Hazelinks
Ambulance Victoria data: Time Series Analyses (First Data Extraction)

Version 1.0
November 2018

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Acknowledgements

The Hazelwood Health Study is a large program of work that comprises a number of research streams in addition to this Hazelinks stream. Those research streams are run by a multidisciplinary group of academic and administrative staff from several Institutions including Monash University, the University of Tasmania, Federation University and the Commonwealth Scientific and Industrial Research Organisation. All of these staff are thanked for their contribution to this collaborative work.

We would like to take this opportunity to thank the following researchers and clinicians who have provided important input to the research presented in this report: Dr Fay Johnston, Dr Matthew Carroll and Dr Grant Williamson.

This research was funded by the Victorian Department of Health and Human Services. The report presents the views of the authors and does not represent the views of the Department.

Caveat

This report presents a preliminary analysis which has not been submitted to independent peer review. Subsequent scientific manuscripts which undergo independent peer review may vary in their findings or interpretation.

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Abbreviations

ASGC	Australian Standard Geographical Classification
ASGS	Australian Statistical Geography Standard
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DHHS	Department of Health and Human Services
GLM	Generalised linear model
LGA	Local Government Area
PCR	Patient Care Record
$PM_{2.5}$	Particulate matter with an aerodynamic diameter of 2.5 micrometres (thousandths of a millimetre) or less
PM_{10}	Particulate matter with an aerodynamic diameter of 10 micrometres (thousandths of a millimetre) or less
RR	Relative Risk
SA	Statistical area level
VACIS	Victorian Ambulance Clinical Information System
95% CI	95% Confidence Interval

Glossary of terms

1. **Mine fire period**: The 30 day period between 9 February and 10 March 2014 when the daily modelled fire-generated $PM_{2.5}$ concentration, averaged across the Latrobe Valley SA3 area, exceeded 1 μg/m^3.

2. **Entire analysis period**: Period 1 July 2010 to 31 March 2015 excluding 25 September to 31 December 2014.

3. **All conditions**: All ambulance attendance records irrespective of the final primary diagnosis recorded at the point of care by paramedic.

4. **Remainder of the analysis period-** Period 1 July 2010 to 31 March 2015 excluding 25 September to 31 December 2014 and mine fire period from 9 February and 10 March 2014.

5. **Fire impacted SA2 areas**: SA2 areas where the modelled daily $PM_{2.5}$ concentrations from the fire reached 1μg/m^3 for at least one day.

Executive Summary

From 9 February 2014, smoke and ash from a fire in the Morwell open cut brown coal mine adjacent to the Hazelwood power station covered parts of the Latrobe Valley, eastern Victoria, for up to 6 weeks. In response, the Hazelwood Health Study was established in order to monitor any long-term or short-term health effects of that smoke event. This report describes analyses which aimed to answer: 1) whether there were increased ambulance attendances during the mine fire; and 2) whether increases in mine fire-related air pollutants ($PM_{2.5}$) were associated with increased ambulance attendances over subsequent days for cardiovascular and respiratory conditions.

The analyses utilised modelled daily concentrations of mine fire-related fine particulate matter with diameter ≤2.5 micrometers ($PM_{2.5}$). Daily counts of ambulance attendances obtained from Ambulance Victoria were analysed for the period July 2010 to March 2015. Time series models were used to evaluate the relative risk of ambulance attendances during the mine fire in comparison with the *remainder of the analysis period* and to also assess the relative risk of ambulance attendances associated with daily mine fire-related $PM_{2.5}$ levels. The models used for these analyses controlled for factors likely to influence ambulance attendance rates including seasonality, long-term temporal trends, day of the week, daily maximum temperature and public holidays.

The main results of the analyses indicated that there was a 15% increased risk for ambulance attendances for *all conditions* and a 41% increased risk for attendances for respiratory conditions during the *mine fire period*, compared with the *remainder of the analysis period* after controlling for influential factors. This corresponds to an estimated total of 236 attendances for *all conditions* and 42 attendances for respiratory conditions associated with the mine-fire during the mine-fire period.

Similar results were identified when assessing the lag-response relationship between mine fire-related $PM_{2.5}$ concentrations and ambulance attendances. When assuming that the effect of $PM_{2.5}$ lasted for 7 days, an immediate response that lasted for 5 days was identified for ambulance attendances for respiratory conditions, whereas for *all conditions*, the association wasn't apparent until the third day after exposure and lasted for 5 days. Analysis of cumulative relative risk for a number of specified lag day ranges found strong and consistent evidence for an association between mine fire-related $PM_{2.5}$ and attendance rates for respiratory conditions. There was weak evidence for *all conditions* when assuming the lag day range of 0-20 days.

Although, this study adjusted for the main confounding factors, there are unknown factors that cannot be controlled for, such as proportion of population leaving the area, which would cause underestimation of the effect. Using simulated $PM_{2.5}$ exposure data as well as aggregating data at Statistical Area Level 2 would introduce measurement error of exposure, and therefore, bias effect estimates towards no associations.

1 Introduction

On 9 February 2014, the Morwell open cut brown coal mine adjacent to the Hazelwood power station in the Latrobe Valley, eastern Victoria, caught fire resulting in nearby areas being covered in plumes of smoke and ash over a six-week period. Subsequently, a Monash University-led consortium of researchers were contracted by the Victorian Department of Health and Human Services to undertake a comprehensive study of the long term health and wellbeing of Latrobe Valley residents following exposure to the smoke from the Hazelwood mine fire.

The Hazelinks component of the Hazelwood Health Study aims to use administrative health data sets to investigate short, medium and long-term health outcomes in the fire impacted region. This report draws upon data routinely collected by the Ambulance Victoria for all ambulance attendances.

2 Background

The adverse effect of air pollution on health has long been appreciated and, due to improved methods of monitoring and measurement, has become a more active research area in the last twenty years. Extensive clinical, epidemiological, and toxicological studies have provided evidence of relationships between exposure to ambient urban air pollutants and human health (Brunekreef et al., 2002, Beelen et al., 2014). The short-term effects of air pollution from traffic, industries and bushfires have mainly been demonstrated by increases in respiratory (Haikerwal et al., 2016, Strickland et al., 2010, Faustini et al., 2012) and cardiovascular morbidity (Dennekamp et al., 2010, Colais et al., 2012, Pope et al., 2006, Haikerwal et al., 2015) and mortality (Johnston et al., 2011, Atkinson et al., 2014).

Large, destructive coal mine fires, such as the Hazelwood mine fire, are often beyond human control despite technologically advanced fire-fighting services and the resources allocated to fire control. Pollutants generated by coal combustion are similar to those generated from domestic solid fuel combustion and outdoor biomass fires (Melody et al., 2015). Pollutants may be broadly categorised as gases, particles with a median aerodynamic diameter less than 10µm or 2.5µm (PM_{10} or $PM_{2.5}$), volatile organic compounds and trace elements. Many of these are known to be deleterious to human health. The immediate impact of coal mine fires can be devastating, with loss of life, livelihood and infrastructure at the fire fronts. However, to date there is limited evidence on the impacts of smoke from coal mine fires on health outcomes.

3 Aim and objectives

The aims of the analyses were to examine: 1) whether ambulance attendances increased during the *mine fire period* relative to comparable time periods before and after the fire in the mine-fire impacted areas; and 2) whether the daily levels of mine fire-related $PM_{2.5}$ were related to increased ambulance attendances on subsequent days for respiratory and cardiovascular conditions in the mine-fire impacted areas.

4 Human Research Ethics Committee and other approvals

Monash University Human Research Ethics Committee (MUHREC) approved the Hazelwood Adult Survey & Health Record Linkage Study on 21 May 2015; this included approval to request ambulance attendance data from Ambulance Victoria. An application to access Ambulance Victoria data was also submitted and approved by Ambulance Victoria.

5 Methods

5.1 Datasets

Data on ambulance attendances

Data on ambulance attendances were collected from the Victorian Ambulance Clinical Information System (VACIS). VACIS holds electronic Patient Care Records (PCRs) that are created by paramedics at the point of care and includes complex clinical and operational information (such as event location, patient details and paramedic diagnosis and outcome). Since 2008 the completion of electronic PCRs has been compulsory for paramedics, with paper PCRs only used in exceptional circumstances (e.g. broken tablet, computer etc.). The completeness of data capture is high with >95% in 2008 increasing to 99% in more recent years.

Computer Aided Dispatch (CAD) location data were used to determine the geocodes (x/y geographical coordinates) of where the paramedic was called to (exact event location).

Data on air pollution

The CSIRO Oceans & Atmosphere Flagship provided modelled exposure fields for $PM_{2.5}$ ranging from 100-500 m resolution close to the fire, to 3-9 km resolution further away from the fire. The 24 hourly average $PM_{2.5}$ concentrations were calculated for each Statistical Area Level 2 (SA2) area around Morwell. Further details of the modelling approach can be found in the CSIRO report (Emmerson et al., 2016).

Data on ambient maximum temperature

As ambient temperature can have significant impacts on health (Guo et al., 2014, Guo et al., 2017) temperature was controlled for when the associations between air pollution and health outcomes were assessed. Daily maximum temperatures were collected from the Australian Bureau of Meteorology (http://www.bom.gov.au/climate/data-services/station-data.shtml) for the study period.

Data on population

Population data for this study was obtained from ABS Population Estimates by Statistical Area Level 2 between 2005 and 2015 (http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3218.02014-15?OpenDocument).

5.2 Dataset parameters for analysis

5.2.1 Geographical boundaries

Ambulance attendance data for all ages were extracted for the period 1 January 2009 to 31 March 2015 for events that occurred in areas that were considered exposed. The geographical boundaries used to extract data were defined using the Australian Standard Geographical Classification (ASGC) 2011 Local Government Area (LGA) structures. Ambulance attendance records for events that occurred in an LGA in the east of Victoria (specifically Hume, Gippsland and Eastern Metropolitan regions) were included in the extract.

Since the AGSC was replaced with the Australian Statistical Geography Standard (ASGS) in 2011, LGA structures were replaced with Statistical Area spatial units. As the Hazelwood Health Study used SA2 to define the areas that were considered exposed (refer to Figure 1) records outside of the specified SA2 areas (based on CAD geocodes) were removed from the dataset for this analysis. As all SA2 areas that were considered exposed were captured by the LGAs that defined the geographical boundaries of the data extract, complete data for all SA2 areas were included in the analysis. The CAD geocodes (which provided the exact coordinates of an ambulance call out) were then used to create SA2 groups for the analysis.

Figure 1 Geographical location of the fire impacted SA2 areas

The CSIRO modelled $PM_{2.5}$ from the coal mine fire (Emmerson et al., 2016) was used to calculate daily average exposure in each of the SA2 areas.

Only *fire impacted SA2 areas* were included in the analysis and these were defined as those SA2s where the modelled daily $PM_{2.5}$ concentrations from the fire reached 1μg/m^3 for at least one day.

5.2.2 Mine fire period

The *mine fire period* used in the analyses was determined by the modelled average daily $PM_{2.5}$ concentrations. For this report, the *mine fire period* was defined as that period of time during which the modelled fire-generated $PM_{2.5}$ concentration, averaged across the Latrobe Valley SA3 area, exceeded 1 μg/m^3. This corresponded with the 30 day period between 9 February and 10 March 2014. After 10 March 2014, daily average $PM_{2.5}$ concentrations attributable to the coal mine fire fell below 1μg/m^3.

5.2.3 The ambulance attendance analysis period

Although ambulance attendance data from the period 1 January 2009 to 31 March 2015 were extracted, only data between 1 July 2010 and 31 March 2015 were used in the analysis due to unexpected low attendance rates in the *fire impacted SA2 areas* between August 2009 and May 2010. This was possibly due to problems with the VACIS data collection system. Data between 25 September 2014 and 31 December 2014 were also excluded due to the impact of industrial action on VACIS data collection. In summary, the analysis period in this report is defined as 1 July 2010 to 31 March 2015, excluding 25 September to 31 December 2014 and will be referred to as the *entire analysis period* in this report.

5.3 Condition categories

Table 1 Ambulance attendance condition categories

Category	Paramedic Reported 'Final Principal Diagnosis'
All Conditions	All conditions combined irrespective of the final primary diagnosis
All Cardiovascular Conditions	
Ischaemic Heart Disease	Acute Coronary Syndrome, Acute Myocardial Infarction, Angina
Cerebrovascular Disease	Stroke, Transient Ischaemic Attack, Intracranial Haemorrhage
Other Cardiovascular Diseases	Cardiac Arrest, Cardiac Failure, Arrhythmia, Aortic Dissection, Deep Vein Thrombosis, Pulmonary Embolism, Acute Pulmonary Oedema
All Respiratory Conditions	
Asthma	Asthma
COPD	Chronic Obstructive Pulmonary Disease
Pneumonia and Acute Bronchitis	Bronchitis, Pneumonia, Bronchiolitis, Pulmonary Aspiration
Cough	Cough
Shortness of Breath	Short of Breath
Other Respiratory Diseases	Chest Infection, Flu-like Illness, Pneumothorax, Respiratory Failure, Respiratory Arrest, Respiratory Tract Infection, Croup, Chest Infection
Injury	Laceration , Fracture/s, Wound / Puncture, Burn/s, Head Injury

Table 1 presents the condition categories that were used in the analysis as determined by the 'final primary diagnosis' reported by paramedics. Attendances for laceration, fractures, wounds, burns and head injuries were combined to form a comparison group with category name 'injury'. Where the analysis used the category name *all conditions* this referred to all ambulance attendances irrespective of the final primary diagnosis.

5.4 Statistical analyses

Descriptive analysis

Distributions of mine fire-related $PM_{2.5}$ were investigated for fire-impacted SA2 areas surrounding Morwell. Distributions of daily ambulance attendance counts were also explored. Two SA2 areas (Bunyip - Garfield, Upper Yarra Valley) were excluded from the subsequent analysis due to very low ambulance attendance counts throughout the period of interest.

Ambulance attendance counts for conditions of interest were examined in a preliminary analysis. The analysis indicated that the number of records were too few for many of the specific conditions to yield reliable statistical inference. Hence, the main analyses using time series models were performed only for broader categories of conditions, specifically for: all respiratory conditions, all cardiovascular conditions, injuries and *all conditions*.

Initial exploration of ambulance attendance data involved time series plots of weekly counts over the *entire analysis period* (i.e. 1 July 2010 to 31 March 2015, excluding 25 September to 31 December 2014). These provided insights in regard to the potential time dependent patterns to be taken into account in subsequent modelling, such as long-term trends and/or seasonality. In addition, daily ambulance attendance counts were used to ascertain whether utilisation differed in the 30-day *mine fire period* compared to the 30 days immediately pre and post the fire, and compared to the same 30 day period one year pre and one year post the fire.

Time series analysis for fire-related $PM_{2.5}$

Time-series analyses relating daily data on air pollutants to health outcomes are frequently used to assess the short-term health effects of air pollution (Bhaskaran et al., 2013). The method allows for adjustment for potential confounders (such as temperature and seasonality) when estimating the outcome-exposure relationship in the exposed population. These analyses were divided into two parts.

The first part involved assessing the impact of mine-fire related $PM_{2.5}$ on ambulance attendances. The relationship between mine-fire related $PM_{2.5}$ and daily ambulance attendances was evaluated using a generalised additive model (GAM). To allow for the large variation in daily counts, negative binomial models were used. For many environmental health factors, such as temperature and pollution, there is commonly a delay in short-term effect on mortality and morbidity, commonly known as the lagged effect. The lagged effects of $PM_{2.5}$ were estimated through a "distributed lag" model", which created a cross-basis function specifying exposure-response and lag-response relationships simultaneously. For the cross-basis function, we assumed a linear dose-response relationship and a non-linear lag-response relationship described using a natural cubic spline.

Short term effects of $PM_{2.5}$ (lags less than 7 days) on deaths, hospitalizations and emergency department presentations have been commonly examined in the literature (Dockery et al., 1994, Bell et al., 2008, Huang et al., 2012). More recently, the development of non-linear distributed lag models has allowed researchers to use flexible models to examine longer lag periods and investigate `harvesting effects' (Zanobetti et al., 2000). 'Harvesting effects', also known as 'mortality displacement effects', refer to short-term forward shifts in the rate of mortality/morbidity responding to environment factors such as heat waves or pollution. In this study, we first modelled the relationships with a 7 days lag period (with 3 degrees of freedom [df]). Lagged associations were investigated. Then lag periods of 0-3, 0-5, 0-15 and 0-20 days were all examined to provide a more comprehensive understanding of the associations.

Potential confounders were also included: seasonality modelled using a natural cubic spline with 4 df for day of the year; long-term trend modelled simply as year of the event; day of the week included as a 7-category variable; maximum ambient temperature characterised using a distributed lag model with non-linear exposure relationship and lags of up to 21 days and public holidays included as a binary variable (public holiday yes or no). To adjust for inherent spatial variations in ambulance service needs, random intercepts for modelled SA2 areas were included in the GAM.

With the nonlinear distributed lag model, the relative risks (RR) on each lag day were first estimated and then combined as the cumulative RR to represent the overall effect of exposure. To make it comparable with the published literature the cumulative relative risk (RR) per 10µg/m^3 increase in mine fire-related $PM_{2.5}$ was reported. Cumulative RR can be interpreted as the sum of the effect of $PM_{2.5}$ exposure over the estimated lag days on ambulance attendances. Estimated cumulative RR >1 indicated elevated risks for ambulance service use associated with mine fire-related $PM_{2.5}$. The 95% Confidence Interval (CI) indicated the range of uncertainty around the cumulative RR value as an estimate of the true underlying association between the air pollutant and the health outcome. Smaller p-values indicated stronger evidence of the existence of a true underlying association, with the threshold of $p<0.05$ referred to as statistically significant. It should be noted that p-values and the width of the confidence interval were dependent on both the size of the estimated cumulative RR, and the number of occurrences of the attendances analysed.

Sensitivity analyses were performed to check the robustness of our findings. Models specifying different degrees of freedom in spline terms (3-5 for lags of air pollution, 3-6 for temperature and 5-9 for seasonality) and different lag days (3-20 lag days for temperature) were tested. Sensitivity analyses were performed to investigate the impact of including or excluding the SA2 areas of Bunyip – Garfield and Upper Yarra Valley.

Time series analysis for mine fire period

In the second part of the overall analysis, we examined whether ambulance attendances were increased during the *mine fire period*, compared to the *remainder of the analysis period* (i.e. *entire analysis period* excluding the 30 day *mine fire period*). This analysis was undertaken to address the issue in the first part of the analysis that the lag effects might be different for condition sub-groups, causing estimated cumulative RRs to be sensitive to number of lag days specified. With this in mind, the same model as in the first part of the overall analysis was implemented, but with replacement of the cross-basis predictors for $PM_{2.5}$ with a single binary predictor indicating the presence of the mine fire (value 1) or not (value 0). RRs and 95% CI for the effect of the presence of the mine fire were estimated. For these analysis, an estimated RR >1 indicated elevated risks of ambulance attendances during the *mine fire period* in comparison with the *remainder of the analysis period*.

Attributable counts and fractions due to mine fire were also calculated. Attributable counts are estimates of the number of additional ambulance attendances due to coal mine fire $PM_{2.5}$ that occurred during the mine fire in the impacted areas.

6 Results

6.1 Descriptive analysis

The distribution of modelled daily average $PM_{2.5}$ concentration attributable to the coal mine fire during the 30 day *mine fire period* for selected *fire impacted SA2 areas* are shown in Figure 2 using violin plots. The violin plot displays the mirrored smoothed density distribution, which can better visually illustrate the skewed distributions of $PM_{2.5}$ concentration with extreme values. The outer shape represents the range of modelled $PM_{2.5}$ concentrations, and the thickness of the bar indicates the probability that the modelled $PM_{2.5}$ concentration will take on the given value. As shown in Figure 2, the daily fire-related $PM_{2.5}$ concentration was highest in Morwell, but extreme pollutant levels were common across a wide range of geospatial areas.

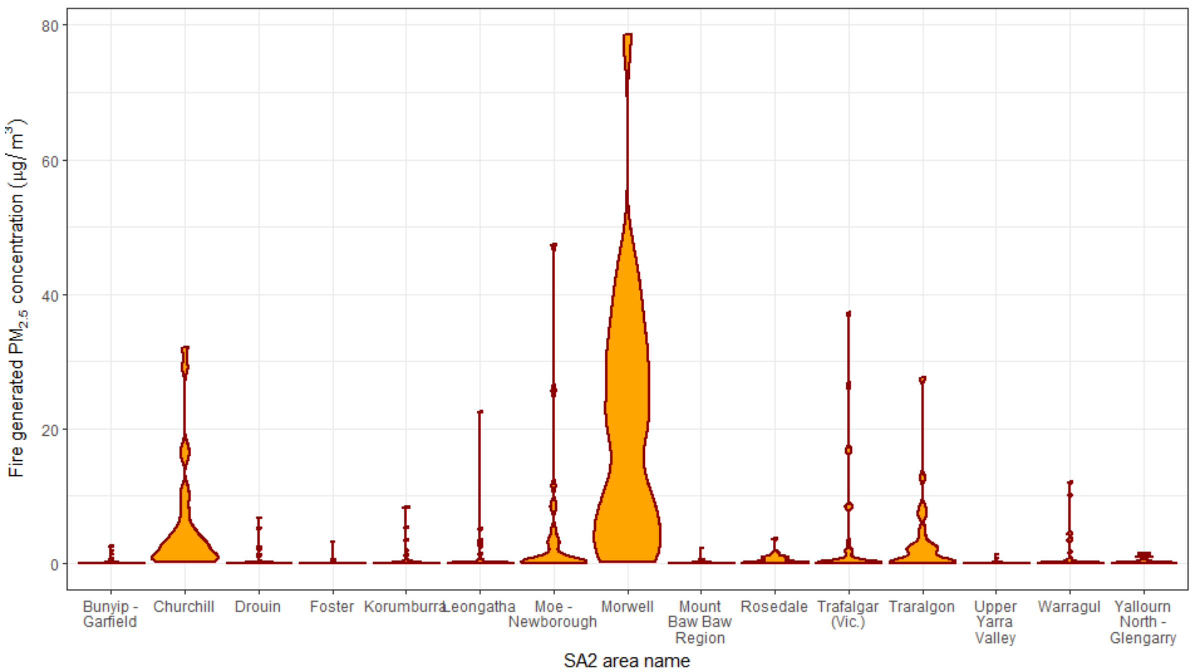

Figure 2. Distribution of modelled daily $PM_{2.5}$ emissions (μg/m³) from the coal mine fire during the mine fire period for selected fire impacted SA2 areas

Daily rates of ambulance attendances for both the *entire analysis period* and the *mine fire period* in each SA2 area are summarised in Table 2. There was spatial variation in the daily rates of ambulance attendances when looking at the *entire analysis period*, for example Morwell had the highest rate of ambulance attendances. This background of elevated rates in certain SA2s was important since it indicated that when assessing the impact of mine fire-related $PM_{2.5}$ on ambulance attendances, the spatial differences between SA2 areas had to be adjusted for.

The results in Table 2 also suggest that most *fire impacted SA2 areas* had higher rates of ambulance attendances during the *mine fire period* (9 February 2014 to 10 March 2014) compared with the *entire analysis period*.

Table 2 Distribution of daily ambulance attendance rates per 10,000 population by SA2

	Entire analysis period*		Mine fire period	
SA2 area name	Median rates	Interquartile range	Median rates	Interquartile range
Bunyip - Garfield	0.0	0.0-0.0	0.0	0.0-0.0
Churchill	2.6	1.7-3.5	4.2	3.4-3.5
Drouin	2.1	1.4-3.3	2.7	1.5-3.3
Foster	2.4	1.2-3.6	2.4	2.4-3.6
Korumburra	2.3	1.1-3.4	3.3	2.2-3.4
Leongatha	2.8	0.9-3.7	3.2	2.8-3.7
Moe - Newborough	4.8	3.6-6.0	6.4	4.9-6.0
Morwell	**5.6**	**4.2-7.7**	**6.4**	**5.1-7.7**
Mount Baw Baw Region	1.7	0.0-3.3	1.7	0.0-3.3
Rosedale	2.1	0.0-4.2	2.1	2.1-4.2
Trafalgar (Vic.)	1.4	1.3-2.8	2.0	1.4-2.8
Traralgon	3.4	2.6-4.5	3.6	3.0-4.5
Upper Yarra Valley	0.0	0.0-0.0	0.0	0.0-0.0
Warragul	2.9	1.8-4.0	3.4	2.8-4.0
Yallourn North - Glengarry	2.2	0.0-2.2	0.0	0.0-2.2

* Between July 2010 and September 2014, excluding 25 September to 31 December 2014

In Table 3, the daily number of ambulance attendances for all *fire impacted SA2 areas* are summarised by condition type. Numbers were very low for most of the specific conditions of interest, confirming that the approach taken in our analyses was best focussed on groups of conditions, rather than individual conditions.

The weekly time series plots for ambulance attendances display the underlying seasonality and temporal trends (

Figure **3**). A gradually increasing trend can be observed for *all conditions* across the *entire analysis period*. A seasonal trend is particularly noticeable in the respiratory conditions data. There was some evidence of increases in attendance rates during the *mine fire period* for all respiratory conditions and for *all conditions*.

Table 3 Median number of daily ambulance attendances by condition type for all mine fire-impacted SA2 areas combined

	Entire analysis period*		During the mine fire	
Category	Median counts	Interquartile range	Median counts	Interquartile range
All Respiratory Conditions	**4**	**3-7**	**4**	**3-7**
Cough	0	0-0	0	0-1
Asthma	0	0-1	0	0-1
COPD	0	0-1	0	0-0
Pneumonia and Acute Bronchitis	0	0-0	0	0-0
Shortness of Breath	1	0-1	2	1-2
Other Respiratory Diseases	2	1-4	2	0-4
All Cardiovascular Conditions	**4**	**2-5**	**4**	**3-5**
Ischaemic heart disease	1	1-2	2	2-3
Cerebrovascular disease	1	0-1	1	0-1
Other cardiovascular diseases	1	0-2	1	0-2
Injury	**3**	**2-4**	**4**	**2-5**
All conditions	**49**	**43-55**	**60**	**53-65**

* Between July 2010 and September 2014, excluding 25 September to 31 December 2014

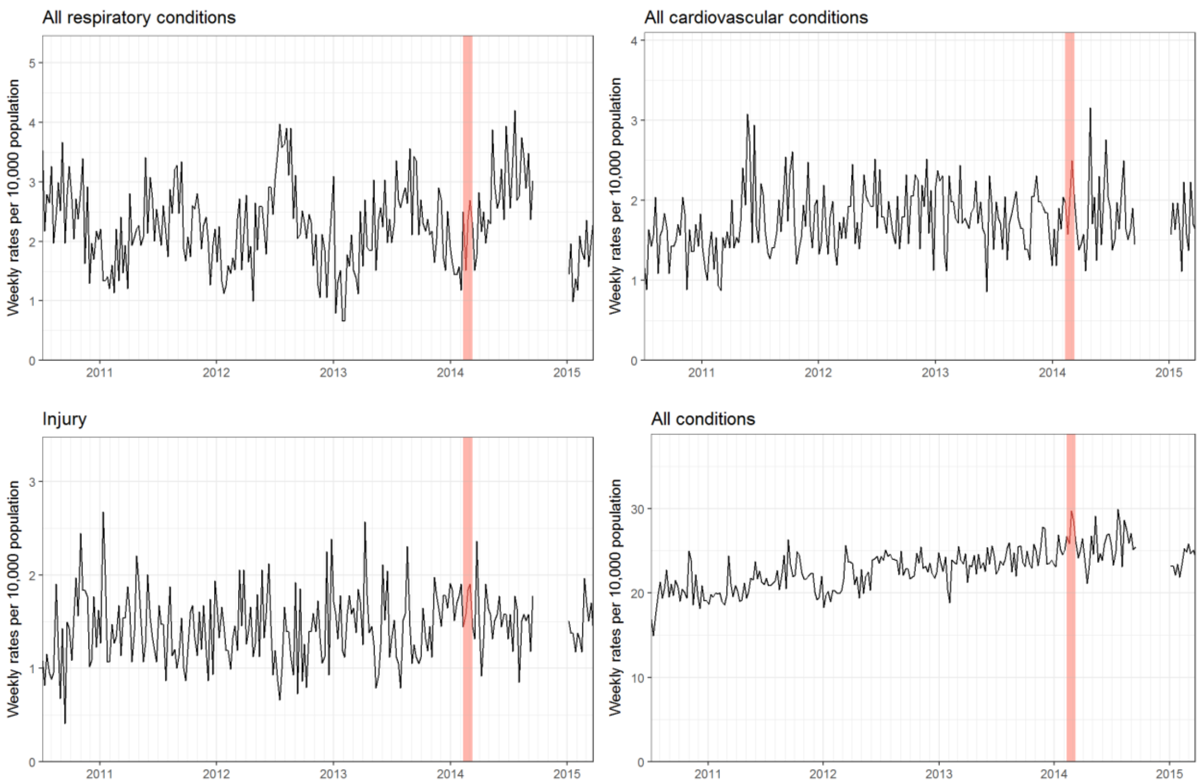

Figure 3 Raw unadjusted weekly time series for ambulance attendance rates for all fire impacted SA2 areas, 1 July 2010 to 31 March 2015.

Note: Red bars indicate the mine fire period. Missing data between 25/09/2014 and 31/12/2014 were due to industrial action.

Figure 4 shows ambulance attendance rates for the 30 day *mine fire period* compared with those 30 days pre and 30 days post the fire. Figure 5 shows ambulance attendance rates for the 30 day *mine fire period* compared with the same 30 day period one year pre and one year post the fire. The graphs indicate higher ambulance attendance rates for *all conditions* during the mine fire relative to the other periods. The comparisons for each specific group of conditions do not show a clear pattern of increased or decreased rates.

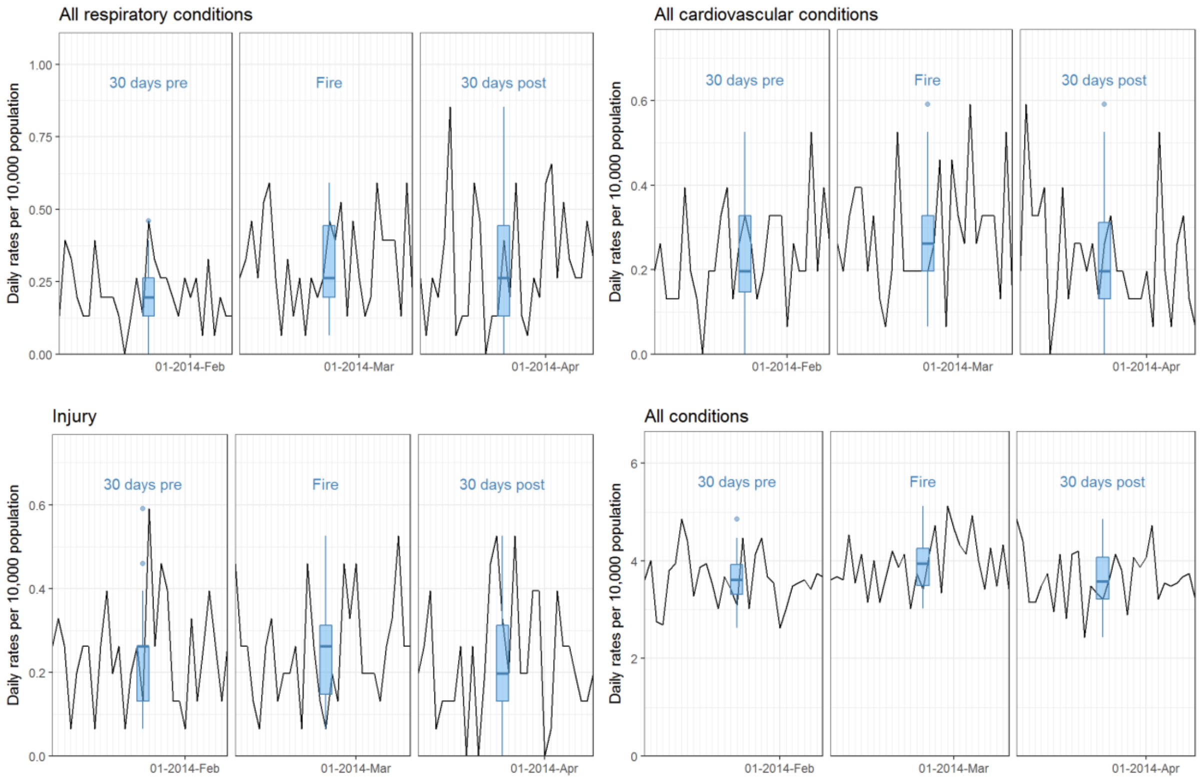

Figure 4 Raw unadjusted daily time series for ambulance attendance rates for all fire impacted SA2 areas, for the 30 days during the fire, 30 days before the fire and 30 days after the fire.

Note: the blue bar is the boxplot of the distribution of daily counts within the 25th and 75th percentiles, the horizontal blue line indicates the median and the vertical blue lines indicate the lowest and highest values.

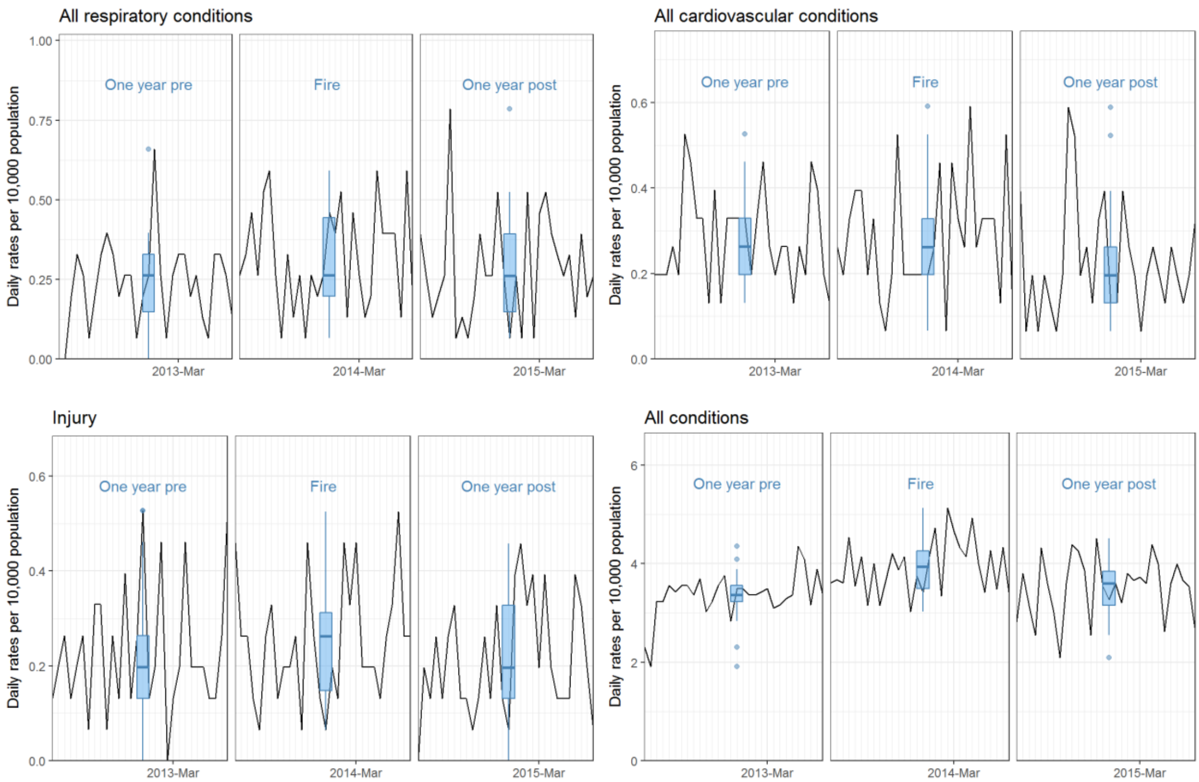

Figure 5 Raw unadjusted daily time series for ambulance attendance rates for fire impacted SA2 areas, for the 30 days during the fire and the same 30-day period one year before the fire and one year after the fire.

Note: The blue bar is the boxplot of the distribution of daily rates per 10,000 within the 25th and 75th percentiles, the horizontal blue line indicates the median, and the vertical blue lines indicate the lowest and highest values.

6.2 Time series analysis for mine fire-related $PM_{2.5}$

Figure 6 shows the lag effects from the non-linear distributed lag model with a 7 days lag period. Each RR (shown by the red dots) represents the risk of the health outcome on the specified lag day, associated with a $PM_{2.5}$ exposure level of 10 μg/m^3 on day zero relative to no exposure on day zero.

The lag-relationships between mine fire-related $PM_{2.5}$ and ambulance attendances were different depending on the disease condition investigated. For *all respiratory conditions*, the lag plot suggested that there was increased risk over the first five day after the exposure. Similarly a positive association between exposure and ambulance attendances for *all conditions* was also found between lag 3-7 days, potentially lasting for longer than 7 days. The pattern of the lag distribution for cardiovascular conditions suggests possible increased risk between lag 2 to 5 days. For injuries, the estimated risk was decreased between lag 2 to 5 days, possibly due to reduction of service availability driven by increasing callouts for other conditions.

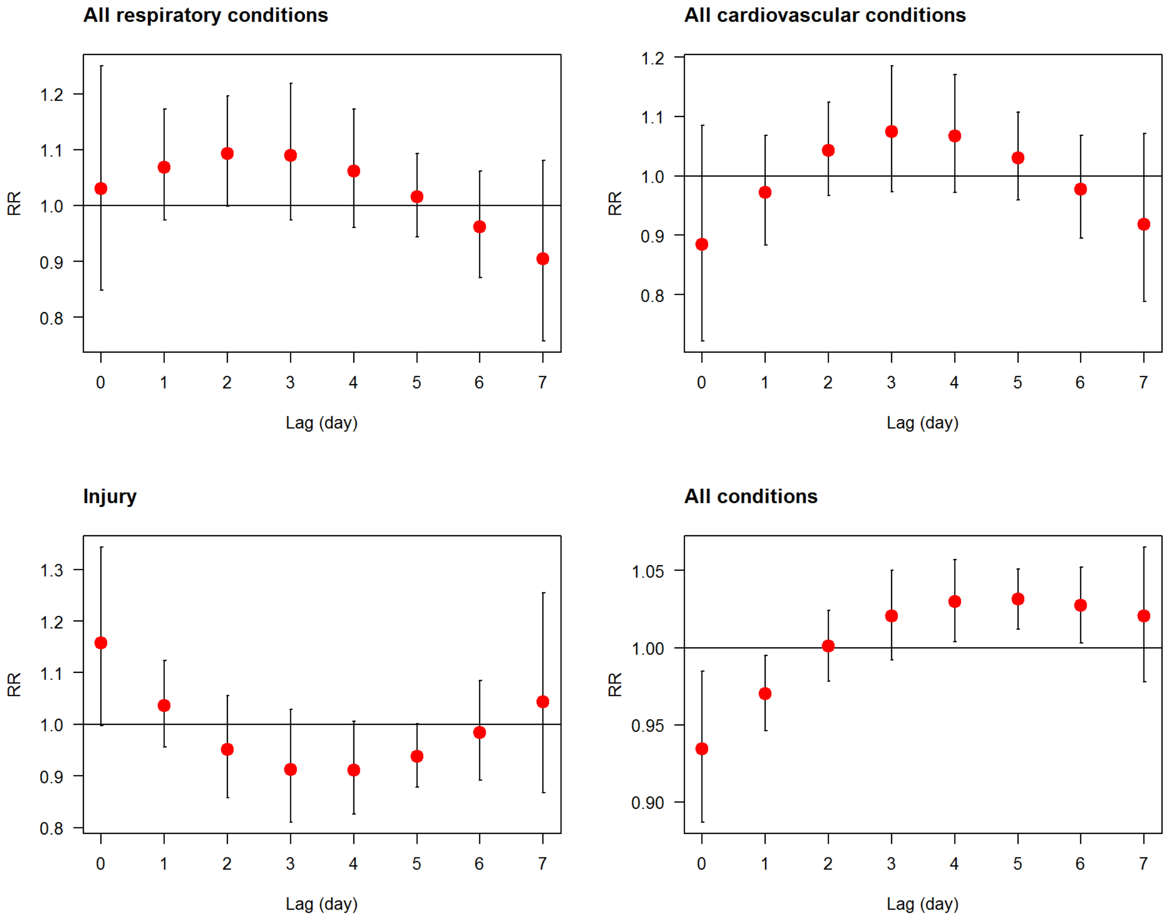

Figure 6 Exposure lag relationships for 10 µg/m³ increase in fire-related $PM_{2.5}$ and ambulance attendances, after controlling for seasonality, public holidays, day of the week, long-term temporal trends and daily maximum temperature (0-7 lag days specified in the model).

Results from models with different lag days for $PM_{2.5}$ concentration are shown in Table 4. Results are expressed as cumulative effects. As an illustration of the interpretations that can be drawn from this table, when assuming the lag effect lasted for 3 days, each 10 µg/m³ increase in fire-related $PM_{2.5}$ on day zero was associated with a 27% increase (95% CI: 2-58%) in the likelihood of ambulance attendances for all respiratory conditions. When assuming a 20 day lag period, a 47% increase in risk was estimated (95% CI: 11-94%). With longer lags there was weak evidence for a larger effect size for *all conditions*. At an assumed lag of 20 days, each 10 µg/m³ increase in fire-related $PM_{2.5}$ on day zero was associated with a 7% increase in risk (95% CI: 0-15% for attendances for *all conditions*). No statistically significant associations were found for cardiovascular conditions or injury for any lag period specified.

Table 4 Cumulative RRs of daily ambulance attendances associated with 10 μg/m^3 increase in fire-related $PM_{2.5}$ for different lag periods

Condition	Specified lag days for $PM_{2.5}$	Cumulative RR*	95% CI	p-value
All Respiratory Conditions	**0-3**	**1.27**	**1.02 - 1.58**	**0.030**
	0-5	**1.27**	**1.02 - 1.59**	**0.034**
	0-7	1.23	0.97 - 1.55	0.086
	0-15	**1.44**	**1.11 - 1.85**	**0.005**
	0-20	**1.47**	**1.11 - 1.94**	**0.008**
All Cardiovascular Conditions	0-3	0.96	0.78 - 1.18	0.727
	0-5	0.98	0.80 - 1.21	0.841
	0-7	0.95	0.76 - 1.19	0.658
	0-15	1.05	0.83 - 1.32	0.674
	0-20	1.15	0.90 - 1.46	0.268
Injury	0-3	0.93	0.73 - 1.17	0.522
	0-5	0.91	0.71 - 1.16	0.429
	0-7	0.91	0.72 - 1.17	0.471
	0-15	0.9	0.68 - 1.19	0.447
	0-20	0.93	0.69 - 1.24	0.613
All Conditions	0-3	1.01	0.96 - 1.07	0.711
	0-5	1.02	0.96 - 1.08	0.474
	0-7	1.03	0.97 - 1.09	0.291
	0-15	1.06	0.99 - 1.13	0.081
	0-20	**1.07**	**1.00 - 1.15**	**0.048**

* Cumulative relative risks (RR) were adjusted for seasonality, public holidays, day of the week, and daily maximum temperature, long-term temporal trends and their associated 95% confidence intervals (CIs).

6.3 Time series analysis for the mine fire period

Table 5 shows the relative risks of ambulance attendances during the *mine fire period*, in comparison with the *remainder of the analysis period*. The pattern of results was similar to the time series analysis for $PM_{2.5}$. There was an estimated 41% (95%CI 11% - 78%) increase in risk for ambulance attendances for respiratory conditions and a 15% (9% - 22%) increase for attendances for *all conditions* during the *mine fire period*, compared with the *remainder of the analysis period*.

Table 5 RRs for daily ambulance attendances during the mine fire period compared with the remainder of the analysis period.

Condition	RR	95% CI	p-value
All Respiratory Conditions	**1.41**	**1.11 - 1.78**	**0.005**
All Cardiovascular Conditions	1.11	0.91 - 1.36	0.296
Injury	1.13	0.91 - 1.40	0.261
All conditions	**1.15**	**1.09 - 1.22**	**<0.001**

Note: Relative risks (RR) were adjusted for seasonality, public holidays, day of the week, and daily maximum temperature, long-term temporal trends and their associated 95% confidence intervals (CIs).

As shown in Table 6, it was estimated that there were an additional 42 (29%) respiratory related attendances, which formed part of an estimated additional 236 (13%) attendances for *all conditions* during the *mine fire period*.

Table 6 Attributable fraction and attributable counts of ambulance attendances during the mine fire period in the fire impacted SA2 areas

Condition	Mean attributable fraction (95% CI)	Total attributable counts (95% CI)
All Respiratory Conditions	**0.29 (0.10, 0.44)**	**42 (14, 64)**
All Cardiovascular Conditions	0.10 (-0.10, 0.26)	13 (-13, 34)
Injury	0.11 (-0.09, 0.28)	13 (-11, 32)
All conditions	**0.13 (0.08, 0.18)**	**236 (144, 323)**

7 Discussion

7.1 Summary of main findings

This is the first study to examine the impacts of the 2014 Hazelwood coal mine fire on ambulance attendances. Time series analyses showed that the *mine fire period* and related $PM_{2.5}$ pollution were significantly associated with an increase in the attendances for respiratory conditions and *all conditions* but not for cardiovascular conditions or injury.

Descriptive analyses

Most *fire impacted SA2 areas* had higher rates of ambulance attendances during the *mine fire period* compared with the *entire analysis period*. More specifically, rates of ambulance attendances were elevated during the *mine fire period*, in comparison to the period 30 days prior and after the fire as well as the same 30 day period one year pre and one year post the fire. However, care should be taken when interpreting these results as they simply compare the raw data without any statistical correction for confounders or measurement error.

Time series analyses for fire related $PM_{2.5}$

The relationships between mine fire-related $PM_{2.5}$ exposure and ambulance attendances for respiratory and cardiovascular conditions showed that there was a consistent association between exposure and ambulance attendances for respiratory conditions. A positive response relationship was estimated for respiratory related attendances immediately after exposure, followed by a `harvesting effect'. The 'harvesting effect', widely acknowledged in environmental epidemiology, refers to the negative associations estimated after a few days of positive associations, due to the depletion of the people at risk (Zanobetti et al., 2000, Schwartz, 2000). When a longer lag period was examined, larger effect sizes were estimated, this is due to another period with positive associations observed after the 'harvesting period', possibly caused by increased recruitment of people at risk (Zanobetti et al., 2000) or by a sub group of respiratory conditions with a delayed response.

Negative associations were found for lag 0-1 days for ambulance attendance for *all conditions* and cardiovascular conditions (see Figure 6). The cause of this was unclear. One possible explanation could be a higher proportion of the population at risk leaving the area when the smoke was most severe. There was weak evidence that the estimated effects were larger when a longer lag period was specified in the model for *all conditions*. This was potentially due to the increase in respiratory conditions or delayed responses from other conditions that are not specifically evaluated in the study. No association for cumulative relative risk was confirmed for cardiovascular condition attendances, however due to the low number of cases the true association remains unclear.

Time series analyses for mine fire period

After statistically adjusting for long-term trend, seasonality, temperature, day of the week and public holidays, there were estimated to be 29% of respiratory related ambulance attendances and 13% of attendances for *all conditions* attributable to the mine fire during the mine fire period. This estimated burden could be attributable to the fire-related pollutants or some other feature of the fire event, e.g. fear or worry generated by the event could lead to anxiety- related respiratory distress.

7.2 Relationship to previous published work

Hospitalization and emergency department visits are commonly used as morbidity indicators when studying relationships with ambient air pollution. More recently, ambulance dispatch data have been used in studying the effect of air pollution (Zauli Sajani et al., 2014, Elliot et al., 2016, Michikawa et al., 2015, Liu et al., 2017). Only a few studies were found in the literature studying the association between bushfire-related $PM_{2.5}$ with ambulance dispatches (Salimi et al., 2017, Haikerwal et al., 2015). However, there have been no previously published studies on the associations between coal mine fire-related $PM_{2.5}$ concentrations and ambulance attendances.

Our analyses show clear evidence that the mine fire-related $PM_{2.5}$ was significantly associated with an increased risk of ambulance attendances for respiratory conditions, and moderate evidence for *all conditions*, but no evidence for cardiovascular conditions. The findings are consistent with Hazelinks results from hospital admissions (VAED) and emergency department (VEMD) analysis

(Dennekamp et al., 2017) and also with some other published epidemiological studies of air pollution. The associations between short-term $PM_{2.5}$ exposure from traffic, industrial emissions, bushfires and wildfires, and respiratory morbidity based on hospitalizations and emergency presentations, are well documented in the literature (Atkinson et al., 2014, Reid et al., 2016, Xu et al., 2016, Haikerwal et al., 2016, Lee et al., 2014, Langrish et al., 2012). Possible associations with urban background $PM_{2.5}$ exposure and cardiovascular morbidity have been reported (Lee et al., 2014, Langrish et al., 2012). However, our findings were more consistent with previous studies on wildfires or bushfires (Reid et al., 2016, Delfino et al., 2009, Alman et al., 2016), where no association between $PM_{2.5}$ exposure and cardiovascular conditions was reported.

Based on ambulance dispatch data, Liu et al (2017) reported a 0.7% (95% CI 0.19 - 1.21%) increase in dispatches for respiratory conditions and a 0.45% (95%CI 0.03 - 0.88%) increase for cardiovascular conditions per 10 μg/m^3 increase in ambient $PM_{2.5}$ in Chengdu China. Elliot and colleagues (2016) also reported elevated risks for respiratory-related ambulance dispatches during two high pollution episodes caused by 'Sahara dust' in London, however effect sizes were not estimated in that study. Salimi and colleagues (2017) studied the impact of all source $PM_{2.5}$ and ambulance dispatches in Sydney, reporting a 3% (95%CI 2 - 4%) increase in dispatches for breathing problems and a 3% (95%CI 0 - 6%) increase for respiratory or cardiac arrest. None of these studies used data recorded by the paramedic at point of care to evaluate cause-specific ambulance attendances. The ambulance dispatch data are more likely to suffer from measurement errors based on callers' reported symptoms, and the influence of these errors may be to bias risk estimates toward the null.

Phung and colleagues used linked emergency department diagnoses to identify cause of the ambulance attendances (Phung et al., 2018). In their study, a 1.88% (95%CI 1.00 - 2.76%) increase in respiratory dispatches were found to be associated with 10 μg/m^3 increases in ambient $PM_{2.5}$ in Japan whilst no significant effect was observed for cardiovascular outcomes (Phung et al., 2018). However, causes for attendances with mild conditions that were not transported to hospital, could not be determined.

Victorian Ambulance Cardiac Arrest Registry data were used by Haikerwal and colleagues to investigate the impact of extensive 2006/2007 bushfires in Victoria. They reported a 6.98% (95%CI 1.03% - 13.29%) increase in on out-of-hospital cardiac arrests (Haikerwal et al., 2015). It is likely that the population impacted by the Hazelwood mine fire was smaller compared with the 2006/2007 Victoria bushfires and hence our study had lower power to detect an effect.

It should be noted that the estimated RRs in this study are not directly comparable with incident rate ratios reported by Straney et al (Straney et al., 2016), which were estimated using a relative smoke exposure scale before the modelled $PM_{2.5}$ data were available. Also, an advanced spatial and temporal model has been developed in this analysis to allow for better control of temperature, seasonal variation and inherent spatial differences. However total attributable fractions estimated in these two analyses were similar.

7.3 Strengths & weaknesses

These Hazelinks analyses have several strengths:

- This research provides the first known report of ambulance attendances after a prolonged brown coal open cut mine fire event, providing direct evidence regarding the impact of prolonged coal mine fire smoke on human health in the pre-hospital phase, in particular respiratory conditions occurring a few days after the high exposure.
- The use of a distributed nonlinear lag model to examine the potential delayed effects aids in understanding which days of exposure were associated with estimated increases in ambulance attendances. A major benefit of using these statistical models is that they are able to account for the delayed and nonlinear effects of ambient maximum temperature and pollutants to provide cumulative risk estimates for health outcomes along with lag specific ones. We were able to identify a lagged impact of $PM_{2.5}$ across a number of days and establish where the significant lagged effects lay. The flexibility of this type of modelling technique lies in the ability to set the number of degrees of freedom, number of lags and type of smoothing spline used.
- The analyses controlled for the potential confounding effects of maximum daily ambient temperature, long-term trend, public holidays, day of the week and seasonality.
- The use of a high spatial resolution air exposure model allowed $PM_{2.5}$ smoke concentrations, attributable to the coal mine fire, to be estimated for geographic areas where air quality monitor measurements were not available.

However these analyses also have some limitations:

- This study design was ecological and, therefore, it was not possible to examine associations at an individual level. Time series models were established at SA2 level resolution (townships), due to low number of records at the SA1 level (smallest geographical unit for the release of census data). Hence the heterogeneity of exposure levels within each SA2, particularly within Morwell was not considered. Therefore it is possible that the impact of the mine fire has been an under estimated for the most highly exposed residents.

- Our analyses only investigated the impact of coal mine fire-related $PM_{2.5}$ and did not include other criterion pollutants such as carbon monoxide, ozone, nitrogen dioxide or sulphur dioxide.
- The use of modelled $PM_{2.5}$ concentrations in lieu of individual level measurements may have introduced exposure misclassification. This would bias effect estimates towards the null, reducing the likelihood of detecting an association.
- The datasets used in these analyses were collected for administrative purposes and, therefore, presented some limitations. One limitation relates to the difficulties for paramedics to accurately diagnose and classify conditions. Final principal diagnosis was used in the analysis, however the diagnosis may have changed after patients arrived at hospital and underwent further investigations. Also, many of the attendances were classified to diagnostic groups for symptoms such as cough, shortness of breath etc. rather than underlying conditions. Hence, there might be an underestimation for attendance rate for specific conditions. There were missing data between 25 September 2014 and 31 December 2014 due to industrial action. Although, the missing data were not during the mine-fire period, it may still impact the accuracy of model estimation.

8 Conclusions

This analysis shows clear evidence that the coal mine fire and related $PM_{2.5}$ were associated with an increase in ambulance attendances for respiratory conditions, and moderate evidence of association for *all conditions*. This contributes to filling the knowledge gap which currently exists regarding the health impact of open cut brown coal mine fire smoke exposure. Such robust evidence-based research is important to improve health impact assessment of at-risk groups, and to improve targeted health advice and emergency health services. This study should be helpful to develop and implement effective and more timely adaptive strategies and health planning to respond to and mitigate health risks due to possible future coal mine fire derived air pollution exposures in the community.

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