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Understanding the impacts of air pollution on human experience: Two case studies

Folk Costumes, Indo Pacific Air (APE,2022)

It has long been known that substances in the air can have adverse effects on human health. Today, with the impacts of climate change and human activity changing the world in untold ways, air pollution represents a considerable and global threat to our health.

Between 2005 and 2010, the death rate associated with exposure to outdoor air pollution increased globally by 4 per cent, by 5 per cent in China and by a staggering 12 per cent in India (Kumar et al., 2019). The Organisation for Economic Co-operation and Development (OECD) has stated that outdoor air pollution exposure is predicted to become the leading environmental cause of premature death by 2050 (WHO Regional Office for Europe, 2015). In 2012 alone, it was estimated that approximately 7 million deaths were related to outdoor air pollution (World Health Organization, 2016). Pollution exposure also has a negative impact on economies, with a reported ~USD$ 1.7 trillion spent on health-related costs in 2010 (Kitamori et al., 2012).

Whilst a proportion of air pollution results from natural processes such as bushfire smoke, pollen release and surface dust, in cities large quantities of pollutants are produced from fossil fuel emissions, which comprise a mixture of solid particulate matter (PM) and gases, including oxides of sulphur (SOx), oxides of nitrogen (NOx), carbon monoxide (CO), carbon dioxide (CO2), and ozone (Bai et al., 2018).

By examining industrial pollution in China and the pollution resulting from the recent Australian bushfires, we can see how our changing planet is influencing both manmade and biomass generated sources of air pollution. But first, it is important to have an understanding of the pollutants and their risk profiles.

The pollutants

Particulate matter (PM) encompasses a complex and diverse range of organic and inorganic particles that exist in either suspended solid or liquid phases. PM is defined by the particle aerodynamic diameter in µm, and is classed accordingly (PM_{10}, $PM_{7.5}$, PM_5, $PM_{2.5}$ or $PM_{<0.1}$). PM can be generated in ambient environments by human activities such as vehicle emissions, road dust, fossil fuels, industrial activities, and indoors from heating, cleaning activities and cooking (Reisen et al., 2019).

PM is widely recognised as one of the most dangerous pollutants for human health, with the smaller fractions of PM ($PM_{2.5}$ and $PM_{<0.1}$) being directly associated with over 2 million deaths per annum worldwide (Lelieveld et al., 2015, Van der Wall, 2015). Due to their small size, $PM_{2.5}$ and $PM_{<0.1}$ pose a greater risk to human health than larger PM classes as they can penetrate and embed into the alveoli and thus translocate into the blood, potentially transferring large volumes of toxic compounds (Jayaram et al., 2011). This is cause for concern worldwide, as mechanically ventilated commercial buildings generally have insufficient filtration capabilities to effectively remove PM of the smaller size fractions (Morawska et al., 2017).

Nitrogen dioxide (NO_2) is a relatively reactive atmospheric gas and is often detected in indoor environments at concentrations that pose a threat to human health, as gas stoves and ovens are the major sources of NO_2 and other nitrogen oxides (NO_x) (Yin et al., 2019). Vehicular emissions are the primary ambient source of NO_2, and thus concentrations are generally higher in dense urban areas (Shon and Kim, 2011).

Ozone is a secondary contaminant that is primarily formed in the troposphere from chemical reactions between various reactive agents (Bräuner et al., 2014). In some indoor environments, elevated concentrations are released from typical office and domestic equipment such as electrostatic air cleaners and photocopying machines (Hyttinen et al., 2003).

Much like NO_2, sulphur dioxide (SO_2) is mainly combustion derived, however it is only produced in problematic concentrations when fuels containing sulphur, such as coal and oil, are burned. Indoors, kerosene-burning devices such as heaters and cooking stoves, and especially solid fuel cooking and heating appliances may be significant sources (Lam et al., 2012). However, in developed countries, elevated indoor SO_2 concentrations and resultant exposure have primarily been attributed to infiltration of ambient vehicular emissions (Mason et al., 2019). Globally, SO_2 emissions have fallen by up to 75 per cent in metropolitan and industrial areas, mainly due to the now widespread use of low sulphur diesel fuel (Hoesly et al., 2018), however in dense urban environments, ambient and indoor SO_2 remains an issue (Conley et al., 2018).

Carbon monoxide (CO) is a relatively unreactive gas that can pass freely through building envelopes and ventilation systems (Zhong et al., 2013). In many cases, indoor concentrations are higher than those in ambient environments due to the use of combustion appliances such as gas cooking stoves and ovens, flueless gas and kerosene heaters or fireplaces, tobacco smoking and similar combustion processes (Fazlzadeh et al., 2015).

Impact of industrialisation on the atmosphere: China

Developing countries suffer the most from poor air quality, with exceptional economic growth and industrialisation leading to high level air pollution, along with water contamination and land degradation (Mannucci and Franchini, 2017). These serious environmental issues are thus the focus of considerable research and public attention (Bowler et al., 2010, Lee et al., 2014, Wang et al., 2015). Although reductions in air pollution will clearly lead to improvements in human and environmental health, very little data is available on the public health benefits of air pollution control measures and policies, especially for developing countries (Molina et al., 2019). This issue is important since the disease burden associated with air pollution has increased in the past decade, especially in low-income and middle-income countries (Goyal et al., 2019). Additionally, although air pollution is a universal issue, it causes the greatest harm in susceptible individuals who are exposed to high air pollution concentrations. People with chronic diseases (particularly cardiorespiratory illnesses), little social support, and poor access to medical services are most at risk from air pollution. In developing countries, such cases may largely go unreported.

The largest developing country, China, has been changing rapidly over the last three decades and its economic expansion is largely driven by the use of fossil fuels, which have led to a dramatic increase in emissions of both ambient air pollutants and greenhouse gases (GHGs) (Zheng et al., 2015). It is now the largest emitter of carbon dioxide (Wang et al., 2016), and a large emitter of methane and black carbon, the other two major GHGs contributing to global warming (Zhang et al., 2016). Ambient air pollution and climate change are placing Chinese residents at significant risk healthwise.

With growing energy consumption and rapid urbanization, an increase in ambient air pollution is an inescapable reality. Even though ambient air quality in Chinese cities has remained stable or even improved slightly in recent years – an accomplishment achieved through the relocation of polluting industries, a switch to less polluting fuels, the enforcement of zoning regulations and stricter emission standards for mobile and stationary sources (Zhang et al., 2020), better city planning, and increased investments in city infrastructure (Li et al., 2020) – China is still amongst the countries with the worst air quality globally. Megacities such as Beijing, Shanghai, and Chongqing are frequently among the cities with the highest levels of air pollutants in the world (Wang et al., 2017).

Additionally, the makeup of China's air pollution is changing. Coal is still the major source of energy, constituting about 75 per cent of all energy sources (Chai et al., 2019). Consequently, air pollution in China predominantly consists of coal smoke, with suspended particulate matter and sulphur dioxide the principal air pollutants (Chen and Bloom, 2019). In Chinese cities, however, with the rapid increase in the number of motor vehicles, air pollution is gradually transforming from coal combustion-sourced to a mixed coal combustion/motor vehicle emission type (Sun et al., 2019).

In recent years, the ‘grey sky’ phenomenon caused by fine particles ($PM_{2.5}$ and smaller) has become an increasing public concern. This effect, which occurs predominantly in urban areas, poses a serious health risk to Chinese residents (Meng et al., 2020). $PM_{2.5}$ is not yet a routinely monitored air pollutant in most Chinese cities. China’s reported annual average concentrations of $PM_{2.5}$ in the 2000s were in the range of 56 to 122 $\mu g/m^3$. In Beijing, for example, the annual average $PM_{2.5}$ concentrations in 2001–2004 ranged from 96.5 to 106.7 $\mu g/m^3$ (Duan et al., 2006), which was approximately seven times the ambient air quality standard recommended by the US Environmental Protection Agency (15 $\mu g/m^3$) and ten times the WHO Global Air Quality Guideline (AQG) (10 $\mu g/m^3$). In Shanghai, the annual average $PM_{2.5}$ concentration in 2005 reached 56 µg/m3, which was also much higher than the WHO AQG (Cao et al., 2012). There is an on-going plan to include $PM_{2.5}$ in air quality monitoring in Chinese cities (Tilt, 2019).

So far, the information available on the health benefits of air quality improvements in developing countries is limited to modelling studies, although they do provide important information, especially with respect to China. For example, Wang et al., (2019) used county-level $PM_{2.5}$ and mortality data to estimate $PM_{2.5}$-associated disease burden in 2020 along with forecasts for 2030. They reported that the projected health benefit of the Air Pollution Prevention and Control Action Plan would be considerable, and could reduce the number of $PM_{2.5}$-related premature deaths by approximately 130,000 (13.5 per cent) in 2020 and by 220,000 (22.8 per cent) in 2030. However, the health benefits resulting from air quality improvements could be potentially offset by the effect of population growth and an aging population. Thus, to reduce future disease burden, the implementation of more stringent measures for air quality improvement and public health protection are needed in China. Further, collaborative and focused efforts are needed to deal with a growing and aging population.

Impact of wildfires in the atmosphere

Australia has relatively good air quality, with annual average $PM_{2.5}$ concentrations around 8 μg/m^3, which are below the World Health Organization guideline of 10 μg/m^3. As with any developed country, there are a number of important sources of air pollutant emissions in Australia, including fossil fuel combustion, specifically motor vehicle derived pollutants, coal-fired power stations, industrial processes, ships and domestic wood heaters in winter (Broome et al., 2020). The ambient air quality in Australia is exceptionally good compared to many other countries, although concentrations of PM and NO_2 can exceed national standards on occasions. These instances are generally related to stable meteorological patterns, and bushfire-hazard-reduction burns in summer, which can cause severe pollution events for a few days in most years.

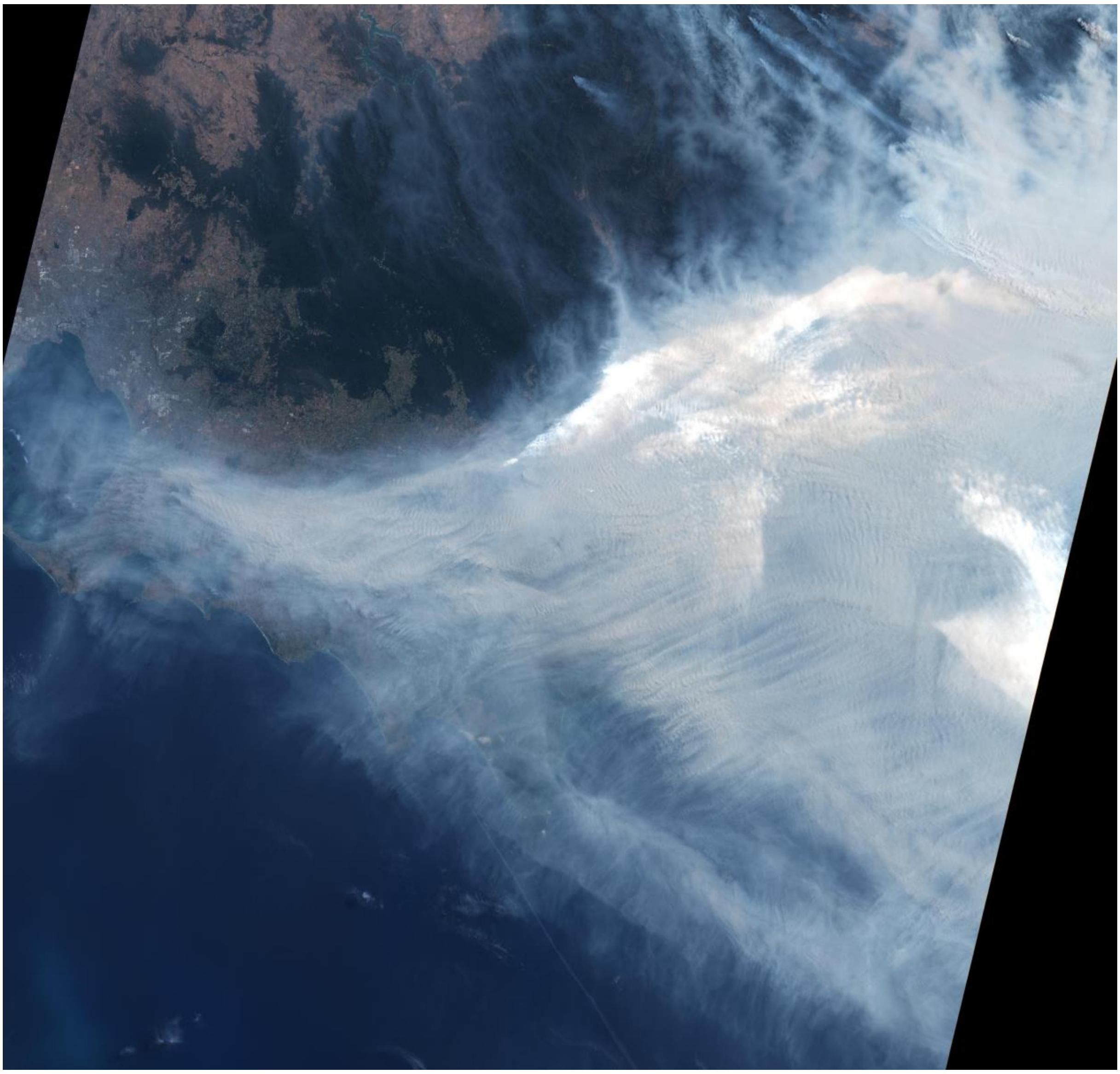

Figure 1. Smoke from Australian bushfires extending across the Tasman Sea and blanketing New Zealand

In Australia, human generated sources of pollution pale in comparison to those from biomass sources: smoke from bushfires, wildfires and planned hazard reduction burns can contribute up to 43 per cent of the emissions over a yearly period (Hibberd et al., 2016). While bushfires and their associated emissions have always been part of Australia's history, the recent 2019–2020 bushfire season, – known as the 'black summer' – was the worst in recent memory.

Both New South Wales and Queensland declared a state of emergency after new record property losses during this fire season. At least 2.7 million hectares in New South Wales burned, with widespread fires starting in September 2019 – a much earlier start to the fire season than in previous years. The burnt area was three times larger than 2019 fires in the Amazon (906 000 hectares).

These bushfires confirmed researchers' warnings from several years ago about an increase in wildfires resulting from climate change in Australia (Prichard et al., 2020). Fire-susceptible vegetation has been promoted by both a decrease in rainfall and an increase in extremely hot temperatures (see fig. 2). According to the Australian Bureau of Meteorology, the Southern Downs (QLD) and Northern Tablelands (NSW) experienced record low rainfall from January to August 2019, making large areas of vegetation very dry and flammable. Australia has warmed by more than 1°C since 1910. The warming climate in Australia has been accompanied by heatwaves that have increased in frequency, duration, and maximum temperatures. In 2019, both states entered the bushfire season after a year of hot temperatures and low rainfall, putting many districts under high risk. A similar situation occurred in the 2009 Black Saturday fires in Victoria, when Melbourne reached a record-breaking high temperature (46·4°C) following a long drought.

The bushfires in New South Wales destroyed about 700 homes and untold wildlife, including seriously threatening koala populations due to habitat loss. The fate of many species in the bushfire affected areas remains widely unknown, with ancient ecosystems impacted. Additionally, it has been estimated that major Australian bushfires during 1967–2013 resulted in over 8000 direct human injuries and 433 direct fatalities, costing approximately Australian $4.7 billion. However, this estimate did not consider indirect costs, which mainly result from the adverse health effects of bushfire smoke. By way of comparison, the US Environmental Protection Agency has estimated the indirect effects of air pollution from wildland fires on excess premature deaths and morbidity in the USA during 2008–12 led to health costs of US$513 billion.

Health effects of wildfire smoke have been well documented worldwide, through large studies and hospital admissions data, namely from Australia, the United States and Canada. A recent study estimated that an average of 339,000 people died in 2012 due to wildfire smoke related causes worldwide. Johnston et al., (2012) and colleagues also estimated that when climatic events such as El Niño occur, deaths could increase to as high as 532,000. As our climate changes, there is compelling evidence that the likelihood of extreme weather events, like El Niño, will increase.

The parts of Australia most affected by the bushfires lie on a coastal lowland plain between the Pacific Ocean and elevated sandstone tablelands. The climate for these areas is warm and temperate, and have been described as sub-tropical (Stewart, 2017). Days in which rainfall events occur are evenly distributed throughout the year, however rainfall volume is maximal in Autumn (March–May).

The most hazardous component of bushfire smoke is suspended particulate matter. As a result of bushfire smoke, in December 2020 most areas of Sydney recorded, over a twenty-four-hour period, average $PM_{2.5}$ concentrations that exceeded 100 μg/m^3 (and as high as 500 μg/m^3), which is four-times higher than the WHO guideline value of 25 μg/m^3. By comparison, the daily average $PM_{2.5}$ concentration before the bushfire was approximately 20 μg/m^3.

Furthermore, bushfire smoke has also been associated with increased risks of hospitalisation and emergency department visits due to respiratory diseases such as asthma, chronic obstructive pulmonary disease, and respiratory infections. Increasing evidence also suggests bushfire smoke might increase cardiovascular morbidity, psychological disorders, adverse birth outcomes, and eye irritation. However, our knowledge about the health effects of bushfire smoke is still insufficient. The long-term and lasting effects of bushfire smoke and which subgroups are most vulnerable to its effects remain largely unknown. It has been suggested that PM_{10} generated from bushfires might have different health effects compared with PM_{10} from urban background sources (such as traffic emissions). Therefore, more studies focusing on air pollutants from bushfires are needed.

Unfortunately, there is no current effective way to reduce the effects of bushfire smoke on human health, although wearing facemasks and staying indoors are commonly recommended, and many people consider facemasks the best protection. Yet facemasks might be not effective or sometimes provide a false sense of security. Their effectiveness depends on their filtration capacity: fine particles can still get through them if their filtration capacity is low. Additionally, an individual’s behaviour and characteristics (such as facial hair or the duration and frequency of use) also affect the efficiency of the facemask. Importantly, wearing a facemask can be uncomfortable in very hot weather when bushfires are most frequent. Even if facemasks could protect adults, it is still questionable whether they could protect children, older individuals, pregnant women, and those with chronic diseases, as these groups often cannot tolerate the inconvenience and discomfort of wearing a mask.

Staying indoors might provide some protection against bushfire smoke, but this depends on building quality and ventilation. In general, most residential houses are not equipped with air purifiers or air conditioning systems with high-efficiency filters. Hence, outdoor pollutants can still penetrate the interior. Subsequently, indoor and outdoor concentrations of fine particles are often very similar in many buildings, especially residential ones.

Climate change will continue to exacerbate catastrophic bushfire conditions. It has been estimated that days with a high-to-extreme risk of fire will increase by 15–70 per cent by 2050, and by more than 100 per cent by 2100, as compared with 2010.1 Although some politicians claim that climate action is too expensive, the increasing intensity and frequency of bushfires clearly indicate that the price of climate inaction is even higher. Unfortunately, the Australian Government has not engaged well in climate action over the past decade. Australia is on track to meet less than half of its carbon emission reduction targets, which are to reduce emissions by 26–28 per cent relative to 2005 by 2030, and achieve net zero emissions by 2050.

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