Editorial

Composition and oxidative potential of PM2.5 pollution and health

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Overview

There is evidence that the health damage from PM2.5 pollution varies with particle composition and that particles with high proportions of elemental or organic carbon, or high oxidative potential (OP) might be more detrimental to pulmonary health. A study in Ontario, Canada with relatively low average PM2.5 (7.1 μg/m^3) measured the depletion of anti-oxidants glutathione (GSH) and ascorbate (AA) in PM2.5 sampled from 19 locations. At low PM2.5 pollution (3-day mean <10 μg/m^3), the effect of increasing PM2.5 exposure on respiratory diseases was worse in locations with high GSH depletion. As well as indicating a possible mechanism for the health damage from PM2.5 exposure, this research confirms that PM2.5 pollution is detrimental to health at levels well below current guidelines. In Canada, 55% of PM2.5 emissions (excluding open and natural sources) originate from home firewood burning, despite only 6% of Canadian households using wood as the main form of heating. A good strategy would be to use all cost-effective means to reduce PM2.5 exposure, including effective education programs on the sources and health hazards of PM2.5 pollution and heeding the UN Environment Program recommendation to phase out log-burning stoves in developed countries.

PM2.5 composition and health impacts

Several studies show the composition of air pollution particles can be important, e.g., a study of PM2.5 across 4 US cities concluded that "*among the primary PM2.5 sources assessed, biomass burning PM2.5 was most strongly associated with respiratory health*" (1). An analysis of deaths and hospital admissions for cardiovascular and respiratory diseases in two polluted cities in Chile concluded: "*there is greater risk when people are exposed to air polluted with wood smoke*" (2). For 119 U.S. urban communities: "*Ambient levels of elemental carbon (EC) and organic carbon matter (OCM), which are generated primarily from vehicle emissions, diesel, and wood burning, were associated with the largest risks of emergency hospitalization across the major chemical constituents of PM2.5.*" (3). Across 72 urban U.S. communities, an inter-quartile range increase in, respectively OCM, all PM2.5 and EC the previous day increased non-accidental mortality by 0.39%, 0.30% and 0.22% respectively (4), implicating OCM as one of the more hazardous constituents of PM2.5 pollution.

Significant health impacts at average PM2.5 of 7 μg/m^3

Weichenthal and colleagues investigated whether the impact of PM2.5 on health is affected by the OP of the particles. Emergency room (ER) visits for asthma, COPD and all respiratory diseases were obtained for 19 locations (15 cities, including 3 separate areas in each of Hamilton and Toronto) in Ontario, Canada from 2004–2011 (5). Although PM2.5 pollution (mean 7.1, SD 6.2 μg/m^3) was well below current guidelines (6), significant adverse health effects were observed. An increase in 3-day mean PM2.5 of 5.9 μg/m^3 (equal to the inter-quartile range, IQR) increased ER visits for asthma, COPD and all respiratory complaints by 3.5%, 2.2% and 1.9% respectively. The greatest impact was for visits of children with asthma, which increased by 7.2% per IQR increase in 3-day PM2.5. The statistical model accounted for the effects of temperature, humidity and numbers of visits for influenza. Other pollutants were also considered—similar models were fitted for NO_2 and O_3 and a redox-weighted index: $Ox^{wt} = (1.07 \times NO_2 + 2.075 \times O_3)/3.145$ (to account for the fact that O_3 is a stronger oxidant than NO_2), as well as multi-pollutant models, which showed significant effects, in addition to PM2.5, of O_3 and Ox^{wt}, but not NO_2.

Effect of oxidative potential

Glutathione (GSH) and ascorbate (AA) are two antioxidants that help defend the lung against inhaled pollutants. PM2.5 (sampled in 2012–2013 from pollution monitors in the 19 areas) were assessed for glutathione and ascorbate depletion in simulated respiratory tract lining fluid. Depletion varied substantially between cities and was assumed to reflect the long-term OP of the 19 areas. Areas with high glutathione-related oxidative potential (OP^{GSH}) tended to have lower ascorbate-related oxidative potential (OP^{AA}). Oxidative burdens of PM2.5 pollution for glutathione and ascorbate were estimated by multiplying PM2.5 measurements for each day in 2004–2011 by the estimated OP^{GSH} and OP^{AA} of the area (5).

Over the entire range of PM2.5 measurements, city-wide estimates of OP^{GSH} or OP^{AA} did not have a significant effect on the health damage from of PM2.5 pollution. However, the concentration-response plots suggested an effect of OP^{GSH} at low pollution levels. This was tested by restricting the analysis to days with 3-day mean PM2.5 below or equal to 10 µg/m^3. More than 80% of visits were on days when PM2.5 pollution was less than or equal to 10 µg/m^3; on these days, the effect of increased PM2.5 pollution increasing the risk of ER visits for asthma (P=0.007) and all respiratory visits (P=0.001) was greater in areas with higher OP^{GSH}.

A major limitation of the analysis of Weichenthal and colleagues (5) is the use of area-wide measurements of OP^{GSH} and OP^{AA} from assays of pollution collected on filters in 2012–2013 to indicate the severity of health damage of PM2.5 exposure in earlier years. Different assays are sensitive to different aerosol components. In the south-eastern United States (SE-US), OP^{AA} was higher in summer and autumn than winter, with highest levels near heavily trafficked highways, suggesting sensitivity to road dust and traffic emissions. By contrast another OP assay (dithiothreitol, DTT) was higher in winter and was affected by both traffic and biomass burning (7). The SE-US study used information on pollution sources to estimate OP^{AA} and OP^{DTT} of PM2.5 in earlier years. Consistent with the results of Weichenthal and colleagues (5), AA activity was not statistically associated with any tested health outcome, but DTT activity was associated with ED visits for both asthma or wheeze and congestive heart failure (7).

Accurate estimates of the health effects of air pollution require accurate estimates of pollution exposure, otherwise the effect will be under-estimated (8). The stronger concentration-response relationship for PM2.5 × OP^{GSH} in the Ontario study suggests that previous estimates of the health damage of low levels of PM2.5 pollution may have been under-estimated.

Implications and future considerations

This study confirms that adverse health effects are evident at levels well below the current World Health Organization guidelines of 10 µg/m^3 (annual) and 25 µg/m^3 (daily average). Adverse health effects have also been noted for long-term exposure to what was previously considered low pollution, e.g., a Canada-wide study with median PM2.5 of 7.4 µg/m^3 found non-accidental deaths increased by 7.5% per 5 µg/m^3 increase in PM2.5 (9). This implies that current guidelines should not be described as (or considered) safe and that the public will benefit from greater efforts to reduce PM2.5 exposure.

As well as studies of particle composition, OP and source apportionment, emissions inventories are an important tool to determine the costs and benefits of reducing emissions. In Ontario: "*PM2.5 emissions from point, area and transportation sources (excluding emissions from open and natural sources) indicate residential fuel combustion accounted for 57 per cent*" (6). A Canadian Government report notes: "*Excluding open sources shows the contribution of other sources that have more of an impact on the population given they are generally emitted in areas of high population*" (10).

Almost all (97%) of Ontario's PM2.5 emissions from residential fuel combustion are from home wood burning (11), which represents just 7% of home energy use in Ontario and the main form of heating for 3% of households (12). *Figure 1* compares PM2.5 pollution at selected locations in the Ontario study (downtown Toronto and the area with the highest OP^{AA} [Thunderbay], the highest OP^{GSH} [Barrie], and lowest OP^{GSH} [Petawawa]) with 3 sites in British Columbia (BC: north Vancouver, Courtenay [population 22,000] and Duncan [population 5,000]). Despite generally low wood

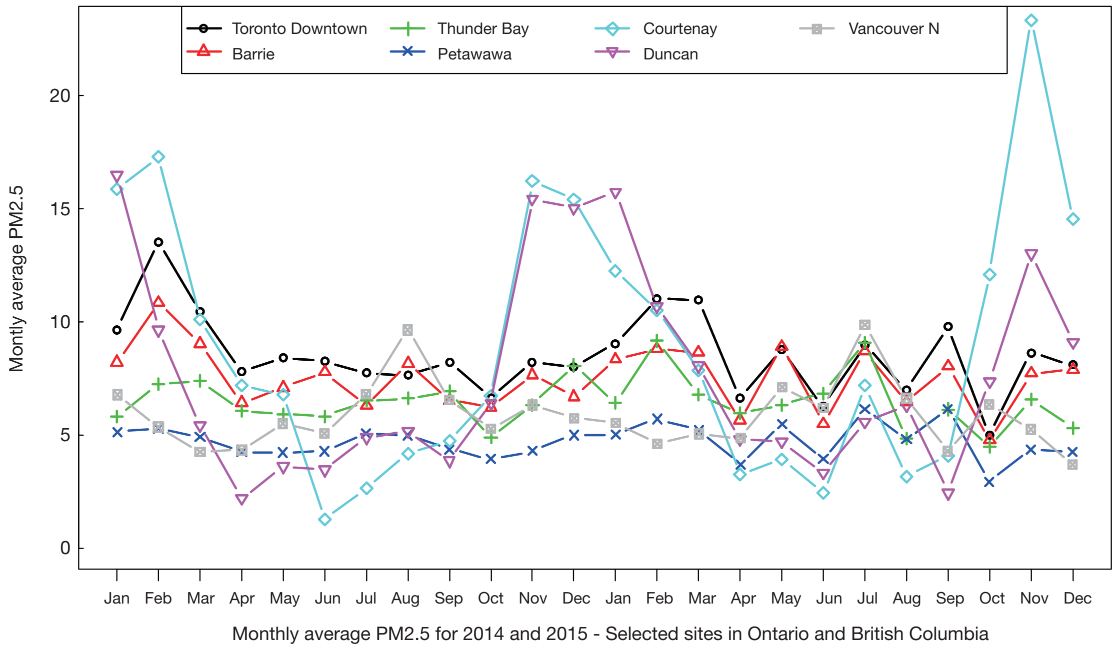

Figure 1 Monthly average PM2.5 in 2014 and 2015 at selected sites in Ontario and British Columbia, Canada.

heater use in BC (used by 5% of households as the main form of heating), measurements in Courtenay and Duncan demonstrate the wintertime build-up of PM2.5 pollution to unhealthy levels in areas with above-average wood heater use.

The large proportion of PM2.5 emissions from home wood burning is an unfortunate legacy from earlier times before the widespread availability of affordable, non-polluting heating and when little was known about the harmful effects of PM2.5 pollution. In the mild climate enjoyed by coastal areas of British Columbia such as Duncan and Courtenay, modern, efficient heat pumps have superseded wood stoves and natural gas as the most cost-effective heating. They can deliver 5 or 6 times as much heat to the home as they use in electric power and are effective at low temperatures, providing 3 to 4.5 times as much heat even when the temperature outside is −10 ℃ (10 degrees below freezing). They are affordable (cheaper than buying a wood heater), cause less global warming (zero in households that use green power) and have lower running costs than buying firewood (13).

Low-cost air pollution monitors in woodsmoke-affected areas show that pollution in the vicinity of a wood stove can build up much higher levels than measured at the nearest air pollution monitor (14). Australian and New Zealand studies imply estimated health costs of thousands of dollars per stove per year, even for new wood stoves (15,16). The particle composition and source apportionment studies (1,3,4) identified OCM, EC, and emissions from biomass burning as particularly harmful for respiratory health. Substantial public health benefits would therefore be gained by adopting the successful techniques used elsewhere to increase awareness of the substantial health and environmental costs of wood compared to non-polluting alternatives. In New South Wales, Australia, the estimated health cost of the state's 372,000 wood stoves was A$8 billion (over 20 years), but 3 simple measures—not allowing new wood stoves to be installed, requiring existing ones to be removed before houses are offered for sale and annual licencing fees for wood heater use were predicted to reduce the costs by at least 75%.

Phasing out log-burning stoves in developed countries was one of a package of 16 measures recommended by the UN Environment Program and World Meteorological Organization to reduce global warming from short-lived climate pollutants as well as health damage from air pollution (17). After the publication of local studies showing greater risk for exposure to wood smoke than other pollutants, a total ban on wood heating was introduced in the Province of Santiago, Chile.

As well as suggesting that some particles might be more harmful than others, the results of the Ontario study, like many others, reinforce the message that there is no safe level of PM2.5 pollution, and that all cost-effective measures, including phasing out log-burning stoves in developed countries, should be implemented.

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None.

Footnote

Conflicts of Interest: The author has no conflicts of interest to declare.

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