The Journal of Climate Change and Health 6 (2022) 100113

Contents lists available at ScienceDirect

The Journal of Climate Change and Health

journal homepage: www.elsevier.com/joclim

Research article

Impact of fine particulate matter (PM2.5) smoke during the 2019 / 2020 Australian bushfire disaster on emergency department patient presentations

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ARTICLE INFO

Article History:
Received 17 September 2021
Accepted 6 January 2022
Available online 13 January 2022

Keywords:
Wildfires
Bushfires
Smoke
Emergency department
Respiratory

ABSTRACT

Aim: The aim of this paper was to describe the patient characteristics and outcomes from a metropolitan emergency department (ED) during the 2019/2020 'Black Summer Bushfires' disaster in Australia and compare the patient characteristics and outcomes to a matched period from the same ED one year earlier.

Background: Years of drought, low relative humidity, high temperatures, and high forest fuel loads led to catastrophic fire conditions across Australia during 2019 and 2020. As a result; 33 people died, 3 billion animals and 24 to 40 million hectares were lost, and 3,000 homes were destroyed. The impact of wildfire smoke is emerging in the literature regarding an exacerbation of respiratory, cardiac and cardiovascular disease. However, the impact on Australian EDs is minimally reported in the literature.

Method: This retrospective cross-sectional cohort study used routinely collected data from the ED patient information system from one metropolitan Australian ED. Data were obtained for patient presentations during the 2019/2020 Black Summer Bushfire period and a matched period, 2018/2019, one year earlier. Daily mean air quality indicators ($PM_{2.5}$, PM_{10}) were obtained from the nearest air quality monitoring station. Data analysis included descriptive statistics, correlation coefficient and inferential statistics. Statistical significance was set at $p \leq 0.05$.

Results: The 2019/2020 study period had a statistically significantly higher airborne particulate matter ($PM_{2.5}$) when compared to the matched period (p=<0.001), with comparable presentations between the study periods. However, an increase in respiratory related presentations ($p<0.001$; $\chi^2 = 34.31$) was noted in the 2019/2020 period, with a positive correlation between daily increasing mean air quality ($PM_{2.5}$, PM_{10}) and increasing patient presentations with respiratory related illness ($p<0.001$). Proportionately, patient demographics; mode of arrival, triage category, length of stay and admissions did not differ between periods. However, there was an increase in the raw number of patients being admitted to hospital with respiratory related illnesses, with a statistically significantly longer stay in the ED when compared to those discharged home ($p<0.001$).

Conclusions: Wildfires produce smoke and subsequently poor air quality. The 2019/2020 Black Summer wildfire disaster in Australia resulted in an increase in respiratory-related patient presentations to the ED. Targeted public warning systems could be implemented in an attempt to limit an individual's exposure to wildfire smoke. Further, health services should monitor air quality as a predictor of patient presentations and subsequent health service demand, in support of ED preparedness.

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https://doi.org/10.1016/j.joclim.2022.100113

Introduction

The impact from wildfires globally is becoming recognized as a threat to human health [1]. Across Australia, the combination of years of drought, prolonged periods of low relative humidity, high temperatures, and high forest fuel loads led to catastrophic fire conditions during 2019 and 2020 [2]. Given the catastrophic fire conditions of the 2019/2020 bushfires, a Royal Commission into the National Natural Disaster Arrangements was established. An interim report from this Commission identified that as a direct result of the 2019/2020 fires, 33 people died; however, many more may have succumbed to the effects of associated wildfire smoke. Additionally, over 3 billion animals died, with the fire destruction of between 24 and 40 million hectares of bushland [3]. Much of the attention regarding the 2019/2020 wildfire season was focused on the south-eastern region of Australia from December 2019 to January 2020, with these fires resulting in the loss of over 3,000 homes and numerous communities being evacuated [3]. During the wildfire season of 2019/2020, the Copernicus Atmosphere Monitoring Service estimated over 400 megatonnes of carbon dioxide were emitted [4]. Smoke was seen on satellite imagery travelling over 2,000 kilometers to New Zealand, with a smoke haze being reported in Argentina and Chile over 10,000 kilometers away [5]. Canberra, the Capital of Australia, is an inland city with a population of 400,000 people nested on the mountainous Great Dividing Range (Eastern seaboard), approximately 600 meters above sea level. For extended periods during the 2019/2020 wildfires, Canberra was blanketed in smoke, reportedly having the worst air quality in the world [6].

The measurement of particulate matter (PM) is now common practice at many air quality measuring stations. Particulate matter measurements are classified based on the size of airborne particles [7], including $PM_{2.5}$ and PM_{10}. A measurement of $PM_{2.5}$ identifies fine particle measurements with an aerodynamic diameter of $2.5\mu m$ or less, whereas a measurement of PM_{10} identifies course particles measuring an aerodynamic diameter of $10\mu m$ or less. Both $PM_{2.5}$ and PM_{10} can enter the lungs, and $PM_{2.5}$ can enter the bloodstream [8]. The World Health Organization recommends that safe daily mean $PM_{2.5}$ target measures should be less than $15\mu g/m^3$ and an annual mean should be less than $5\mu g/m^3$. For PM_{10}, the daily mean should be less than $45\mu g/m^3$ and an annual mean should be less than $15\mu g/m^3$ [9]. It is well established that bushfire smoke contains PM_{10} and $PM_{2.5}$, with ill health effects of wildfire smoke increasingly being reported. Such ill health effects during the 2019/2020 Australian wildfires included estimates of 417 (95% CI, 153−680) excess deaths, 1,124 (95% CI, 211−2,047) hospitalizations for cardiovascular problems and 2,027 (95% CI, 0−4,252) for respiratory problems [10].

The existing literature regarding patient presentations to emergency departments (ED) secondary to wildfires identifies that patient presentation characteristics vary; however, there is a growing body of literature to suggest that wildfire smoke results in an increase in the proportion of patients who present to EDs with respiratory [11,12], cerebrovascular [13] and/or cardiovascular [14] related primary complaints. Most of the existing studies are from regions prone to wildfires in the United States of America and Australia. In particular, the literature suggests a positive correlation found between smoke density and ED presentation numbers in Northern and Central California in the summer of 2015 [15]. Further, a wildfire in Southern California resulted in patient presentations to EDs increasing by an average of 3.2 patients per day with dyspnea, and 2.6 patients per day with asthma during the fire period [16]. One Australian study of the 2019/2020 wildfires estimated presentations to EDs with asthma, predicting 1,305 (95% CI, 705−1,908) presentations as a result of the wildfire smoke [17,18].

Aim

The aim of this paper was to describe the patient characteristics and outcomes from one metropolitan ED during the 2019/2020 ‘Black Summer Bushfires’ disaster in one Australian city and compare the patient characteristics and outcomes to a matched period from the same ED one year earlier.

Methods

Design

This research used a retrospective cross-sectional cohort study design using routinely collected ED data.

Setting

This study was set in a metropolitan Australian ED, Calvary Public Hospital Bruce, one of two major hospitals of an inland city, Canberra, with a primary catchment of approximately 400,000 people. The hospital has approximately 250 beds, with approximately 53,000 ED patient presentations per year.

Population and sample

The population included all patients presenting to the ED during the 2019/2020 Black Summer Bushfire period 01 December 2019 – 31 January 2020, inclusive, and the matched period one year earlier, that being, 01 December 2018 – 31 January 2019, inclusive. All patient presentations during the study periods were included.

Data collection

Data were obtained from the hospital ED patient information system. Data included the total daily patient presentations and daily presentations by final diagnosis. Additionally, individual patient presentation information was obtained including gender, age, mode of arrival, date and time of presentation, assigned Australasian Triage Scale (ATS) category, time and date of discharge and discharge destination. Daily mean air quality indicators ($PM_{2.5}$, PM_{10}) were obtained from the Canberra City air quality monitoring station for the study periods. This monitoring station is located centrally in the city, being only 5 kilometers from the study ED.

Data analysis

Descriptive statistics (median, interquartile range, frequency, percentage) were used to summarise daily mean air quality and patient demographics. Inferential statistics included Pearson's Correlation Coefficient, Kruskal Wallis, and Chi Square (χ^2) tests. Pearson's Correlation Coefficient was used to determine the correlation between the continuous variables of total presentations per day, total daily presentations by final diagnosis, and daily mean air quality. Pearson's Correlation Coefficient was used with same day and lagged days of one [lag+1], two [lag+2], and three [lag+3] days to determine if patient presentations were delayed when compared to $PM_{2.5}$ and PM_{10} smoke days. The Pearson Correlation Coefficient was determined to be of a high degree of correlation if the coefficient value lies between $\pm$ 0.50 and $\pm$ 1. Kruskal Wallis was used to compare median length of stay in the ED between the two study periods. Chi Square test was used to compare categorical variables between the two study periods, including ‘mode of arrival’, ‘Australasian Triage Scale category’, ‘ICD-10 groupings’, and ‘discharge disposition’. For Chi Square tested categorical variables that are statistically significant, an Odds Ratio with 95% confidence intervals was performed to understand the magnitude of association between the study periods. For the outcome characteristic of disposition, patients who were 'transferred to another hospital', 'admitted to the hospital' or 'admitted to the short stay or clinical decision unit', were considered to be 'admitted'. Those patients who 'did not wait to commence treatment', or 'left prior to the completion of treatment' were considered as 'did not wait'. Those who had their treatment commenced and completed in the ED, and were not admitted for further care were considered as 'discharged'. Statistical significance was set at $p \leq 0.05$. Analysis was undertaken using StataMP 16 (StataCorp LLC, Texas, USA).

Protection of human participants

This research received ethical approval from the Calvary Public Hospital Bruce Human Research Ethics Committee (reference: 11-2020). Data wereobtained from the health service in a de-identified manner and stored on health service secured information technology systems.

Results

Air quality

In the study period 2018/2019 the daily mean $PM_{2.5}$ air quality reading was $7.41\mu m/m^3$ [IQR: 5.82-10.66], PM_{10} air quality readings were not available for the 2018/2019 study period due to the air quality monitoring station not collecting this variable for this period. In the study period 2019/2020 the daily mean $PM_{2.5}$ air quality reading was $45.80\mu m/m^3$ [IQR: 21.12-86.46], and the daily mean PM_{10} air quality reading was 66.97 [IQR: 38.28-119.34]. The $PM_{2.5}$ air quality between the two study periods was statistically different p=<0.0001 [U=505.5, z=7.08], with the 2019/2020 study period having a statistically significant higher level of airborne particulate matter, suggesting poor air quality. Given that PM_{10} was only reported in one of the study periods, this was unable to be used for comparative analysis between the two study periods.

All presentations

The number of patient presentations were comparable between the study periods with 9,564 in the 2018/2019 study period, and 9,575 in the 2019/2020 study period. The types of presentations by the 10th revision of the International Statistical Classification of Diseases and Related Health Problems [ICD-10] groups are outlined in Table 1. The type of presentation were statistically significantly different in 2019/2020 when compared to 2018/2019, with an increase in respiratory related presentations ($p<0.0001$; $\chi^2 = 34.31$; OR: 1.45 [95% CI: 1.27-1.65]) and a decrease in injury related presentations ($p=0.026$; $\chi^2 = 4.94$; OR: 0.93 [95% CI: 0.87 – 0.99]). Given the statistically significant increase in respiratory related presentations, respiratory related presentations will be the focus of the remainder of analysis.

Respiratory

Air quality

For the period 2019/2020 there was a strong positive correlation between the same-day daily mean air quality readings and the number of patients presenting with respiratory illness to the ED. This was the case for both the $PM_{2.5}$ daily mean air quality reading (r= 0.719 [95% CI: 0.57 - 0.82]; p<0.001), and for the PM_{10} daily mean air quality reading (r= 0.713 [95% CI: 0.57 - 0.82]; p<0.001). This suggests that air quality for either $PM_{2.5}$ or PM_{10} had the strongest correlation to a same-day increase in respiratory related presentations to the ED. The correlation dampened one day post-poor air quality with $PM_{2.5}$ (lag+1 r= 0.396 [95% CI: 0.16 - 0.59]; p=0.002), and PM_{10} (lag+1 r= 0.370 [95% CI: 0.13 - 0.59]; p=0.003) remaining statistically significant. However, at two days post-poor air quality the correlation was weak and the lag effect was not statistically significant for both $PM_{2.5}$ (lag+2 r=0.252 [95% CI: -0.01 – 0.47]; p=0.052), and PM_{10} (lag+2 r=0.241 [95% CI: -0.01 – 0.47]; p=0.064). Similar to day two, at day three post-poor air quality, the correlation was considered weak (lag +3 r=0.278 [95% CI: 0.023 – 0.50]; p=0.033), and PM_{10} (lag+3 r=0.269 [95% CI: 0.014 – 0.491]; p=0.019).

Demographics

The age and gender of patients presenting with respiratory related complaints did not differ between the study periods (see Table 2). However, more females than males presented in both study periods.

Presentation characteristics

The mode of arrival and Australasian Triage Scale (ATS) category for patients with respiratory related presentations did not differ proportionately between the study periods (see Table 3).

Outcomes characteristics

The proportion of patients with respiratory related complaints that were admitted to hospital or discharged home did not differ between the two study periods (see Table 4). However, while the proportion did not change, there was an increase in the raw number of patients being admitted to hospital, with an additional 78 patients admitted in the 2019/2020 study period with respiratory related illnesses. This may be of clinical importance regarding in-patient bed capacity, with an additional mean daily respiratory in-patient bed increase of 1.25 per day.

The length of stay in the ED for patients with respiratory related complaints did not differ between the study periods. This was also the case when comparing the length of stay for those admitted versus

Table 2
Demographics of respiratory related presentations

	2018/19	2019/20	p-value	Statistic
Age, *M (SD)*	39.7 (24.4)	40.6 (24.4)	0.059	*t* = -1.89
Gender			0.072	$\chi^2 = 3.34$
Male, *n (%)*	186 (47.69)	231 (41.70)		
Female, *n (%)*	204 (52.31)	323 (58.30)		

M = Mean; SD = Standard Deviation.

Table 1
Comparison of presentations by ICD-10 groups between study periods

	2018/19	2019/20	χ^2 Statistic	p-value	OR [95% CI]
Respiratory, *n (%)*	390 (4.08)	554 (5.79)	$\chi^2 = 29.77$	<0.0001*	1.45 [1.27-1.65]
Cardiology, *n (%)*	990 (10.35)	1018 (10.63)	$\chi^2 = 0.40$	0.527	1.03 [0.94-1.13]
Abdominal, *n (%)*	1366 (14.28)	1411 (14.74)	$\chi^2 = 0.79$	0.374	1.04 [0.96-1.12]
Injury, *n (%)*	2322 (24.28)	2194 (22.91)	$\chi^2 = 4.94$	0.026*	0.93 [0.87-0.99]
All other, *n (%)*	4496 (47.01)	4398 (45.93)	$\chi^2 = 2.23$	0.135	0.96 [0.90-1.01]
TOTAL	**9564 (100.00)**	**9575 (100.00)**			

* Statistically significant at p = <0.05; CI: Confidence Interval; OR: Odds Ratio; χ^2 Chi Square.

Table 3
Presentation characteristics of respiratory related presentations

	2018/19	2019/20	p-value	Statistic
Mode of arrival				
Ambulance, *n (%)*	111 (28.46)	170 (30.69)	0.507	$\chi^2 = 0.470$
Walked in/public or private transport, *n (%)*	279 (71.54)	384 (69.31)		
Australasian Triage Scale category				
1, *n (%)*	6 (1.54)	13 (2.35)	0.573	$\chi^2 = 2.91$
2, *n (%)*	53 (13.59)	88 (15.88)		
3, *n (%)*	270 (69.23)	369 (66.61)		
4, *n (%)*	58 (14.87)	77 (13.90)		
5, *n (%)*	3 (0.77)	7 (1.26)		

Table 4
Outcome characteristics of respiratory related presentations

	2018/19	2019/20	p-value	Statistic
Discharge disposition				
Discharged, n *(%)*	209 (53.59)	295 (53.25)	0.947	$\chi^2 = 0.92$
Admitted, n *(%)*	181 (46.41)	259 (46.75)		
Length of stay				
All patients mins, *median (IQR)*	189 (117-301)	187 (115-302)	0.653	U = 109898.5 z = -0.45
Admitted patients mins, *median (IQR)*	268 (160-539)	271 (148-550)	0.347	U = 23472.5 z = -0.94
Discharged patients mins, *median (IQR)*	176 (111-262)	177 (112-264)	0.960	U = 30704.5 z = - 0.05

mins = minutes; IQR = Interquartile Range; M = Mean; SD = Standard Deviation.

those discharged between study periods. However, when exploring the median length of stay within study periods, there was statistically significant difference between those admitted and discharged, with those being admitted having a statistically significantly longer stay in the ED in both the 2018/2019 ($p<0.0001$; U=7052.5, z=10.58) and 2019/2020 ($p<0.0001$; U=14207.5, z=12.26) study periods. Given, there is an increased length of stay in the ED for respiratory related patients requiring hospital admission in both study periods, it is unlikely that this increased length of stay is related to the air quality measures.

Discussion

Wildfire smoke and health effects

With wildfires occurring more frequently [19], poignantly it is suggested that wildfire smoke is more harmful to human health when compared to 'normal' air pollutants [13]. Our study showed that the air quality for the 2019/2020 study period was well above the daily acceptable and recognised safe target levels, with a daily mean of $PM_{2.5}$ and PM_{10} of 45.80gm/m^3 and 66.97gm/m^3 respectively. This poor air quality during the 2019/2020 wildfire period resulted in an increase in same-day respiratory-related patient presentations to the ED, statistically significant when compared to the previous year, with a dampening lag effect over the subsequent days. This is a similar finding to those described by other authors that show an increase in patient presentations to EDs as a result of wildfires, particularly relating to respiratory, cardiac and cardiovascular problems [11,12,13,14,20, 21]. Whilst the impact of increased presentations to the EDs is noted, the longer-term effects from wildfire smoke on the health and well-being of a community, both physical and mental, are emerging in the literature [22,23]. These long-term effects may impact multiple cohorts, such as those with chronic conditions and those with extended exposure such as wildfire fire-fighters..

Wildfire smoke warning systems for individuals

Given the strong correlation between poor air quality from wildfire smoke and an increase in respiratory related patient presentations to EDs, robust public warning systems should be implemented in an attempt to limit an individual's exposure to wildfire smoke. Some countries use public wildfire rating systems to communicate the immediate consequences of a wildfire, should a wildfire ignite [24]. The aim of these rating systems is to communicate risk and empower individuals to take appropriate actions to minimise loss of life and property [25]. The Australian rating system uses six-points from 'low-moderate' risk to 'catastrophic' risk. However, long after the immediate threat of fire from a wildfire has passed, smoke may linger for extended periods of potentially months [26]. Public health warning systems relating to anticipated wildfire smoke would provide guidance to the public regarding the risks of poor air quality and strategies to limit exposure to poor air quality. In particular, such warning systems and subsequent communication to the public could target vulnerable populations and those with pre-existing comorbidities exacerbated by wildfire smoke [27,28]. Introducing such warning systems may decrease the likelihood of the ill-effects of wildfire smoke and therefore a decrease in smoke related respiratory presentations to the ED.

Mitigation strategies and wildfire warning systems for health services

Air quality monitoring indicators should be closely observed by health services to predict the impact of wildfire smoke on patient presentations and subsequent health service demand. Over the past decade, there is an increasing volume of research reporting on the impacts of wildfires and wildfire smoke on ED patient presentations [11,12,13,14,20]. This current paper adds to this growing body of literature, adding to other Australian perspectives regarding the impact of wildfire smoke on ED patient presentations [21,29]. Emergency departments should anticipate and be prepared for an influx of respiratory related presentations on the same day as increasing poor air quality related to bushfire smoke. A recent literature review regarding the impact of disasters, such as wildfires, on ED resources suggests that altered standards of care may occur during and/or following disasters due to an increased demand on services, particularly related to the depletion of available human, consumable and physical resources [30]. As such, EDs should ensure adequate supplies such as supplemental oxygen and respiratory related medications are available during wildfire disasters. Further, our research has demonstrated that inpatient wards and EDs both need to prepare for respiratory related presentations, during a period of significant poor air quality, as the raw number of patients requiring hospital admission with respiratory related illness will increase.

Study limitations

This research was conducted at a single site ED; given this, generalizations broader and beyond this ED should be made judiciously. Given the extent of bushfire smoke, traveling for hundreds of kilometers, future research should consider including populations at distant locations, as these populations still have a great potential to experience adverse health effects from wildfire smoke exposure. Additionally, future studies should include other aspects of emergency health care such as Ambulance Service usage. No secondary diagnosis was recorded in the dataset used. This may result in underreporting of some patient diagnoses. Meteorological factors, such as wind and temperature, may influence air quality. Our study was limited to $PM_{2.5}$ and PM_{10} as reported by the air quality monitoring station; unfortunately, this air quality monitoring station does not capture meteorological characteristics relating to temperature or wind.

Conclusion

Extreme weather leading to wildfire-related disasters are occurring more frequently, resulting in poor air quality that is deemed to be more harmful to human health than normal air pollutants. Air quality during the Australian 2019/2020 Black Summer wildfires demonstrated particulate matter well above the recommended safe levels. Subsequently, as demonstrated in this study, wildfire smoke resulted in an increase in respiratory related patient presentations to the ED. Targeted public warning systems should be implemented to provide guidance and practical strategies to individuals in an attempt to limit exposure to wildfire smoke, therefore limiting ED presentations. Health Service monitoring of air quality indicators should occur during wildfire seasons to assist EDs and health services predict and prepare for patient presentations and overall health service demand, in order to minimise wildfire smoke-associated morbidity and mortality.

Contributor roles taxonomy (CRediT) / contributor statement

The following author contribution statement is based on the Contributor Roles Taxonomy (CRediT) found at: https://www.elsevier.com/authors/journal-authors/policies-and-ethics/credit-author-statement

Conceptualization [ML, JR], methodology [ML, JR, RS, AH], formal analysis [JR], investigation [JR, ML], data curation [JR], writing the original draft [JR], reviewing and editing drafts [ML, JR, RS, AH], visualization [JR], supervision [ML, JR], project administration [ML, JR]. All authors have approved the final submitted version of this paper.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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