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# Earth, wind and fire

## Using satellite imagery to map the health effects of landscape fire smoke on Perth metropolitan residents

**Executive Report** July 2021

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**Acknowledgement**

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**Special Note:** This Executive Report should be considered as a high level summary of the full project report.  For the full report please search https://ww2.health.wa.gov.au/ or contact the project lead Dr Jianguo Xiao at the Department of Health Western Australia via email at Jianguo.Xiao@health.wa.gov.au.

**Cover photograph:**
Courtesy of Department of Fire and Emergency Services Incident photographer Morten Boe.

Report overview

# What is the health impact of smoke exposure due to landscape fires?

Landscape fires (LFs) are controlled (prescribed burns) or uncontrolled fires (e.g. wild fires) that occur in forest grass, scrub, bush or grasslands. Landscape fires are an important source of short-term air pollution. Information on the impact of acute exposure to landscape fires on members of the general population is currently limited. Findings from this study have relevance to health policy, partnerships, spatial application and policy.

## Study aim

To expand understanding of:

- appropriate methods to measure population LF smoke exposure
- the impact of landscape fires on the general population, including the identification of vulnerable groups.

## Methods

Satellite image analysis of smoke plumes via earth observation data.

Earth observation data linked to air quality and climate data to model and validate smoke exposure.

Air quality measure $PM_{2.5}$ linked to health utilisation data (i.e.hospital admissions, emergency department attendance and ambulance callouts).

## Vulnerable groups

Older adults (60+ years), children, low socioeconomic areas, people with heart or lung conditions.

## Key findings

LF smoke-related particulate matter ($PM_{2.5}$) was significantly associated with previous day $PM_{2.5}$ levels, venting index, fire radiative power, aerosol optical depth, fire danger rating and smoke plume masks.

A significant association was found between LF smoke-related $PM_{2.5}$ and emergency department attendances and hospital admissions for respiratory and cardiovascular conditions.

Health service utilisation peaked on the same day and 1, 2, or 3 days after exposure to landscape fire smoke.

## Recommendations

Health professionals and policy makers should enhance education programs about the harms associated with landscape fires.

Programs should emphasise medical conditions involved and possible delayed smoke effects.

Regular and real time fire data should be collected to determine population and geographical areas at risk.

Project partners:

Government of Western Australia Department of Health

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# Contents

# Introduction

Landscape fires (LFs) includes wildfires (WFs) and prescribed/planned burns (PBs) and are defined as fires that occur in forest, scrub, or grassland (bushfires). These fires are a significant source of short-term increases in particulate air pollution. Prescibed Burning is the process of planning and applying controlled fires to predetermined areas, under specific environmental conditions to reduce the fuel load available for bushfires. Landscape fires, particularly WFs, are a growing concern globally as they are expected to increase in frequency and intensity due to changes in our climate.  In a preliminary analysis of landscape fires project in Western Australia, there were approximately 8,000 LFs during 2015-2017, including approximately 1,773 (22%) LFs in the Perth metropolitan and Southwest areas. Of these, 377 (21.2%) were PBs and 1396 (78.7%) were WFs (internal unpublished government data).

The effects of LF smoke on air quality and consequently human health depend greatly on factors such as the existing health condition of individuals, length of exposure, concentration and size of air pollutants. The main, but not only, pollutant of concern for LF smoke is particulate matter (PM), particularly fine PM ($PM_{2.5}$). Short-term increases in PM has been associated with a wide range of health effects, including exacerbations of respiratory symptoms, impaired lung function, medication use, physician visits, emergency department attendance (EDA), hospital admissions, paramedic services, cardiovascular effects and premature mortality.

Like background urban air pollution, LF smoke contains a complex mixture of particulate matter, water vapour and gases, many of which are known to be air pollutants or greenhouse gases and can affect the health of human communities. This occurs because bushfire smoke often disperses over long distances (hundreds of kilometres) and might persist for days or even weeks. Severe bushfires can cause widespread economic, social and environmental impacts across spatial and temporal dimensions and can be responsible for periods of extremely poor air quality. Studies of health effects of LFs have used a variety of population exposure methods, most of which are limited. The extensive fires across Australia in the 2019/20 fire season are a clear, recent example of these impacts, with significant health concerns and protective equipment shortages experienced across Western Australia, Australian Capital Territory, Victoria and New South Wales. Therefore, methods to more precisely estimate exposure to the LF effects (rather than only focusing on communities in the immediate vicinity) as well as gaining an understanding of the spatio-temporal variations associated with the LF effects are needed to accurately correlate such events with health outcomes.

This is the first WA study that employs spatio-temporal analysis and earth observation data to explore population smoke exposure and examine the effects of LFs on a large population, covering the whole metropolitan area of Perth.

# Approach

The study area covered the whole Perth metropolitan area, Western Australia and the data used for the study were from July 2015 – December 2017. The statistical, epidemiological and spatial analyses were conducted in four steps as shown below.

**Step 1: Analyse images to identify smoke plume masks and affected areas**

Tracings, visual interpretation and digitisation of hourly smoke plume images were made using imagery from Japanese Meteorological Agency's Himawari 8 satellites. Hourly shape files were then collated to provide daily estimates of the proportion of each of the metropolitan Statistical Area Level 2 (SA2) areas covered and potentially affected by the smoke plumes.

**Step 2: Establish empirical smoke exposure models**

A total number of 3,898 grid cells with a resolution of 1.5km by 1.5km over the Perth metropolitan area were created as the base grids for modelling. This resolution was chosen to be consistent with the resolution for the venting index (VI) and fire danger rating (FDR) data from Bureau of Meteorology. We modeled smoke related $PM_{2.5}$ concentrations in a day for a specific grid cell in the study area that were not covered by the air quality monitoring network. The model inputs included $PM_{2.5}$ in the day for the grid cell, $PM_{2.5}$ in the previous day for the grid cell, remotely sensed fire radiative power (FRP), aerosol optical depth (AOD), smoke plume masks (SPM) established in Step 1, fire danger rating (FDR), and a venting index (VI) that indicated pollutant dispersion potential.

**Step 3: Conduct air quality relationship model fitting/validation assessment**

Grid cells that contained at least one surface $PM_{2.5}$ monitoring station operated by Department of Water and Environmental Regulation during the study period were selected and treated as training cells to allow the creation of a model using the data from these cells. The model was established to estimate $PM_{2.5}$ concentrations based on training cells, and this model was validated using an 80% sample, a 100% sample and leave-one-year-out approaches. This allowed a variety of validations methods to be used in order to select the most suitable model to apply to all grid cells for the whole study area.

**Step 4: Conduct LF smoke related $PM_{2.5}$ and health utilisation relationship assessment**

The median of $PM_{2.5}$ values was calculated from the gridded cells corresponding to a specific SA2. The database with SA2 codes and the predicted smoke related $PM_{2.5}$ was used for health data analysis in the next section. The association between exposure to smoke related $PM_{2.5}$ and selected adverse health outcomes was estimated. The adverse health outcomes included cardiovascular diseases (CVD) and respiratory diseases for hospitalisations, emergency department attendances (EDA), and ambulance callouts (AC). The lag effects of 1 to 3 days (ie, lag 1 to lag 3) were also estimated between exposure to smoke related $PM_{2.5}$ and selected adverse health outcomes including hospitalisations, EDA and AC due to CVD and respiratory diseases, as the smoke impacts might occur on the same day of a LF event, or 1 to 3 days after a LF event.

# Key findings

The key findings of the study are categorised under the following four areas: image analysis to identify smoke plumes and affected areas; an empirical smoke model; assessment of smoke related $PM_{2.5}$ and health utilisation relationship and spatio-temporal variations of the effects of smoke related $PM_{2.5}$ on EDA utilisation.

## 1. Image analysis to identify smoke plumes and affected areas

a. Smoke plume identification and spatial analysis was a useful and effective tool in more precisely identifying the movement of smoke and affected geographical areas, thus, in theory, providing better population exposure estimates.

b. Through this study, a systematic way of identifying, digitalising, and rasterising smoke plumes from satellite images into spatial grid cells was developed. Such a system could be potentially used in other similar studies (Figure 1).

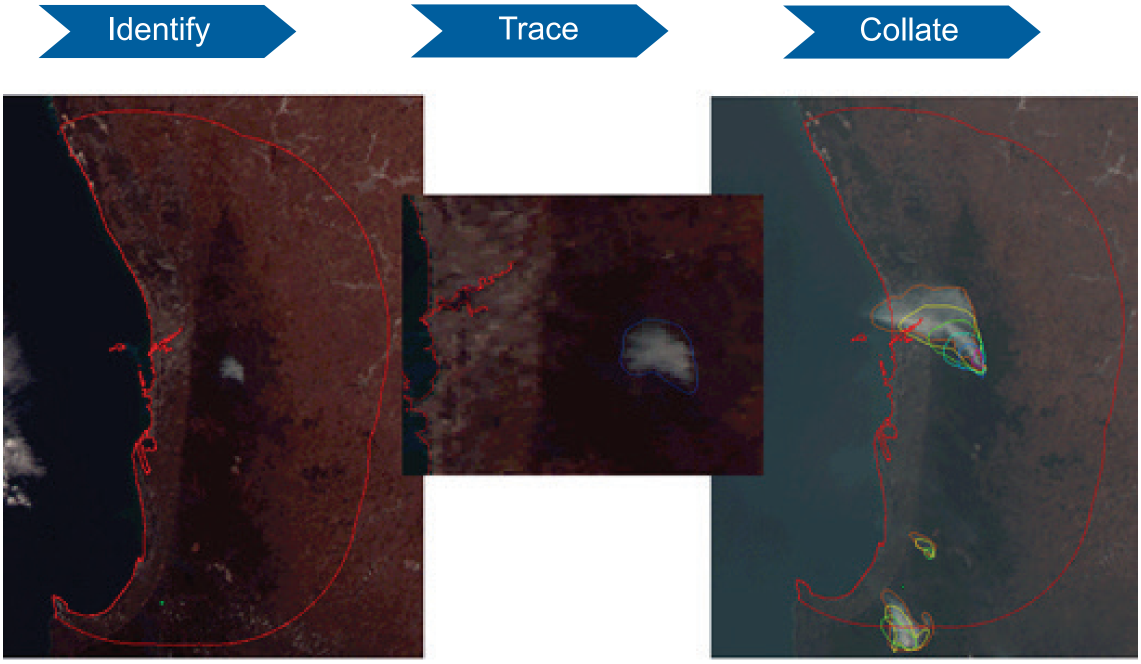



**Figure 1. Smoke plume digitisation**

## 2. An empirical smoke exposure model

a. A systematic methodology was employed in this study to model and validate smoke related $PM_{2.5}$ concentrations in the Perth metropolitan area and model the $PM_{2.5}$ gaps in the existing air quality monitoring network.

b. The LFs smoke related $PM_{2.5}$ for a day was significantly associated with all independent variables in the established model ($P<0.05$). Such variables included observed $PM_{2.5}$ concentrations in previous day ($R2=0.175$), followed by Venting Index ($R2=0.036$), Fire Radiative Power ($R2=0.031$), Aerosol Optical Depth ($R2=0.015$), Fire Danger Rating ($R2=0.006$), and Smoke Plume Masks ($R2=0.002$) (Table 1). The model explained a total of 24% variance in the $PM_{2.5}$ values for a day. The proportion of variance explained was relatively low most likely due to a relatively short study period (i.e., two and half years) and a limited number (i.e., only 4 stations) of air quality stations available in the Perth metropolitan area.

**Table 1. Multiple linear regression results of predictors for smoke related $PM_{2.5}$**

| Predictor | Estimate | SE[a] | T Value | P value | Partial $R^{2b}$ |
|---|---|---|---|---|---|
| $PM_{2.5}$lag1[c] | 0.380 | 0.040 | 7.790 | <0.001 | 0.175 |
| AOD[d] | 4.404 | 0.860 | 5.110 | <0.001 | 0.015 |
| FRP[e] | 1.760 | 0.460 | 3.790 | <0.001 | 0.031 |
| FDR[f] | 0.524 | 0.080 | 6.550 | <0.001 | 0.006 |
| SPM[g] | 0.990 | 0.440 | 2.220 | 0.026 | 0.002 |
| VI[h] | 0.830 | 0.050 | 16.040 | <0.001 | 0.036 |

N=3,660, R squared = 0.245, RMSE= 3.14; a SE=standard error; b Importance calculated as the proportion of variance explained attributable to the variable without adjusting for other factors; c Previous day PM2.5 (mg/m3); d Aerosol Optimal Depth; e Fire Radiative Power in Gigawatts; f Fire Danger Rating; g Smoke Plume Mask (whether smoke plume covered the centroid of a grid cell: 0=not covered and 1=covered); h Venting Index (m2/s). All predictor measures are at grid cell level.

## 3. Assessment of smoke related $PM_{2.5}$ and health utilisation relationship

a. There was a strong link between smoke related $PM_{2.5}$ and health utilisation for a wide range of respiratory and cardiovascular responses related emergency department attendance and hospital admissions.

b. Landscape fire smoke exposure significantly increased both general emergency department visits and general hospital admissions by up to 5% on an annual basis.

c. There was a significant dose-response association in delayed effects of lag 1 and lag 3 with 8% to 19% increased risk for acute lower respiratory tract infections attending emergency departments (Figure 2 below).

d. There was also non-significant 25% increase in ambulance callouts due to respiratory arrest.

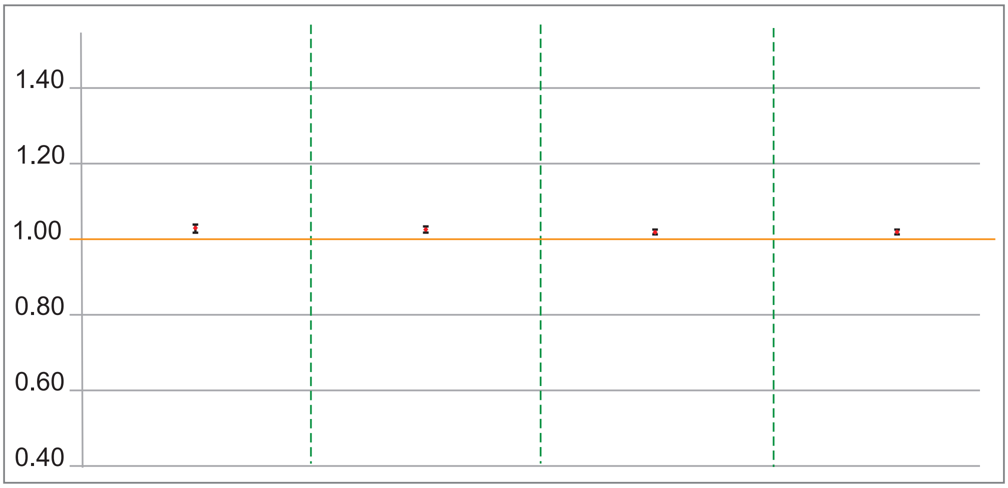
e. There was a strong effect for cardiovascular diagnosis with a 2% to 7% significant increased risk at the high exposure level to smoke related $PM_{2.5}$ in both EDA (Figure 2) and hospital admissions in the general cardiovascular category.

f. There was a significant increased EDA due to diagnosis related to transient ischemic attack with a significant dose-response increased risk up to 25%.

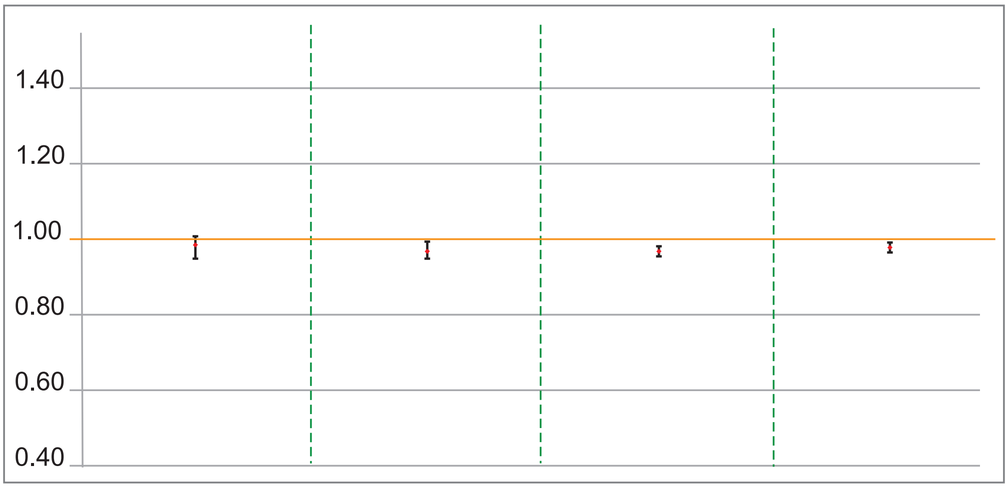
g. Older people aged 60 years and above, people from low socioeconomic areas and those with heart or lung problems were more susceptible community members to LFs smoke.

h. There was a non-significant dose-response effect for the impact of LF smoke-related $PM_{2.5}$ on respiratory effects for asthma with a 3 to 10% non-significant increased risk seeking emergency department and 2% to 18% non-significant increased risk in hospital admissions, and up to 11% non-significant increased risk in ambulance callouts on the same day and in almost all delayed lag effects.

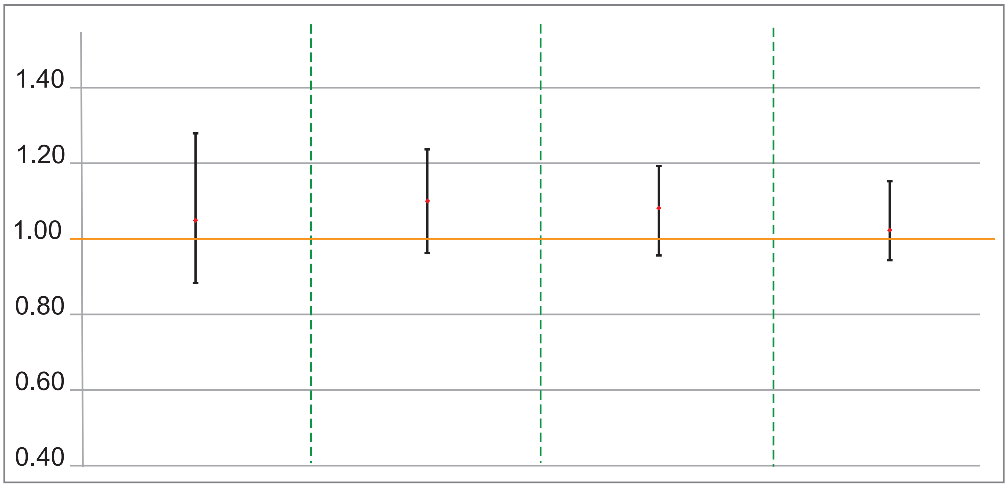
a) Total EDA



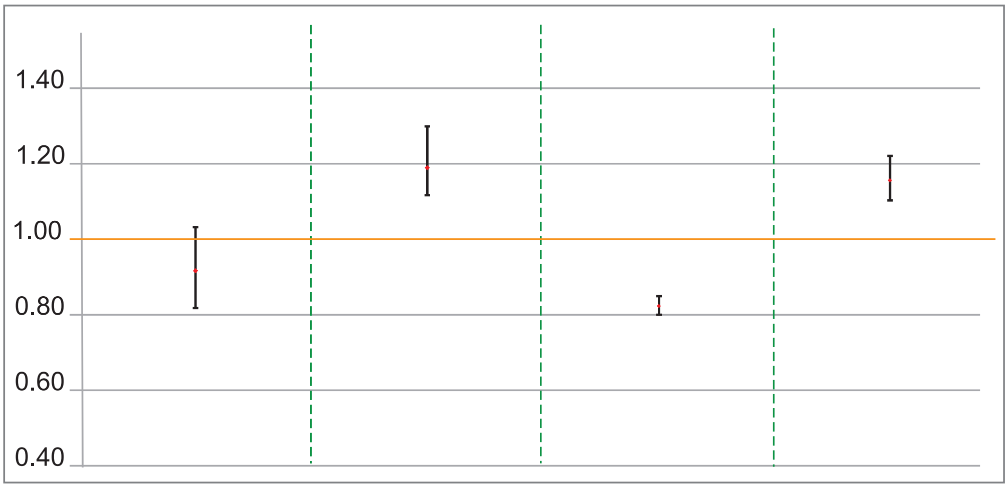

b) All respiratory



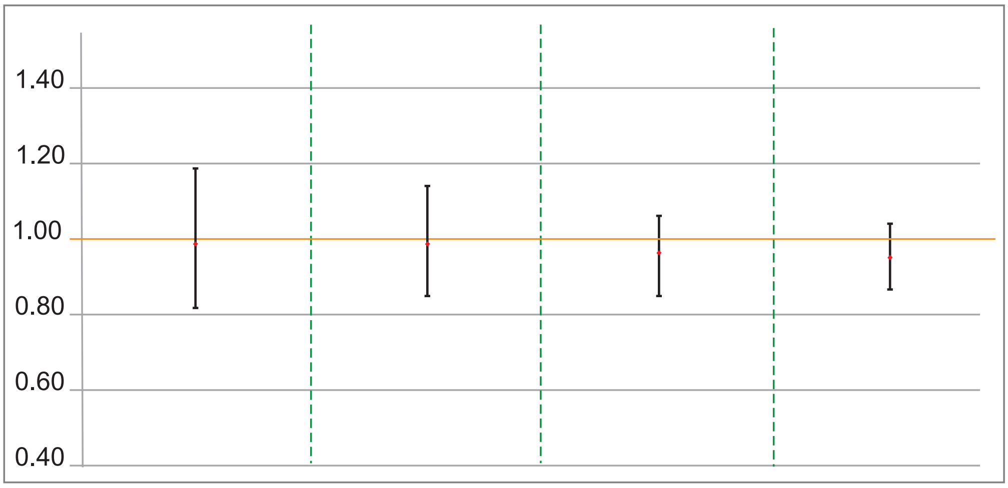

c) Asthma



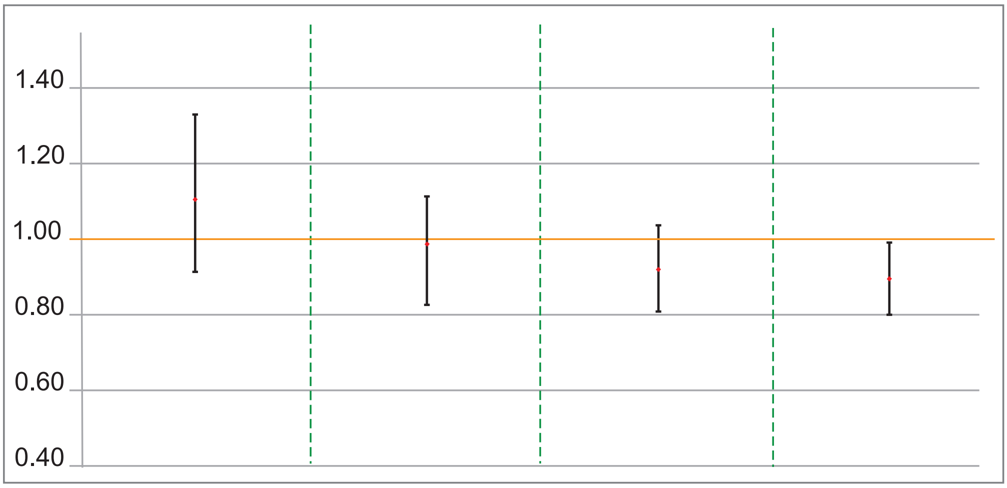
d) ALTRI



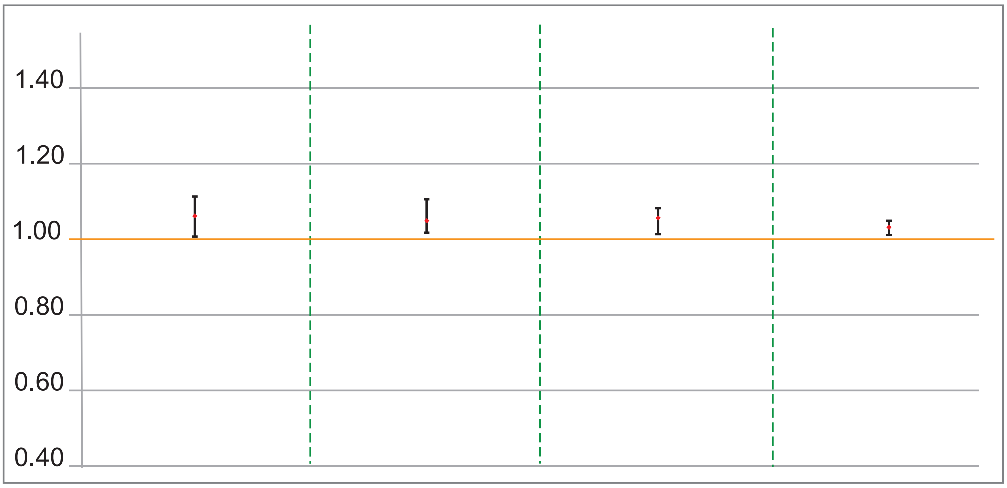

e) COPD



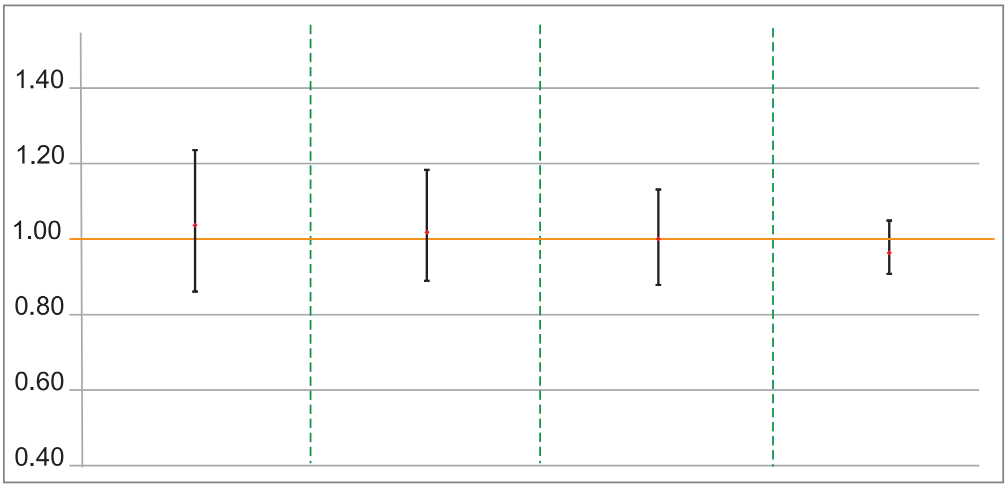

f) Croup



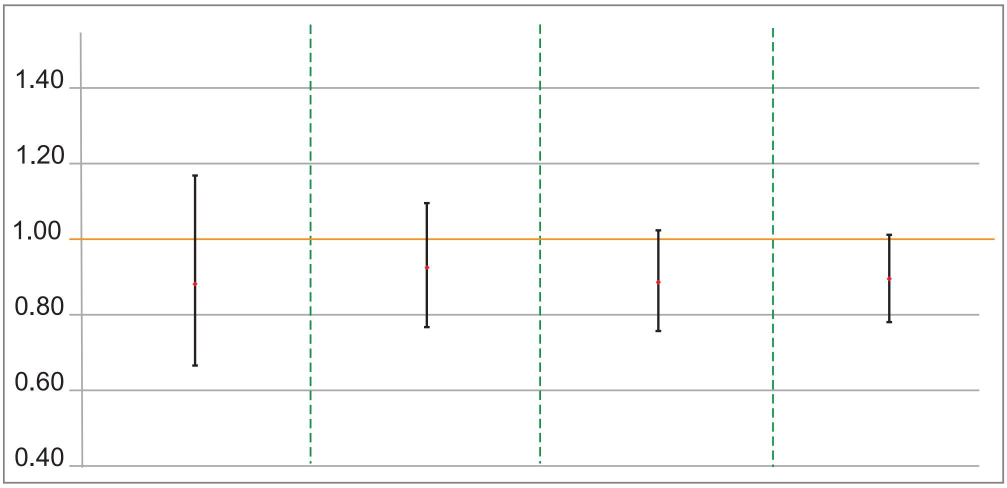
g) All cardiovascular



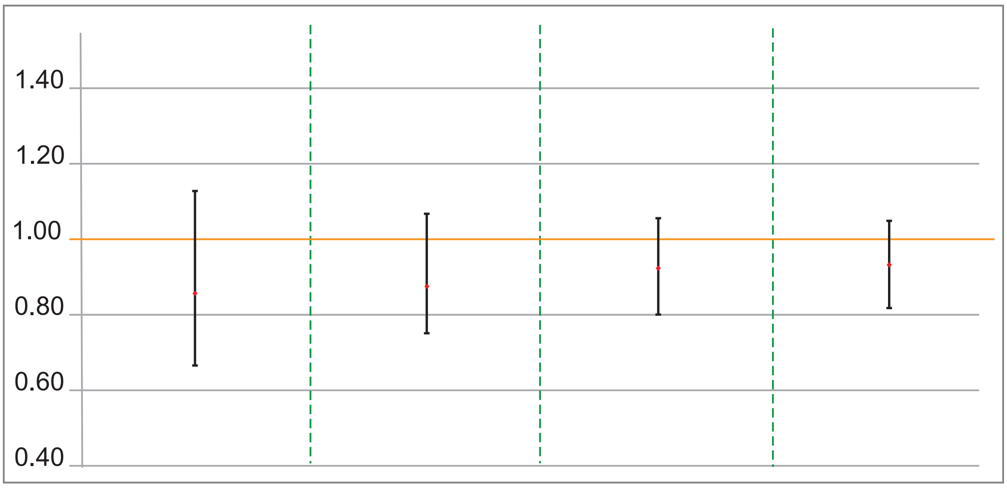

h) Arrhthmia



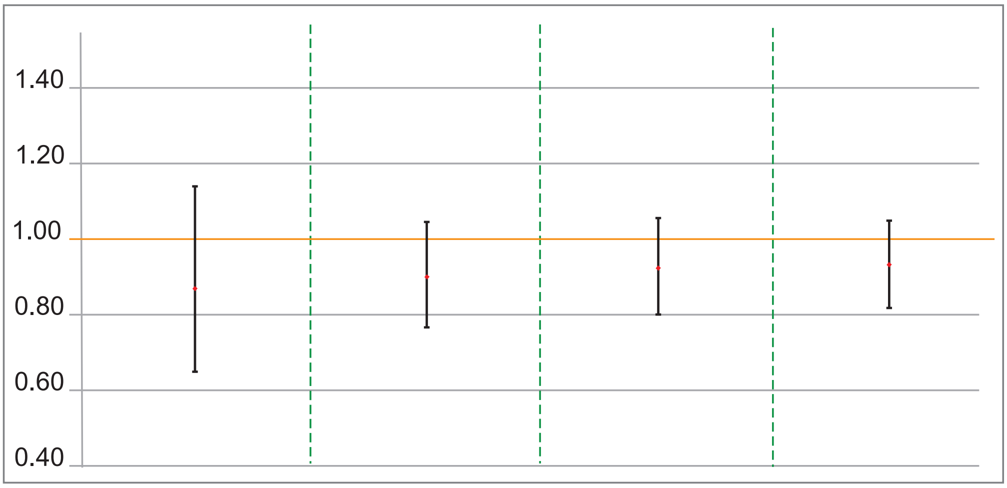

i) Angina



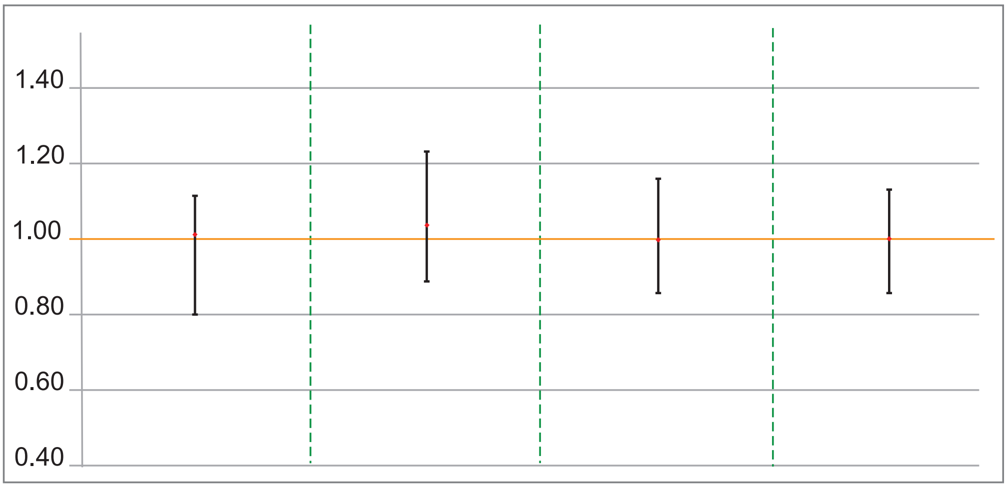
j) Stroke




k) Heart failure




l) ACS



m) TIA

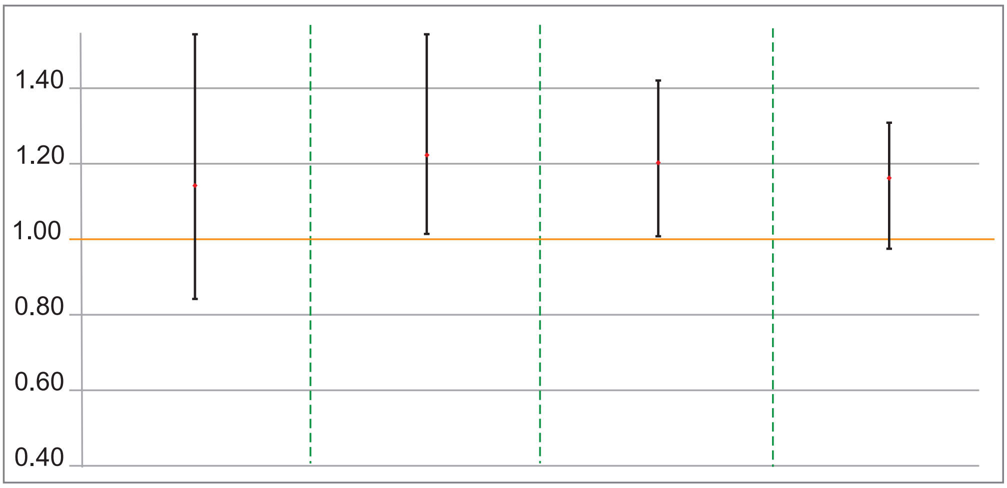



**Figure 2. Risk ratio and 95% confidence intervals for assessment of effects of LF smoke at high level on daily EDA for respiratory and cardiovascular conditions**

In each graph, 1st to 4th bars show risk ratios and 95% CIs for lag 0 on the left and to lag 3 on the right, respectively. Y axis denotes risk ratios. Horizontal yellow line indicates reference group (ie, low level fire smoke) risk ratio (eg, a value of 1). ALRTI = Acute Lower Respiratory Tract Infections; COPD = Chronic Obstructive Pulmonary Disease; ACS = Acute Coronary Syndrome; TIA = Transient Ischemic Attack

## 4. Spatio-temporal variations of the effects of LF smoke related $PM_{2.5}$ on EDA utilisation

a. Figure 3 shows the distribution of fires by fire type over the study period. The largest number of wildfires occurred in spring (ie, Season 4, September to November) and summer (Season1, December to February), while prescribed burns had their largest numbers in autumn (Season 2, March to May) and winter (Season 3, June to August), although the number of wildfires appears to have decreased from September 2016.

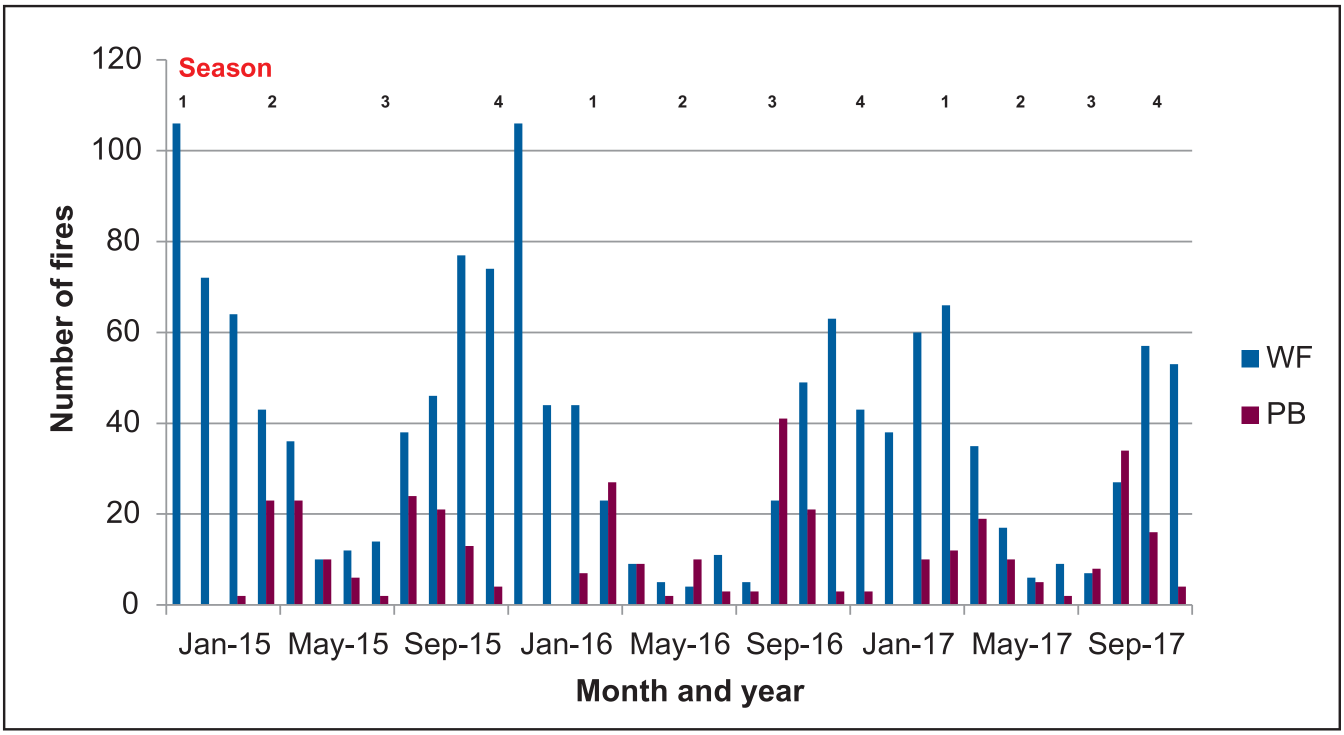



**Figure 3. Temporal distribution of all fire events, by burn type, Perth metro and South West regions, 2015 to 2017, WA**

b. Figure 4 shows the SA3-based geographical variations of the effects of smoke-related $PM_{2.5}$ on the ED presentation rates by season. Blue colour indicates a relatively small effects; brown colour intermediate effects; and red colour great effects. There were no significant differences between geographical areas when we compared medium level smoke related $PM_{2.5}$ with low level. However, most areas with high level smoke related $PM_{2.5}$ had a higher risk of ED presentation when comparing with low level areas. The landscape fire smoke affected all areas especially when the smoke related $PM_{2.5}$ concentrations were very high although the extent of effects varied.

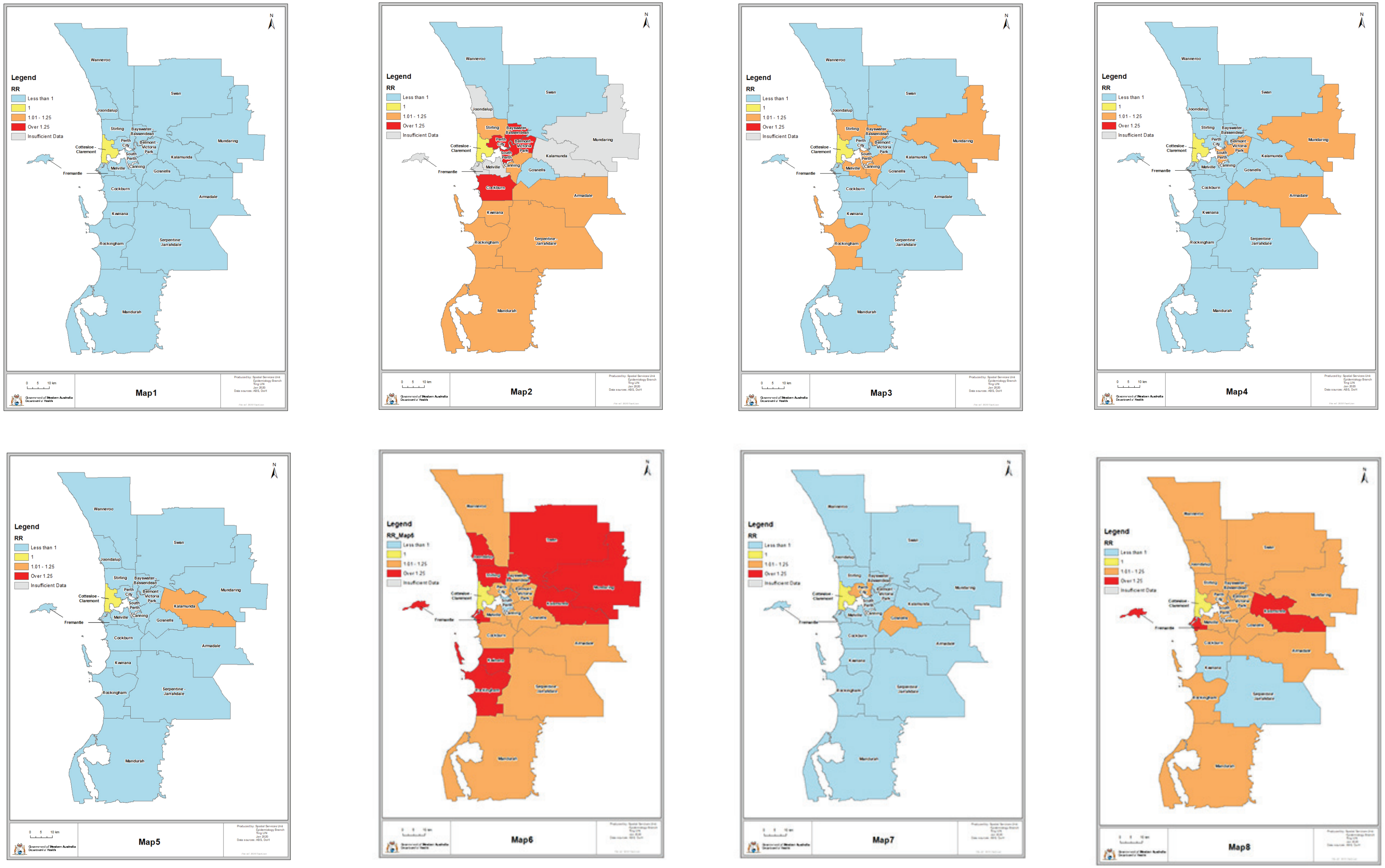



**Figure 4. Temporal and spatial distribution of the SA3 based geographical variations of the effect of LF smoke-related $PM_{2.5}$ on the ED presentation rate, Perth, WA, July 2015-December 2017**

(Notes: 1. Adjusted for the age, sex, SEIFA, public holiday, weekend, season, wood fire season, geographical areas and temperature dew point. 2. Effect expressed as risk ratio compared with low level of smoke related $PM_{2.5}$ exposure. 3. Maps 1, 3, 5 and 7 at the top showing the effect of medium level of smoke related $PM_{2.5}$ on emergency department attendances for seasons 1 to 4, respectively. 4. Maps 2, 4, 6 and 8 at the bottom showing the effect of high level of smoke related $PM_{2.5}$ on ED attendances for seasons 1 to 4, respectively.)

# Strengths and limitations

## Strengths

1. This is the first study in Western Australia to evaluate the effect of landscape bushfire smoke on a wide range of adverse respiratory and cardiovascular events using three large WA health care datasets (hospitalisations, ED attendances and ambulance callouts).
2. The main strength of the study was the use of earth observation data including digitalised smoke plumes for wildfires and prescribed burns identified via NASA's satellite, aerosol optical depth from NASA, fire radiative power from the Geoscience Australia online grid, and venting index and fire danger rating from BOM.
3. Temporally and spatially resolved modelled air exposure data were used from a wider Perth metropolitan area including areas with no monitoring facilities.
4. A well-established smoke-optimised empirical exposure model was modified and improved to estimate LF smoke-related $PM_{2.5}$ concentrations.
5. We were able to assess specific conditions including a wide range of respiratory and cardiovascular diseases.
6. We were also able to assess the dose-response relationship which is an important aspect of the epidemiological evidence in relation to harms caused by landscape fire air pollution exposure.

## Limitations

1. We could not distinguish between the effects of wildfires and prescribed burns on daily smoke related $PM_{2.5}$ count as there was a possibility of observing WFs and PBs within a geographical proximity and within the days of each other.
2. There were limited numbers of air quality monitoring stations in the Perth metropolitan area to estimate smoke related $PM_{2.5}$. To address this limitation, we tried GWRR and IDW modelling and finally selected IDW method to derive estimation on air quality for the whole Perth metropolitan area including the area where we didn't have air quality monitoring stations.
3. There was also a possibility of exposure misclassification, as all persons may not have been exposed to the same levels of $PM_{2.5.}$
4. Smoke episodes were of short duration. We investigated the lag effects of 3 days and about 1.5 million emergency attendances, more than half-million hospital admissions and about 80, 000 ambulance callouts for two and half years. However, statistical power could be increased by studying larger populations and over longer periods.
5. We also had a lack of information on smoke plumes caused by bushfires managed by local government or Department of Fire Emergency Services, agricultural burning, burning of debris associated with land development activities as there was no relevant/complete data available for the project.

# Main recommendations

Based on the study findings we recommend the following two categories of recommendations.

## Policy recommendations

1. Policy makers and health professionals should initiate and enhance community education programs on the harms caused by landscape fires. The programs should emphasise the main respiratory and cardiovascular conditions identified in the study.
2. Health education programs should be developed with a focus on adapting personal protective behaviours during a smoke episode and taking sensible precautions to avoid LF smoke inhalation including the emphasis of delayed smoke effects. The programs should start prior to the LF seasons (i.e., September to June).
3. Elderly people, children and populations living in lower socio-economic areas should be made aware of the effects of air pollution including landscape fire smoke in health promotion programs.
4. The resources should be increased to establish more air quality stations than the current number, especially in the southern, eastern and northern outskirts of the Perth metropolitan area and Southwest areas where LFs occur frequently.

## Technical recommendations

5. Regular and real time capturing of landscape fire data should be implemented to determine population/geographical areas at risk. Smoke plumes identified via the satellites and other earth observation data collected should be used to assist in capturing LFs and/or monitoring their movement for improving early warning systems.
6. Spatial services could assist with mapping smoke plumes and at-risk populations in the affected area. The existing spatial service at jurisdictions should be expanded to accommodate the increased need if required. In particular, the development of automatic mapping/digitalisation of smoke plumes should be considered so that timeliness and effectiveness of tracking the trajectory of smoke plumes can be realised.
7. Mobile apps such as AirRater (https://airrater.org/what-does-it-monitor/) or mobile messaging services such as asthma alert that are being developed in WA may incorporate such LF data so that LF exposed vulnerable populations can be informed and preventative measures can be taken in a timely manner. Mobile messaging services for alerting other relevant respiratory and cardiovascular conditions identified in the study should be considered at the same time during the design phase.

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Produced by the Epidemiology Branch


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