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A study of particulate emissions during 23 major industrial fires: Implications for human health

Simon D. Griffiths[a], Philip Chappell[b], Jane A. Entwistle[a], Frank J. Kelly[c], Michael E. Deary[a,*]

[a] *Faculty of Engineering and Environment, Department of Geography and Environmental Sciences, University of Northumbria, Ellison Building, Newcastle upon Tyne NE1 8ST, UK*
[b] *National Incident Management, Incident Management and Resilience Services, Environment Agency, Lateral, 8 City Walk, Leeds LS11 9AT, UK*
[c] *NIHR Health Impact of Environmental Hazards Health Protection Research Unit, Facility of Life Sciences and Medicine, King's College London, 150 Stamford Street, London SE1 9NH, UK*

ABSTRACT

Public exposure to significantly elevated levels of particulate matter (PM) as a result of major fires at industrial sites is a worldwide problem. Our paper describes how the United Kingdom developed its Air Quality in Major Incidents (AQinMI) service to provide fire emission plume concentration data for use by managers at the time of the incident and to allow an informed public health response. It is one of the first civilian services of its type anywhere in the world. Based on the involvement of several of the authors in the AQinMI service, we describe the service's function, detail the nature of fires covered by the service, and report for the first time on the concentration ranges of PM to which populations may be exposed in major incident fires. We also consider the human health impacts of short-term exposure to significantly elevated PM concentrations and reflect on the appropriateness of current short-term guideline values in providing public health advice. We have analysed monitoring data for airborne PM ($\leq 10\ \mu m$, PM_{10}; $\leq 2.5\ \mu m$, $PM_{2.5}$ and $\leq 1.0\ \mu m$, PM_1) collected by AQinMI teams using an Osiris laser light scattering monitor, the UK Environment Agency's 'indicative standard' equipment, during deployment to 23 major incident industrial fires. In this context, 'indicative' is applied to monitoring equipment that provides confirmation of the presence of particulates and indicates a measured mass concentration value. Incident-averaged concentrations ranged from 38 to 1450 $\mu g\ m^{-3}$ for PM_{10} and 7 to 258 $\mu g\ m^{-3}$ for $PM_{2.5}$. Of concern was that, for several incidents, 15-min averaged concentrations reached > 6500 $\mu g\ m^{-3}$ for PM_{10} and 650 $\mu g\ m^{-3}$ for $PM_{2.5}$, though such excursions tended to be of relatively short duration. In the absence of accepted very short-term (15-min to 1-h) guideline values for PM_{10} and $PM_{2.5,}$ we have analysed the relationship between the 1-h and 24-h threshold values and whether the former can be used as a predictor of longer-term exposure. Based on this analysis, for PM_{10}, our tentative 1-h threshold value for use in deciding whether to close public buildings or to evacuate areas is 510 $\mu g\ m^{-3}$. For $PM_{2.5}$, 1-h concentrations exceeding 350 $\mu g\ m^{-3}$ might indicate longer-term exposure problems. We conclude that whilst services such as AQinMI are a positive development, there is a need to consider further the accuracy of the data provided and for the development of very short-term guideline values (i.e. minutes to hours) that responders can use to determine the appropriate public health response.

1. Introduction

Episodic, acute, exposure of populations to airborne particulate matter (PM, where: $\leq 10\ \mu m$, PM_{10}; $\leq 2.5\ \mu m$, $PM_{2.5}$ and $\leq 1.0\ \mu m$, PM_1) at concentrations in the hundreds, and even thousands, of micrograms per cubic metre can occur under a variety of different scenarios, including: forest fires (Delfino et al., 2009; Heil and Goldammer, 2001; Sastry, 2002), dust storms (Godri et al., 2011; Hefflin et al., 1994; Karanasiou et al., 2012; Lee et al., 2013; Pey et al., 2013; Sajani et al., 2011; Stafoggia et al., 2016; Vodonos et al., 2014), crop residue burning (Gupta et al., 2016; Yang et al., 2008), festivals and celebrations involving fireworks (Barman et al., 2008; Beig et al., 2013; Godri et al., 2010; Wang et al., 2007), volcanic eruptions (Horwell and Baxter, 2006; Nania and Bruya, 1982), and industrial/urban emissions under adverse meteorological conditions (Macintyre et al., 2016; Schwartz, 1994; Zhou et al., 2015). These episodes, as summarised in Table 1, are known to have adverse health impacts, with probably the most well-known example being the London smog episode of 1952 when total

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[*] Corresponding author at: Faculty of Engineering and Environment, Department of Geography and Environmental Sciences, Ellison Building, Newcastle upon Tyne NE1 8ST, UK.
E-mail address: michael.deary@northumbria.ac.uk (M.E. Deary).

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Table 1
Average daily particulate concentrations, and associated health impacts, recorded during air pollution episodes arising from various sources.

No.	Source and location	Year(s)	Maximum average daily particulate concentration (μg m^{-3})	Health impacts Note: RR = Relative Risk	Ref
1	Atmospheric particulate matter episode, London	1952	2000 (TSP)[a]	RR = 1.06 for all-cause mortality per 100 μg m^{-3} increase	Schwartz (1994)
2	Atmospheric particulate matter episode, Ji County in Tianjin, China	2013	607 ($PM_{2.5}$)	RR = 1.069 (Confidence interval, CI 0.998 to 1.150) for all-cause mortality following a smog episode; RR = 1.013 (CI 1.0074 to 1.019) for all-cause mortality per 10 μg m^{-3} increase in $PM_{2.5}$.	Zhou et al. (2015)
3	Atmospheric particulate matter episodes, United Kingdom	2014	83 ($PM_{2.5}$)	Two episodes (10 days total) associated with 600 deaths and 1570 emergency respiratory and cardiovascular admissions.	Macintyre et al. (2016)
4	Forest Fires (S.E. Asia), measured in Kuala Lumpar, Malaysia.	1997	424 (PM_{10})	RR = 1.19 for all-cause mortality the day after a > 210 μg m^{-3} event	Sastry (2002)
5	Californian wildfires, measured at	2003	76 ($PM_{2.5}$)	RR = 1.143 for respiratory admissions per 10 μg m^{-3}	Delfino et al. (2009)
6	Forest Fires (S.E. Asia), measured in Palangkaraya, Indonesia.	1997	4000 (TSP)	See item 4	Heil and Goldammer (2001)
7	Forest Fires (S.E. Asia), measured in Kuching, NW Borneo-Malaysia.	1997	930 (PM_{10})	See item 4	Heil and Goldammer, (2001)
8	Seasonal dust storm, Southeast Washington State	1991	> 1000 (PM_{10})	3.5% and 4.5% increases in emergency room visits for bronchitis and sinusitis respectively per 100 μg m^{-3} increase in PM_{10}.	Hefflin et al. (1994)
9	African dust outbreaks, measured in the Emilia-Romanga region of Italy	2002 to 2006	100 (PM_{10})	Respiratory mortality increased by 22% on dust storm days for people over 75.	Sajani et al. (2011)
10	African dust outbreaks, measured across the Mediterranean basin	2004	300 (PM_{10})	Not determined	Pey et al. (2013)
11	African dust outbreaks, measured in Be'er Sheva, Israel	2001 to 2010	4797 (PM_{10})	RR = 1.16 for hospitalisation due to chronic obstructive pulmonary disease (COPD) exacerbation on dust storm days (> 71 μg m^{-3})	Vodonos et al. (2014)
12	African dust outbreaks, measured in Les Palmas, Gran Canaria.	2001 to 2005	612 (PM_{10}); 242 ($PM_{2.5}$)	RR = 1.22 (CI 1.07 to 1.39) for asthma admissions per 10 μg m^{-3} increase in PM2.5.	Lopez-Villarrubia et al. (2016)
13	Fireworks, Beijing, China	2006	466 (PM_{10}); 184.3 ($PM_{2.5}$) (12 h sampling period)	Not determined	Wang et al. (2007)
14	Fireworks, Lucknow, India	2005	963 (PM_{10})	Not determined	Barman et al. (2008)
15	Fireworks, London	2007	60 (PM_{10})	Not determined	Godri et al. (2010)
16	Crop residue burning, Suqian, China	2006	340 (PM_{10})	Not determined	Yang et al. (2008)
17	Crop residue burning	2013 to 2014	167 (PM_{10}) 107 ($PM_{2.5}$)	Decrease of between 4 and 6% in Peak Expiratory Flow during burning periods.	Gupta et al. (2016)
18	Volcanic eruption, Mount St Helens	1980	3000 to 33,000 (TSP)	10% increase in hospital visits	Horwell and Baxter (2006), Nania and Bruya (1982)

[a] TSP can be converted to PM_{10} using a factor of 0.55 (Pope et al., 1995).