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Supporting Information

Detailed methodology and supplementary results

This appendix was part of the submitted manuscript and has been peer reviewed.
It is posted as supplied by the authors.

Appendix to: Borchers Arriagada N, Palmer AJ, Bowman DMJS, et al. Unprecedented smoke-related health burden associated with the 2019–20 bushfires in eastern Australia. *Med J Aust* 2020; doi: 10.5694/mja2.50545.

Unprecedented smoke-related health burden associated with the extreme 2019-20 bushfires in eastern Australia

To estimate health impacts, we used a standard approach (1,2), represented by the following figure:

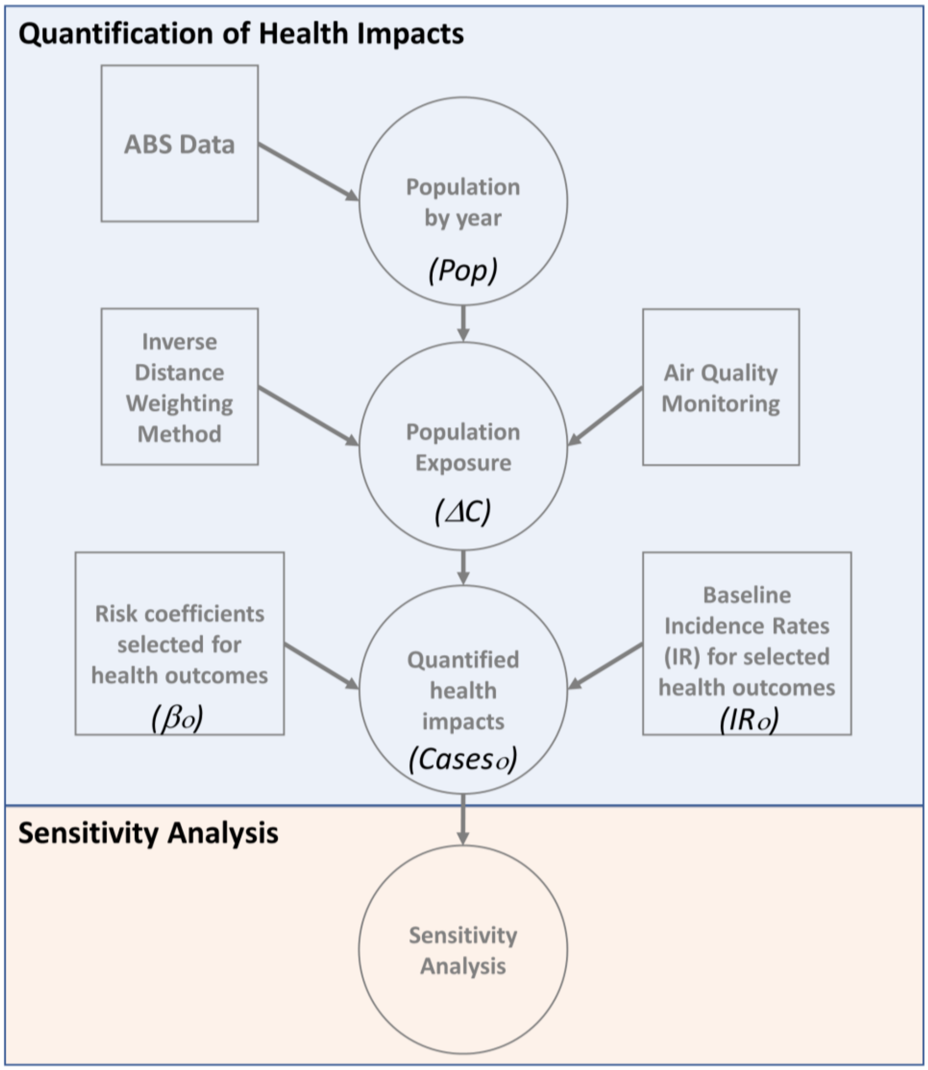

Figure 1 Approach used to estimate health impacts and costs. Adapted from (3)

The following sections detail specific methods used, show estimated population-weighted exposure by State, present a sensitivity analysis on the methods used to identify bushfire smoke affected days, and highlight the main assumptions and limitations for this analysis.

1. Estimation of health impacts

We considered the following four outcomes:

1. Premature Mortality
2. Cardiovascular (CVD) hospitalisations
3. Respiratory (RSP) hospitalisations
4. Asthma Emergency Department (ED) presentations

We estimated the number of attributable cases (deaths, hospitalisations and ED visits) using the following equation (2,4), which considers the use of health risk coefficients obtained from different epidemiological studies (5,6):

$$Cases_O = IR_O \times Pop \times \left(e^{\beta_O \times \Delta C} - 1\right)$$

Where

- $Cases_O$: number of estimated cases for outcomes 'o'
- IR_O: base incidence rate for outcome 'o'
- Pop: estimated exposed population
- β_O: health outcome risk coefficient for outcome 'o'
- ΔC: change in $PM_{2.5}$ concentration

For all three states, we estimated all-cause mortality IR using state-wide death counts obtained from the Australian Bureau of Statistics (7). Circulatory and respiratory hospitalisation incidence rates were obtained from the online tables for Measure 1.04: Respiratory disease and Measure 1.05: Circulatory disease from the Aboriginal and Torres Strait islander Health Performance Framework (8). For Queensland, ACT and Victoria, Asthma ED visit counts were obtained from the Emergency Department Care reports for 2014-15, 2015-16 and 2016-17 (9–11). For New South Wales, we used statistics on emergency department presentations for asthma like illness from HealthStats NSW (12). Population was obtained from the Australian Bureau of Statistics (13).

Table 1 Base incidence rates by state and age group for mortality and hospitalisations (cases/100,000 persons-year)

	New South Wales	Queensland	Australian Capital Territory	Victoria
All-cause Mortality				
0-4 yrs	57.0	74.3	119.3	49.4
5-9 yrs	6.1	5.9	21.6	4.9
10-14 yrs	8.6	7.0	62.6	6.1
15-19 yrs	25.4	32.3	76.9	16.4
20-24 yrs	33.8	43.9	37.3	22.1
25-29 yrs	34.6	45.8	37.4	28.2
30-34 yrs	43.7	67.3	56.4	36.7
35-39 yrs	67.8	90.6	78.5	63.4
40-44 yrs	97.9	118.0	114.9	82.7
45-49 yrs	144.1	165.3	109.6	131.6
50-54 yrs	231.6	250.8	225.8	194.5
55-59 yrs	376.3	383.9	288.8	300.9
60-64 yrs	545.6	580.0	595.3	493.7
65-69 yrs	836.9	857.4	644.5	760.8
70-74 yrs	1,356.0	1,434.8	1,093.8	1,255.3
75-79 yrs	2,381.4	2,421.7	2,425.4	2,190.7
80-84 yrs	4,338.4	4,622.6	4,444.8	4,073.6
85+ yrs	11,473.7	11,795.3	12,617.6	11,327.4
CVD hospital admissions				
0-4 yrs	88.6	105.7	107.5	75.5
5-9 yrs	106.0	147.4	90.4	99.9
10-14 yrs	106.0	147.4	90.3	99.9
15-19 yrs	159.1	189.1	138.5	174.7
20-24 yrs	159.0	189.0	138.1	174.6
25-29 yrs	249.1	305.0	221.1	262.0
30-34 yrs	248.8	304.7	221.3	262.0
35-39 yrs	614.7	730.7	566.9	623.4
40-44 yrs	614.5	730.5	567.7	623.4
45-49 yrs	1,418.5	1,651.0	1,281.3	1,379.9
50-54 yrs	1,418.6	1,651.4	1,279.1	1,380.7
55-59 yrs	3,000.3	3,306.8	2,631.0	2,937.9
60-64 yrs	2,990.6	3,304.2	2,616.3	2,927.7
65-69 yrs	9,064.3	9,595.5	8,602.4	8,921.9
70-74 yrs	9,073.3	9,607.3	8,609.2	8,926.6
75-79 yrs	9,015.8	9,569.6	8,559.4	8,888.7
80-84 yrs	8,921.1	9,497.7	8,491.1	8,801.3
85+ yrs	8,684.3	9,259.3	8,251.2	8,595.2
RSP hospital admissions				
0-4 yrs	5,314.3	5,752.9	3,566.9	4,151.0
5-9 yrs	1,356.5	1,323.9	989.5	1,146.4
10-14 yrs	1,356.8	1,324.3	989.3	1,146.5
15-19 yrs	909.0	968.6	927.6	1,003.5
20-24 yrs	909.9	971.9	934.1	1,002.0
25-29 yrs	677.6	727.2	618.2	705.9
30-34 yrs	678.3	728.1	618.6	707.0
35-39 yrs	722.9	846.6	720.8	795.9
40-44 yrs	722.9	846.7	720.7	795.9
45-49 yrs	889.5	1,040.0	690.0	911.8
50-54 yrs	889.4	1,040.0	689.9	911.7
55-59 yrs	1,446.8	1,707.8	1,219.6	1,448.1
60-64 yrs	1,446.8	1,708.0	1,217.9	1,447.8
65-69 yrs	4,607.7	4,738.6	4,236.7	4,546.8
70-74 yrs	4,610.3	4,742.3	4,238.5	4,548.7
75-79 yrs	4,593.7	4,730.3	4,225.0	4,533.2
80-84 yrs	4,566.4	4,707.6	4,206.5	4,497.6
85+ yrs	4,498.1	4,632.0	4,141.5	4,413.8

Table 2 Base incidence rates by state for asthma ED visits (cases/100,000 persons-year)

State	ED visits – Asthma
New South Wales	341.5
Queensland	248.2
Australian Capital Territory	249.6
Victoria	332.2

We used the following short-term exposure-response functions:

Table 3 Selected exposure-response functions

Effect	Cause	Age Group	Exposure	Beta (*)	Standard Error	RR per 10 ($\mu g/m^3$)	Reference
Premature Mortality	All-cause	All	24h $PM_{2.5}$	0.001222	0.000393	1.0123 (1.0045-1.0201)	(5)
Hospital Admissions	Cardiovascular	All	24h $PM_{2.5}$	0.000906	0.000377	1.0091 (1.0017 – 1.0166)	(5)
	Respiratory	All	24h $PM_{2.5}$	0.001882	0.001051	1.019 (0.9982 – 1.0402)	(5)
ED visits	Asthma	All	24h $PM_{2.5}$	0.00639	0.001344	1.066 (1.038 – 1.094)	(6)

(*) Beta estimated using the following equation: $\beta = {\ln(RR)}/{\Delta C} = {\ln(RR)}/{10}$

Exposure was estimated at a statistical level 2 (SA2) administrative division, using an inverse distance weighting method (14). An SA2 has an average population of 10,000, but can range between 3,000 and 25,000. We estimated daily $PM_{2.5}$ averages for each SA2, using station-level data, whenever at least 1 monitoring station was within a 100 km range from the SA2 centroid. This method captures 90% of the population with almost 80% of the included population being within 20 kms of an air quality monitoring station (Figure 2).

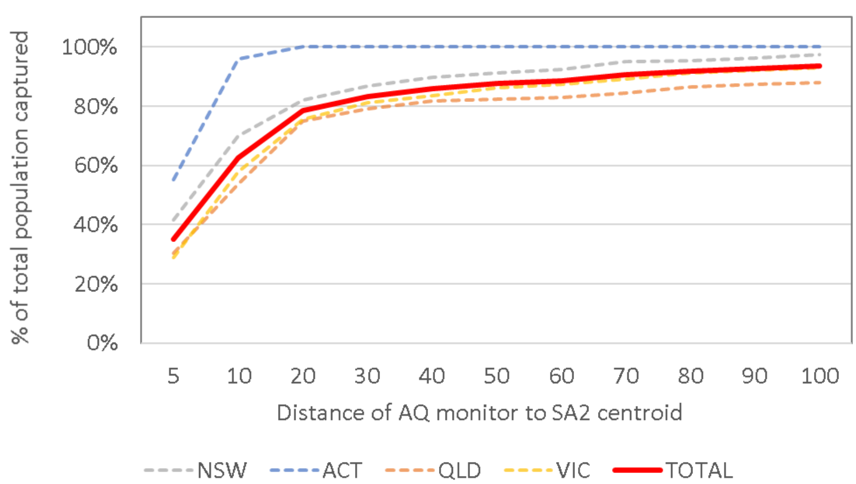

Figure 2 Percentage (%) of exposed population captured with respect to distance from an air quality monitoring stations for NSW, QLD, ACT and VIC

PM_{10} and $PM_{2.5}$ hourly averages at station level were obtained from the Department of Planning, Industry and Environment (NSW Government) air quality website (15), Live Air Quality Data from the Queensland Government website (16), from the Air Quality Monitoring Data from the ACT Government Open Data Portal data ACT (17), and from EPA AirWatch from the Environmental Protection Agency Victoria (18).

We estimated daily PM (PM_{10} and $PM_{2.5}$) averages using hourly data. Whenever $PM_{2.5}$ averages were not available for a specific station, we estimated $PM_{2.5}$ ($PM_{2.5} = PM_{10} \times PM2.5/PM10_{ratio}$), and prioritised the use of the $PM2.5/PM10_{ratio}$ using the following order:

1) $PM2.5/PM10_{ratio}$ for each station and month
2) $PM2.5/PM10_{ratio}$ for each urban area and month.
3) $PM2.5/PM10_{ratio}$ for each month

We defined a fire-smoke affected day as being a day in which the $PM_{2.5}$ was above the 95th percentile of historical values for a given station-month in a location during the study period. We did a sensitivity analysis using days above 90th or 99th percentile of historical values, and considering all days within the study period.

The excess $PM_{2.5}$ (ΔC) was estimated as the difference between the daily $PM_{2.5}$ for a particular SA2 and the long term historical average $PM_{2.5}$ for that SA2-month combination. To estimate historical average $PM_{2.5}$ for each SA2-month combination, we did not exclude the 2019/2020 or previous fire seasons.

2. Daily population-weighted exposure to $PM_{2.5}$

Since October 1st 2019, the population-weighted 24-h $PM_{2.5}$ was of 23.7 $\mu g/m^3$ on average for the 4 states, with 18.9 $\mu g/m^3$ for QLD, 21.5 $\mu g/m^3$ for NSW, 113.1 $\mu g/m^3$ for ACT, and 26.9 $\mu g/m^3$ for VIC. The maximum population-weighted 24-h $PM_{2.5}$ was experienced on the 14th January 2020 with 98.5 $\mu g/m^3$. This situation varied by state with maximum values of 87.2 $\mu g/m^3$ on the 11th November 2019 in QLD, 80.9 $\mu g/m^3$ on the 10th December 2019 in NSW, 920.1 $\mu g/m^3$ on the 1st January 2020 in ACT, and 270.6 $\mu g/m^3$ on the 14th January 2020 in VIC.

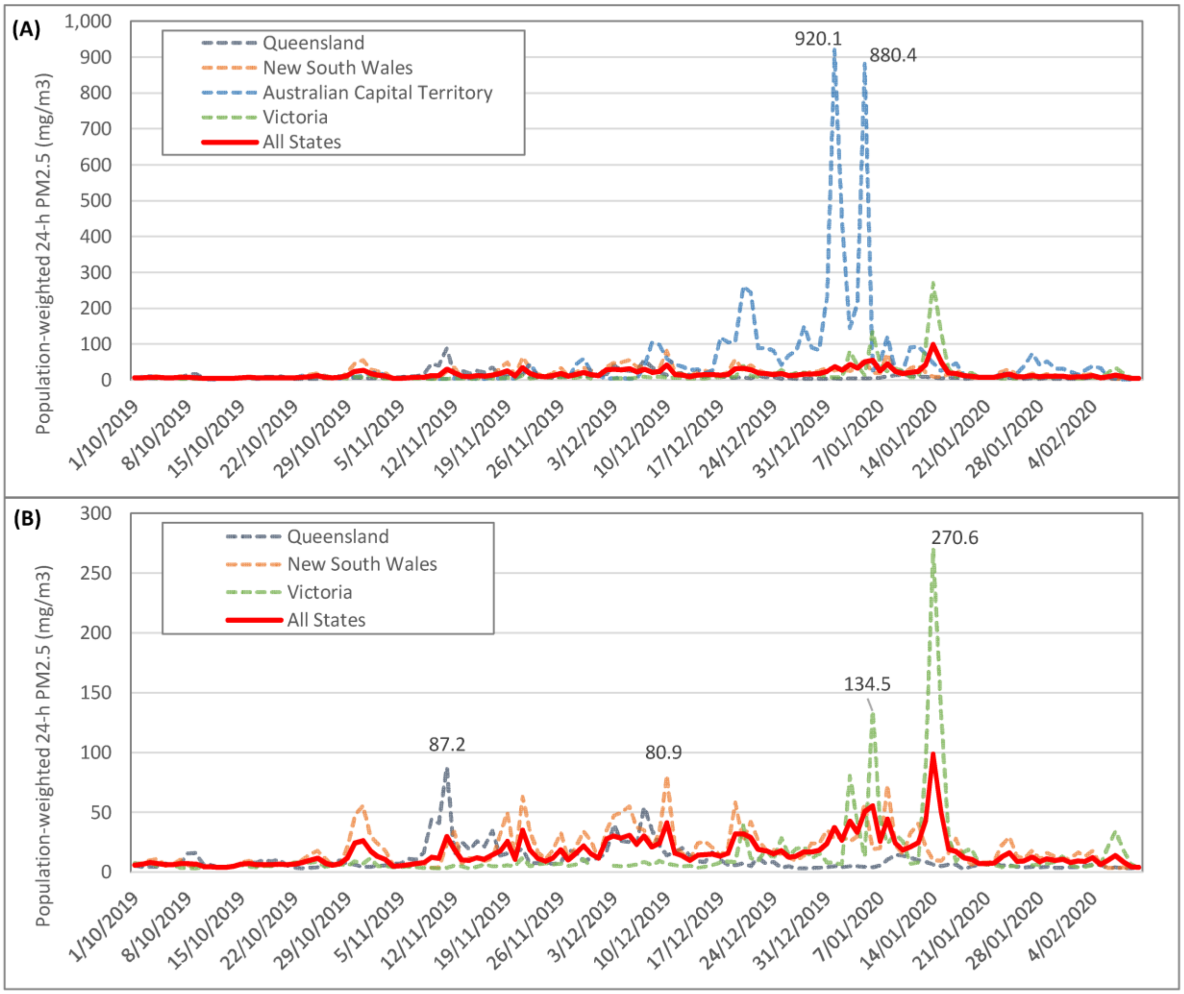

Figure 3 Population-weighted $PM_{2.5}$ by: (A) State and all States, (B) State (excluding ACT) and all States, highlighting the maximum population-weighted $PM_{2.5}$ for each State.

3. Sensitivity Analysis

We calculated the sensitivity of our results to the threshold used for defining bushfire smoke affected days:

1) No threshold, includes all days since October 1, 2019
2) Daily $PM_{2.5}$ above 90^{th} percentile of historical values
3) Daily $PM_{2.5}$ above 95^{th} percentile of historical values (**principal analysis**)
4) Daily $PM_{2.5}$ above 99^{th} percentile of historical values

The estimated total health burden varies between 346 (95% CI, 127 – 564) premature deaths, 2,609 (95% CI, 175 – 5,215) cardiorespiratory hospital admissions, and 1,092 (95% CI, 589 – 1,596) ED attendances for asthma only considering those days where $PM_{2.5}$ was above the 99^{th} percentile of historical values (90 out of 133 days) to 429 (95% CI, 158 – 699), 3,240 (95% CI, 217 – 6,477) cardiorespiratory hospital admissions, and 1,340 (95% CI, 723 – 1,959) ED attendances for asthma (Table 6). Results were not very sensitive to varying the threshold used to define a bushfire smoke affected day, except for only including those days which were above the 99^{th} percentile of historical daily $PM_{2.5}$ averages.

Table 4 Sensitivity analysis for estimated # of cases (premature deaths/hospitalisations/asthma ED attendances) by fire identification threshold

Outcome	No threshold (all days included) N (95% CI)	P90 N (95% CI)	P95 (*) N (95% CI)	P99 N (95% CI)
All-cause Mortality	429 (95% CI, 158 - 699)	427 (95% CI, 157 - 695)	417 (95% CI, 153 - 680)	346 (95% CI, 127 - 564)
Cardiovascular hospital admissions	1,156 (95% CI, 217 - 2,105)	1149 (95% CI, 215 - 2093)	1124 (95% CI, 211 - 2047)	931 (95% CI, 175 - 1695)
Respiratory hospital admissions	2,084 (95% CI, 0 - 4,372)	2072 (95% CI, 0 - 4346)	2027 (95% CI, 0 - 4252)	1678 (95% CI, 0 - 3520)
Emergency Department attendances for asthma	1,340 (95% CI, 723 - 1,959)	1333 (95% CI, 719 - 1948)	1305 (95% CI, 705 - 1908)	1092 (95% CI, 589 - 1596)

(*) principal analysis

4. Main assumptions and limitations

As with all such analyses, our rapid health impact assessment contains multiple assumptions and limitations with respect to exposure estimation and health quantification.

4.1. Exposure estimation

Spatial interpolation of data from air monitoring stations to estimate $PM_{2.5}$ is less sophisticated than other methods, such as blended estimates which combine data such as air pollution from monitored and modelled data (19). Although the smoke emissions are geographically widespread, there is likely considerable spatial variation that cannot be captured with this approach.

The use of the 95^{th} percentile as the threshold to classify a bushfire smoke affected day during the fire period is conservative, as it is likely that most (if not all) days were affected by some level of fire smoke. In a previous detailed study of days in which air pollution exceeded the historical 95th percentile in New South Wales, more than 95% of these days were conclusively verified as being attributable to landscape fire smoke from bushfires or planned burns (20).

4.2. Exposure response coefficients

We used standard WHO coefficients for exposure response outcomes associated with $PM_{2.5}$. There is not strong evidence that health impacts of $PM_{2.5}$ associated with fire smoke are different from PM from other sources (21) except for respiratory impacts including asthma for which fire-smoke specific coefficients have been developed (6). For mortality, we used a short-term coefficient (24h $PM_{2.5}$ exposure) as opposed to long-term coefficients (annual $PM_{2.5}$ exposure) which are around five times larger (5). Where bushfire smoke impacts are severe enough to measurably increased annual PM2.5 such as in the USA (22) and in the case that these types of bushfire events became the new norm, the use of long-term coefficients could be justified. Our use of a risk coefficient for short term fluctuations in daily mortality was a more conservative approach.

7. Conclusions

While acknowledging the limitations of this analysis, we believe that timely communication is important. Our results clearly demonstrate that fire smoke health impacts in the Spring and summer of 2019-20 was severe. Further epidemiological analysis using sophisticated exposure estimation and empirical health data will provide more detailed and precise information about the human toll from smoke during this episode. As the trajectory of landscape fire and impacts and the associated pollution in association with climate change appears to be escalating, this further highlights the need for urgent action to mitigate climate change and for Australian society to adapt to living with repeated exposure to severe heat, fires and air pollution.

5. References

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