Health Effects of Air Pollution

October 2022

Air pollution is a major hazard to human health and a leading cause of illness and death worldwide. After reviewing the best available scientific knowledge, in September 2021 the World Health Organisation (WHO) published revised recommendations for air quality levels to protect human health (WHO 2021). Informed by epidemiological evidence, the new guidelines are significantly lower than previous guidelines (WHO 2006).

Key Facts

- Clean air is fundamental to health. The World Health Organisation (WHO) estimates that air pollution – both ambient (outdoor) and household (indoor) – is the biggest environmental risk to health, carrying responsibility for about one in every nine deaths annually (WHO 2016a).

- In May 2015, the World Health Assembly endorsed a resolution recognising air pollution as a risk factor for noncommunicable diseases such as ischaemic heart disease, stroke, chronic obstructive pulmonary disease, asthma and cancer and stating the need for Member States and WHO to intensify efforts to protect populations from the health risks of air pollution (WHA, 2015).

- In July 2022, the United Nations adopted resolution A/RES/76/300 recognising the human right to a clean, healthy and sustainable environment (UN 2022). This includes the right to breathe clean air (Human Rights Council 2019).

- To reduce air pollution mortality (death) and morbidity (disease), the World Health Organisation (WHO) reviewed the best available scientific knowledge and in September 2021 released revised global air quality guidelines (WHO 2021).

- In New Zealand, the HAPINZ 3.0 study (Kuschel *et al.* 2022), estimates that in 2016, the health outcomes attributable to anthropogenic (human-generated) air pollution resulted in:
  - the premature deaths of more than 3,300 adult New Zealanders
  - more than 13,100 hospital admissions for respiratory and cardiac illnesses, including 845 asthma hospitalisations for children
  - over 13,200 cases of childhood asthma

- Of the more than 3,300 deaths approximately 60% (2,000) were associated with nitrogen dioxide (NO_2) pollution – which is largely from motor vehicles – whilst the rest (nearly 1,300) were associated with fine particulate ($PM_{2.5}$) pollution – largely from domestic fires. For context, 30,422 New Zealanders died in 2016 from natural causes (Ministry of Health 2022). [1]

- To improve air quality in New Zealand concerted action will need to be taken in sectors like transport, energy (particularly home heating), urban planning and industry. Reducing emissions from these sectors will also reduce New Zealand's greenhouse gas emissions.

Background

Air pollution is a major environmental hazard to human health and a leading cause of illness (morbidity) and death (mortality) worldwide.

WHO has identified air quality as the world's largest environmental health risk and among the largest global health risks – comparable with 'traditional' health risks such as smoking, high cholesterol, and obesity. The WHO estimates that indoor and outdoor air pollution exposure currently kills about seven million people worldwide every year due to cardiovascular diseases, such as strokes and ischaemic heart disease, as well as respiratory diseases including acute respiratory infections, chronic obstructive pulmonary diseases and lung cancer. According to the World Bank, the global health cost of mortality and morbidity attributed to air pollution was $8.1 trillion in 2019 (World Bank 2022).

Most air pollution related deaths are from non-communicable diseases such as stroke, lung cancer and chronic respiratory disease. However, air pollution also has other impacts – including damaging natural ecosystems, biodiversity and crops, limiting enjoyment of the outdoors and harming our quality of life. Health impacts from air pollution can also be exacerbated for certain portions of the population due to proximity to air pollution sources, sensitivity to health effects or the resilience of that population to respond to these effects.
The impacts of air pollution are assessed through short-term (acute) or long-term (chronic) exposure. Short-term exposures cover minutes, hours, or days. Long-term exposures are usually over months or years. The major impacts of air pollution occur due to chronic exposure. Depending on the circumstances (e.g., duration and magnitude of exposure) the health burden due to chronic exposure to air pollution may be 10 times greater than that for acute exposure, based on the relative risk ratios (WHO 2021).

[1] Excludes motor vehicle accidents, intentional self-harm & assault

WHO 2021 Global Air Quality Guidelines

The 2021 WHO Global Air Quality Guidelines (the Guidelines) note "*compared to 15 years ago, when the previous edition of these guidelines was published, there is now a much stronger body of evidence to show how air pollution affects different aspects of health at even lower concentrations than previously understood*" (WHO 2021). The Guidelines provide global guidance on thresholds and limits for key air pollutants that pose health risks and offer quantitative, health-based recommendations for air quality management derived from epidemiological evidence.

To support the Guidelines update, WHO published a series of systematic reviews, using meta-analyses to evaluate the best available evidence on the effects of air pollutants on human health (Whaley *et al*. 2020-21). Brief plain English summaries of these review papers are available (Wickham *et al*. 2022a-g) on the ESR website.

The Guidelines apply worldwide to both outdoor and indoor environments and are expressed as long-term or short-term concentrations.

WHO noted that the new Guidelines do not identify 'safe' levels and are not based on a defined level of acceptable risk (i.e., the guidelines are not "no adverse effect levels"). WHO advises that the risks of long-term exposure to elevated concentrations of air pollutants are significantly (an order of magnitude) higher than the risks of short-term exposure. This means that long-term air quality guideline levels for most health outcomes are more protective of health than short-term air quality guideline levels. However, both short-term and long-term guidelines are needed to protect against different health effects for different pollutants that can occur over different exposure periods.

The Guidelines also include qualitative good practice recommendations for black carbon/elemental carbon, ultrafine particles (<1 μm) and particles derived from sand and dust storms. Not all the air pollutant's averaging times were considered in the Guidelines update; some averaging times were carried over from previous publications (WHO 2000, WHO 2006, WHO 2010).

The classical air pollutants

WHO's new guidelines recommend air quality levels for six pollutants where evidence has advanced the most on health effects from exposure. WHO refers to these pollutants as 'classical' air pollutants. They are particulate matter (PM), ozone (O_3), nitrogen dioxide (NO_2) sulfur dioxide (SO_2) and carbon monoxide (CO).

Particulate matter (PM)

Worldwide (and in New Zealand), the worst human health impacts from poor air quality are estimated to be caused by particulate matter (PM) (Health Effects Institute 2020). PM is a collective term for solid and liquid particles suspended in the air and small enough to be inhaled. The major components of PM are sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water.

PM is classified by particle size defined through aerodynamic diameter:

- **PM_{10}** – particulate matter less than 10 micrometres;
- **$PM_{2.5}$** – particulate matter less than 2.5 micrometres;
- **$PM_{0.1}$** – particulate matter less than 0.1 micrometres.

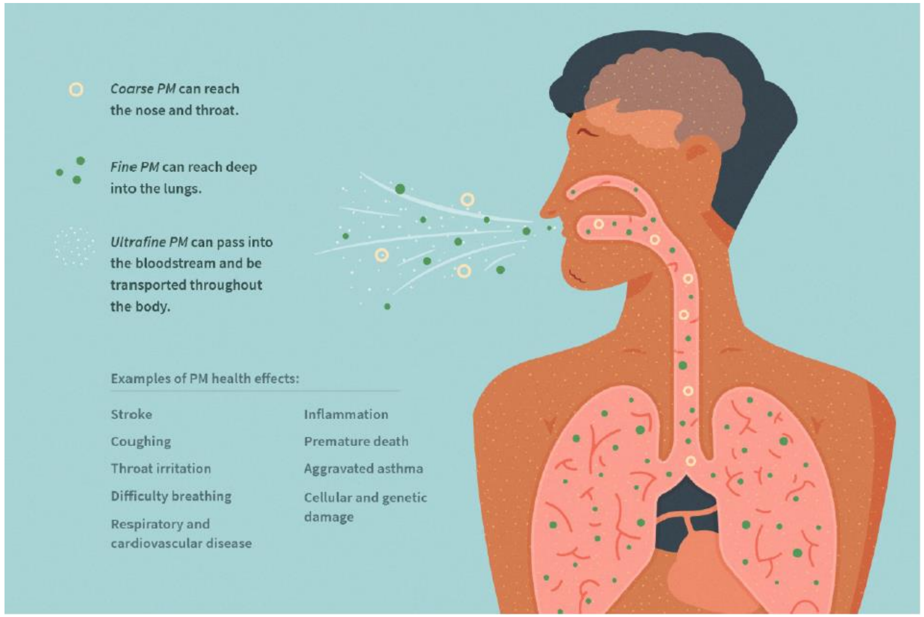
In general, $PM_{2.5}$ (fine particulate) and smaller tends to be more closely associated with anthropogenic activities, whereas the $PM_{10\text{-}2.5}$ fraction (coarse particulate matter) can have a substantial natural source component. The main sources of PM in New Zealand are home heating, industry, agricultural practices, road dust and sea salt. The main anthropogenic (human caused) sources of PM in New Zealand are domestic fires, motor vehicles and industry.

Health effects of PM

Different sizes of PM can result in different health effects. This is because they deposit in different parts of the respiratory tract, they have diverse sources, and they can interact through different biological mechanisms (WHO 2013). In general, the smaller a particle is, the farther into the respiratory tract it can penetrate (to interact and cause adverse health effects).

There is scientific consensus that exposure to particulate pollution causes predominantly respiratory and cardiovascular effects, ranging from subclinical functional changes (e.g. reduced lung function) to symptoms (increased cough, exacerbated asthma) and impaired activities (e.g. school or work absenteeism) through to doctors' or emergency room visits, hospital admissions and death (WHO 2006). The effects, in terms of escalating severity, are described as increased visits to doctors for many individuals, hospital admission for some individuals and death for a few individuals. People with pre-existing heart or lung disease, young children, and the elderly, are most likely to suffer adverse health effects. The exposure-response relationship is essentially linear and there is no 'safe' threshold; adverse health effects are observed at all measured levels (USEPA 2020a; WHO, 2021).

The impact of particulate matter on the human body



[Source: Ministry for the Environment and Stats NZ 2018]

In 2013, the International Agency for Research on Cancer (IARC) classified particulate matter (as a component of outdoor pollution) as carcinogenic based on an increased risk of lung cancer (IARC 2013). Additional research further indicates particulate matter is associated with atherosclerosis, adverse birth outcomes, childhood respiratory disease (WHO 2013) as well as Alzheimer's disease and other neurological endpoints, cognitive impairment, diabetes, systemic inflammation and aging (WHO 2016b).

More recently, WHO has concluded that chronic exposure to PM is causal, or likely to be causal, for (WHO 2021):

- All-cause mortality
- Cardiovascular mortality (all, cerebrovascular, ischaemic heart disease)
- Respiratory mortality (any, chronic obstructive pulmonary disease, acute lower respiratory infections)
- Lung cancer

WHO Guidelines for PM

Pollutant / Time Average	Guideline ($\mu g/m^3$)	Permitted Exceedances per year
$PM_{2.5}$		
Annual	5	n/a
24-hours	15	3-4
PM_{10}		
Annual	15	n/a
24-hours	45	3-4

Additional reading

- Health effects of long-term exposure to PM (Wickham *et al*. 2022a) – A plain English summary of the paper evaluating the health effects of long-term exposure to PM for the Guidelines update (Chen and Hoek 2020)
- Health effects of short-term exposure to PM and NO_2 (Wickham *et al*. 2022b) – A plain English summary of the paper evaluating the health effects of short-term exposure to PM and NO_2 for the Guidelines update (Orellano *et al*. 2020)
- Supporting Information for Air Quality Factsheets (Wickham *et al*. 2022g) – supporting technical information for the plain English summaries.

Nitrogen dioxide (NO_2)

Nitrogen dioxide (NO_2) is a reddish brown coloured acidic gas with a characteristic pungent odour. The main sources of NO_2 worldwide are combustion processes such as motor vehicles, domestic heating, industrial combustion sources, electricity generation, shipping and construction machinery. NO_2 is both a primary and secondary pollutant i.e., it is both emitted and forms downwind from other pollutants.

Nitrogen dioxide is the main source of nitrate aerosols, which form an important fraction of $PM_{2.5}$ and, in the presence of sunlight, ozone. It is also a major component of brown haze. In New Zealand the main source of nitrogen dioxide is motor vehicles.

Health effects of nitrogen dioxide

Long-term exposure to NO_2 increases the risk of premature death (mortality) and respiratory illnesses (morbidity) (Huangfu & Atkinson 2020). Epidemiolocal studies have also shown that symptoms of bronchitis in asthmatic children increase with long-term exposure to NO_2 (Orellano *et al*. 2020). Short-term exposure to high concentrations of nitrogen dioxide (NO_2) causes significant inflammation of the airways and respiratory problems and can also trigger asthma attacks (WHO 2021).

Reduced lung function is linked to measured levels within cities of Europe and North America (WHO 2005). There is also evidence that suggests exposure may increase the risk of premature death and trigger heart attacks (Orellano 2020, USEPA 2016).

WHO Guidelines for nitrogen dioxide

Time Average	NO_2 Guideline (µg/m^3)	Permitted Exceedances per year
Annual	10	n/a
24-hours	25	3-4
1-hour	200	-

Additional reading

- Health effects of long-term exposure to NO_2. (Wickham *et al*. 2022c) – A plain English summary of the paper evaluating the best available evidence on the health effects of long-term exposure to NO_2 for the Guidelines update (Huangfu & Atkinson 2020)

- Health effects of short-term exposure to PM and NO_2 (Wickham *et al*. 2022b) – A plain English summary of the paper evaluating the best available evidence on the health effects of short-term exposure to PM and NO_2 for the Guidelines update (Orellano *et al*. 2020)

- Effects of short-term exposure to NO_2 and SO_2 on asthma (Wickham *et al*. 2022d) – A plain English summary of the paper evaluating the best available evidence on the effects of short-term exposure to nitrogen dioxide and sulphur dioxide and asthma exacerbations (Zheng *et al*. 2021)

- Supporting Information for Air Quality Factsheets (Wickham *et al*. 2022g) – supporting technical information for the plain English summaries.

Sulphur dioxide (SO_2)

Sulphur dioxide (SO_2) is a colourless gas with a sharp odour. It is produced from the combustion of fossil fuels and natural geothermal processes. SO_2 is both a primary and secondary pollutant i.e., it is both emitted and forms downwind from other pollutants. SO_2 is also a known precursor for PM formation.

In New Zealand the major anthropogenic sources are industrial processes (aluminium manufacture, fertiliser manufacturing) and the combustion of fossil fuels that contain sulphur (coal fired boilers).

Health effects of sulphur dioxide

Sulphur dioxide can cause respiratory problems, such as bronchitis, and it can irritate the nose, throat and lungs. This is because inhaled sulphur dioxide readily reacts with the moisture of mucous membranes to form sulphurous acid (which is a severe irritant). It may cause coughing, wheezing, phlegm and asthma attacks (MfE 2014).

Studies have shown that asthmatics and people with lung disease are particularly sensitive to sulphur dioxide. Children may also be more sensitive to the effects of sulphur dioxide due to their relatively higher respiration rate and smaller body mass. Key points to note are (WHO 2006):

- There appears to be a continuous spectrum of sensitivity to sulphur dioxide. This means that some people will be completely unaffected by concentrations that lead to severe bronchoconstriction in others. Asthmatics are particularly sensitive.

- The maximum effect is usually reached within a few minutes. Effects are generally short-lived. Lung function returns to normal after some minutes to hours, varying with the individual and the severity of the response.

Levels of 500 µg/m^3 should not be exceeded for averaging periods of 10 minutes as asthmatics can experience changes in pulmonary function and respiratory symptoms (WHO 2006).

The association between short-term SO_2 and asthma hospital admissions and emergency room visits was judged to be causal for respiratory effects (WHO 2021).

WHO Guidelines for sulphur dioxide

Time Average	SO_2 Guideline (µg/m³)	Permitted Exceedances per year
24-hours	40	3-4
10-minutes	500	-

Additional reading

- Health effects of short-term exposure to SO_2 (Wickham *et al*. 2022e) – A plain English summary of the paper evaluating the best available evidence on the health effects of short-term exposure to SO_2 for the Guidelines update (Orellano *et al*. 2021)
- Effects of short-term exposure to NO_2 and SO_2 on asthma (Wickham *et al*. 2022d) – A plain English summary of the paper evaluating the best available evidence on the effects of short-term exposure to nitrogen dioxide and sulphur dioxide and asthma exacerbations (Zheng *et al*. 2021)
- Supporting Information for Air Quality Factsheets (Wickham *et al*. 2022g) supporting technical information for the plain English summaries.

Ozone (O_3)

Ozone (O_3) is a reactive gas that exists in two layers in the atmosphere: the stratosphere and the troposphere (at ground level and up to 15 km). Stratospheric ozone protects life on Earth from UV radiation, but tropospheric ozone is an air pollutant affecting human and ecosystem health.

Ozone is a secondary gas and is produced by a chemical reaction between hydrocarbons, including methane, and nitrogen oxides in the presence of sunlight. Because sunlight is required to form ozone, concentrations are usually highest in mid to late afternoon in summer. Ozone is also a major component of photochemical smog. Ozone is widely considered to be at very good (i.e., relatively low) levels in New Zealand.

Health effects of ozone

People most at risk from breathing air containing ozone include people with asthma, children, older adults, and people who are exercising outdoors. Breathing ozone can trigger a variety of health problems including chest pain, coughing, throat irritation, and airway inflammation. It also can reduce lung function and harm lung tissue. Ozone can worsen bronchitis, emphysema, and asthma, leading to increased medical care. People with lung or cardiovascular diseases are particularly at risk (USEPA 2020b).

WHO Guidelines for ozone

Time Average	O_3 Guideline (µg/m³)	Permitted Exceedances per year
8-hour daily maximum	100	3-4
8-hour mean, peak season [a]	60	-

[a] Peak season is defined as an average of daily maximum 8-hour mean ozone concentration in the six consecutive months with the highest six-month running average ozone concentration (usually summer)

Carbon monoxide (CO)

Carbon monoxide (CO) is a colourless, odourless and tasteless toxic gas. It is produced by the incomplete combustion of carbonaceous fuels such as wood, petrol, coal and natural gas.

Levels of ambient carbon monoxide in New Zealand are relatively low.

Health effects of carbon monoxide

In the human body carbon dioxide reacts with haemoglobin to form carboxyhaemoglobin. Short term exposure to high concentrations of carbon monoxide can cause acute ischaemic heart attacks (myocardial infarction) and damage the foetuses of non-smoking pregnant women due to untoward hypoxic effects (WHO 2010).

WHO Guidelines for carbon monoxide

Time Average	CO Guideline (mg/m³)	Permitted Exceedances per year
24-hours	4	3-4
8-hour	10	-
1-hour	35	-
30-minute	60	-
15-minute	100	-

Additional reading

- Effects of CO exposure on heart attacks (Wickham *et al*. 2022f) – A plain English summary of the paper evaluating the best available evidence on the effects of short-term exposure to carbon monoxide (CO) and myocardial infarction (Lee *et al*. 2021)
- Supporting Information for Air Quality Factsheets (Wickham *et al*. 2022g) – supporting information for the plain English summaries.

Air Pollution in New Zealand

New Zealand is fortunate in having relatively low levels of air pollution compared with other countries. Despite this, in some parts of New Zealand, ground level concentrations of particulate matter (PM) can be elevated in winter due to build-up of emissions from home heating and motor vehicles in cold, calm, weather conditions. In addition, levels of nitrogen dioxide (NO_2) can concentrate around transport corridors in urban environments.

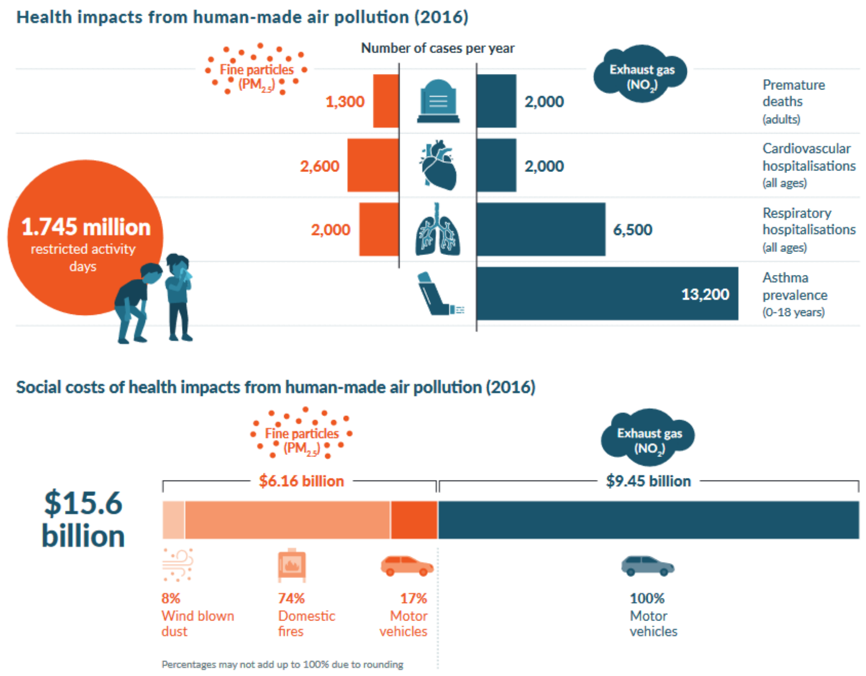
New Zealand's latest research, the HAPINZ 3.0 study (Kuschel *et al*. 2022), estimated that in 2016, the health outcomes attributable to anthropogenic (human-generated) air pollution resulted in:

- the premature deaths of more than 3,300 adult New Zealanders
- more than 13,100 hospital admissions for respiratory and cardiac illnesses, including 845 asthma hospitalisations for children
- over 13,200 cases of childhood asthma
- approximately 1.745 million restricted activity days (days on which people could not do the things they might otherwise have done if air pollution had not been present).

Of the more than 3,300 deaths approximately 60% (2,000) were associated with NO_2 pollution which is largely from motor vehicles, whilst the rest (nearly 1,300) were associated with fine particulate ($PM_{2.5}$) pollution largely from domestic fires. For context, 30,422 New Zealanders died in 2016 from natural causes (Ministry of Health 2022).

Whilst air pollution impacts many New Zealander's health, these adverse health impacts are not always evenly distributed. Susceptible groups include elderly people, children, people with pre-existing heart or lung disease, people with respiratory conditions (such as asthmatics), diabetics and pregnant women (Ministry for the Environment 2011).

Health impacts and social costs of air pollution in New Zealand



[Source: Ministry for the Environment 2022]

There is also an environmental justice aspect to these unevenly distributed health impacts. Lower socio-economic groups also tend to have housing close to significant emission sources such as arterial transport routes and industry. The HAPINZ 3.0 exposure model (Sridhar *et al*. 2022) indicates that lower socio-economic groups are disproportionately exposed to higher concentrations of nitrogen dioxide with corresponding disproportionate adverse health effects.

New Zealand has various air quality standards and guidelines for a range of pollutants and a range of time periods. Both short-term and long-term limits are set for each pollutant to provide a minimum level of health protection for all New Zealanders. The Ministry for the Environment has more information on the air quality standards and guidelines for New Zealand (MfE 2022).

Glossary

Acute exposure	Short-term exposure, typically hours or days.
Aerodynamic diameter	Airborne particles have irregular shapes, and how they behave in the air is expressed in terms of the diameter of an idealised spherical particle known as aerodynamic diameter. This is the size of a unit-density sphere with the same aerodynamic characteristics as the particle of interest. Particles having the same aerodynamic diameter may have different dimensions and shapes.
Aerosol	An aerosol is a suspension of fine solid particles or liquid droplets in air.
All-cause mortality	Death from all causes except external causes (such as accidents, intentional self-harm and homicide). Also referred to as natural mortality.
Bias	Any systematic error in an epidemiological study that results in an incorrect estimate of the true effect of an exposure on the outcome of interest.
Coarse particles	This typically refers to the fraction of particulate matter that is smaller than 10 micrometres in diameter but larger than 2.5 micrometres in diameter ($PM_{10-2.5}$). These particles are small enough to be inhaled into the thoracic region but too large to reach the alveolar region of the lungs. Coarse particles are composed largely of crustal material, sea salt and biological material.
Chronic exposure	Long-term exposure, typically months or years.
Epidemiology	The study and analysis of the distribution (who, when and where), patterns and determinants of health and disease conditions in defined populations.
Fine particles	This typically refers to particulate matter less than 2.5 micrometres in diameter. These are small enough to reach the alveolar region of the lungs where inhaled gases can be absorbed by the blood. Fine particles originate primarily from combustion sources.
Meta-analysis	A survey in which the results of the studies included in the review are statistically similar and are combined and analysed as if they were one study.
microgram (µg)	One millionth of a gram (1×10^{-6} g)
micrometre (µm)	One millionth of a metre (1×10^{-6} m)
Morbidity	Illness and disease, e.g., hospitalisations
Mortality	Death
Particulate matter (PM)	Particulate matter is a complex mixture of suspended particles and aerosols with components having diverse chemical and physical characteristics. It is generally classified by aerodynamic diameter (a summary indicator of particle size) because this determines dispersion and removal processes in the air and deposition sites and clearance pathways within the respiratory tract. The smaller the particle, the longer it remains suspended in the air. Particles larger than 50 micrometres (µm) in diameter will settle out quickly. However, for fine particles of 1 µm any settling due to gravity is negligible (i.e. they will stay suspended in the air).
PM_{10}	Particulate matter smaller than 10 micrometres (µm) in diameter. PM_{10} is so small that it behaves like a gas, travelling for significant distances once emitted to air. PM_{10} includes inhalable particles that are sufficiently small to penetrate to the thoracic region of the lung. The coarse fraction of PM_{10} (i.e., $PM_{10-2.5}$) is primarily produced by mechanical processes such as construction activities, road dust resuspension and wind-blown dust, however, it also includes natural sources such as sea salt, pollen, mould and plant parts.
$PM_{2.5}$	Particulate matter smaller than 2.5 micrometres (µm) in diameter, also called fine particulate. $PM_{2.5}$ has a high probability of deposition in the smaller conducting airways and alveoli of the lungs where inhaled gases can be absorbed by the blood (WHO, 2006). $PM_{2.5}$ is mainly produced by combustion of fossil fuels and through secondary particle formation from nitrate, sulphate and organic aerosols and particles.

$PM_{0.1}$	Particulate matter smaller than 0.1 micrometres (µm) in diameter, also called ultrafine particulate. These particles are small enough to cross into the blood and circulate through the body.
Systematic review	Literature review designed to provide a complete, exhaustive summary of current evidence that is methodical, comprehensive, transparent, and replicable.
Time average	The length of time over which exposure is measured. This is an important element of understanding air pollution and air pollution effects. For example, a concentration of PM_{10} as a 24-hour average, is the concentration of PM_{10} when averaged out over a whole day. The hourly concentrations of PM_{10} may increase overnight then rise in the morning with peak hour traffic but drop off in the afternoon and evening. However, the daily concentration will reflect the average concentration over the full 24-hour period from midnight to midnight. Similarly, an annual average PM_{10} concentration is the concentration of PM_{10} when averaged out over all 365 days (or 8,760 hours) in a year. Typical urban areas of New Zealand have elevated daily concentrations of PM_{10} in winter (due to high emissions from domestic heating combining with still wind conditions). However, spring and summer winds typically result in much lower daily PM_{10} concentrations and the annual average is reduced accordingly when averaged over all the seasons.
µg/m^3	microgram per cubic metre. This is the mass measured in millionths of a gram per unit of (cube) space comprising 1 metre x 1 metre x 1 metre. In New Zealand concentrations are typically specified at 0°C (MfE, 2009).

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