Exposure to mine fire related particulate matter and mortality: A time series analysis from the Hazelwood Health Study

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ABSTRACT

Background: In 2014, the Morwell brown coal mine, located in the Latrobe Valley of South eastern Australia, caught fire covering nearby areas in plumes of smoke over a 6-week period.

Aims: To investigate the association between exposure to mine fire related air pollution and the risk of mortality.

Methods: Time series models were used to evaluate the risk of mortality during the first 30 days of the mine fire, when the smoke was most intense, and in the following six months. Associations were also investigated between mine fire related PM 2.5 and mortality.

Results: During the 30-day mine fire period, there was an increased risk of death from injury in the most exposed town of Morwell, however no increased risk was observed for all-cause, cardiovascular or respiratory mortality. In the broader Latrobe Valley, males and residents aged 80 and above were at greatest risk of death from injury during the mine fire. In Morwell, during the six months after the mine fire there was an increased risk of all-cause mortality and death from Ischaemic Heart Disease (IHD). Males and residents aged 80 and above in the broader Latrobe Valley, were at increased risk of death from IHD six months after the fire.

Conclusions: Coal mine fire exposure was associated with an increase in injury deaths during the mine fire and cardiovascular deaths in the six months after the fire. These findings assist in identifying at risk groups, and improving targeted health advice for future air pollution exposures in the community.

1. Introduction

Large, destructive coal mine fires are often beyond human control and can be devastating, with loss of life, livelihood and infrastructure at the fire front (Stracher, 2004). There are currently many coal mine fires active throughout the world, some of which have been burning for years (Stracher and Taylor, 2004). Typically, mine fires are triggered by wildfires, spontaneous combustion or other human activities (Stracher and Taylor, 2004). With an increase in the number of wildfires due to climate change (decrease in rainfall, longer heatwaves, and more frequent extremely hot temperature periods) (Yu et al., 2020; Westerling et al., 2006), an accompanying increased risk of coal mine fire ignition from embers may be expected.

Coal mine fires release large amounts of toxic gases and particulate matter (PM) into the environment, which are pollutants known to be harmful to human health (Stracher, 2004; Johnson et al., 2019a). Although there is limited research specific to health outcomes from coal mine fire smoke, pollutants are similar to those generated from wildfires (Melody and Johnston, 2015). Exposure to wildfire smoke has been associated with increases in respiratory (Haikerwal et al., 2016; Martin et al., 2013; Reid et al., 2016) and cardiovascular morbidity (Haikerwal et al., 2015; Dennekamp et al., 2015) and mortality (Reid et al., 2016; Johnston et al., 2011), with a substantial number of deaths attributable to PM2.5 (fine PM with aerodynamic diameters of <2.5 μm) from wildfire smoke (Matz et al., 2020; BorchersArriagada et al., 2020). For cause specific mortality, wildfire emissions have been linked to increases in respiratory mortality (Analitis et al., 2012; Doubleday et al., 2020) and cardiovascular mortality (Analitis et al., 2012; Faustini et al., 2015), although the evidence is inconclusive (Xu et al., 2020).

A recent systematic review on the health impacts of ambient urban air pollution, that usually has a lower PM concentration and is less toxic compared to wildfires (Dennekamp and Abramson, 2011), found that air pollution was associated with all-cause mortality (Chen and Hoek, 2020). Studies of adults aged over 65 have also found associations...
between mortality and ambient air pollution (Li et al., 2018; Saldiva et al., 1995). For specific causes of death, ambient air pollution has been associated with increased mortality from cardiovascular (Chen and Hoek, 2020; Hayes et al., 2020), respiratory conditions (Chen and Hoek, 2020; Mokoena et al., 2019), and unintentional injury (Ha et al., 2015). Adverse effects of ambient air pollution have also been observed on mental health outcomes (Szyszkowicz et al., 2009; Lim et al., 2012).

In February 2014, the Morwell open cut brown coal mine ignited resulting in 6-weeks when smoke and ash covered the nearby areas of the Latrobe Valley, in South Eastern Australia. For areas that were in closest proximity to the mine, the hourly PM2.5 concentrations were estimated to reach 3700 μg/m³ and the daily PM2.5 average exceeded the National Environment Protection Measure (NEPM) on 23 days of the six week period in the most heavily impacted residential areas (Luhar et al., 2020). The Hazelwood Health Study was established to monitor the long and short term health effects of that smoke event. The study has found that mine fire related air pollutants were associated with increased risks of emergency presentations (Guo et al., 2020) and ambulance attendances for respiratory conditions (Gao et al., 2020), and dispensing of respiratory, cardiovascular and psychiatric medications (Johnson et al., 2019b). The adverse effects of coal mine fire smoke on health, found in the Hazelwood Health Study, particularly for respiratory conditions, are also commonly observed in wildfire studies (Reid et al., 2016). For the mortality risks from a mine fire and related air pollution the evidence is limited.

The aims of this study were to examine whether mortality rates increased during the mine fire period and in the six months after the mine fire, relative to comparable time periods. In addition, associations were investigated between daily levels of mine fire related PM2.5 and increased all-cause mortality and cause-specific mortality.

2. Methods

2.1. Data collection for the Hazelwood Health Study

2.1.1. Geographical boundary definitions

Geographical areas were defined according to the 2011 Australian Statistical Geography Standard (Australian Bureau of Statistics, 2010). The smallest geographical unit used in the analysis was Statistical Areas Level 2 (SA2s), which represent communities that are grouped together based on social and economic interactions. Due to small populations in some SA2s, Statistical Areas Level 3 (SA3s), that consisted of groups of SA2s that have similar regional characteristics, were also used to evaluate the combined effect of the mine fire in a larger area. SA2s closely align with regional towns, and SA3 with local government areas.

2.1.2. Data on air pollution

Due to lack of ground-level air quality monitoring at the time of the mine fire, the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) Oceans and Atmosphere provided modelled spatial and temporal exposure fields for PM2.5 using CSIRO’s Air Pollution Model (TAPM vn4.0.5) combined with a chemical transport model (CTM) (Hurley et al., 2008). The model estimated how the smoke plume transported and dispersed to the surrounding areas using 100–500 m resolution in close proximity to the fire, to 3–9 km resolution further away from the fire. Background PM2.5 concentrations, excluding the mine fire, were modelled and found to be minimal when compared to the concentrations estimated during the fire. The model was validated with available ground level monitoring data including windspeed, temperature and PM2.5 concentrations (measured in Morwell from about ten days after the mine fire started). The modelling results showed good agreement with measured data for wind speed and temperature (index of agreement [IOA] around 0.95) and for PM2.5 (IOA of 0.73). Further details of the modelling can be found elsewhere (Luhar et al., 2020).

Using these data, average daily fire related PM2.5 concentrations were calculated for Morwell which is the SA2 in which the mine was located, and the SA2s surrounding Morwell. SA2s where the modelled daily PM2.5 concentrations from the fire exceeded 1 μg/m³ for at least one day were considered to be fire impacted areas (Fig. 1). The Latrobe Valley SA3 (outlined red in Fig. 1), comprises of Morwell and the SA2 areas directly surrounding Morwell which also had high levels of mine fire related exposure. Location groups were defined as Morwell alone, the Latrobe Valley SA3 including Morwell (all), Latrobe Valley excluding Morwell (rest), as well as the surrounding areas, to assess whether areas closer to the mine fire were more likely to be impacted.

For these analyses, the mine fire period was defined as the 30-day period from 9 February to March 10, 2014 when the modelled daily average fire related PM2.5 concentration exceeded 1 μg/m³. After this period daily average PM2.5 concentrations attributable to the coal mine fire fell below 1 μg/m³.

2.1.3. Mortality data

Mortality data were extracted from the National Mortality Database (NMD) held by the Australian Institute of Health and Welfare (AIHW). The NMD contains de-identified mortality unit records with information such as sex, age at death and SA2 based on usual place of residence. Cause of death (COD) data which included one underlying (main cause of death) and up to 14 associated causes was also recorded. Deaths that occurred from July 1, 2009 to June 30, 2015, for all ages, in the fire impacted SA2 areas were extracted from the NMD.

The broad and specific cause of death categories with the associated ICD-10 codes included in the analysis are shown in supplementary table S1. Injury related deaths include all causes external to the body, for example transport accidents, falls, poisoning and self-harm. The category all deaths refers to the total number of deaths irrespective of the cause, also known as all-cause mortality or overall mortality. As many cause-specific numbers of deaths were too low to yield reliable statistical inference when considering only underlying cause, both underlying and associated causes were used in the analysis (Redelings et al., 2006). Hence deaths with multiple causes in different cause of death categories contributed to multiple cause-specific analyses. Although cause of death data included up to 14 associated causes, the majority of deaths recorded included only one cause, 24% two causes and less than 3% included in three or more cause of death categories.

2.1.4. Data on ambient temperature

Ambient temperature was controlled for when assessing the impact of mine fire related air pollution on mortality, as temperature has been found to be associated with mortality (Guo et al., 2014). Daily maximum temperature data were sourced from the Australian Bureau of Meteorology for the study period (http://www.bom.gov.au/climate/data-services/station-data.shtml).

2.1.5. Population data


2.2. Data analysis

2.2.1. Descriptive analysis

Distributions of the mine fire related PM2.5 were described for all fire impacted SA2 areas, using violin plots. Distributions of crude monthly mortality rates were investigated for each fire impacted SA2 area for the entire analysis period from July 1, 2009 to June 30, 2015, the mine fire period from 9 February to March 10, 2014 and in the six months after the mine fire from 11 March to September 11, 2014. Mortality rates by cause of death categories were also examined (results not shown). Age standardised monthly mortality rates were not calculated due to small cell counts by age groups. Time series plots of weekly counts over the analysis period were used to investigate potential time dependent patterns to be accounted for in subsequent modelling, such as seasonality
2.2.2. Time series analyses for impacts of coal mine fire on mortality

To estimate the relative risk (RR) of deaths during and after the mine fire, and in association with coal mine fire related PM$_{2.5}$, an interrupted time series quasi-Poisson regression was used for all analyses, with a random effect for location (SA2). The Quasi-Poisson Regression, a generalization of the Poisson regression, was used to control for over-dispersion in death counts (violation of Poisson distribution assumption). Random effect for location was used to control for the spatial variation.

Potential confounding factors included temperature, seasonality, long term trend, day of the week and population age distribution, which were controlled in the time series models. Long-term trend was modelled as year of the event and day of the week was included as a seven-category variable. In addition, seasonality was modelled using a natural cubic spline with 4 degrees of freedom (df) for day of the year, and public holidays classified as a binary variable. A distributed lag non-linear model (DLNM) with non-linear dose-response relationship (modelled using natural cubic spline [ns] with 3 df), and non-linear lag response relationship (modelled using natural cubic spline with 3 df for a seven-day lag period) was used to control for maximum ambient temperature. The dfs were chosen by evaluating the model fitting in dexes including Akaike information criterion (AIC) and Bayesian information criterion (BIC). To adjust for potential population age structure differences across SA2 areas, the proportion of the population aged 80 years and over was also included as a time varying covariate. The population on each day was extrapolated using local weighted regression (LOESS) model based on ABS mid-year population data in each SA2, which was then used as an offset term.

2.2.2.1. Risk of mortality during the mine fire period and the following six months.

This analysis examined whether there was an increased risk of mortality overall, or an increased risk of mortality from cause of death categories of interest, during the mine fire period or in the six months afterwards. The interrupted time series were created by introducing two sets of dummy variables indicating the period during the mine fire and the period six months after, for each exposure group. As number of deaths associated with some categories of interest were relatively low (e.g. mental health), two sets of analysis were carried out. The first set of analysis evaluated mortality during the mine fire period in two exposure location groups (Latrobe Valley vs surrounding areas), and the second set of analysis subdivided the Latrobe Valley into Morwell and the rest of Latrobe Valley. Stratified analyses by age group (under 80 vs. 80 years and above), gender and deaths from specific causes were also conducted, however not with the subdivision of Latrobe Valley because numbers were too small to evaluate associations in Morwell.

2.2.2.2. Risk of mortality associated with fire related PM$_{2.5}$.

This analysis investigated any possible dose response relationship between mortality and coal mine fire related PM$_{2.5}$. The same model was fitted, with the exception that daily exposure estimates for PM$_{2.5}$ in each SA2 were used instead of the fire period variable. To examine whether air pollution was related to risk of death on the same day and following days, a distributed lag model was used assuming a linear dose-response relationship between PM$_{2.5}$ and the outcome and a non-linear lag-response relationship described using a natural cubic spline. Lag periods of 0–3 (3 df), 0–5 (3 df), 0–7 (3 df), 0–14 (3 df) and 0–21 (4 df) days were examined to

(results shown in figure S1).

Fig. 1. Geographical location of the fire impacted statistical areas (SA2s).
provide a more comprehensive understanding of the associations. All analyses were conducted using the statistical analysis software package R (version 3.5.1).

3. Results

3.1. Descriptive analysis

The distributions of modelled daily average PM$_{2.5}$ concentrations attributable to the coal mine fire during the 30 day mine fire period for fire impacted SA2s are shown in Fig. 2. The daily average fire related PM$_{2.5}$ concentration varied substantially across SA2s, with Morwell experiencing the highest exposure, followed by other SA2s in the Latrobe Valley.

Crude mortality rates for the entire analysis period, the mine fire period and the six months after the mine fire in each SA2 are shown in Table 1. There was spatial variation in mortality rates across SA2s, most likely due to the differences in population structure. The monthly mortality rate in Upper Yarra Valley was very low, and therefore this area was excluded from further analysis. Spatial variation in crude mortality rates was found across SA2 areas, which was subsequently accounted for in time series models by including random intercepts at SA2 level.

3.2. Time series analyses for impacts of coal mine fire on mortality

3.2.1. Risk of mortality during the mine fire period and the following six months

**In the Latrobe Valley (including Morwell) and in the surrounding fire impacted areas.**

Fig. 3 shows the estimated relative risks for mortality overall, and by cause of death categories, during the mine fire period and the six months after the mine fire period, compared to the remainder of the analysis period in two location groups: all of the Latrobe Valley (including Morwell) and the surrounding fire impacted areas.

During the 30 day mine fire period, the risks of all-cause mortality in the Latrobe Valley and in surrounding smoke impacted areas, were similar to expected. However, there was a 27% increase in risk of death from cardiovascular conditions in the Latrobe Valley (95%CI: 9, 47%), particularly IHD deaths, where a 35% increase was observed (95%CI: 9, 66%) in that six-month period.

Fig. 4 adds stratification by gender, Fig. 4(a), and by age group, Fig. 4(b). Fig. 4 shows that the increased risk of death from injuries in the Latrobe Valley during the 30 day mine fire period was primarily observed in males and in people aged 80 or older. Amongst females there was weak evidence of an increase in the risk of death from mental health conditions in the Latrobe Valley during the mine fire and in the six months after the mine fire. The increased risk of death from IHD in the Latrobe Valley during this six-month period, compared to the remainder of the analysis period, was found to be the highest in males and in people aged 80 or older.

**In Morwell, the Latrobe Valley (excluding Morwell) and in the surrounding fire impacted areas.**

similar to expected. However, there was a 27% increase in risk of death from cardiovascular conditions in the Latrobe Valley (95%CI: 9, 47%), particularly IHD deaths, where a 35% increase was observed (95%CI: 9, 66%) in that six-month period.

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![Distribution of modelled daily average PM$_{2.5}$ concentrations (μg/m$^3$) emitted from the coal mine fire during the mine fire period for fire impacted SA2s. Note: The violin plot displays the mirrored smoothed density distribution, which illustrates the distributions of PM$_{2.5}$ concentrations with extreme values being present. The length of each plot represents the range of modelled PM$_{2.5}$ concentrations in that SA2. The wider the violin shape is at each PM$_{2.5}$ level, the more likely the population was exposed at that value.](image-url)
Fig. 3. RRs for daily mortality rate overall, and by cause of death categories, during the mine fire period, and six months after the mine fire by two locations; Latrobe Valley including Morwell and surrounding areas. Note: Relative risks (RRs) were adjusted for seasonality, public holidays, day of the week, daily maximum temperature, long-term temporal trends and fraction of population aged 80 and over. RRs, CIs and p-values are shown in supplementary table S2.

Fig. 5 shows the RRs for mortality overall, and by cause of death categories, during the mine fire period and the six months after the mine fire compared to the remainder of the analysis period in three location groups: Morwell alone, the rest of the Latrobe Valley and the surrounding areas. During the 30 day mine fire period, the risks of all-cause mortality in these three localities were similar to expected. However, there was an estimated 325% increase in the risk of death from injuries in Morwell (95%CI: 53, 1078%) and weak evidence of increased injury mortality in the rest of the Latrobe Valley and surrounding areas.

During the six months after the mine fire there was a 29% increase in the risk of all-cause mortality observed in Morwell (95%CI: 4, 59%). Further, there was a 62% increase in risk of death from all cardiovascular conditions (95%CI: 25, 110%), and an 88% increase in risk of death specifically from IHD (95%CI: 32, 167%) in Morwell. No increased risk was observed in the rest of the Latrobe Valley (which excluded Morwell) or in the surrounding areas during the six months after the mine fire.

There was no increase observed for respiratory related deaths in any of the time periods at any of the locations.

3.2.2. Risk of mortality associated with fire related PM$_{2.5}$

The relative risks over the lag period (cumulative RR) for mortality overall, and by cause of death categories, associated with each 10 $\mu$g/m$^3$ increase in mine fire related PM$_{2.5}$, are shown in Table 2. When assuming the lag effect lasted for three days, each 10 $\mu$g/m$^3$ increase in fire related PM$_{2.5}$ on the day of exposure was associated with a 59% (95%CI: 2, 146%) increased risk of death from injuries. Similarly, there was an 80% (95%CI: 24, 163%) increase in risk when assuming the lag effect lasted for 5 days, a 78% (95%CI: 20, 164%) increase for up to 7 days, a 92% (95%CI: 24, 197%) increase for up to 14 days, and a 113% (95%CI: 14, 297%) increase for up to 21 days. No other associations were found between fire related PM$_{2.5}$ and overall mortality, or mortality by specific causes of interest for any of the specified lag periods.

4. Discussion

This study provides valuable insights into the health impacts of exposure to air pollution, specifically from a coal mine fire. The findings showed clear evidence of an increase in injury deaths during the coal mine fire, and cardiovascular deaths in the six months after the fire in Morwell. An increase in all-cause mortality was also observed in Morwell in the six months after the mine fire, that was driven by an increase in cardiovascular related deaths.

There are very few studies that have explored an association between air pollution and injury outcomes (neither mortality nor morbidity), particularly no study of coal mine fire related air pollution. One Korean study reported evidence of an association between exposure to ambient air pollution and risk of death due to unintentional injury (Ha et al., 2015). The potential mechanism between air pollution and injury might be explained by the adverse impact of exposure to environmental pollutants on neurological and behavioural effects, such as poor cognitive judgment, anxiety and depression (Calderón-Garciduenas et al., 2008; Cho et al., 2014; Freire et al., 2010; Weuve et al., 2012) and self-harm (Bakian et al., 2015). Our study observed an increased risk of mortality during the mine fire period, and a dose response relationship between injury and daily mine fire-related PM$_{2.5}$ pollution levels for up to 21 days. The small sample size did not allow further categorisation of injury types and it was also not possible to infer what activities or behaviours led to the injury-related deaths. However, there are possible explanations for the increased risk of injury deaths such as poor visibility as a result of smoke haze could affect driving conditions and increase the risk of collisions (Abdel-Aty et al., 2011). The use of power tools, ladders and heavy equipment to clear obstacles and remove ash or flammable debris from roofing may increase injury risk. For residents aged 80 and above a pre-existing health condition may have been exacerbated by the mine fire, triggering a fall.

The impact of exposure on mortality was found to have continued beyond the duration of the mine fire, with an increase in the overall risk of death in Morwell observed during the six months after the mine fire period. Although previous research has found wildfire exposure to be associated with immediate increases in all-cause mortality post exposure (Johnston et al., 2011; Doubleday et al., 2020), our study did not observe short term impacts during the mine fire period on all-cause mortality. This could be related to lack of statistical power to detect a small effect in our study due to low population density. Johnston et al. (2011) found a 5% increase in mortality associated with smoke events at a lag of one day and Doubleday et al. (2020) found a 2% increase in...
mortality after exposure to wildfire smoke at a lag of one day, however these studies did not investigate longer term effects of exposure.

Literature on the impact of wildfire smoke exposure on cardiovascular mortality is inconclusive (Xu et al., 2020). In our study, an increased risk of cardiovascular mortality was not observed during the fire period, but appeared in the following six months, which indicates a possible longer-term association. This association may relate to the longer-term toxicity of particulate matter or other changes that the mine fire introduced in the local community i.e. poorer management of chronic diseases. The absence of a significant short term effect on cardiovascular mortality in our study might be explained by residents with cardiovascular diseases proactively protecting themselves with preventive medications as shown in our previous research (Johnson et al., 2019b). It is also possible that the analyses lacked statistical power to detect a small effect, due to low population density.

This study found that residents aged 80 years and above were those most affected by the coal mine fire, which is consistent with studies that have shown that older people are more sensitive to air pollution than the young (Guo et al., 2013; Kan et al., 2008; Chen et al., 2012). A study examining the impact of forest fires on mortality found that after a high air pollution day, there was a 56% increase in all-cause mortality among adults aged 65–74 years (Sastry, 2002). Similarly, a study of ambient air pollution found that long term PM$_{2.5}$ exposure was associated with an increased risk of mortality in adults aged 65 years and older (Li et al.,
longer terms associations between the mine fire event and mental health. The elderly may have weaker immune systems, or undiagnosed chronic respiratory or cardiovascular conditions, making them particularly susceptible to air pollution.

Previous findings from the Hazelwood Health Study found short and longer term associations between the mine fire event and mental health outcomes. Mine fire related PM$_{2.5}$ was found to be associated with increased mental health consultations and dispensing of psychiatric medications. For residents closest to the Hazelwood mine fire, moderate levels of distress relating to the event were observed more than two years after the mine fire. Consistent with previous Hazelwood Health Study findings, our analysis found some evidence of an increased risk of death from mental health conditions amongst females during the mine fire and in the six months after the fire. Other studies have shown the effects of ambient air pollution on a range of mental health outcomes including depression, anxiety, psychotic illnesses and cognitive development.

A 2016 review of studies on wildfire smoke exposure and health showed consistent evidence of associations between smoke and general respiratory health effects, but not between smoke and respiratory mortality. However, a more recent study found that exposure to wildfire smoke was associated with a 9% increase in respiratory deaths, particularly COPD related deaths where a 14% increase was observed. Whilst no association between the mine fire smoke and respiratory mortality was observed in our analysis, it is unlikely the smoke posed no threat to people with respiratory illnesses. Instead, vulnerable people with respiratory illnesses may have taken protective measures including leaving the smoke impacted areas, wearing protective masks and/or increasing their use of preventive medications and seeking treatment when needed. Previous Hazelwood Health Study research has shown respiratory health effects associated with exposure from the coal mine fire.

This research provides valuable insights into the impact of an open cut brown coal mine fire event on mortality overall and from specific causes. Using distributed nonlinear lag models allowed for the examination of potential delayed effects to assist in identifying which days of exposure were associated with increased mortality. In addition, the statistical models accounted 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.

However, the analyses also had some limitations. The use of de-identified data extracts did not account for people moving in and out of the area of interest during the study period. For example, a person who

### Table 2

Cumulative RRs for daily rates of mortality overall, and by cause of death categories, associated with each 10 μg/m$^3$ increase in fire related PM$_{2.5}$ for different lag periods in all fire impacted SA2s.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Specified lag days for PM$_{2.5}$</th>
<th>Cumulative RR (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>All respiratory</td>
<td>0–3</td>
<td>0.88 (0.52, 1.50)</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>0–5</td>
<td>0.58 (0.24, 1.43)</td>
<td>0.24</td>
</tr>
<tr>
<td></td>
<td>0–7</td>
<td>0.34 (0.08, 1.39)</td>
<td>0.13</td>
</tr>
<tr>
<td></td>
<td>0–14</td>
<td>0.21 (0.04, 1.08)</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td>0–21</td>
<td>0.25 (0.05, 1.18)</td>
<td>0.08</td>
</tr>
<tr>
<td>Ischaemic heart disease</td>
<td>0–3</td>
<td>0.90 (0.52, 1.57)</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>0–5</td>
<td>0.84 (0.46, 1.54)</td>
<td>0.58</td>
</tr>
<tr>
<td></td>
<td>0–7</td>
<td>0.83 (0.44, 1.55)</td>
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</tr>
<tr>
<td></td>
<td>0–14</td>
<td>1.04 (0.61, 1.79)</td>
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<td></td>
<td>0–21</td>
<td>1.00 (0.53, 1.87)</td>
<td>0.99</td>
</tr>
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<td>All cardiovascular</td>
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<td>All injuries</td>
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<td></td>
<td>0–5</td>
<td>0.98 (0.76, 1.27)</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>0–7</td>
<td>0.97 (0.74, 1.26)</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>0–14</td>
<td>0.94 (0.69, 1.33)</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>0–21</td>
<td>0.96 (0.69, 1.33)</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Note: Cumulative relative risks (RR) were adjusted for seasonality, public holidays, day of the week, daily maximum temperature, long-term temporal trends and fraction of population aged 80 and over.
moved into the study area after the fire may be included in the death counts, or a person who moved out of the study area after the fire may be missed in the death counts, depending on their usual place of residence at time of death. There was a small number of deaths from specific causes in the fire impacted areas, due to low population density. As some analyses were based on small numbers, these results should be interpreted with caution. Individual-level mine fire exposure, historical environmental exposures and other risk factors were not evaluated. In the absence of more detailed information on injury related deaths, it was not feasible to explore whether there were increases in certain activities or behaviours during the mine fire period. Coronial data or more detailed death certificate data could be considered in future research.

Analysis could not be undertaken at an SA1 level (smaller geographical unit than SA2), due to the small number of records at the SA1 level. Hence the heterogeneity of exposure levels within each SA2, particularly within Morwell, was not considered. The analyses also did not include other criterion pollutants such as ozone, nitrogen dioxide or sulphur dioxide, but these were not elevated during the mine fire period. Effects of carbon monoxide could not be evaluated due to strong co-linearity with PM2.5.

5. Conclusions

This study showed clear evidence of an increase in the risk of injury related deaths during the coal mine fire, and an increase in the risk of cardiovascular related deaths in the six months after the fire. Acute increases in coal mine fire related PM2.5 were also associated with increases in injury related deaths. There was no increase observed for respiratory related deaths. These findings assist in understanding the health impacts specific to exposure from an open cut brown coal mine fire, where there was limited research available. The results will assist in targeting health advice and emergency health services to at risk groups in future fires.

Ethical statement

The Monash University Human Research Ethics Committee (MUHREC) approved the Hazelwood Adult Survey & Health Record Linkage Study on the May 21, 2015. This included approval to request national death data from the Australian Institute of Health and Welfare (AIHW). An application to access death data was submitted and approved by the AIHW ethics committee.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Michael Abramson holds investigator-initiated grants for unrelated relationships which may be considered as potential competing interests: Michael Abramson holds investigator-initiated grants for unrelated research from Pfizer and Boehringer-Ingelheim, has conducted an unrelated consultancy and received assistance with conference attendance from Sanofi. He also received a speaker’s fee from GSK. The other authors declare they have no actual or potential competing financial interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.chemosphere.2021.131351.

Credit author statement

Christina Dimitriadis: Data curation, Writing – original draft, Project administration; Caroline X. Gao: Methodology, Formal analysis, Visualization, Writing – review & editing, Jillian Ikin: Investigation, Writing – review & editing, Supervision, Project administration; Rory Wolfe: Methodology, Writing – review & editing, Supervision; Belinda J. Gabbe: Writing – review & editing; Malcolm R. Sim: Writing – review & editing; Michael J. Abramson: Conceptualization, Investigation, Writing – review & editing, Supervision; Yuming Guo: Conceptualization, Methodology, Investigation, Writing – review & editing, Supervision.

References


