



Scientific Facts on **Air Pollution** Ozone

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GreenFacts

Level 2 - Details on Air Pollution

Ozone

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This Digest is a faithful summary of two leading scientific consensus reports produced in 2003 and 2004 by the World Health Organization (WHO):
"Health Aspects of Air Pollution with Particulate Matter, Ozone and Nitrogen Dioxide" and "Answer to follow-up questions from CAFE (2004)"

The full Digest is available at: <https://www.greenfacts.org/en/ozone-o3/>



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- Each question is answered in Level 1 with a short summary.
- These answers are developed in more detail in Level 2.
- Level 3 consists of the Source document, the internationally recognised scientific consensus report which is faithfully summarised in Level 2 and further in Level 1.

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1. What is Ozone (O₃)

Ozone (O₃) is a gas that can form and react under the action of light and that is present in two layers of the atmosphere: the stratosphere and the troposphere.

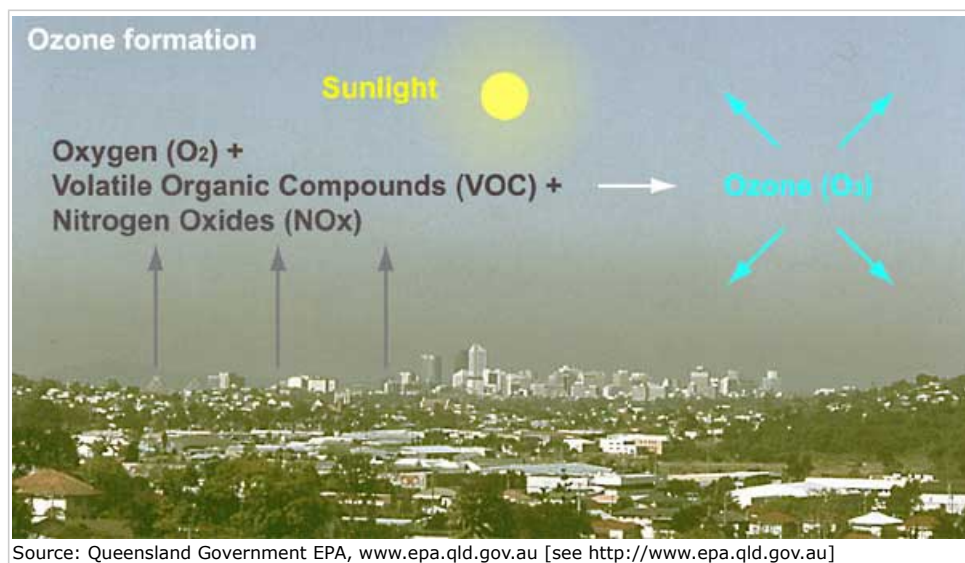
In the stratosphere, ozone forms a layer that shields the Earth from ultraviolet rays.

However, in the **lower atmosphere** (troposphere), ozone (O₃) is the most important photochemical oxidant. There, it is a secondary pollutant formed when precursor pollutants such as nitrogen oxides (NO_x) and volatile organic compounds react under the action of light.

Near strong emission sources of nitrogen oxides (NO_x), where there is an abundance of NO, ozone is "scavenged" as it reacts with NO. As a result its concentrations are often low in busy urban centres and higher in suburban and adjacent rural areas. However, ozone is also transported long distances in the atmosphere and is therefore considered a trans-boundary problem.

Because the formation of ozone requires light, ozone concentrations fluctuate depending on season and time of day, with higher concentrations in the summer and in the afternoons.

Controlled exposure studies on humans and animals have provided evidence that ozone can cause adverse health effects. However, more research is needed, especially addressing the spatial and seasonal patterns of ozone exposure and related health effects.



2. How does Ozone (O₃) affect human health?

Adverse health effects have been documented after short-term exposure to ozone (O₃) peaks, as well as following long-term exposure to relatively low concentrations.

Studies have shown that short-term exposure to peak levels of ozone can temporarily affect the lungs, the respiratory tract, and the eyes, and can also increase susceptibility to inhaled allergens. Long term exposure to ozone has primarily been found to reduce lung function.

2.1 Effects of long-term exposure to levels of Ozone observed currently in Europe

WHO states: "There are few epidemiological studies on the chronic effects of ozone on human health. Incidence of asthma, a decreased lung function growth, lung cancer and total mortality are the main outcomes studied. At levels currently observed in Europe, the evidence linking O₃ exposure to asthma incidence and prevalence in children and adults is not consistent. Available evidence suggests that long-term O₃ exposure reduces lung function growth in children. There is little evidence for an independent long-term O₃ effect on lung cancer or total mortality.

The plausibility of chronic damage to the human lung from prolonged O₃ exposure is supported by the results of a series of chronic animal exposure studies."

"Long-term O₃ effects have been studied in two cohort studies. There is little evidence of an independent long-term O₃ effect on mortality so that no major loss of years of life is expected. The issue of harvesting, i.e. the advancement of mortality by only relatively few days, has not been addressed in short-term exposure studies of O₃."

Source & ©: WHO Europe "Health Aspects of Air Pollution" (2003) Section 6.2 [see <http://www.who.dk/document/e79097.pdf>]

2.2 Is Ozone per se responsible for effects on health?

Short-term studies have shown independent effects of ozone (O₃) especially in the summer. Independently of the effects of other pollutants, ozone exposure influences pulmonary function, lung inflammation, lung permeability, respiratory symptoms, levels of medication usage, morbidity, and mortality.

The results of epidemiological studies addressing long-term effects of ozone are not entirely consistent. Several studies have used models that take into account other pollutants and their effects. For instance, considering the effect of particle acidity has partly explained effects previously attributed to ozone. A few studies in North America found effects of ozone on asthma incidence and lung function. These effects were independent of the effects of other classical pollutants including particulate matter, but particle acidity was not considered.

Experimental studies show the potential of ozone to cause these health effects.

2.3 Are health effects of Ozone influenced by the presence of other air pollutants?

Epidemiological studies show that short-term effects of ozone (O₃) can be enhanced by particulate matter, and vice versa. At higher ozone concentrations, experimental studies show synergistic, additive, or antagonistic effects, depending on the experimental design, but the relevance of this evidence for ambient exposures is unclear. Ozone may facilitate responses to allergens.

2.4 Characteristics of individuals that may influence how Ozone affects them

Are effects of ozone dependent upon the subjects' characteristics such as age, gender, underlying disease, smoking status, atopy, education etc? What are the critical characteristics?

How readily individuals respond to ozone (O₃) exposure, and hence experience different ozone related health effects, varies between persons. The reasons for this remain largely unexplained but appear to be partly linked to genetic differences.

There is some evidence that short-term ozone exposure effects on mortality and hospital admissions increase with age. Results on gender differences in responses to ozone exposure are not consistent. It appears that the effects of ozone exposure are greater in asthmatic children compared to general population children or healthy children. For asthmatic children, decreases in lung function have been associated with O₃ exposure in children with low birth weight or premature birth.

One important factor modifying the effect of ozone on lung function is ventilation rate. With deeper breaths, for instance when exercising, ozone penetrates deeper into the lungs.

Duration of exposure is also a critical factor, as ozone effects accumulate over many hours. When the respiratory system is exposed repeatedly over several days, it adapts, leading to a reduction in the functional responses to ozone exposure. However, inflammatory responses to ozone exposure are not reduced.

In children who exercise more or spend more time outdoors, the effects of ozone exposure on lung function, symptoms, and school absences are greater.

2.5 Is there a threshold below which nobody's health is affected by Ozone?

WHO states: "There is little evidence from short-term effect epidemiological studies to suggest a threshold at the population level. It should be noted that many studies have not investigated this issue. Long-term studies on lung function do not indicate a threshold either. However, there may well be different concentration-response curves for individuals in the population, since in controlled human exposure and panel studies there is considerable individual variation in response to O₃ exposure. From human controlled exposure studies, which generally do not include especially sensitive subjects, there is evidence for a threshold for lung damage and inflammation at about 60 to 80 ppb (120-160 mg/m³) for short-term exposure (6.6 hours) with intermittent moderate exercise. Where there are thresholds, they depend on the individual exercise levels."

Source & ©: WHO Europe "Health Aspects of Air Pollution" (2003) Section 6.2 [see <http://www.who.dk/document/e79097.pdf>]

See also: General Issues and Recommendations on Air Pollutants:

- Question 5.3 on uncertainties in defining thresholds
- Question 7.1 recommendations regarding the concept of thresholds

3. How are we exposed to Ozone (O₃)?

3.1 Critical sources of Ozone responsible for health effects

Ozone is a secondary pollutant produced by photochemical activity in the presence of precursors. O₃ is also subject to long-range atmospheric transport and may be considered as a trans-boundary problem.

3.2 Relationship between ambient levels and personal exposure to Ozone

Can the differences influence the results of studies?

Personal ozone (O₃) exposure measurements are not well correlated with ambient ozone concentrations measured at fixed sites.

To account for this, additional information (e.g., activity patterns) was used in some studies to improve personal exposure estimates based on fixed site measurements. As O₃ is a highly reactive gas, concentrations indoors are generally lower (less than 50%) than those in ambient air. There are very few indoor sources (such as photocopiers or electrostatic air cleaners) in most homes. Outdoor ozone levels vary across city areas because ozone is scavenged as it reacts with NO. Early morning and late night exposures outdoors are lower because of the daily cycle of ambient ozone concentrations. Thus, for ozone, cumulative daily or long-term average exposures are largely determined by exposures occurring outdoors in the afternoon. Exposure underestimations may occur in studies on human populations when outdoor ozone concentration measurements are used to estimate short-term personal ozone exposure. Such misclassifications may cause true effects to appear less strong or be concealed.



See also our summary on Indoor Air Pollution [see <https://publications.greenfacts.org/en/indoor-air-pollution/index.htm>]

3.3 Short-term exposure to high peak levels or exposure in hot spots of Ozone

Adverse health effects have been documented after short-term exposure to ozone peaks, as well as following long-term exposure to relatively low concentrations.

Studies have shown that short-term exposure to peak levels of ozone can temporarily affect the lungs, the respiratory tract, and the eyes, and increase susceptibility to inhaled allergens. Long term exposure to ozone has primarily been found to reduce lung function.

Some studies found a clear relationship between variations in peak ozone levels and the intensity of adverse health effects. Because days with very high ozone concentrations are rare, the largest burden on public health is likely to be due to the frequently occurring mildly elevated ozone concentrations.

Being a secondary pollutant, ozone concentrations are usually not significantly higher at specific urban "hot spots". On the contrary, levels of ozone tend to be lower in polluted urban atmospheres because traffic-induced NO reacts with ozone, causing ground level ozone concentrations to drop.

4. Should current O₃ guidelines be reconsidered?

4.1 Have positive impacts on public health of Ozone reductions been shown?

"There are very few opportunities to evaluate O₃ reduction per se. One study of intra-state migrants showed a beneficial effect on lung function in children who moved to lower PM and O₃ areas. A decrease in O₃ during the 1996 Olympics was associated with a reduction of asthma admissions. The interpretation of these findings is unclear."

Source & ©: WHO Europe "Health Aspects of Air Pollution" (2003) Section 6.2 [see <http://www.who.dk/document/e79097.pdf>]



See also our Digest on Respiratory Diseases in Children [see <https://www.greenfacts.org/en/respiratory-diseases/index.htm>]

4.2 Averaging period most relevant for Ozone standards to protect human health

"For short-term exposure, it is clear that the effects increase over multiple hours (e.g., 6–8 hours for respiratory function effects and lung inflammation). Thus, an 8-hour averaging time is preferable to a 1 hour averaging time. The relationship between long term O₃ exposure and health effects is not yet sufficiently understood to allow for establishing a long-term guideline."

Source & ©: WHO Europe "Health Aspects of Air Pollution" (2003) Section 6.2 [see <http://www.who.dk/document/e79097.pdf>]

4.3 Reconsideration of the current WHO Guidelines for Ozone

"The current WHO Air quality guidelines (AQG) (WHO, 2000) for O₃ provide a guideline value of 120µg/m³ (60 ppb), based on controlled human exposure studies, for a maximum 8-hour concentration. The AQG also provide two concentration-response tables, one for health effects estimated from controlled human exposure studies and one from epidemiological studies. No guideline for long-term effects was provided. Since the time these guidelines were agreed, there is sufficient [new] evidence for their reconsideration. Issues to be considered are: the averaging time(s) for the short-term guidelines and their associated levels, the [concentration-response] functions used in the tables, the outcomes included in the concentration-response tables, whether a long-term guideline and/or complementary guidelines (e.g. restricting personal activity) should be adopted."

Recent epidemiological studies have strengthened the evidence that there are short-term O₃ effects on mortality and respiratory morbidity and provided further information on exposure-response relationships and effect modification. There is new epidemiological evidence on long-term O₃ effects and experimental evidence on lung damage and inflammatory responses. There is also new information on the relationship between [ambient concentrations measured by] fixed site ambient monitors and [total] personal exposure, which affects the interpretation of epidemiological results."

Source & ©: WHO Europe "Health Aspects of Air Pollution" (2003) Section 6.2 [see <http://www.who.dk/document/e79097.pdf>]

5. What are the uncertainties regarding this study?

5.1 Uncertainties of the WHO answers, guidelines, and risk assessments

How could these influence the conclusions for policy-makers?

Uncertainties linked to gaps in knowledge exist and will continue to exist in the future. The expert group which wrote the reference documents for this Digest was aware of these uncertainties, and tried to take them into account – to the best of their knowledge – when drawing their conclusions.

Uncertainties were addressed in a systematic way, following the recommendations of a WHO guideline document. It was not feasible to quantify the uncertainties linked to all answers within this study.

It was stressed that, in accordance with the precautionary principle, uncertainties should not be taken as a cause for not acting, if the potential risks are high and measures to reduce the risks are available at a reasonable cost.

Examples of uncertainties related to this study are:

- Potential **publication bias**. For example, studies that have found no association between a pollutant and a particular effect may not have been published (see question 5.2).
- **Diverging evidence**. For example, data suggesting either the existence or non-existence of a threshold for ozone (see question 5.3).
- Uncertainties regarding the **contribution of different sources** of particulate matter to health effects (see question 5.4).
- Uncertainty related to the use of different **models** (see question 5.5).
- Uncertainties regarding **regional differences** in the effects of air pollution (see question 5.6).

5.2 Consideration of publication bias in the review

WHO states: Publication bias occurs when the publication process is influenced by the size of the effect or direction of results. The bias is usually towards statistical significant and larger effects. It can be detected and adjusted for using statistical techniques. Bias may also occur when literature is selectively ascertained and cited.

This review used a systematic approach to identify all short-term exposure studies, but it did not formally investigate publication bias. The reviewers were aware that evidence of publication bias has been identified in meta-analyses of single city time series studies, but when estimates were corrected for this bias, significant positive associations remained. Furthermore, the multi-city time series studies, which have published results from all participating cities and are free from publication bias, have reported significant positive associations.

Because of the size and experience of the review group and referees, it is unlikely that any important published long-term study has been missed. Formal assessment of a possible publication bias has not been undertaken. Every effort was made to systematically ascertain long-term exposure studies.

5.3 Consistency of epidemiological and toxicological evidence in defining thresholds

5.3.1 WHO states:

Multiple factors determine whether a threshold is seen [for effects due to exposure to air pollutants] and the level at which it can occur. Exposure-response curves depend on the age and gender of the subjects, their health status, their level of exercise (ventilation) and, especially the health effect selected. For highly uniform population groups, with a specific exposure pattern, a full range of concentrations, and a specific health outcome, one could identify a specific threshold. However, when there are different exposure-response curves for different groups, thresholds are harder to discern in population studies, and may ultimately disappear. Therefore, the evidence coming from the epidemiological and toxicological studies is not contradictory.

5.3.2 Ozone: "Chamber studies [(controlled exposure studies)] may show thresholds for mean effects of ozone on lung function and airway inflammation but a few individuals show these responses below these levels. As mentioned previously, a particular threshold in a particular experimental situation does not necessarily contradict a finding of effects below these levels in other situations. The time-series results often have insufficient data to distinguish between a linear and non-linear model with confidence. In addition, the statistical analyses applied to investigate thresholds in datasets on particles have not been applied to the same extent to datasets on ozone. There remain uncertainties in interpreting the shape of exposure-response relationships in epidemiological studies due to different patterns of confounding by other pollutants and correlations with personal exposure across the range of ozone concentrations. Although there is evidence that associations exist below the current [ozone] guideline value, our confidence in the existence of associations with health outcomes decreases as concentrations decrease. The answer and rationale [in question 2.3] refer to acute effects of ozone, as this is most important for health impact assessment of the effects of ozone.

5.3.3 Particulate matter: "Most epidemiological studies on large populations have been unable to identify a threshold concentration below which ambient PM has no effect on mortality and morbidity. It is likely that within any large human population, there is a wide range in susceptibility so that some subjects are at risk even at the low end of current concentrations.

Source & ©: WHO Europe (2004)

5.4 Contribution of different sources to PM-related health effects

WHO states: Only a few epidemiological studies have addressed source contributions specifically. These studies have suggested that combustion sources are particularly important.

Toxicology, because of its simpler models and potential to tightly control exposures, provides an opportunity to determine the relative toxic potency of components of the PM mix, in contrast to epidemiology. Such toxicology studies have highlighted the primary, combustion-derived particles having a high toxic potency. These are often rich in transition metals and organics [organic compounds and matter], in addition to their relatively high surface area. By contrast, several other components of the PM mix are lower in toxic potency, e.g. ammonium salts, chlorides, sulphates, nitrates and wind-blown crustal dust such as silicate clays.

Despite these differences among constituents under laboratory conditions, it is currently not possible to precisely quantify the contributions from different sources and different PM components to health effects from exposure to ambient PM.

Source & ©: WHO Europe (2004)

5.5 Impact of methods of analysis used in epidemiological studies

WHO states: This answer addresses matters relating to uncertainties in methods of analysis used. Epidemiological studies use statistical models of various types, including Poisson and logistic regression. The estimates of effect provided by air pollution studies are generally accompanied by confidence intervals. These convey the precision of the estimate or statistical uncertainty that arises because the analyses are subject to a degree of random error. To a varying degree, the results of these analyses are sensitive to the details of the model and the specification of confounding and interacting factors. Extensive sensitivity analyses have shown that associations between air pollution and health remain irrespective of the methods of analyses used.

Source & ©: WHO Europe (2004)

5.6 Possible regional characteristics modifying the effects of air pollution

WHO states: Potentially this could be a very influential issue since the characteristics of populations, environments and pollution (including particle concentration, size distribution and composition) vary throughout Europe. However, at this stage there is not sufficient evidence to advocate different guidelines for particles or other priority pollutants in different parts of Europe.

Several studies on short and long-term effects of particulate matter have consistently reported an association between pollution levels and mortality; however, there are differences in the size of the estimated effects of PM according to geographical region or according to the levels of other variables (potential effect modifiers). For example, it has been reported that the short-term effects of PM₁₀ are greater where long term average NO₂ concentration is higher, when the proportion of the elderly is larger and in warmer climates. Modification by socioeconomic factors, such as the level of education, has also been reported. Plausible explanations for some of these observations have been proposed.

Effect modification, for example by the age distribution in a population and by climate should, if possible, be taken into account in sensitivity analysis of health impact assessments or risk assessments.

Possible effect modifiers of other criteria pollutants have not been investigated to any extent so far.

Source & ©: WHO Europe (2004)

6. Are certain population groups particularly vulnerable?

Are there specific population groups that should be brought into special attention?

WHO states: A number of groups within the population have potentially increased vulnerability to the effects of exposure to air pollutants.

These groups comprise:

- those who are innately more susceptible to the effects of exposure to air pollutants than others,
- those who become more susceptible for example as a result of environmental or social factors or personal behaviour and
- those who are exposed to unusually large amounts of air pollutants.

Members of the last group are vulnerable by virtue of exposure rather than as a result of personal susceptibility.

Groups with innate susceptibility include those with genetic predisposition that render them unusually sensitive, for example, to the broncho-constrictor effects of ozone or liable to produce an unusually marked inflammatory response on exposure to allergens. Very young children and unborn babies are also particularly sensitive to some pollutants.

Groups which develop increased sensitivity include the aged, those with cardio-respiratory disease or diabetes, those who are exposed to other toxic materials that add to or interact with air pollutants and those who are socioeconomically deprived. When compared with healthy people, those with respiratory disorders (such as asthma or chronic bronchitis) may react more strongly to a given exposure both as a result of increased responsiveness to a specific dose and/or as a result of a larger internal dose of some pollutants than in normal individuals exposed to the same concentration of pollutants. Increased particle deposition and retention has been demonstrated in the airways of subjects suffering from obstructive lung diseases.

Lastly, those exposed to unusually large amounts of air pollutants perhaps as a result of living near a main road or spending long hours outdoors, may be vulnerable as result of their high exposure.

Source & ©: WHO Europe (2004)

7. General Conclusions

7.1 Recommendations

Clean air policies aim to develop strategies to reduce the risk of adverse consequences of ambient air pollution for human health and for the environment as a whole. In the case of air pollutants, the concept of thresholds may no longer be useful in setting standards to protect public health. This is because certain population groups are very susceptible and are affected even at low levels, and because we are now able to detect even rare cases. Therefore, the application of the policy principle of providing an adequate margin of safety in order to eliminate adverse effects even for the most susceptible groups may not be realistic.

Risk reduction strategies are nevertheless effective in promoting public health. To develop such strategies, both qualitative and quantitative knowledge about the most relevant effects is required.

Therefore, for ozone and particulate matter, a meta-analysis of available data was recommended. This analysis should evaluate the relative risk increase (risk coefficients)

related to ozone and to specific fractions of particulate matter for different health effects (endpoints).

It was also recommended:

- to update the concentration-response table for ozone in the current WHO Air quality guidelines,
- to identify which risk coefficients should be used in order to estimate long term mortality in relation to PM exposure, and
- to carry out a more comprehensive monitoring programme for PM-related health effects (not only relying on PM_{2.5}) in different European cities.

7.2 What other aspects of air pollution are important to address in the development of air pollution policy in Europe?

Other substances and pollutants posing risk to health which are currently not adequately addressed in the development of air pollution policy in Europe include:

- Carbon monoxide (CO) and sulphur dioxide (SO₂), with new evidence of links to severe health effects.
- Persistent organic pollutants (POP) such as PAH.
- Heavy metals, in particular lead and some transition metals. Lead is of concern since there are new studies suggesting effects at low concentrations.
- The carcinogenic volatile organic compounds 1,3-butadiene and benzene.
- Nitrogen trichloride, since there is evidence of health effects from this substance from epidemiological studies.

Few experts suggested assessing the health effects from diesel versus gasoline exhaust fumes.

An important issue that remains unresolved concerns the combined effects on health of urban air pollution mix.

7.3 Concluding remarks

- The body of evidence has grown stronger over the past few years regarding the health effects of air pollution at levels currently common in Europe.
- There is sufficient evidence to strongly recommend further policy action to reduce levels of particulate matter (PM), nitrogen dioxide (NO₂), and ozone (O₃) in air. This would lead to considerable health benefits.
- Further targeted research and subsequent systematic evaluation is needed to reduce the existing uncertainty.