Natural Hazards PARTNERSHIP

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NERC Science of the Environment

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# Air Pollution

This Science Note is one of a series of short guides covering a range of natural hazards. Air pollution in the UK, whilst having overwhelmingly man-made sources, is often influenced in severity through interactions with natural factors associated with meteorology. As a hazard it falls therefore within the scope of the Natural Hazards Partnership. These guides aim to provide non-experts with a brief introduction to each hazard and to highlight key aspects that may need to be taken into account during an emergency involving this hazard. They are not intended to be fully comprehensive, detailed analyses or to indicate what will happen on any particular occasion. Instead they will signpost issues that are likely to be important and provide links to sources of more detailed information.

## What is Air Pollution?

Air pollution is the presence of elevated concentrations of trace gases or particulate matter (PM) at levels that can be harmful to human health, ecosystems or agricultural crops. Air pollution can impact on humans or the environment through long-term exposure or in short-term episodic form, where air pollution worsens over a period of days, often in connection with specific meteorological conditions. However it is the impact of short-term air pollution episodes - at times coinciding with other natural hazards, such as heat waves – that is more likely to result in acute effects that may need to be addressed by immediate action. Sources of air pollution are very diverse, including combustion processes, road transport, aviation, shipping, industrial activities and agriculture.  Many pollutants can be transported long distances in the atmosphere. Exposure to air pollution is a therefore influenced by local, national and international emissions.

Several factors play a part in the formation and severity of air pollution events, including:

- Quantity of direct emissions of primary air pollutants *(e.g. primary particulate matter, nitrogen dioxide, sulphur dioxide, carbon monoxide).*
- Quantity of emissions of precursor substances, and the efficiency of their chemical transformation into secondary pollutants *(e.g. ground level ozone, secondary organic or inorganic aerosols)*.
- Meteorological conditions which may influence dispersion, mixing or the photochemical environment *(e.g. a temperature inversion, anticyclone etc)*.

The main air pollutants currently of concern with regard to UK human health are particulate matter (PM) typically expressed at $PM_{10}$ and $PM_{2.5}$ (referring to particles of aerodynamic diameters of less than 10 μm[1] and less than 2.5 μm respectively), nitrogen dioxide ($NO_2$) and ground level ozone ($O_3$). Other air pollutants regulated by law include sulphur dioxide ($SO_2$), carbon monoxide (CO), benzene, 1,3 butadiene, and various persistent organic pollutants. This latter group of pollutants now generally falls within air quality limit values in the UK even during poor air quality events.

More information can be found at the Air Pollution Information System(1) and UK-Air(2) websites, see also the final section 'Where to find more information'. This includes information about:

- The air quality information that is available to the public and where to find it.
- The Daily Air Quality Index used in pollution forecasts and summaries.
- Other sources of information which may be useful.

## How does Air Pollution affect the UK?

Air pollution impacts in two distinct ways on the UK. The first is associated with reduction in human heath and the second associated with impacts on ecosystems and natural heritage.

### Air pollution and human health

Air pollution has both acute and long-term impacts on human health. The most significant risks are borne by vulnerable groups within the population. Groups such as children, the elderly or people with respiratory or cardio-vascular diseases (Asthma, COPD) may experience a higher risk of exacerbation of existing conditions, possibly triggering asthma attacks or other acute effects that may require medical attention, or hospitalization. It is not possible however to define in every case specific thresholds for the health effects of all air pollutants. The Department for Environment, Food and Rural Affairs (Defra) estimates the costs to health arising from man-made $PM_{2.5}$ pollution in a typical year (e.g. 2008) may be £15 billion (within the range 8-17 billion). This estimate is based on life-years lost and reflects best estimates of the UK population's 'willingness to pay' to avoid these health impacts.

### Air pollution, ecosystems and natural heritage

Air pollution has significant negative impacts on natural and semi-natural ecosystems, and the production of agricultural crops. Direct plant damage can occur through exposure to high ambient pollutant levels (e.g. through ground-level ozone), as well as the effects of acidification or excess nutrient deposition from sulphur and nitrogen compounds. Ecosystem effects can include biodiversity loss, a reduction in growth rate, change in species distributions and increased susceptibility to disease and pests. To a lesser extent, air pollution can also affect natural heritage (e.g. acidification effects on buildings and monuments) and materials (e.g. ozone effects on plastic and rubber products). Ozone pollution impacts on the yield of UK crops with estimated losses of £183 million, in a typical current year (e.g. 2008), representing 6.6% of the total value for 8 crops studied(3).

### Predicting air pollution events

Episodic occurrences of elevated air pollution levels are often triggered by specific meteorological conditions and these can be predicted some days in advance. Chronic or short term occurrences of harmful

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[1] $PM_{10}$ for example is typically reported as a mass concentration (expressed in micrograms per cubic metre air or μg $m^{-3}$) of particulate matter that is generally less than 10 millionths of a metre (10 μm) in diameter

pollutant levels e.g. in urban hotspots, are often identified by fixed-site monitoring, and air quality management areas (AQMA[4]) implemented to reduce pollution levels. The automatic air pollution monitoring network in the UK (comprising of the order 200 fixed monitoring stations) is supplemented with regional and urban scale modeling to provide air pollution estimates across the country.

In the case of accidental or natural releases of air pollutants from a point source, (e.g. industrial accident, volcano) dispersion models can predict the location severity and timing of pollution events, e.g. http://www.metoffice.gov.uk/publicsector/CHEMET .

**Reducing the impacts during air pollution episodes**

The primary strategy for reducing the health impacts of air pollution is to take personal actions that avoid or reduce exposure to pollutants during episodic conditions. This can be achieved for example by modifying physical activity and behaviour, or changing working or commuting patterns. Risk reduction measures are initiated through warnings targeted specifically at vulnerable groups, but that are of relevance to the population as a whole. To avoid or to reduce the impact of air pollution episodes, the general public can consult the current and five day forecast of air quality in their area, e.g. using the Daily Air Quality Index (DAQI) forecast on the UK Air web portal[5], a banding system that provides real-time and daily forecasts on the level of air pollution. These bands provide an indication of potential health effects associated with these levels and simple measures that susceptible groups (i.e. those with lung problems, asthma, and adults with health conditions) and the general public can take to avoid or minimise associated health effects. These same air quality forecasts and advice are also given when appropriate by the Met Office alongside national weather forecasts.

Real-time data on current air pollution is also a key source of information to inform risk reduction, and this is disseminated by Defra via UK-Air and also by a number of local authorities.

## What are the Impacts of Air Pollution?

There are numerous different types of impact associated with air pollution, these range from human health effects to impacts on crops, natural and semi-natural ecosystems and materials. In terms of economic cost, health effects are greatest, followed by crop losses, while material effects are considered to be lower. However, damage to heritage sites and historic buildings (e.g. through acid rain) could be considerable and non-reversible. Air pollution impacts that may be relevant to the UK include:

**1. Health-related impacts**

The health effects of air pollution can vary both spatially and temporally and be dependent on the pollutants people are exposed to. The symptoms and magnitude of health effects that may be observed vary from mild/less severe outcomes such as irritation, through to exacerbation of symptoms and more frequent use of medication, hospital admissions and mortality.

$PM_{10}$ and $NO_2$ tend to be highest in urban centres, whereas ozone is suppressed through reactions with another pollutant nitrogen oxide (NO). By contrast ozone is generally highest in suburban and rural locations. Effects include restricted activity days and sick-leave days, GP consultation and hospital admissions (e.g. due to respiratory effects) and increased mortality (in particular in vulnerable populations). At high concentrations even the general public may experience sore eyes, cough or sore throat.

Health effects which may be relevant for the UK population include[6]:

| Pollutant | Health effects at very high levels |
|---|---|
| Nitrogen dioxide, Sulphur dioxide, Ozone | These gases irritate the airways of the lungs, increasing the symptoms of those suffering from lung diseases |
| Particulate Matter ($PM_{10}$, $PM_{2.5}$ ) | Fine particles can be carried deep into the lungs where they can cause inflammation and a worsening of heart and lung diseases |
| Carbon monoxide | This gas prevents the uptake of oxygen by the blood. This can lead to a significant reduction in the supply of oxygen to the heart particularly in people suffering from heart disease |

**$NO_2$ effects on health**

Human exposure to nitrogen dioxide as a pollutant is primarily controlled by the proximity to road transport sources, the volume of traffic and the make up the vehicle fleet. Its impacts are controlled only to a lesser extent by additive natural factors associated with meteorology or natural events. It is therefore treated in somewhat less depth in this Natural Hazards Science Note. Current evidence links short-term exposure to $NO_2$ (over periods of 30 minutes to one day) with adverse respiratory effects, such as airway inflammation, and increased respiratory symptoms in people with asthma.

**PM effects on health**

The Department of Health's Committee On the Medical Effects of Air Pollution (COMEAP) report[7] of 2009 provides an analysis of the currently understood impacts of  the long term effects of particulate matter on mortality, and this is also summarised in the AQEG report on PM2.5 in the UK. In brief, particulate matter enters the respiratory system and, depending on particle size, can travel far into the lungs. Acute effects of PM exposure include increased hospital admissions and early death of the old and sick due to failure of the respiratory and cardiovascular systems. Long-term exposure to particles is also associated with increased levels of deaths due to cardiovascular and respiratory diseases including lung cancer. COMEAP reported that a 6% increase in the risk of death from all causes is associated with a 10 micrograms $m^{-3}$ increase in $PM_{2.5}$ concentration. There is currently no agreed view of which particle properties, for example particle numbers, chemical composition or size confer the most toxic effects.

**Ozone effects on health**

Ozone ($O_3$) is an oxidising agent and acts as an irritant, causing inflammation of the respiratory tract. At high concentrations $O_3$ irritates the eyes, nose, and throat, causing coughing and discomfort whilst breathing. Exposure to elevated levels over several hours can lead to damage of the lining of the airways. This is followed by inflammation and narrowing of the airways and increased sensitivity to stimuli such as cold air and exercise. This is called 'airway hyper-responsiveness'. There is a wide variation in individuals' sensitivity to the effects of $O_3$. During pollution episodes, high levels of $O_3$ may exacerbate asthma or trigger asthma attacks. Some non-asthmatic individuals might also experience discomfort when breathing, particularly if they are exercising vigorously outdoors. It is possible that very sensitive individuals may experience health effects even on low air pollution days[8]. Further details can be found in the COMEAP review of the Air Quality Index, see reference 18.

**2. Ecosystem impacts**

**Reduction / loss of agricultural production**

Using the mean farm gate price for the period 1996 – 2009, ozone pollution impacts on the yield of UK crops in a typical current year (e.g. 2008) are around £183 million of losses, representing 6.6% of the total value for the 8 crops studied. Affected crops include cereals (wheat 5.6% yield loss, barley 3.1% and maize 1%), root crops (sugar beet 2%, potato 0.04%), oilseed rape (7.2%), peas and beans (9.7%) and salad leaf crops (ca. 24%)[3].

**Acidification**

A natural process, acidification is the term used to describe the loss of nutrient bases (calcium, magnesium and potassium) through the process of leaching and their replacement by acidic elements (hydrogen and aluminium). However, acidification is also associated with atmospheric pollution arising from sulphur (S) and nitrogen (N) as nitrogen oxides or ammonia. Pollutant deposition can enhance rates of acidification, which may then exceed the natural neutralising capacity of soils. The environmental impacts of acidification are one of the major contemporary environmental issues, both in the UK and globally. Acidification affects all aspects of the natural environment: soils, waters, flora and fauna[9].

**Eutrophication**

Atmospheric nitrogen (N) is a source of essential nutrients, which commonly limits growth in temperate ecosystems. This fertiliser effect results in increased plant growth and an increased demand for other plant nutrients. The gradual increase and enrichment of ecosystems by nutrients such as N and/or phosphorous (P) is termed eutrophication.

Increased availability of N from pollution impacts species composition, favouring those plants with a high demand for nitrogen. Where there are large inputs of reduced nitrogen (ammonia), which are not immobilised in the soil, this may result in the suppression of the uptake of other essential plant nutrients.

As most temperate natural and semi-natural ecosystems are N limited, additional N inputs in the first instance act to stimulate plant growth. However, there is a limit to how much additional N input can be utilised. Soils and ecosystems with N inputs in excess of plant nutritional requirements are often referred to as N saturated. Ultimately, increased losses of both inorganic and organic N from terrestrial systems may contribute to freshwater, coastal and marine eutrophication, where N is a limiting nutrient[10].

## Timeline of an Air Pollution Episode

Air pollution episodes (e.g. the *Great London Smog of 1952* or the *2003 Heatwave*, see below) typically form due to a combination of natural meteorological factors combining with underlying chemical emission conditions. The most significant pollutants can vary between air pollution events depending on the prevailing emissions, location and time of year. Summertime episodes are characterized by elevated ozone, whilst wintertime episodes are associated most commonly with elevated PM and $NO_2$. For example boundary layer inversions (where exchange of polluted air in the lowermost atmosphere with cleaner air aloft is suppressed) and atmospheric transport can both lead to accumulations of ambient pollutant levels over days.

In the case specifically of summertime ozone (and example of which is the August 2003 event below), the European Environment Agency definition[11] of an air pollution episode is, as follows: *'A period of usually a few days up to 2-3 weeks with high ozone concentrations, characterised by daily exceedances of the thresholds set to protect human health. Ozone episodes occur under specific meteorological conditions characterised by large stagnant areas of high pressure. Since the formation of ozone requires sunlight, ozone episodes mainly occur during summer.*'

## Historic Examples

There have been many examples of high air pollution episodes in the UK:

- **1952: The Great London Smog**

  The most significant historical air pollution event in the UK was the Great Smog affecting London during December 1952. Meteorological conditions consisting of a period of cold weather, in combination with an anticyclone and low wind-speed conditions, led to an accumulation of airborne pollutants connected with high sulphur domestic coal combustion that was prevalent at the time. This formed a thick layer of particulate matter over the city, greatly reducing visibility and giving the appearance of night-time even in the middle of the day. The episode lasted from Friday 5 to Tuesday 9 December 1952, after which it dispersed quickly due to a weather change.

  It caused major disruption due to the effect on visibility, and even penetrated indoor areas, but was not thought to be a significant event at the time, with London having experienced many such smog events in the past. According to government medical reports in the following weeks, however, about 4,000 people had died prematurely and 100,000 more had been experiencing respiratory health effects because of the smog. More recently conducted research indicates that the total number of deaths was substantially larger (~12,000)[12]. The Great London Smog is known to be the worst air pollution event in the history of the UK and subsequently led to government regulation to control emissions, environmental research and public awareness of the relationship between air quality and health. As a result, changes to practices and regulations related to air pollution were introduced, including the *Clean Air Act* of 1956[13] have largely eliminated the risk of future UK sulphur-dominated smogs.

- **2003 August Heatwave**

  The heat wave of August 2003 was distinguished by very high temperatures across the UK and continental Europe, leading to substantial increases in mortality rates. About 15,000 people died due to the heat in France, as well as in the UK, Portugal (2,100), Italy (3,100), Holland (1,500) and Germany (300). The 2003 example provides a contrasting example of changing pollution factors, when compared to the great smog of 1956. The heat wave conditions lead to elevated concentrations of ozone[14,15] and secondary particulate matter in the UK. Overall, there were 2139 (16%) excess deaths in England and Wales. Of these, 113-297 deaths were attributable to ozone, with 251-662 respiratory hospital admissions attributable to ozone, 207 deaths attributable to $PM_{10}$, and 211 respiratory hospital admissions attributable to $PM_{10}$ and 212 cardio-vascular hospital admissions attributable to $PM_{10}$[16]. Worst affected were people over the age of 75 years. The impact was greatest in the London region where deaths in those over the age of 75 increased by 59%.

- **2014 spring episode**

  A more recent poor air pollution event occurred the first week of April 2014, gaining considerable media coverage particularly in the Southeast of England. This event highlighted how a combination of natural and man-made factors can produce an event with poor air quality characteristics. During this period air with high loadings of natural dust was drawn to the UK with origins in the Sahara. Whilst the air masses originated in the Sahara they then passed at low levels over continental Europe gaining additional air pollutants from mainland Europe and from secondary sources such as agricultural emissions before arriving in the UK, where further national emissions were then added. The concentrations of PM during the event were at the highest alert level on the Air quality index, with public concern amplified due to the noticeable PM deposition.

## Further Information (web references accessed on 15th August 2016)

UK Air Information Resource (Defra)
http://uk-air.defra.gov.uk/
http://uk-air.defra.gov.uk/forecasting/
http://uk-air.defra.gov.uk/forecasting/what-forecasts-mean

UK Pollutant Deposition website (Defra)
http://pollutantdeposition.defra.gov.uk/

UK Met Office Air Quality Forecast
http://www.metoffice.gov.uk/about-us/help/guides/air-quality-forecast

Air Pollution in the UK – Defra Reports
http://uk-air.defra.gov.uk/library/annualreport/

Defra (2010) 'Valuing the overall impact of air pollution'
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/182393/air-quality-valuing-env-limits-100303.pdf

Economic Analysis of UK Air Quality
https://www.gov.uk/air-quality-economic-analysis

World Health Organization (WHO) Air Pollution information
http://www.who.int/topics/air_pollution/en/index.html

European Environment Agency (EEA) Topic Air Pollution
http://www.eea.europa.eu/themes/air

Cooke, S. and Murrells, T. (2011). Impacts of Ozone Pollution on Food Security in the UK: A Case Study for Two Contrasting years, 2006 and 2008. Report for Defra contract AQ08610, available at http://icpvegetation.ceh.ac.uk/ and http://uk-air.defra.gov.uk/library/

## References (web references accessed on 15th August 2016)


(1) APIS. Starter's Guide to Air Pollution and Pollution Sources. (2015). http://www.apis.ac.uk/starters-guide-air-pollution

(2) Defra. About Air Pollution. (2014). http://uk-air.defra.gov.uk/air-pollution/

(3) Mills, G., Hayes, F., Norris, D., Hall, J., Coyle, M., Cambridge, H., Cinderby, S., Abbott. J., Cooke, S. and Murrells, T. (2011). Impacts of Ozone Pollution on Food Security in the UK: A Case Study for Two Contrasting years, 2006 and 2008. Report for Defra contract AQ08610, available at http://icpvegetation.ceh.ac.uk/ and http://uk-air.defra.gov.uk/library/

(4) Defra. Air Quality Management Areas (AQMAs). http://aqma.defra.gov.uk/aqma/home.html

(5) Defra. Pollution Forecast. http://uk-air.defra.gov.uk/forecasting/

(6) Defra. Effects of air pollution. (2013). http://uk-air.defra.gov.uk/air-pollution/effects

(7) COMEAP. (2010). Mortality effects of long-term exposure to particulate air pollution in the UK. ISBN 978-0-85951-685-3. https://www.gov.uk/government/publications/comeap-mortality-effects-of-long-term-exposure-to-particulate-air-pollution-in-the-uk

(8) Defra. Air Pollution in the UK, (2015). http://uk-air.defra.gov.uk/library/annualreport/index

(9) APIS. Acid deposition. (2015). http://www.apis.ac.uk/overview/issues/overview_acidification.htm

(10) APIS. Nitrogen deposition. (2015). http://www.apis.ac.uk/overview/issues/overview_eutrophication.htm

(11) European Environment Agency. Ozone episode. http://www.eea.europa.eu/themes/air/air-quality/resources/glossary/ozone-episode

(12) Bell, M.L. and Davis, D.L. (2001). Reassessment of the lethal London fog of 1952: novel indicators of acute and chronic consequences of acute exposure to air pollution. *Environmental Health Perspective*, 109, 389-392.

(13) Met Office. The Great Smog of 1952. (2015). http://www.metoffice.gov.uk/education/teens/case-studies/great-smog

(14) Vieno, M., Dore, A. J., Stevenson, D. S., Doherty, R., Heal, M., Reis, S., Hallsworth, S., Tarrason, L., Wind, P. and Sutton, M.A. (2008). Modelling surface ozone during the 2003 heat wave in the UK. *Croatian Meteorological Journal*, 43, H12_161. 83-87.

(15) Lee, J. D., Lewis, A.C., Monks, P.S., Jacob, M., Hamilton, J.F., Hopkins, J.R., Watson, N., Saxton, J., Ennis, C., Carpenter, L.J., Fleming, Z., Bandy, B.J., Oran, D.E., Penkett, S.A., Slemr, J., Norton, E., Rickard, A., Whalley, L.K., Heard, D.E., Bloss, W.J., Gravestock, T., Ingham, T., Smith, S., Stanton, J., Pilling, M.J. and Jenkin, M.E. (2006). Ozone Photochemistry And Elevated Isoprene During The U.K. Heat Wave Of August 2003. *Atmospheric Environment*, 40, 7598-7613.

(16) Johnson, H., Kovats, R.S., McGregor, G., Stedman, J., Gibbs, M. And Walton, H. (2005). The impacts of the 2003 heat wave on daily mortality in England and Wales and the use of rapid weekly mortality estimates. *Eurosurveillance*, 10(7), 558. http://www.eurosurveillance.org/ViewArticle.aspx?ArticleId=558