: Particulates with a diameter of more than about 10 microns get trapped in the naso-pharyngeal cavity and particulates of less than 3–5 microns can penetrate into the alveoli.

Epidemiological studies show correlations between the concentration of sulfates and nitrates in the respirable particulates and the occurrence of chronic disorders or the respiratory tracts, particularly bronchitis and asthma.

Acid aerosols

In experimental studies adverse effects on the lung function and airway resistance of asthmatics have been shown from sulfuric acid aerosols.

In epidemiological studies correlations between the estimated sulfuric acid concentration and mortality and disorders of the respiratory tracts have been observed.

Only a few more recent epidemiological studies have included measurements of the acid components in aerosols. The question remains open which components of the acid aerosols are the most suitable indicators of the effects and by which methods the pollutants should be measured. Whether or not the acid aerosols, alongside the known pollutants such as ozone and nitrogen dioxide, might be additional indicators of health effects must be shown by further studies.

Further pollutants having detrimental effects on health are *hydrocarbons* and *volatile organic compounds* (VOC) e.g. benzene, toluene, trichloroethylene, tetrachloroethylene and formaldehyde. The vapours of these compounds can have acute effects (e.g. headache, nausea, dizziness) and chronic effects on the nervous system. Benzene is known to have human carcinogenic properties.

Air quality guidelines

The question now arises what concentrations of the individual pollutants are acceptable from a health perspective. In addition it is necessary to consider the protection of the environment. For this purpose air quality guidelines and air quality standards have been established. These are based – as for example the air quality guidelines published by the World Health Organization[15] – particularly on the effects of air pollutants on human health made known by scientific investigations. Health and well-being, as understood by the World Health Organization (WHO), are only possible over the long term in a healthy environment. For this reason ecotoxicological criteria are also considered in the evaluation of air pollution effects.

In reference to these *WHO guidelines* the following points must be considered[1]:

The guidelines which have been worked out to protect the general public are valid as a rule only for individual pollutants. However, the simultaneous occurrence of different pollutants can produce stronger (additive, synergistic) or in certain cases also weaker (antagonistic) resulting effects. As yet the combined effects of air pollutants have in general not been investigated sufficiently, particularly in the area of human toxicology. They have only been considered in individual cases such as the combination of sulphur dioxide and suspended particulates.

There is no absolute assurance that air pollution levels below the proposed guidelines do not have damaging effects. In particular, *high risk groups such as children and the ill can react more sensitively*. The simultaneous occurrence of several pollutants can also lower the so-called effect threshold.

If the limits are exceeded, it does not mean that in every case, or immediately, damaging effects are to be expected. There will, however, be an increased risk of adverse effects on health which will gradually result and often will only be recognized after longer periods of exposure.

In establishing the guidelines, no real distinction is made between indoor and outdoor air pollution because, in relation to the investigated air pollutants, the same dose effect relationship would be valid for indoor as for outdoor areas. In relation to the frequency, the amount and the effect of emitted air pollutants outdoor pollution is considered to be more important because it not only effects human beings but also animals, vegetation, water and materials.

The guidelines have been established to protect the whole population, including children, the elderly and those with chronic illness. Therefore the values are distinctly lower than the threshold limits for workplaces, which consider only the exposure of adults during working-time.

Guidelines for air quality do not have the importance of legally binding air quality standards. They are in a certain sense 'values to be aimed for' and are part of the European WHO progam "Health for All" within which all people of the European area should be protected by 1995 against recognized air pollution health risks.

The WHO guidelines will be updated and a second edition will probably be published in 1996.

Similar considerations are also valid for the 'Swiss air quality standards'[4,7] which, in accordance with Article 14 of the Federal Law on the Protection of the Environment, are to be established in accordance with the state of scientific knowledge or of experience. The aim is to ensure that emissions below the values set in these standards

- do not endanger human beings, animals or plants, their environment and biological communities;
- do not seriously disturb the well-being of the population;
- do not damage buildings;
- do not harm the fertility of the soil, vegetation and water quality.

These effects must be judged individually and collectively in consideration of their combined effects (Art. 8). Finally the effects on groups of the population with increased susceptibility such as children, the sick, the elderly, and pregnant women (Art. 13) must be determined.

Exceeding the emission limits always results in an increased risk of adverse health effects, damage to plants and even to whole ecosystems. The consequences are mostly recognized only gradually or after a long period. Therefore excesses also always signal the necessity and the urgency of implementing protective measures without further delay. Emission limits therefore have a double function: They are necessary for the evaluation of air quality and the possibility of damage; at the same time they are important instruments in the fight against air pollution.

On the basis of the known pollution emissions in most countries, it is clear where the main emphasis for counteraction needs to be placed. Particularly the emissions of nitrous oxides and hydrocarbons – the precursor pollutants of ozone – need to be reduced. In countries where coal and heavy oils are used for energy production, the pollution from particulates and sulfur compounds must of course also be urgently reduced.

Finally, we have to note that by far the greatest challenge is the struggle against the greenhouse effect and global warming. For this reason, a drastic reduction in the use of fossil fuels is urgent, as carbon dioxide contributes up to 50% of the greenhouse effect. The worldwide consumption of heating oils, benzine and aviation fuel are still increasing. This use should be reduced as soon as possible. More efficient fuel use and the promotion of alternative energies – in particular solar energy – are therefore necessary. These are also long term the most effective measures against air pollution.

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