Age-standardised mortality and cause of death in the Latrobe Valley at the time of (and five years prior to) the Hazelwood coalmine fire in Morwell, Victoria

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Executive Summary

This report examines mortality data from the Latrobe Valley postcodes during the period of the Hazelwood mine fire in February and March 2014. In this report, the mortality data for February and March 2014 are compared to the same summer months for the same postcodes in the previous five years. This comparison examines the epidemiological evidence for any excess number of deaths during this period, and the role of air quality and temperature on numbers of deaths. The mortality from the period February to June 2014 is included also in this report, and compared to the same period in the previous five years to examine whether there were associations of the Hazelwood fire on mortality beyond the summer months when the fire occurred.

Key findings in this report are to be interpreted cautiously, with the understanding that the finding of no statistical evidence of association cannot be interpreted as evidence for or against a particular cause of death.

The analyses examine these associations in terms of the statistical evidence linking the deaths with the occurrence of the mine fire. The findings reported are based on the small number of deaths in the affected postcodes, which limits the interpretation of the results.[1]

The analysis of these data shows no statistical evidence that 2014 mortality rates differ from comparable rates for the same months in 2009, a season similar to 2014 with respect to high temperatures and high particulate matter from bushfire smoke. Broad confidence intervals for each of the rate ratios for the years 2009–2013, which approach or overlap the confidence intervals of the 2014 rates, express the lack of statistical evidence for an overall higher rate of mortality in 2014.

There is statistical evidence that air quality exceedances are associated with mortality throughout the study period, not just during the period of the 2014 Hazelwood coalmine fire, or the 2009 bushfire.[2] Overall for the 2009–2014, February-June study period, most deaths that occurred on days with air quality over 50µg/m^3 for PM_{10} in the affected postcodes occurred outside of the February-March period and 85% of these occurred in 2012 and 2013. Mortality in all age groups was 2.13 times higher on

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[1] The associations reported herein are given as point estimates of rates with associated 95% confidence intervals. The 95% confidence intervals given with a point estimate is equivalent to the statement that there is a 95% probability that the value of the point estimate lies within the stated range of values. These intervals can be broader or narrower depending on several factors, including sample size and population variability. When the confidence interval contains one (1), the evidence for an association is weak. We note that non-significant results in the case of small sample sizes such as those in this report are prone to misinterpretation, leading to the conclusion of an effect where there is none, or the conclusion of no effect where there is one (see Altman DG and Bland JM, 1995, Absence of evidence is not evidence of absence, British Med J 311:485).

[2] An exceedance is an instance or condition where the observed concentration of a pollutant goes beyond the permitted quality standard or threshold. The 'threshold' level used for the purposes of this analysis is the daily mean value of 50µg/m^3 although particulate matter is a non-threshold pollutant, and thus is not associated with a threshold level (http://www.epa.vic.gov.au/your-environment/air/bushfires-and-air-quality; see also Table 1, Standards and goals for pollutants other than particles as $PM_{2.5}$, National Environment Protection (Ambient Air Quality) Measure, http://www.comlaw.gov.au/Details/C2004H03935).

days with air quality over 50µg/ m^3 for PM_{10}, compared to days with lower levels for the entire period February-March, 2009–2014 ($p<0.01$). The mortality in the vulnerable age group 65 years and older was 2.0 times higher on days with air quality over 50µg/ m^3 for PM_{10} compared to days with lower levels for the same period ($p<0.01$). As mortality was associated with air quality over 50µg/ m^3 for PM_{10}, and the fire may have contributed to this measure of air quality, it is possible that a proportion of deaths in 2014 could have been due to the fire in February-March, 2014. However, as we do not know the individual circumstances of deaths on days with air quality over 50µg/m^3 for PM_{10} we cannot offer specific conclusions on this matter.

There is no statistical evidence for the association of daily average temperature at or over 30° C with mortality in the February-March period for 2009–2014. There is moderate evidence that colder temperatures are associated with mortality in the February-June period for 2009–2014.

Background
The Hazelwood mine fire occurred during a period of high temperatures with associated health risks in February 2014, during one of the hottest and driest Victorian summers on record. The most likely cause of the mine fire was found to be embers from one or both of two bushfires outside of the mine. (Hazelwood Mine Fire Report 2014, http://www.dpc.vic.gov.au/index.php/news-publications/hazelwood-mine-fire-inquiry-report).

Methods
Births, Deaths, and Marriages Victoria provided the mortality data for these analyses in the form of Stata files containing all Victorian deaths for the period 2009–2014. For each death, the dataset included variables for date of death, age, 5-year age group, sex, cause of death and postcode. Our analysis was restricted to the Latrobe Valley postcodes: 3840 Morwell; 3842 Churchill; 3844 Traralgon; and 3825 Moe.

There were 3414 deaths in the Latrobe Valley postcodes for the years 2009–2014. Our analysis is based on the 3398 deaths for which we have complete data. We excluded 13 deaths listed as 'unascertained'; of these, there were two unascertained deaths in 2014 (May and September). Three additional deaths were excluded from the final analysis due to missing data in other variables.

Cause of death categories and definitions
Cause of death was provided in the form of text description of the underlying cause of death. Using the *regular expressions* command in Stata 13.0, we generated variables for deaths that reasonably would be associated with exposure to fire, airborne particulate matter and/or pollutants. In this report we analysed the number of deaths from *all causes* and the number of deaths due to *respiratory*, *cardiovascular* or *cardiorespiratory* causes.

Deaths associated with exposure to fire, airborne particulate matter and/or pollutants: These categories are deaths by *respiratory* conditions, *cardiovascular* conditions, and deaths with *direct relationship to fire*.

Causes of death due to *respiratory* condition*s* included chronic obstructive pulmonary disease, asthma, pneumonia, bronchitis, bronchopneumonia, pulmonary embolism, pulmonary fibrosis, pulmonary oedema, and respiratory arrest.

Causes of death due to *cardiovascular* conditions included myocardial infarction, ischemic heart disease, congestive heart failure, coronary heart disease, cardiomyopathy, aortic dissection, aortic stenosis, arterial fibrillation, ventricular fibrillation, cardiac amyloidosis, cardiac arrhythmia and tachycardia, and cardiac arrest.

Due to the small number of deaths in the four postcodes of interest, the aggregated variable *cardiorespiratory* conditions for causes of death due to respiratory *and/or* cardiovascular conditions was generated by combining the two variables.

Causes of death from *direct relationship with fire* included carbon monoxide poisoning, inhalation of smoke and fire gases, complications of thermal burn injuries, and general effects of fire.

Temperature and air quality variables
The Morwell Bureau of Meteorology Site 85280 at the Latrobe Valley Airport, closely located to the four Latrobe Valley postcodes in this analysis, provided daily mean temperatures for 2009–2014. The threshold level for this analysis is daily mean temperature in excess of 30° Celsius, which is the threshold that triggers the state's Heat Health Alert System.

The Environmental Protection Agency Traralgon air quality monitoring site, closely located to the four Latrobe Valley postcodes in this analysis, provided daily mean measures of particulate matter in excess of 10 micrometers or less in diameter (PM_{10}) for 2009-2014. The threshold level used for the purposes of our analysis is $50\mu g/m^3$, although particulate matter is a non-threshold pollutant and thus is not associated with a threshold level (http://www.epa.vic.gov.au/your-environment/air/bushfires-and-air-quality, see also Table 1, Standards and goals for pollutants other than particles as $PM_{2.5}$, National Environment Protection (Ambient Air Quality) Measure, http://www.comlaw.gov.au/Details/C2004H03935).

Age-standardisation
Age-standardisation allows for comparison of mortality rates over different years (2009–2014) and populations (the four postcodes of the region) that may have different age distributions. This is done by adjusting each year's deaths based on the age distribution of a single chosen 'standard' population, such as the national population. For example, in the case of the four Latrobe Valley postcodes, there is a five-fold difference in the population size of Churchill compared to Traralgon, and a nine-year difference in the median age of Churchill compared to Morwell (http://www.abs.gov.au/websitedbs/censushome.nsf/home/Census?opendocument#from-banner=GT).

Due to the small population size of the Latrobe Valley, the Morwell, Churchill, Moe and Traralgon postcodes' mortality data were aggregated for age standardisation into three age-categories: under age 50 years, 50-64 years and 65 years and over. For age-standardisation we used the direct method (Australian Institute of Health and Welfare 2011. Principles on the use of direct age-standardisation in administrative data collections: for measuring the gap between Indigenous and non-Indigenous Australians. Cat. No. CSI 12. Canberra: AIHW). We created age-specific population estimates from the Australian Bureau of Statistics using the age distribution of the 2011 Australian standard population (http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Sep%202014?OpenDocument).

Statistical modelling
Poisson regression models adjusted for age and sex and for temperature and air quality were used to calculate mortality rate ratios and associated 95% confidence intervals. These rate ratios were used to compare the mortality observed for the periods February-June and February-March 2014 with the mortality observed during those periods for each year from 2009 to 2013. In this sense, the 2014 mortality rates were the reference rates (mortality rate ratio of 1.0) and the rate ratios for the other years indicate the proportional increase (rate ratios greater than 1.0) or proportional decrease (rate ratios less than 1.0) compared to 2014.

These analyses examined *all-cause* mortality and mortality due to *respiratory*, *cardiovascular* and the combined category of *cardiorespiratory* causes. Mortality rate ratios were calculated for all age groups combined and for the aggregated vulnerable age groups aged 65 years and older. There were insufficient deaths to analyse the vulnerable age groups aged 5 years and younger.

Results

Age-adjusted mortality

The actual number of deaths and the age-standardised death rates for 2014 and the previous five years for the months February to June can be seen in Table 1 and for the months February to March can be seen in Table 2. For both February-March and February-June periods, the age standardised mortality rates were highest for 2014 and 2009 compared to the years 2010-2013. This is best seen in the comparison between February-March, 2009 and 2014, when the age-standardised rates are 1.5 deaths per 1000 person-years[3] and 1.6 deaths per 1000 person-years respectively (Table 2). Deaths in February-March, 2010–2013 were 1.1 to 1.2 per 1000 person-years. The results of the additional statistical analyses should be examined before concluding whether or not these differences in mortality rates are statistically significant and not due merely to annual random fluctuations, or other non-fire related factors.

Table 1. Age-standardised* mortality rates (ASR) in the Latrobe Valley per 1,000 person-years between February-June, 2009–2014**

Age	2009		2010		2011		2012		2013		2014	
category	*n*	*ASR*	*n*	*ASR*	*n*	*ASR*	*n*	*ASR*	*n*	*ASR*	*n*	*ASR*
< 50	24	0.3	18	0.4	12	0.3	18	0.2	29	0.3	18	0.4
50-64	22	0.4	24	0.4	34	0.4	32	0.5	27	0.3	32	0.3
≥ 65	225	2.4	189	2.1	184	2.0	157	2.3	170	2.4	188	2.8
All ages	**271**	**3.4**	**231**	**3.2**	**230**	**3.0**	**207**	**3.3**	**226**	**3.3**	**238**	**3.9**

*Directly age-standardised using the 2011 Australian standard population
**Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844).

Table 2. Age-standardised* mortality rates (ASR) in the Latrobe Valley per 1,000 person-years between February-March, 2009–2014**

Age	2009		2010		2011		2012		2013		2014	
category	*n*	*ASR*	*n*	*ASR*	*n*	*ASR*	*n*	*ASR*	*n*	*ASR*	*n*	*ASR*
< 50	7	0.1	6	0.2	4	0.1	8	0.1	13	0.1	8	0.1
50-64	10	0.2	9	0.1	10	0.2	14	0.1	9	0.1	16	0.1
≥ 65	94	1.1	63	0.7	68	0.7	59	0.9	59	0.8	84	1.2
All ages	**111**	**1.5**	**78**	**1.2**	**82**	**1.2**	**81**	**1.2**	**81**	**1.1**	**108**	**1.6**

*Directly age-standardised using the 2011 Australian standard population
**Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844).

[3] The person-year is a measure of the estimated time-at-risk for the population under review.

Temperature and air quality

For the months of **February to June**, comparison of the mortality records with the environmental observations shows that there were more deaths occurring on days with mean temperatures at or over 30° C in 2009 and 2014 than in the years 2010–2013 (Table 3). There were 27 deaths that occurred on days with mean temperature at or over 30° C in the affected postcodes for these two years, 13 that occurred in 2009 and seven that occurred in 2014. In contrast, there were less deaths occurring on days with mean air quality at or over 50µg/m^3 PM_{10} in 2009 and 2014 than in the years 2010-2013 (Table 3). There were 93 deaths that occurred on days with mean air quality at or over 50µg/m^3 PM_{10} in the affected postcodes for 2009–14, 15 that occurred in 2013 and nine that occurred in 2014.

For the months of **February to March**, there were 27 deaths occurring on days with mean air quality at or over 50µg/m^3 PM_{10}, and more than half occurred in 2009 and 2014 (Table 4). For 2009 and 2014, 67% of the deaths on days with mean air quality at or over 50µg/m^3 PM_{10} occurred during the fire months of February-March, compared to deaths occurring with similar exposures at other times of the year. There were three deaths in 2011, and all were associated with mean air quality levels at or over 50µg/m^3 PM_{10} in the February-March period (100%).

We note that 68% of the total 93 deaths for February-June 2009–2014 deaths occurred on days of air quality at or over 50µg/m^3 PM_{10} in 2012 and 2013, with most occurring outside the months of February-March (compare Tables 3, 4). Overall for 2009–2014, most deaths during days with air quality at or over 50µg/m^3 PM_{10} in the affected postcodes occurred outside of the February-March period during the months April-June; 85% of these occurred in 2012 and 2013, during the months April-June.

Table 3. Latrobe Valley* number of deaths occurring on days with temperature or air quality exceedances, February-June, 2009–2014

	2009	2010	2011	2012	2013	2014	Total
Temperature ≥ 30° C	13	4	0	0	3	7	27
Air quality ≥ 50µg/m^3 PM_{10}	15	3	3	17	46	9	93

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844).

Table 4. Latrobe Valley* number of deaths occurring on days with air quality exceedances, February- March, 2009–2014.

	2009	2010	2011	2012	2013	2014	Total
Air quality ≥ 50µg/m^3 PM_{10}	10	2	3	0	8	6	27

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844).
Deaths on high temperature days are the same as for Table 3 and are not shown here.

Cause of death (Tables 5-8, Figure 1)
Analyses of cause of death are to be interpreted cautiously, with the understanding that the finding of no statistical evidence of association cannot be interpreted as evidence for or against a particular cause of death.

There were 10 deaths from *direct relationship with fire* between 2009 and 2014 in the Latrobe Valley; of these, six deaths occurred in February-June 2009 and one in February-June 2013. No deaths from *direct relationship with fire* occurred in February-June 2010–12 or 2014.

Table 5 provides the mortality rate for the months of February to June, and for February to March for 2009-2013 relative to the mortality rate in 2014. For the months **February-June** 2013, we found moderate statistical evidence for a 16% lower *all-cause* mortality rate compared to the same period in 2014 (Table 5, $p=0.02$). There was no statistical evidence for any differences in mortality between 2014 and any of the years 2009–2012. For the months **February-March**, the *all-cause* mortality rate was 31% lower in 2013 ($p=0.01$) and 24% lower in 2012 ($p=0.05$) compared to the same period in 2014 (Table 5). There was no statistical evidence for other differences in mortality for this period in the individual years 2009–2011. Figure 1 shows the data in Table 5 graphically. Caution should be used in interpreting these results, as the confidence intervals for these estimates are broad, and they overlap the 2014 reference rate, and each other.

Air quality $\geq 50\mu g/m^3$ PM_{10} for the entire period was associated with *all-cause* mortality throughout this period (Table 5). Mortality in the **February-March** period was 2.13 times higher on days with air quality $\geq 50\mu g/m^3$ PM_{10} compared to days with lower levels ($p<0.01$). Mortality in the **February-June** period was 1.83 times higher ($p<0.01$).

Temperature exceedances do not show statistical evidence of association with *all-cause* mortality in the **February-March** period 2009–2013 compared to February-March 2014. We note that for the months of **February to June**, there is moderate statistical evidence for the association of colder temperatures with mortality.

Cardiovascular mortality for all ages was 42% lower in 2009 compared to 2014, for the **February-March** period, after adjusting for age, sex, mean daily temperature and 24-hour air quality (Table 7, $p=0.05$). This finding must be interpreted with caution due to the small number of deaths in this category. There was no statistical evidence for differences in mortality rates due to the other smoke exposure causes (*respiratory* and combined *cardiorespiratory* causes) for these time periods (Table 6, Table 8).

Table 5. Latrobe Valley* *all-cause* mortality in 2009–2013 compared to 2014 for the months February to June and the months February to March

Year	February-June			February-March		
	Rate Ratio	**(95% CI)**	**p-value**	**Rate Ratio**	**(95% CI)**	**p-value**
Year						
2014	1	–	–	1	–	–
2013	**0.84**	**(0.74-0.97)**	**0.02**	**0.69**	**(0.52-0.90)**	**0.01**
2012	0.87	(0.76-1.00)	0.06	**0.76**	**(0.59-1.00)**	**0.05**
2011	0.89	(0.78-1.03)	0.13	0.86	(0.67-1.12)	0.29
2010	0.95	(0.83-1.09)	0.52	0.84	(0.65-1.09)	0.20
2009	0.93	(0.81-1.06)	0.30	1.01	(0.79-1.28)	0.91
Temperature						
< 30° C	1	–	–	1	–	–
≥ 30° C	**0.55**	**(0.34-0.89)**	**0.02**	1.24	(0.78-1.97)	0.35
PM_{10}						
< 50ug/m^3	1	–	–	1	–	–
≥ 50ug/m^3	**1.83**	**(1.57-2.14)**	**<0.01**	**2.13**	**(1.55-2.91)**	**<0.01**

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Figure 1. All cause mortality rate ratios in the Latrobe Valley, 2009–2013 compared to 2014 (Reference rate 1.0)

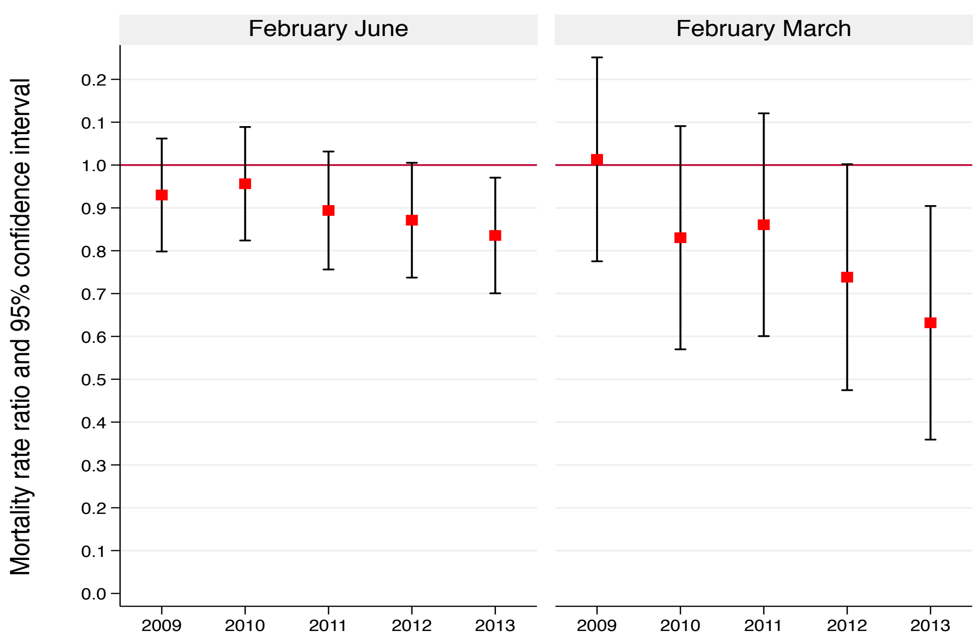

Table 6. Mortality due to respiratory causes in the Latrobe Valley* in 2009–2013 compared to 2014 adjusted for temperature and air quality.

	February-June			February -March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
Year						
2014	1	-	-	1	-	-
2013	1.17	(0.78-1.76)	0.43	1.02	(0.49-2.15)	0.94
2012	1.04	(0.68-1.59)	0.84	1.61	(0.83-3.12)	0.16
2011	1.43	(0.96-2.13)	0.08	1.59	(0.82-3.07)	0.16
2010	1.43	(0.97-2.12)	0.07	1.27	(0.63-2.57)	0.49
2009	0.95	(0.61-1.47)	0.82	1.08	(0.54-2.17)	0.81

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Table 7. Mortality due to cardiovascular causes in the Latrobe Valley* in 2009–2013 compared to 2014 adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	
2013	0.80	(0.57-1.12)	0.21	0.77	(0.46-1.28)	0.32
2012	0.86	(0.62-1.20)	0.39	0.59	(0.34-1.05)	0.08
2011	0.79	(0.56-1.14)	0.22	0.65	(0.38-1.13)	0.14
2010	0.84	(0.60-1.19)	0.34	0.60	(0.34-1.07)	0.09
2009	0.70	(0.49-1.00)	0.06	**0.58**	**(0.34-0.99)**	**0.05**

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Table 8. Mortality due to cardiorespiratory causes in the Latrobe Valley* in 2009–2013 compared to 2014 adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	-
2013	0.95	(0.74-1.22)	0.72	0.89	(0.60-1.33)	0.6
2012	0.97	(0.76-1.24)	0.83	0.94	(0.63-1.39)	0.77
2011	1.07	(0.84-1.37)	0.55	0.99	(0.67-1.45)	0.97
2010	1.06	(0.83-1.35)	0.63	0.84	(0.56-1.28)	0.44
2009	0.81	(0.62-1.05)	0.14	0.78	(0.52-1.15)	0.22

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Mortality in the vulnerable age group 65 years and older (Tables 9-12, Figure 2)
Analyses of cause of death in this age group are to be interpreted cautiously, with the understanding that the finding of no statistical evidence of association cannot be interpreted as evidence for or against a particular cause of death.

Table 9 provides the mortality rate for the months of February to June, and for February to March for 2009-2013 relative to the mortality rate in 2014. For the months **February-June**, we found moderate statistical evidence for a 15% lower *all-cause* mortality rate for February-June 2012 compared to the same period in 2014 (Table 9, p=0.04) for the vulnerable age group 65 years and older, after adjusting for age, sex, mean daily temperature and 24-hour air quality. The mortality rate for the **February-March** 2013 period was 32% lower for this age group compared to the same period in 2014 (Table 9, p=0.01). The ratio of the mortality rates for 2009–2013 to the mortality rates of 2014 has broad and overlapping associated 95% confidence intervals and must be interpreted with caution. Figure 2 shows the data in Table 9 graphically.

Air quality $\geq 50\mu g/m^3$ PM_{10} for the entire period was associated with *all-cause* mortality throughout this period for this age group (Table 9). Mortality in the **February-March** period was 2.0 times higher on days with air quality $\geq 50\mu g/m^3$ PM_{10} compared to days with lower levels ($p<0.01$). Mortality in the **February-June** period was 1.74 times higher ($p<0.01$).

Temperature exceedances do not show statistical evidence of association with *all-cause* mortality in the **February-March** period 2009–2013 compared to February-March 2014 for this age group. We note that there is moderate statistical evidence for the association of colder temperatures with **February-June** mortality for this age group.

Respiratory mortality for this age group was 57% higher in February-June 2011 compared to the same period in 2014, after adjusting for age, sex, mean daily temperature and 24-hour air quality (Table 10, p=0.03).

Cardiovascular mortality for this age group was 36% lower in 2009 compared to 2014, for the February-March period, after adjusting for age, sex, mean daily temperature and 24-hour air quality (Table 11, p=0.03). This finding must be interpreted with caution due to the small number of deaths in this category. There was no statistical evidence for differences in mortality rates due to combined *cardiorespiratory* causes for these time periods for this age group (Table 12).

Table 9. Latrobe Valley¶ all cause mortality in 2009–2013 compared to 2014, *people age 65 years and older* adjusted for temperature and air quality.

	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
Year						
2014	1	–	–	1	–	–
2013	0.86	(0.74-1.00)	0.06	**0.68**	**(0.50-0.92)**	**0.01**
2012	**0.85**	**(0.73-0.98)**	**0.04**	0.75	(0.56-1.00)	0.06
2011	0.88	(0.75-1.02)	0.11	0.79	(0.59-1.07)	0.14
2010	0.93	(0.80-1.09)	0.41	0.78	(0.58-1.05)	0.11
2009	0.95	(0.82-1.10)	0.5	1.01	(0.77-1.32)	0.92
Temperature						
< 30°C	1	–	–	1	–	–
≥ 30°C	**0.23**	**(0.07-0.79)**	**0.02**	0.55	(0.17-1.77)	0.32
PM_{10}						
< 50ug/m^3	1	–	–	1	–	–
≥ 50ug/m^3	**1.74**	**(1.46-2.09)**	**<0.01**	**2.00**	**(1.36-2.95)**	**<0.01**

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Figure 2. All cause mortality rate ratios in the Latrobe Valley, 2009–2013 compared to 2014, *people age 65 years and older,* (Reference rate 1.0)

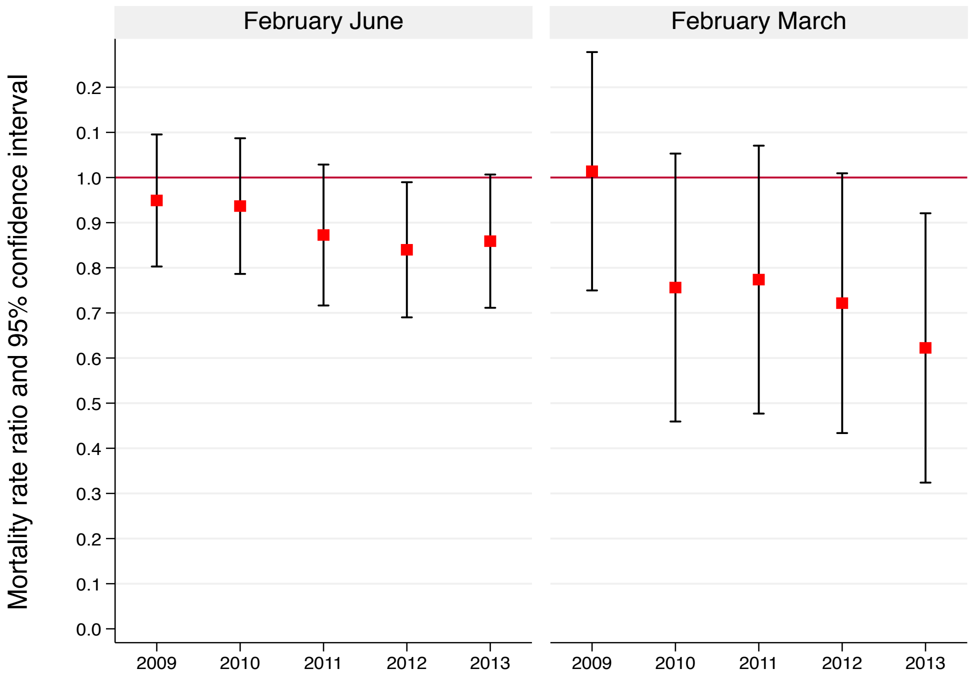

Table 10. Mortality due to respiratory causes in the Latrobe Valley¶ in 2009–2013 compared to 2014, *people age 65 years and older* adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	
2013	1.31	(0.87-1.98)	0.19	1.10	(0.53-2.28)	0.79
2012	1.10	(0.71-1.70)	0.67	1.50	(0.76-2.95)	0.23
2011	**1.57**	**(1.03-2.38)**	**0.03**	1.85	(0.94-3.63)	0.07
2010	1.38	(0.90-2.10)	0.13	1.02	(0.47-2.21)	0.95
2009	0.89	(0.56-1.43)	0.65	0.88	(0.41-1.84)	0.74

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Table 11. Mortality due to cardiovascular causes in the Latrobe Valley¶ in 2009–2013 compared to 2014, *people age 65 years and older* adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	(95% CI)	p-value	Rate Ratio	(95% CI)	p-value
2014	1	-	-	1	-	-
2013	0.87	(0.61-1.24)	0.45	0.89	(0.53-1.50)	0.68
2012	0.84	(0.59-1.20)	0.36	0.64	(0.36-1.15)	0.14
2011	0.82	(0.56-1.21)	0.33	0.64	(0.34-1.19)	0.17
2010	0.83	(0.57-1.21)	0.36	0.74	(0.41-1.32)	0.31
2009	**0.64**	**(0.43-0.96)**	**0.03**	0.60	(0.34-1.05)	0.08

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Table 12. Mortality due to cardiorespiratory causes in the Latrobe Valley¶ in 2009–2013 compared to 2014, *people age 65 years and older* adjusted for temperature and air quality.

Year	February-June			February-March		
	Rate Ratio	**(95% CI)**	**p-value**	**Rate Ratio**	**(95% CI)**	**p-value**
2014	1	-	-	1	-	-
2013	1.05	(0.82-1.35)	0.65	1.00	(0.68-1.48)	0.98
2012	0.99	(0.76-1.28)	0.94	0.96	(0.65-1.42)	0.85
2011	1.14	(0.88-1.47)	0.30	1.05	(0.70-1.57)	0.79
2010	1.04	(0.80-1.35)	0.73	0.84	(0.54-1.31)	0.46
2009	0.76	(0.57-1.02)	0.07	0.71	(0.47-1.09)	0.12

*Latrobe Valley defined as Morwell (3840), Churchill (3842), Moe (3825) and Traralgon (3844). P-value is the probability of observing a rate ratio this small or smaller given there was no difference in rates compared to 2014.

Discussion

This analysis of the Latrobe Valley mortality data is in essence a comparison of the mortality in the region during the period of the Hazelwood mine fire with mortality in the same place and at the same season in previous years. The type of analysis best suited for this context is an ecological epidemiological analysis that compares data for regions across years. However, this analysis is limited with respect to explaining individual circumstances, and is thus one of the weakest methods for assigning cause of deaths. There are important caveats to note for this type of analysis, especially with respect to the limitations due to the small number of deaths for these comparisons.

The large confidence intervals demonstrate the uncertainties around interpretation of mortality comparisons between 2014 and the previous five years in the Latrobe Valley postcodes, as the numbers are small even with aggregating the four postcodes. Estimated mortality rate ratios for each year and cause of death category have broad and overlapping confidence intervals. Statistical evidence for or against associations with exposures to environmental factors must therefore be interpreted with caution. This means that we are not able to rule in or rule out evidence for excess regional deaths because of the coal fire in 2014.

All-cause and specific causes of death were considered separately, as *cardiovascular* and/or *respiratory* mortality are better indicators of the effects of exposure to smoke and particulate matter. However, in these data, there were insufficient numbers of such deaths to conduct any meaningful comparison between the periods of interest in 2009–2013 and 2014. Findings within the specific cause of death categories are to be interpreted with caution.

The same caveat exists for demonstrating the association of exposure to particulate matter from smoke on *all-cause* mortality in the Latrobe Valley. Whilst there were six deaths in the affected postcodes on days with air quality ≥ 50μg/m^3 PM_{10} during the 2014 mine fire, there were ten such deaths in 2009 during the same period and eight such deaths in 2013 during the same period. Overall for 2009–2014, most deaths associated with days of mean air quality ≥ 50μg/m^3 PM_{10} in the affected postcodes occurred outside of the February-March period; 85% of these occurred in 2012 and 2013. On average throughout the study period, *all-cause* mortality for all ages was increased by 83% for the months February-June and 113% for the months February-March (Table 5). For the vulnerable age group 65 years and older, *all-cause* mortality was increased by 74% for the months February-June and 100% for the months February-March (Table 9).

These observations mean that there is statistical evidence that air quality ≥ 50μg/m^3 PM_{10} is associated with mortality throughout the entire 2009–2014 study period, not just during the period of the Hazelwood mine fire. The small number of deaths restricts the analysis to air quality measures on the date of death; it is not possible to analyse each death in association with air quality on the day, week or month before that death.

We note in this regard that air quality records for monitoring stations in the affected postcodes show that the mean daily $PM_{2.5}$ level was exceeded during the February-March 2014 period except in Moe. Whilst we cannot compare these records with the same period in previous years, it does suggest that smoke exposure was variable throughout the Latrobe Valley and there may be associated differences in regional mortality that cannot be captured in our analysis.

Whilst extreme summer temperatures have been associated with increased mortality, we have no statistical evidence for this association with mortality in this dataset, once we have adjusted for the effects of air quality. The January 2014 Victorian heatwave may have affected vulnerable people in the Latrobe Valley who later died during the period of the coalmine fire. However, the small number of deaths in the affected postcodes restricts the analysis to temperatures on the date of death; it is not possible to analyse each death in association with temperatures on the day, week or month before that death.

We note that there is moderate statistical evidence for the association of colder temperatures with February-June mortality for all ages, and for the vulnerable age group 65 years and older. This may explain the 57% excess mortality due to *respiratory* causes in 2011 compared to 2014 in the vulnerable elderly. Statistical evidence of the association of colder temperatures and air quality ≥ 50μg/m^3 PM_{10} with mortality could not be demonstrated with these data; however, this lack of evidence does not rule out the possibility of such an effect.

There is moderate statistical evidence that *cardiovascular* mortality was higher during the period of the 2014 fire compared to the 2009 fire. This finding must be interpreted with caution due to the small number of deaths in these categories. There are not sufficient data to associate these excess deaths with specific extremes in air quality or temperature. However, the proposed prospective study that will track Latrobe Valley residents who were exposed during the Hazelwood fire may contribute useful information about the association of exposure to brown coal particulate matter with cardiovascular health.

Conclusion

Our results are based on an ecological epidemiological analysis that compares data for regions across years. It is therefore limited with respect to individual circumstances, and is one of the weakest methods for assigning cause of deaths. While deaths may have been higher in 2014 than some previous years, we are not able to attribute these deaths to the fire, as there was insufficient number of deaths and lack of personal level data and circumstances of deaths. This means that we are not able to rule in or rule out evidence for excess regional deaths because of the coal fire

The analysis of these data shows that 2014 mortality rates did not differ from comparable rates for the same months in 2009, a season similar to 2014 with respect to high temperatures and high particulate matter from bushfire smoke. However, the statistical uncertainty in these estimates, expressed by broad confidence intervals for each of the rate ratios for the years 2009–2013, shows the lack of statistical evidence for an overall higher rate of mortality in 2014.

Mortality in all age groups was 2.13 times higher on days with air quality over 50µg/ m^3 for PM_{10}, compared to days with lower levels for the period February-March, 2009–2014 ($p<0.01$). The mortality in the vulnerable age group 65 years and older was 2.0 times higher on days with air quality over 50µg/ m^3 for PM_{10} compared to days with lower levels for the same period ($p<0.01$). As mortality was associated with air quality over 50µg/ m^3 for PM_{10}, and the fire may have contributed to this measure of air quality, it is possible that a proportion of deaths in 2014 could have been due to the fire in February-March, 2014. However, as we do not know the source of the particulate matter nor the individual circumstances of deaths on days with air quality over 50µg/m^3 for PM_{10} we cannot offer specific conclusions on this matter.