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Potential health impacts associated with peat smoke: a review

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Abstract

In Western Australia, peat is distributed throughout the Swan Coastal Plain, in the South West and North West regions of the State. Peat is typically associated with wetlands and its distribution has significantly reduced over the past 100 years. The major threats to the current distribution of peat are fire and land use changes. Peat is thought to be at increased risk of fire in particular due to the proximity of residential development and the drying period being experienced in South Western Australia. Peat, largely arising from accumulated plant matter, burns very easily when dry and fire in these systems is often very hard to extinguish due to the depth of material. Peat smoke is made up of a complex mixture of water vapour, gases and fine particles. In general, peat smoke is characterized by high concentrations of organic carbon, elemental carbon, and potassium. The gases in peat smoke include carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, carbonyl compounds, polycyclic aromatic hydrocarbons and other irritant and hazardous volatile organic compounds. All of these have been shown to cause deleterious physiologic responses at high concentrations in laboratory studies of animals and a limited number of chamber studies of humans at lower concentrations. There is little known about the health effects of exposure to peat smoke as few studies have focused specifically on this potential source of air pollution. Information is, however, available on the composition of peat smoke and there are some studies arising from specific fires which resulted from burning of underground environments, including events in Russia, USA and Indonesia. Peat smoke therefore represents a concern for communities living in areas where there is an increased risk of fire and where duration of fire in these systems is lengthy.

This paper presents a review of information available on adverse health effects, notably respiratory diseases and symptoms, associated with components of peat smoke. The health effects reported from epidemiological studies from which exposure to peat fires has been referenced is also reviewed, along with a summary of some of the literature on exposures to bushfire smoke which shares similar components to peat smoke.

Keywords: peat smoke, health, smoke composition

Introduction

Peat is characterized by the presence and accumulation of decaying plant material or organic matter (Ryder 2000). When it is dry, it burns very easily producing smoke. Peat is unique in the way it burns as the heat generated can facilitate fire moving through the soil profile resulting in fires lasting for extended periods lasting for days to months (Hungerford *et al* 1996; Kirk 2002). Peat fires are hard to extinguish due to the fact that fire follows the layers of peat as far as fifteen meters into the earth (Hungerford *et al*. 1996; Kirk 2002). One of the problems of burning forests to clear land is the potential for ignition of fires in outcrop deposits of coal or peat, which can then smoulder underground for many years and re-igniting again given appropriate conditions (Hamilton *et al* 2000). The widespread fires throughout the forested peat lands of Indonesia during 1997 is an example of where deforestation and subsequent fire resulted in the ignition of peat with smoke being produced for months. In Indonesia, Page *et al* (2000) reported that on the Borneo island in Central Kalimantan, 32 % of the area burned was peat and accounted for 91.5 % of the burned material.

Peat fires are characterized by significant quantities of smoke and emissions of which carbon dioxide is a significant component. However, the nature of the pollutants released during peat fire varies according to the composition of the peat, the geology of the area, the depth of the fire and the temperature achieved. Such variables will influence the composition and concentration of smoke components and therefore the potential for health impacts. In addition to the smoke composition, the degree of exposure to smoke by individuals and communities, their health status and the duration of exposure will also influence the potential for adverse health outcomes.

Peat is widely distributed on the Swan Coastal Plain, although there is an estimated seventy percent loss of the original extent due to past land use practices and urban development (Davis & Froend 1999). The remaining peat deposits are under pressure particularly from continued urban development and fire.

With the proximity of residential development to peat deposits, a drying climate and the associated risk of fire, the potential for human exposure to peat smoke exists. If fires occur for extended periods, exposure to smoke and smoke components may also be prolonged.

This paper provides a review of the available literature on the health effects of peat from studies of smoke and peat fires. Use is made of the literature pertaining to bushfires due to the small number of studies reporting health effects associated with burning of peat and the presence of similar compounds in bushfire smoke which have been associated with health effects.

Peat Fire Smoke Composition

Peat smoke is a complex mixture characterized by high concentrations of organic carbon, elemental carbon, potassium and sulphur (Ramadan et al. 2000; Gebhar et al. 2001). Peat burning produces many other potentially harmful gases and combustion by-products, including fine particles (Itkonen & Jantunen 1983; NCDENR 1998). Both PM10 (coarse fraction, with particle diameter < 10 μm) and PM2.5 (fine fraction, with particles diameter < 2.5 μm) have been found in the smoke arising from peat fires with PM2.5 being the predominant fraction (Joseph *et al* 2003). Peat-fire smoke also contains ammonia which reacts with oxides of nitrogen and sulfur to form fine particles (PM2.5) (Breas *et al* 2001; Anderson *et al* 2003).

The gases produced in peat fires include carbon monoxide, carbon dioxide, nitrogen oxides, sulfur oxides, aldehydes, polycyclic aromatic hydrocarbons and other irritant volatile organic compounds (VOCs) (Itkonen & Jantunen 1983). Page *et al* (2002) estimated that in Indonesia in 1997, 0.81 to 2.57 Gt of carbon were released to the atmosphere as a result of burning peat and vegetation. This is equivalent to 13–40 % of the mean annual global carbon emissions from fossil fuels, and contributed greatly to the largest annual increase in atmospheric CO_2 concentration detected since 1957 (Page *et al* 2002). In Russia in 2002, fires emerged across West Russia. Satellite analysis estimated a burned area of more than eleven million hectares of land with the resulting haze reducing visibility in Moscow. Carbon dioxide was measured at three times its usual concentrations (Kirk 2002).

In the 1997 Indonesian forest fires, the particles emitted contained high sulphur to potassium (S/K) ratios. These high ratios originated from the sulphur dioxide (SO_2) released through the combustion of peat below the ground (Ikegami *et al* 2001) The particle emissions from savannah fires in southern Africa also have high S/K ratios from fine particulate samples (Liu et al. 2000). Peat fires in the Amazon bush were found to contain potassium, chlorine and sulphate dominated PM2.5, while calcium and acetate dominated the coarse fraction (Allen & Miguel 1995). In general, savannah and tropical forest biomass burning could be responsible for the emission of about 1 Gg yr^{-1} of copper, 3 Gg yr^{-1} of zinc and 2.2 Tg yr^{-1} of black carbon to the atmosphere (Yamasoe *et al* 2000).

Polycyclic aromatics and dioxin-like compounds have been measured in the smoke from peat fires. In Indonesia in 1997, concentrations of polycyclic aromatic hydrocarbons in areas affected by smoke were 6–14 times higher than levels in unaffected areas (Kunii *et al* 2002). Very low concentrations of dioxin-like compounds (polychlorinated dibenzo-p-dioxins (PCDD) and dibenzofurans (PCDF), non-ortho polychlorinated bi-phenyls (PCB) and mono-ortho PCB) are reported to arise from burnt vegetation and burnt soil (Martinez *et al* 2000). Some authors consider that the main contribution to dioxin emissions is by firewood and peat combustion through incomplete combustion of organic carbon in the presence of chlorine (Kakareka 2002; Perkins 2003).

Other hazardous substances released during peat burning include methyl chloride, non-methane hydrocarbons, ethylene, volatile organic compounds (VOC), methyl bromide, benzene, polynuclear aromatic hydrocarbons and their oxygenated derivatives. Selected VOCs and methyl bromide play an important role in ozone depletion (Keppler 2000) while benzene, polynuclear and polycyclic aromatic hydrocarbons are reported carcinogenic substances (McCauley *et al* 1999; Keppler et al. 2000; Kjallstrand & Petersson 2001; Wippel *et al* 2001; Czapiewski *et al* 2002; Tsapakis *et al* 2002).

There are a number of other substances found in peat smoke. Fires can mobilize radionuclides from contaminated biomass through suspension of gases and particles in the atmosphere or solubilization and enrichment of the ash (Amiro *et al* 1996). In a study of peat combustion, field and laboratory experiments were conducted to determine the fate of iodine (I), cesium (Cs) and chlorine (Cl) in biomass fires (Amiro *et al* 1996). During a typical field fire, 80–90 % of the iodine and chlorine, and 40–70 % of the cesium were lost to the atmosphere, the remainder being left behind in the ash in a soluble form. The authors consider that if the elements were radioactive isotopes, such as ^{129}I, ^{137}Cs and ^{36}Cl, fires could cause an increased radiological dose to people through inhalation, exposure to ash, or ingestion of plants because of increased uptake of ash leachate (Amiro *et al* 1996). In Sweden in 1983, high uranium concentrations were observed in peat ash with external gamma radiation dose rates up to 10 microGy/h (Ehdwall *et al* 1985).

Potential Health Impacts of Peat Smoke Exposure

The concentration of pollutant, extent and duration of exposure, age, individual susceptibility and other factors play a significant role in determining whether or not someone will experience smoke-related health problems.

Several epidemiological studies have been conducted as a result of smoke originating from peat fires the most significant being the Indonesian forest and peat fires of 1997 (Emmanuel 2000; Hamilton *et al* 2000; Ikegami *et al* 2001; Page *et al* 2002).

In June 1997, mainly in the Kalimantan and Sumatra islands, more than 1,500 fires consumed more than 300,000 ha of forests, and generated intense smoke, affecting neighbouring countries (*e.g.*, Singapore, Malaysia, Thailand) and the Indonesian Islands for several months. The local health impact of the Indonesian fires has not been well documented although increases in hospital admissions for respiratory problems have been reported in Singapore (Emmanuel 2000).

Following acute exposure to air pollutants from Russian forest and peat bog fires in 2002, health authorities reported an increase in the number of reports of acute symptoms such as headaches, watery eyes and tiredness (Kirk 2002). Other acute symptoms reported after exposure to peat fire in Craven County, North Carolina included dizziness, weakness, sleepiness, nausea, vomiting, confusion and disorientation (NCDENR 1998).

Several large wildfires and peat fires occurred in Florida during June-July 1998. A survey of selected diseases was conducted in 8 hospitals to determine whether certain medical conditions increased in frequency during the wildfires compared with hospitalisations during the same period in the previous year. From 1997 to 1998, the emergency departments (ED) visits increased substantially for asthma (91 %), bronchitis with acute exacerbation (132 %), and chest pain (37 %) (MMWR 1999).

Health Effects of Specific Components of Peat Smoke

Information is available on the health effects of some of the individual components of peat smoke which are also components of bushfire smoke. Many studies report associations between individual components such as particulates or nitrogen dioxide due to the complexities of assessing the health effects of mixtures such as smoke arising from bushfire or peat fires. Many of the components of peat or bushfire smoke are also found in emissions from industry and motor vehicles and have been associated with a variety of health effects.

Particulate Matter (PM): Particles which may be produced from peat fires are considered harmful to health when the results from studies of particles arising from other sources are considered (Pope & Dockery 1992; Li *et al* 2003). PM10 and PM2.5 particles can be inhaled into the lungs causing lung irritation, damaging lung tissue and causing respiratory and cardiovascular problems (Pope 1996; Joseph *et al* 2003). People with heart disease, like congestive heart disease, might experience chest pain, palpitations, and shortness of breath or fatigue following exposure to particulate matter. People with lung conditions such as chronic bronchitis, chronic obstructive lung disease, emphysema and asthma may not be able to breathe as deeply or as vigorously as usual, and they may experience symptoms such as coughing, phlegm, chest discomfort, wheezing and shortness of breath. (Larson & Koenig 1994; Joseph *et al* 2003). The deposition of particles in the lung induces a systemic inflammatory response detected by increased levels in cytokines. (van Eeden *et al* 2001).

Fine PM has been associated with increased morbidity and mortality among individuals with cardiovascular disease and can aggravate chronic heart and lung diseases (Pope 1996; Hong *et al* 1999; Joseph *et al* 2003). Fine particle matter has been linked to premature deaths in people with these conditions (Burnett *et al* 1998; Hong *et al* 1999; Joseph *et al* 2003). Some studies report that PM may exacerbate asthma and cause coughs and other respiratory symptoms in children (Pope & Dockery 1992; Gauvin *et al* 2002). In addition, prolonged exposure to PM may also affect the growth and functioning of children's lungs producing decreased pulmonary function, increased respiratory symptoms, increased lower respiratory infection and increased chronic lung disease (Larson & Koenig 1994; Gauderman *et al* 2002; Horak *et al* 2002) . This may be important if exposure to peat smoke occurs at an important development stage for children.

In asthmatics, epidemiological studies generally show a positive relationship between the particulate fraction of air pollution and increased morbidity (Goldsmith & Kobzik 1999). The Australian National Environment Protection Council (NEPC) suggests that each increase of 10 $\mu g/m^3$ in the ambient concentration of fine particulate is associated with a 3.0 % increase in asthma exacerbations (NEPC 2000)

Carbon Monoxide: Carbon monoxide (CO) is one of the most important components of smoke from peat fire which can pose a health hazard at high concentrations (NCDENR 1998). CO has been associated with increased respiratory and cardiovascular mortality (Hexter & Goldsmith 1971; Burnett *et al* 1998; Hong *et al* 1999). The health effects associated with exposure to CO range from the more subtle cardiovascular and neurobehavioral effects at low concentrations to unconsciousness and death after acute or chronic exposure to higher concentrations of CO. Symptoms include headache, dizziness, weakness, nausea, confusion, disorientation, and visual disturbances and severe poisoning results in marked hypotension, lethal arrhythmias, and electrocardiographic changes (NCDENR 1998; Raub *et al* 2000; Kirk 2002).

People with angina or heart disease, pregnant women, developing fetuses, and those who exercise outdoors are particularly sensitive to carbon monoxide pollution (NCDENR 1998). Neurological effects of acute CO poisoning includes disorientation, confusion, and coma. (Raub *et al* 2000). The effects can range from mild, annoying symptoms relieved by removal of the source, to severe morbidity with profound central nervous system dysfunction and acute complications (Abelsohn *et al* 2002).

Sulphur dioxide: Increases in hospital admissions for respiratory diseases, particularly asthma, have been associated with elevated concentrations of SO_2 (Guillen *et al* 1995; Brown *et al* 2003). Chronic exposure to PM and SO_2 is associated with up to three-fold increases in non-specific chronic respiratory symptoms in children and long-term outdoor winter concentrations of SO_2 has been associated with wheezing/whistling and with asthma diagnosed by a doctor (Pikhart *et al* 2001). Asthmatic children are susceptible to increased levels of SO_2, even with ambient levels considered within "acceptable" ranges (Chew *et al* 1999). In a case control study of the risk of hospital admission for chronic bronchitis, an increase of 10 % resulted from a 10 ppb increase in SO_2 concentration (in the range 0–60 ppb) (Ciccone *et al* 1995). A similar positive association was observed for exposures to more than 10 ppb of SO_2 and hospitalization for ischemic heart diseases (Ciccone *et al* 1995).

Health effects of exposure to wildfire or bushfire smoke

During the last few years there have also been a number of fires involving exposure of large populations to air pollutants from large uncontrolled fires burning in underground and coal surfaces in countries including China, India and Indonesia. This information can be used to make some inference about the potential health impacts that may be associated with exposure to peat smoke.

Direct exposure to bushfire smoke has been linked to increases in a variety of community respiratory problems. Symptoms from short-term smoke exposure can range from throat irritation, cough, irritated sinuses, headaches, runny nose and eye irritation to more serious effects in persons with asthma, emphysema, heart disease and other existing medical conditions (Kunii *et al*. 2002; Emmanuel 2000; NCDENR 1998).

Duclos *et al* (1990) assessed hospital emergency room attendance in six counties arising from the California forest fires of 1987. They found an increase in the number of visits of persons with asthma, chronic obstructive pulmonary disease, sinusitis, laryngitis and upper respiratory infections were increased however no statistical increase in hospitalisations was observed (Duclos *et al* 1990). Mott *et al* (2002) assessed the health effects of the Californian fires of 1991 and again found increased visits to hospital for respiratory illness of 57 % compared with the previous year.

Between September 1997 and November 1997 in Indonesia, there were 527 haze-related deaths, 298,125 cases of asthma, 58,095 cases of bronchitis, and 1,446,120 cases of acute respiratory infection reported (Kunii *et al* (2002). In South Sumatra, the number of acute respiratory infection cases increased 3.8 times during the aforementioned time period, compared with the previous year. Ninety percent of 543 people interviewed about acute symptoms reported respiratory symptoms, and the elderly reported an overall deterioration of health. Gender, being older, and having a history of asthma was associated with an increased severity of respiratory problems (Kunii *et al* 2002).

In Singapore, the impact of the 1997 Indonesian forest fires was felt as a result of the prevailing winds. Emmanuel *et al* (2000) studied the potential health effects of the daily measured concentrations of the five major air pollutants: sulphur dioxide, particulate matter (PM10), nitrogen dioxide, ozone and carbon monoxide. The authors found a 30 % increase in outpatient attendance for haze-related conditions. An increase in PM10 levels from 50 microg/m^3 to 150 microg/m^3 was significantly associated with increases of 12 % of upper respiratory tract illness, 19 % asthma and 26 % rhinitis. Sizing of the haze particles showed that 94 % of the particles in the haze were below 2.5 μm in diameter (Emmanuel 2000). During the same period, there was also an increase in accident and emergency attendance for haze-related conditions, however there was no significant increase in hospital admissions or in mortality despite particulate levels being substantially higher than usual levels, possibly explained by differences in the particle size distribution during this particular bushfire (Emmanuel, 2000).

In Australia, Johnston *et al* (2002) investigated the relationship between bushfire smoke and emergency attendance at hospital for asthma. The authors of this study considered data from the dry season when bushfire activity is high and found that ED attendance increased significantly on days when PM10 concentrations were above 40μgm^3 compared with days below 10 μgm^3 (Johnston *et al*. 2002).

Studies of the Sydney bushfires have not demonstrated relationships between a variety of health outcomes (Jalaludin *et al* 2000; Smith *et al* 1996).

Concluding Remarks

The specific relationship between peat smoke and health effects has been identified as being of concern but is not well documented. It is clear that peat fires contribute smoke and component air pollutants that have been associated with adverse health impacts in toxicological and epidemiological studies. Additional studies are required to understand the potential health impacts of prolonged or repeated exposures to peat smoke and whether the composition of peat significantly impacts on a variety of health outcomes.

What makes peat fires of concern is the resultant smoke and duration with which they burn, significantly increasing the health risks associated with such fires. There is the possibility of long term health implications depending on the duration of the fires, the composition of the peat, the temperature of the fires and the health status of those exposed. The on-going investigations arising from the Indonesian fires for example, need to be monitored so the potential risks can be further considered.

The potential for health impacts needs to be taken into account when considering the role of fire and peat. Public health professionals have an important role in informing and educating vulnerable communities about the acute and possible long health effects of peat smoke exposure.

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