ATSC413 Final Project: *Public health impact of wildfire smoke in Canada*

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Introduction

The health impact of fire smoke is a subject of increasing interest, as climate change continues to contribute to longer and more severe fire seasons [1]. Unpredictable weather makes it more difficult to predict and contain fire behavior, which thus makes it harder to model and understand the impacts of wildfire smoke, which can be widespread. Populations closest to wildfire activity experience more health impacts, but the long-range transport of wildfire smoke and particulate matter can harm populations that are hundreds of kilometres away [2].

Air pollution is well-known to harm respiratory and cardiovascular health, as well as decrease general quality of life, and pollutants from wildfire smoke are no exception. Climate change is not the only thing impacting wildfire season; historical wildfire management, which prioritized suppression of fires above all else, has created a huge buildup of fuels which is now contributing to the intensity and spread of wildfires we are seeing today. Combustion due to wildfires emit plenty of carbon compounds such as carbon dioxide and carbon monoxide, nitrogen oxides, sulfur oxides, VOCs, toxic residues from pesticides, and a range of other chemicals [3]. Smoke is a complex phenomenon to model, as temperature, wind speed and direction, and the types of fuels burned all play a role on the chemical composition of smoke and the health impact it can have.

Beyond physical health, the mental health of communities who have been forced to evacuate because of wildfires is greatly impacted, even years after the fire itself. Wildfires pose a huge threat to people's property, sense of stability and normalcy, and can create long-lasting disruptions to routines of work, school, and activities. Rebuilding after losing a home can take years, especially in towns where a significant fraction of homes burned down. Higher rates of depression, anxiety, and PTSD have been reported in communities impacted by wildfires, and those who personally lost homes are more greatly affected [4].

In this paper, I will look at the smoke composition of wildfires and structure fires, analyze the physical health impacts from occupational and non-occupational exposure to fire smoke, and conclude with how long-range transport of wildfire aerosols can occur in both the troposphere and stratosphere.

Smoke Composition

To analyze the health impacts of wildfire smoke exposure, the chemical composition of smoke needs to be understood. Smoke composition is a complex mixture that ultimately depends on the location of the wildfire, as structure fires will burn different materials than forest fires, but overall, certain compounds are commonly present [3]. The most well-known pollutant generated from fires is particulate matter (PM); particles of most concern from a public health standpoint are PM_{10} and $PM_{2.5}$, or particles with a diameter less than 10μm and 2.5μm, respectively. Particles larger than 10μm will have a shorter atmospheric lifetime and will not penetrate as deeply into the respiratory system as the smaller particles of $PM_{2.5}$. While the exact chemical makeup of particulates depends on the materials being burned, PM is overall recognized as the component of fire smoke that represents the largest threat to human health [5].

Other chemicals commonly emitted from fires include various forms of carbon: carbon dioxide (CO_2), methane (CH_4), and carbon monoxide (CO), which make up the majority of the carbon-containing species emitted from the combustion of organic materials [6]. CO_2 and CH_4 are familiar as two of the major chemical species contributing to climate change, but can also act as asphyxiants by displacing oxygen. Carbon monoxide (CO) is also an asphyxiant, and is a colorless, odorless gas which can cause life-threatening complications or death if a high enough concentration is breathed in. An estimated two-thirds of deaths related to structure fires were caused by carbon monoxide poisoning from smoke inhalation [7][8]; however, CO poisoning presents less of a lethal risk during wildfires since concentrations are unable to build up quickly outdoors like they can within a confined indoor space.

Respiratory irritants emitted from fires include ammonia, sulfur dioxide, formaldehyde, and acrolein, the latter of which can cause significant eye irritation, lower respiratory frequency, and is thought to be one of the primary chemical factors causing incapacitation and inability to escape from structure fires [8] [3].

Smoke from structure fires has plenty of variation in chemical composition due to the high variation in materials burned. Damage to gas and power lines, water infrastructure, and buildings can lead to the emission of many different substances, such as compounds found in wall insulation, furniture items, home appliances, and garbage. One major category of chemicals not commonly found in wildfire smoke is plastics, which burn easily and emit a range of toxic compounds [9] [10].

A study of a controlled burn of various types of plastics found that low concentrations of toxic heavy metals was present in the soot, which presents concerns for inhalation during combustion but also requires careful cleanup, as the ash containing toxic heavy metals may contaminate soil or water. Other chemicals of concern from plastic combustion included persistent free radicals, which are commonly found in urban areas from combustion of oil or gas, and pose a major influence on lung health [9]. Polycyclic aromatic hydrocarbons (PAHs) are found not only in plastic emissions, but also in wildfires from the combustion of wood; PAHs are known to be carcinogenic, and were detected at higher concentrations in airborne particulate soot than the toxic heavy metals [9].

Furniture, upholstery, and other building materials that have been made to be fire retardant may not reduce health hazards as much as hoped; even though the material may burn more slowly, it may greatly increase the toxicity of the fire smoke by producing higher concentrations of CO and hydrogen cyanide (HCN) than non-fire retardant materials [11].

Woodsmoke can contain carcinogens like benzene, formaldehyde, and PAHs, and soil disruption while fighting wildfires can expose firefighters to minerals in the soil such as silica [12]. Smoke composition is an important component when estimating the respiratory impact of inhalation, and the health effects depend on a lot of factors: the length and frequency of exposure, the age and gender of the individual exposed, respiratory rate, particle size, and others.

Occupational Exposure

To fully analyze the ways in which fire smoke impacts public health, it is necessary to look at the effects of both acute, short-term exposure and chronic, long-term exposure. To do this, I will be looking specifically at the exposure of firefighters, as they regularly experience occupational exposure to fire emissions and are exposed to higher concentrations of the chemicals found in smoke than communities downwind would experience [6]. Relatively few studies have been conducted on the long-term health impacts of working as a firefighter, although this area of research is increasingly a source of interest as wildfires continue to worsen [12][13].

The occupational hazards of firefighting are many: respiratory and cardiovascular disease from smoke exposure, traumatic injury in rescue situations, thermal burns, psychological impact of firefighting, and exposure to toxic chemicals that can cause a variety of acute and chronic health issues [3]. Epidemiological studies have shown that firefighters have an increased risk of cancer and cardiovascular disease [13]. Longer careers in firefighting are associated with higher long-lasting and systemic inflammation, which plays a key role in the development of respiratory and cardiovascular diseases [13]. The health impacts of employment as a firefighter can vary significantly, as many firefighters are volunteer and work only during fire season in the spring and summer, while others are career firefighters.

Wildfire firefighters, while exposed to a different variety of chemicals than found in structure fire smoke, still suffer the effects of exposure to $PM_{2.5}$ and other woodsmoke emissions. A risk assessment of rates of lung cancer and cardiovascular disease in firefighters from PM in wood smoke found that firefighters who had 5-year careers had an 8% greater risk of lung cancer mortality and a 16% greater risk of cardiovascular disease mortality [12]. Firefighters with 25-year careers had a 43% greater risk of lung cancer mortality and a 30% greater risk of cardiovascular disease mortality [12]. A survey of self-reported health outcomes of firefighters most commonly reported hypertension, heart arrhythmia, and knee problems resulting in surgery [14]. Others reported the repeated periods of heat stress, emotional stress, and disrupted sleep posed long-term problems to their health [14].

There are no occupational standards for firefighters' exposure to PM, which complicates estimations of the effects of long-term exposure [6][14]. Respiratory protection is also not standardized or commonly used to fight wildfires, and many firefighters report wearing no respiratory protection at all during long shifts [15] [16]. High quality protection, called self-contained breathing apparatus, are costly and stifling to wear; demanding hours in extremely hot temperatures comes by nature of the job, and while many studies have agreed that protective equipment is an important factor for respiratory health, it must also be made of fire-safe materials so as not to cause harm to firefighters, and raises concerns of affecting firefighters' heat stress, respiratory rate, and other physiological factors [17].

Concerns about how protective equipment might trap heat and decrease performance ability has affected usage of protective clothing, but a study of four different personal protective clothings has demonstrated no increase in physiological response in moderate fire conditions, with temperatures of 30° and relative humidity at 30% [17]. Further research into protective equipment suitable for fighting wildfires is needed, and analysis of in what circumstances this gear would be most effective at reducing exposure is needed to most effectively intervene in current wildfire firefighting practices.

Short-term exposure to wood smoke has been correlated to a decrease in FEV lung function and cardiovascular function, increased inflammation, and increased arterial stiffness [13]. Exposure to high levels of particulate matter from the Fort McMurray fire in Alberta, Canada, lead to firefighters having increased rates of consultation for asthma and hyperreactivity in the lungs, which causes spasms in the bronchial wall which can make breathing difficult [18].

Non-Occupational Exposure

Firefighters are not the only population who experiences increased risk of health issues from exposure to fire smoke - amongst those who experienced non-occupational exposure, higher rates of respiratory-related hospitalizations occurred in those aged 40-64 years, as well as in children younger than 5 years of age [5]. Comparatively few of the articles I found that researched the epidemiological impact of wildfire smoke exposure considered the effect modification of socioeconomic status. In one that did, indigenous Australians were found to have an increased risk of respiratory and emergency admissions to the hospital compared to the general Australian population [19].

Additionally, countries with a lower socioeconomic status had a larger risk estimate between wildfire smoke exposure and rates of asthma and congestive heart failure, compared to countries with a higher socioeconomic status [20]. Countries with a lower socioeconomic status are also at higher risk of experiencing health impacts from air pollutants, in general, not only pollutants from wildfires [20]. This suggests that socioeconomic status is an important factor when researching the health outcomes of a population, on a country-wide scale as well as a community-wide scale, and should be included in future analyses of fire smoke impact.

Numerous studies have noted that increased levels of PM_{10} are associated with increased mortality; although the exact level of increase is difficult to measure quantitatively, it is approximated that a 10 $\mu g/m^3$ increase in PM_{10} levels is associated with a 0.5% to 1.5% increase in daily mortality [21]. Rates of asthma and chronic obstructive pulmonary disease (COPD) increased in people over 65 years of age, and hospital admissions for COPD and cardiovascular disease increased by 1.5% and 1.1% respectively for each 10 $\mu g/m^3$ increase of PM_{10} concentration [21].

Transport of wood smoke from wildfires can affect air quality in communities far away from the fire itself. From a retrospective analysis of wildfire $PM_{2.5}$ health impact in Canada from 2013-2015 and 2017-2018, an estimated 54 - 240 premature fatalities occurred annually from short-term PM exposure, and an additional 570 - 2500 premature fatalities occurred annually from long-term PM exposure [2]. Also taking into account the non-fatal health issues such as cardiovascular events and overall inflammation, the economic cost of the public health impact is estimated to be around 410 million to 1.8 billion dollars annually from the acute health effects, and 4.3 to 19 billion dollars annually for chronic health effects [2]. Globally, $PM_{2.5}$ from all landscape fires is associated with an approximate 339,000 premature fatalities [22].

The proximity of communities to wildfires, as well as the behavior of the smoke plume, play key roles in determining community exposure to smoke [2]. Estimating smoke plume behavior is a complicated modeling issue, as most models depend on emission factors and are limited by the model resolution; these data can be difficult to source and exact emission factors are often not known. Populations across Canada were impacted by wildfire smoke from long-range transport, although communities closest to the fires experienced the greatest impact [2].

Wildfire smoke and particulate matter can travel hundreds of kilometres along Earth's surface in the troposphere, and a developing field of research is studying the impact of wildfire smoke that reaches the stratosphere. Smoke can bypass the tropopause and penetrate the stratosphere if heat from the wildfire lofts the air high enough [23]. The full effects of smoke in the stratosphere remain poorly understood, as it is difficult to recreate in laboratory conditions and is hard to observe in real-time due to the extreme wildfire behavior necessary to bring smoke to the stratosphere. However, recent study has shown that stratospheric wildfire smoke could be contributing to stratospheric ozone depletion by causing chlorine activation. [23]. Depletion of the ozone layer would mean higher levels of UVB radiation at the Earth's surface, leading to more risk for various skin cancers.

Wildfire smoke has a multitude of consequences for human health, both near and far. Improvement of exposure models is needed to better understand how smoke exposure affects acute and chronic human health, and how it may have far-reaching consequences worldwide.

Conclusion

Wildfires and structural fires produce a complex array of particulates, and measuring the health impacts of smoke inhalation both occupationally and non-occupationally is a complicated task. Exposure to fire smoke has been demonstrated to cause a range of health effects, from increased rates of asthma, COPD, and other respiratory diseases, to cardiovascular disease and other inflammatory conditions. Socioeconomic status plays a role in determining health outcomes, and should be taken into account when modeling the impact of smoke exposures; access to healthcare is an important component affecting health outcomes. Further research is needed to understand the full effect on public health and quality of life, in addition to implementing strategies for residential fire safety and firefighter safety.

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