Technical report

What impact did the Fforestfach tyre fire have on health?

GIG CYMRU
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Public Health Wales Observatory

An examination of the association between exposure to air pollutants from the Fforestfach tyre fire plume and respiratory and cardiovascular contacts with General Practice

Project members

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Contents

1 Executive Summary

Background

On 16 June 2011, a fire broke out at an unoccupied warehouse on the Fforestfach Industrial Estate, Swansea. The fire involved rubber tyre 'flock' and released a mixture of pollutants into the atmosphere, affecting local air quality. Due to difficulties extinguishing the fire, it continued to burn for 22 days.

Tyre fires are known to release sulphur dioxide (SO_2) and particulate matter (PM) and exposure to these could potentially cause adverse health effects; potential effects included an increased risk of mortality, cardiovascular and respiratory morbidity, as well as a variety of other health impacts (World Health Organisation, 2013; Brunt, 2012).

The report assesses health impacts associated with the fire, focussing on the occurrence of respiratory and cardiovascular Read codes in patient's General Practice medical records.

Methods

GP record data were extracted from the Secure Anonymised Information Linkage (SAIL) databank at Swansea University. Contacts with General Practice were identified using Read codes recorded in the patient's medical records.

Four General Practice outcomes were considered, these were:

- General Practice contacts recorded for a respiratory condition among the total GP-registered population;
- General Practice contacts recorded for a cardiovascular condition among the total GP-registered population;
- General Practice contacts recorded for a respiratory condition among those on a GPs asthma Quality Outcomes Framework (QOF) register;
- General Practice contacts recorded for a respiratory condition among those on a GPs chronic obstructive pulmonary disease (COPD) QOF register.

The study included GP-registered residents within a 2.5km boundary of the fire. The study period was between 16 June 2011 and 11 August 2011, and includes the three week period of the fire.

Direct standardised rates were calculated for the four outcomes during the study period; rates were also calculated for the four outcomes during same period the previous year as controls.

A cohort study design was also used. Data produced through Met Office modelling of the dispersion of particulate matter with a diameter of <10μm (PM_{10}) were used to estimate the PM_{10} concentrations that residents may have been exposed to. Residents were considered to have had a raised or "above-threshold" exposure if the estimated outdoor 24-hour mean PM_{10} concentration in their area exceeded 50μg/m^3 across 1 to 2 days or 3 and more days.

A logistic regression model was then used to assess potential associations between estimated above-threshold exposures to PM_{10} and General Practice respiratory or cardiovascular events; the model included variables which could be confounding factors. The reference population for the logistic regression analysis were individuals who lived within the 2.5km boundary area during the study period but were not estimated to have exposure days where the outdoor 24-hour mean exposure exceeded guideline levels. A 2.5km boundary area was selected to provide a large enough reference population from individuals that are likely to have experienced similar environmental factors not related to the fire (pollen levels, circulating diseases etc). The exposure estimation was based on modelled levels of PM_{10} provided by the Met office for the period of the fire.

Findings

- An estimated 17,698 people lived in households where the outdoor 24-hour mean concentration of PM_{10} was estimated to have exceeded 50µg/m^3 (categorised here as "above-threshold" exposure) on at least one day; of these 7,314 were estimated to have been exposed to these concentrations on 3 or more days.
- 23,328 additional residents were within the geographical boundaries for potential exposure but were estimated not to have experienced any days where the outdoor 24-hour mean concentration of PM_{10} exceeded 50µg/m^3.
- In the total GP-registered population the logistic regression found no association between days of above-threshold exposure to PM_{10} and General Practice respiratory events or cardiovascular events, after adjustment for confounding variables.
- For the total GP-registered population: direct standardised rates were not statistically significantly different for the study period, compared to the same period the previous year, with respect to respiratory events in men or cardiovascular events in men or women; the standardised rate for respiratory events in females was statistically significantly higher during the study period when compared to the same period the previous year.
- For patients on the QOF asthma register: logistic regression indicated that patients who experienced 3 or more days of above-threshold exposure to PM_{10} were between 1.05 and 1.82 times more likely to have a respiratory event, indicated by a respiratory Read code in their patient record, during the eight week study period than those categorised as having no days of above-threshold exposure to PM_{10}.
- For patients on the QOF COPD register: direct standardised rates for General Practice respiratory events were statistically significantly increased within males during the study period compared to the same period the previous year; However, logistic regression, accounting for confounding variables, did not indicate any association between days of above-threshold exposure to PM_{10} and General Practice respiratory events in males or females on the QOF COPD register.

Strengths and limitations

- This study was able to examine the health events in the whole resident population, rather than a smaller sample, using linked General Practice data.
- The study was able to incorporate both a before & after design and a cohort study allowing for a number of important factors to be accounted for.
- The study was able to control for potential confounding. Several potential confounding factors were recorded and were accounted for in the logistic regression analysis and, using

a contemporary control group controlled for the impact of other factors such as circulating respiratory infections; other factors, such as smoking history and deprivation, are likely to have remained relatively stable in the study population over the period of the study so are unlikely to affect the results.

- The study may have been limited in its ability to detect rarer health events that may have been associated with the fire due to the relatively small number of individuals who were estimated to have been exposed to concentrations of PM_{10} exceeding 50µg/m^3 for an extended period.
- There are limitations with the exposure measure used for this analysis, including being based on a model of the plume, a mean exposure estimate and place of residence.
- There are limitations with the outcome measures as not all health events will have resulted in a GP contact, for example the exacerbation of existing health conditions may have been controlled through self-medication.
- It was not possible to assess the reason for the GP contact. Some contact may have been from patients that were concerned about the fire rather than experiencing adverse effects as a result of exposure to the smoke.
- An eight week observation period was chosen to maximise the likelihood that any short term health outcomes associated with the fire would be captured and to account for any lag period; however, extending the observation period beyond the period that the fire was burning could have diluted any association with the immediate or very short term health effects. Additionally, long term health impacts would not have been detected.

Conclusions

Findings from this report support the current health advice which states that individuals with certain chronic conditions may be more likely to experience symptoms when exposed to 24-hour mean concentrations of PM_{10} exceeding 50µg/m^3; but the risk of significant symptoms as a result of such exposure in the general population is likely to be minimal.

This study was only able to look at external pollution concentrations. Those living in the local area, especially those with long-term conditions, were given the advice to stay indoors and away from the smoke whenever possible. Following this is likely to have reduced their exposure to the smoke.

After accounting for confounding variables, this report found no association between days of above-threshold exposure to PM_{10} and respiratory or cardiovascular events recorded in General Practice for the total GP-registered population. An increased rate of contact for respiratory symptoms was found for males on the COPD register, but this was no longer present after adjustment for confounding variables in the logistic regression.

A significant association was found between above-threshold exposure to PM_{10} and respiratory events recorded in General Practice for patients on the asthma register. This suggests that people with asthma living in areas with above-threshold PM_{10} concentrations at the time of the fire had increased contacts with their General Practice relating to respiratory conditions than those residing in areas that were not above threshold.

Despite the study limitations described, this report adds to the body of evidence around the health impacts of above-threshold exposure to PM_{10}.

A summary of the report will be produced to aid the communication of these findings to the public.

2 Aim

The aim of this project was to assess any associations between the Fforestfach fire incident and respiratory and cardiovascular health outcomes during the subsequent eight weeks, in a General Practice setting within the local population.

2.1 Objectives

- Estimate population with above-threshold exposure to PM_{10} in the total GP-registered population; people with asthma; and those with COPD.
- Compare the rate of General Practice contacts for a respiratory or cardiovascular condition during the study period to the rate in the same period in the previous year (i.e. the reference period).
- Investigate which factors (particularly above-threshold exposure to PM_{10}) are associated with General Practice contact for respiratory/cardiovascular conditions.

3 Introduction

In June 2011 a large tyre fire on the Fforestfach Industrial Estate, Swansea, burned for 22 days. The fire generated a dense plume of smoke, releasing a cocktail of pollutants into the atmosphere and affecting local air quality.

Air pollution is a significant public health concern. Both acute and chronic exposures are known to increase cardiovascular and respiratory morbidity, mortality risks and a variety of other adverse health effects including cancers, premature births and low-birth weight (World Health Organisation, 2013). There is also strong evidence demonstrating a correlation between even short term exposure to air pollution and poor health outcomes (COMEAP, 2011). A fire of this nature may release a wide range of pollutants with the potential to cause adverse health effects in the exposed population (Brunt, 2012).

This report therefore aims to assess the association between the fire and the occurrence of respiratory and cardiovascular Read codes in a patient's GP record.

3.1 Incident context

The fire broke out on the 16th June 2011 and was declared a major incident on the same day. The fire involved over 5,000 tonnes of rubber tyre 'flock', which can be extremely difficult to extinguish, with the fire taking 22 days to put out.

The plume of smoke was visible throughout Swansea particularly in Fforestfach itself, a mixed industrial/residential area, on the outskirts of Swansea. Throughout the duration of the fire there was much public concern and problems with visibility, which resulted in some temporary road closures.

Air quality monitoring stations are able to detect a wide range of chemicals (see appendix 1) but during the period of the fire PM_{10} was the only pollutant that exceeded guideline levels and therefore presented the greatest risk to the public. Those living up to 2km from the fire, an estimated population of 24,812 people, may have been exposed to the greatest increase in air pollution (Brunt, 2012).

Based on all the available information, the decision was taken to advise the public to shelter i.e. remain indoors and keep windows and doors closed. The public were given information regarding possible adverse effects of exposure to smoke from the fire and how to minimise their exposure. People with pre-existing medical conditions, such as respiratory and cardiac conditions, were advised to be particularly cautious. To facilitate effective communication with the local public, announcements were made on local radio and advice leaflets were distributed in local areas.

3.2 Fires, air pollution and respiratory health

Fires involving rubber produce a wide range of pollutants including particulate matter (PM), sulphur dioxide (SO_2), and a range of organic and inorganic irritants; of particular health concern would be fine PM, SO_2, acrolein and polycyclic aromatic hydrocarbons (PAH) (Wakefield, 2010). The pollutants emitted from fires can be categorised as asphyxiants, such as carbon monoxide and SO_2, which in high concentrations can reduce the amount of oxygen available in the bloodstream, or irritants such as PM.

PM with a diameter of <10μm (PM_{10}) can pass through the upper respiratory tract and deposit in the airways; once deposited in the lungs some types of PM_{10} produce free radicals which may provoke oxidative stress, causing an inflammation of lung tissue and may worsen pre-existing chronic respiratory conditions such as chronic obstructive pulmonary disorder (COPD) (Wakefield, 2010). PM with a diameter of <2.5μm ($PM_{2.5}$) penetrate deeper and are deposited into the alveoli; particles with a diameter of <100nm, known as ultra fine particles, can pass through into the blood stream and deposit in other organs causing a range of problems. This process is thought to be responsible for the increase in cardiovascular complaints following exposure to PM (Wakefield, 2010; World Health Organisation, 2013).

The World Health Organisation (WHO) Review of evidence on health impacts of air pollution (REVIHAPP project, 2013) concluded that even at very low concentrations, exposure to PM_{10} over long periods shows a persistent association with increased mortality and morbidity. The European Union (EU) Daughter Directives on Air Quality set limit values for certain pollutants which have been incorporated into law through the Air Quality Standards (Wales) Regulations 2010. For PM_{10} the concentrations should not exceed an annual mean of 40 μg/m^3 and 24-hour mean concentrations should not exceed 50μg/m^3 more than 35 times per year.

Studies have also demonstrated an increase in respiratory and cardiovascular complaints following exposure to higher concentrations of PM over short periods (COMEAP, 2011; Wakefield, 2010). These studies also appear to show that elevations in particulate air pollution can cause a worsening of symptoms in individuals with chronic conditions; cardiovascular disease and lung disease have both been particularly highlighted (COMEAP, 2011; Wakefield, 2010).

In order to quantify the population health impact of exposure to PM_{10}, the Committee on the Medical Effects of Air Pollutants (COMEAP) reviewed several studies and produced estimates of expected increase in ill health following short term exposure to different concentrations of PM_{10}. Concentrations below 50 µg/m^3 were considered to have a small impact on the general population, an estimated increase of one hospital admission in a population of one million is expected. Concentrations between 75-100 µg/m^3 were associated with a 1.25% increase in short term mortality and concentrations above 100 µg/m^3 were estimated to increase short term mortality by 2.5% (COMEAP, 2011).

Additionally, the COMEAP has undertaken a review of the UK Daily Air Quality Index (DAQI) which categorises the possible effects of short term exposures into a 10 point scale. The 10 point scale is grouped into exposure categories of "low", "moderate", "high" and "very high" (COMEAP, 2011). Table 1a describes the index bands for exposure to PM_{10}. COMEAP has also published health advice to compliment the index (table 1b).

Table 1a The index for exposure to PM_{10} (COMEAP, 2011)

Band	Index	24-hour mean (µg m3)
	1	0-16
Low	2	17-33
	3	34-50
	4	51-58
Moderate	5	59-66
	6	67-75
	7	76-83
High	8	84-91
	9	92-100
Very High	10	101 or more

Table 1b Health advice to accompany the air pollution index (COMEAP, 2011)

C Health Advice to Accompany the Air Quality Index

Air pollution banding	Value	Accompanying health messages for at-risk groups and the general population	
		At-risk individuals*	**General population**
Low	1–3	***Enjoy*** your usual outdoor activities	***Enjoy*** your usual outdoor activities
Moderate	4–6	Adults and children with lung problems, and adults with heart problems, ***who experience symptoms***, should ***consider reducing*** strenuous physical activity, particularly outdoors	***Enjoy*** your usual outdoor activities
High	7–9	Adults and children with lung problems, and adults with heart problems, should ***reduce*** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also ***reduce*** physical exertion	Anyone experiencing discomfort such as sore eyes, cough or sore throat should ***consider reducing*** activity, particularly outdoors
Very High	10	Adults and children with lung problems, adults with heart problems, and older people, should ***avoid*** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often	***Reduce*** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat

* Adults and children with heart or lung problems are at greater risk of symptoms. Follow your doctor's usual advice about exercising and managing your condition

4 Methods

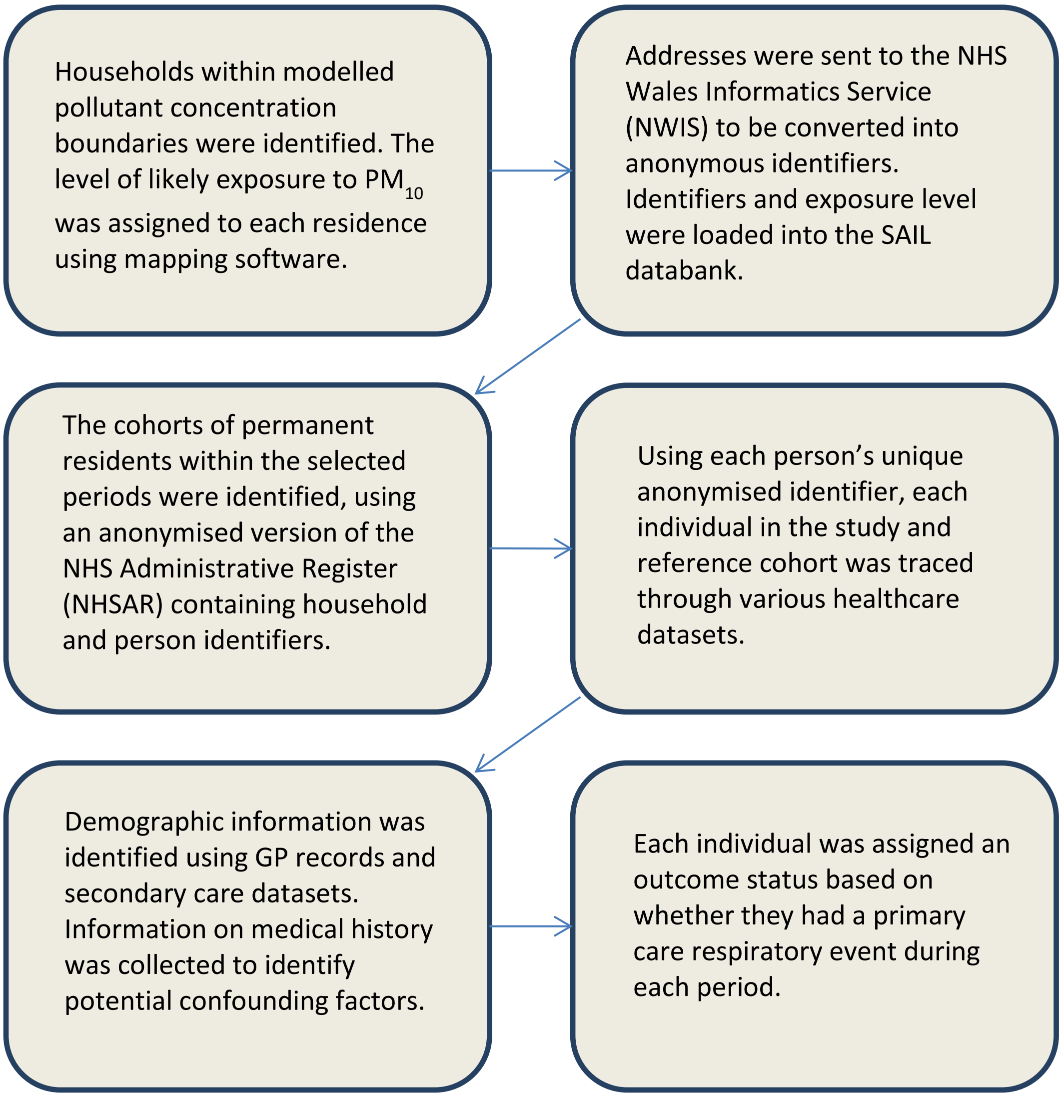
4.1 Study design

A cohort study design was used to identify factors associated with contact with General Practice for respiratory or cardiovascular conditions. The cohort included people that were identified as being resident within a 2.5km boundary of the fire. Within this geographical area, exposure boundaries provided by the Met Office during the eight week study period identified those that were likely to have been exposed to above-threshold concentrations of PM_{10} (see section 4.2 below).

The selected study period was between 16th June 2011 and 11th August 2011, and included the three week period of the fire. An eight week study period was selected in order to maximise the chance of capturing any acute events that could potentially be associated with above-threshold exposure to PM_{10}.

The Secure Anonymised Information Linkage (SAIL) databank, held at Swansea University, contains a variety of anonymised datasets, including General Practice and secondary care (hospital data). SAIL is a world leading privacy protecting system in which those analysing the data cannot identify individuals or the houses in which they live. Using matching techniques involving unique identifiers, the modelled exposure data was linked to General Practice health outcomes for each individual. A summary of the way in which the data have been extracted can be seen in figure 1.

Figure 1 overview of the method used to extract data



Contact with General Practice for respiratory or cardiovascular conditions was measured through the occurrences of a Read code in a patient's medical record. Read codes are not exclusively used to record face to face contact with the doctor, they are also used for other contacts including telephone consultations or contact with the practice nurse.

The following outcome measures were considered:

- General Practice contacts recorded for a respiratory condition among the total GP-registered population;
- General Practice contacts recorded for a cardiovascular condition among the total GP-registered population;
- General Practice contacts recorded for a respiratory condition among those on a GPs chronic obstructive pulmonary disease (COPD) Quality Outcomes Framework (QOF) register;
- General Practice contacts recorded for a respiratory condition among those on a GPs asthma QOF register.

A logistic regression model was used to assess any potential associations between above-threshold exposure to PM_{10} and General Practice respiratory or cardiovascular events, the model included variables which could be confounding factors.

All analyses were undertaken using STATA 12.1.

4.2 Above-threshold exposure to PM_{10}

During the period of the fire, monitoring stations indicated that PM_{10} concentrations were the only pollutant measured to exceed guideline levels. For this reason, local PM_{10} dispersion was modelled by the Met Office to determine which areas were likely to have been affected during the three week period of the fire. Modelling of the plume dispersion was carried out using a dispersion model known as Numerical Atmospheric-dispersion Modelling Environment (NAME) (Jones, 2007). The model accounted for wind direction and speed, modelling the movement of the plume based on an estimated dispersion rate. The model was compared to permanent air quality sites, as well as those established during the event; generally the modelled values were in good agreement with the results from air quality stations. Figure 2 is an example of the exposure data that was provided by the Met Office.

Data produced through the modelling were used as the basis for the estimated geographical exposure which were used to attribute an exposure category to each person (see below). Modelled data were preferred to actual measurements because they provided boundaries of differing exposure levels which account for wind direction, rather than a point measurement. The good correlation between the data collected at these sites and the model estimates enhanced confidence in the modelled estimates.

Figure 2 Example of exposure boundaries, number of days when 24 hour mean PM_{10} levels exceed 50 µg/m^3, event week 1

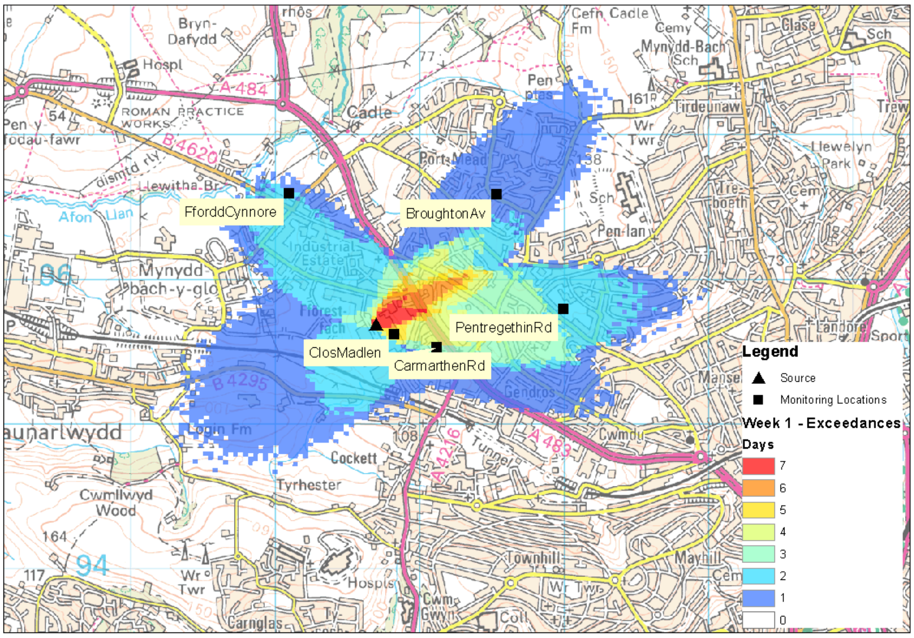


Image provided by the Met Office, using maps provided by Ordnance Survey (OS).

PM_{10} is a non-threshold pollutant, and adverse health effects may occur at low concentrations in some vulnerable groups. However, the COMEAP guidelines (COMEAP, 2011) suggest that concentrations not exceeding a 24-hour mean of 50µg/m^3 can be considered a lower risk. The COMEAP guidelines, suggest that exposure to PM_{10} concentrations over 50µg/m^3 could have an adverse effect on health at a population level, in particular for people with chronic conditions. Based on this advice, a threshold of a 24-hour mean exposure concentration of 50µg/m^3 or above was considered appropriate. Within this measure it is possible that PM_{10} concentrations were far in excess of 50µg/m^3.

Modelled exposure data, providing the number of days that the 24 hour mean concentrations of PM_{10} exceeded 50µg/m^3, was made available for the entire period. For the purpose of this analysis, exposure categories were based on the number of days of above-threshold exposure to PM_{10} experienced by each resident and were grouped as 0, 1-2 days and 3 or more days. The grouping was chosen based on the distribution of events within each category.

Households within the geographical boundaries of each exposure category were identified using digital mapping software. Addresses were identified using the Royal Mail Postcode Address File (PAF) which contains standardised address data for 28 million addresses. The PAF address keys were identified and assigned an exposure category. This was then sent to NWIS who converted the address key into a Residential Anonymous Linkage Field (RALF). These data were then loaded into the SAIL databank so that they could be linked to other datasets.

4.3 Statistical Methods

4.3.1 Direct standardised rates

As a basic measure of how the use of General Practices for respiratory and cardiovascular conditions changed during the fire, crude and age-standardised rates were calculated for the same 8 week period used in the regression models (further described below), and were compared to the rate of events during the same 8 week period in the previous year. These rates account for age, and to some extent season; these rates are unable to account for underlying rates of events, which may vary due to variation in levels of circulating infections for example, and do not account for any other confounding factors.

The analysis counted a patient once in each period, this was to adjust for potential over counting where, for example, a patient could be recorded multiple times for one complaint; the patient may telephone for test results following a consultation and the call would be recorded as a respiratory Read code. This approach also sought to measure the impact of the fire on the population, rather than the burden that was placed on General Practice services.

Rates were standardised to the European standard population and presented per 1000 population with 95% confidence intervals (intervals calculated using a method proposed by Dobson *et al*, (1991)).

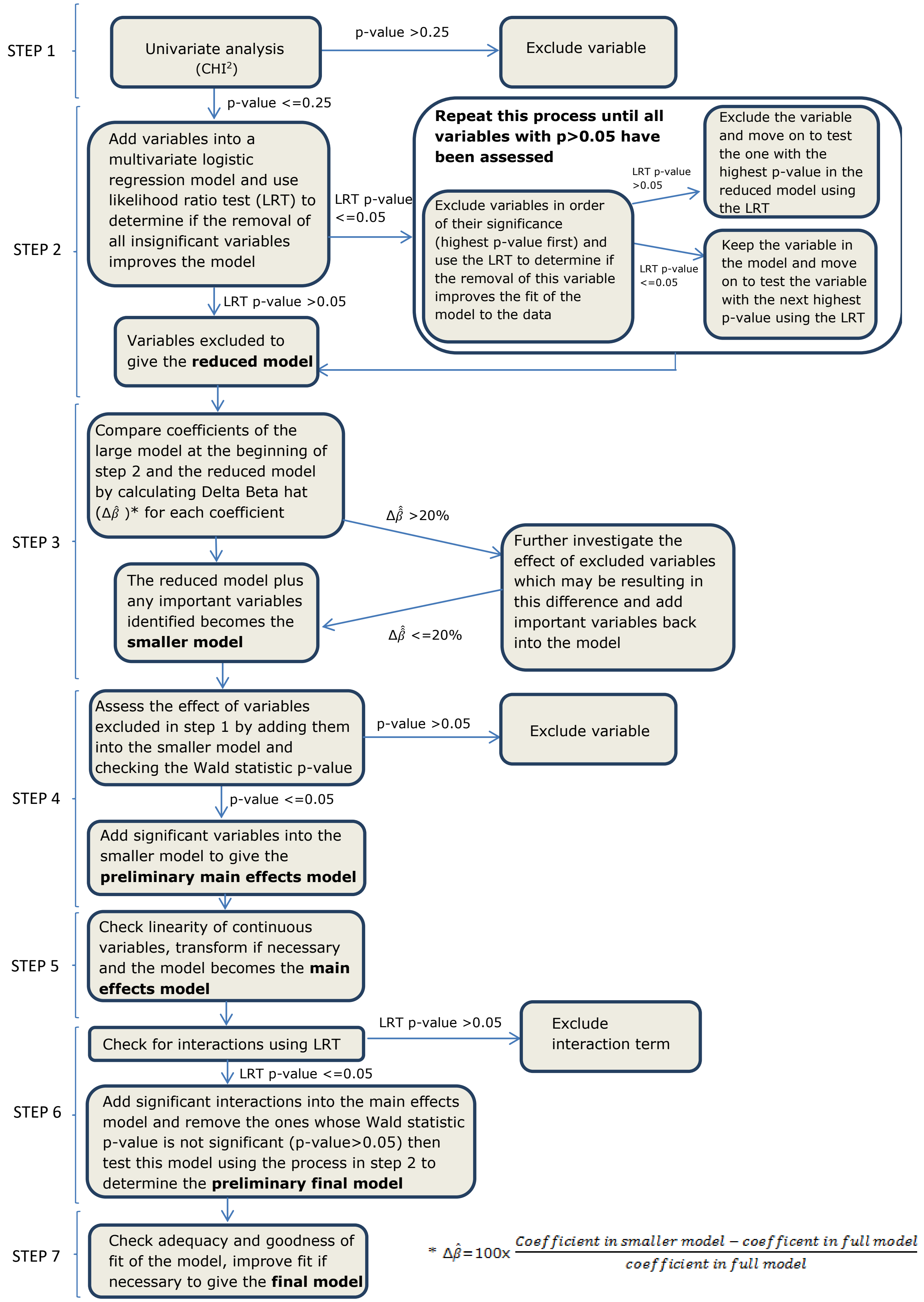
4.3.2 Regression analyses

In order to build a meaningful regression model, strategies and methods proposed by Hosmer *et al* (2013) were followed. Figure 3 describes the process used to identify variables which can predict the occurrence of a General Practice Read code within a patient record.

The process described in figure 3 was followed for the four outcomes of interest: Respiratory Read codes recorded within the total GP-registered population, cardiovascular Read codes recorded within the total GP-registered population, respiratory Read codes recorded for those with COPD and respiratory Read codes recorded for those with asthma. In all models, people with no days of above-threshold exposure to PM_{10} (defined as days where 24-hour mean exposure exceeded of 50μg/m^3) were considered the reference population.

In all four regression models, the distribution of events against age (the only continuous variable) did not satisfy the assumptions of the model. Various transformations were attempted but were unsuccessful. In order to continue with the analysis age was categorised into standard age groups. For some regression models age-groups were collapsed to remove zero cell counts following the process for finalising each regression model proposed by Hosmer *et al*.

Figure 3 Flow diagram of the logistic regression process



4.4 Data extraction

Access to the de-identified data in the SAIL databank was given following a privacy protection review by the independent Information Governance Review Panel, which includes experts on data protection and members of the public. Following the review and approval of the application, data were extracted using Structured Query Language (SQL) and analysed on the SAIL Gateway. No data are removed from the SAIL computers. The data were checked for accuracy by an Advanced Analyst in the Public Health Wales Observatory.

The following datasets were used in the analysis:

- Exposure data described in section 4.2
- NHS Administration Register (NHSAR)
- General Practice data (Medical records)
- Patient Episode Database Wales (PEDW)

The NHSAR contains the Residential Anonymous Linkage Field (RALF) and a unique identifier for each resident within the household, as well as dates that the household was occupied. Each resident was identified using the Anonymised Linkage Field (ALF) which allows analysts to track patients through various healthcare systems. Each resident was assigned an exposure status.

People were only included in the cohort if they were resident for the entire study period (16th June 2011 – 11th August 2011). Some people were identified that appeared to have moved in and out of the same address on the same date, these moves were deemed to be data errors, rather than actual moves, and these individuals were considered to be part of the cohort.

Demographic information was selected for each person from their GP records. General Practice activity was captured using Read codes version 2. In order to identify chronic conditions such as Chronic Obstructive Pulmonary Disorder (COPD) or asthma, the Quality and Outcome Framework (QOF) definitions (version 25) were used (QOF business rules V25 (2013)). QOF definitions have a standard Read code rule set. GPs are required to keep a register of patients with selected chronic conditions using these definitions. As a consequence it is more likely that, for these conditions, the Read coding is standardised. Each patient was assigned a status of 1 if they had the condition within the previous 12 months of each period and 0 if they had not.

History of the occurrence of these Read codes in General Practice was also recorded as it was felt this could be a potential confounding factor. Patients in the selected cohort were assigned 1 if they had an event recorded within the previous 12 months of the beginning of the study/reference period and 0 if not. Specific groups of Read codes used to identify the variables used in the analysis can be found in table 3, a link to the QOF definitions has been provided in the references.

History of unscheduled hospital admissions was identified using the PEDW dataset. Patients were flagged with 1 if they had an unscheduled hospital admission for a respiratory or cardiovascular admission. Hospital events were captured using ICD-10 codes and were only included if it was the primary diagnosis on the admitting episode. These criteria were applied to best capture admissions relating specifically to the condition of interest. Specific ICD-10 codes used in the analysis can be found in table 3.

A GP local to the Fforestfach area was consulted for the best way in which to capture GP events relating to respiratory and cardiovascular complaints. The advice was to use broad definitions to allow for any possible variation in which the events were recorded.

All patients permanently resident during the eight week study period, identified using the flags described above, were selected for analysis. Table 3 describes in brief the codes used to identify events in primary and secondary care. A link to QOF definitions can be found in the references, they have not been included in the table below due to the large number of Read codes.

Table 3 Summary of ICD-10/Read codes used to identify patient activity.

Variable description	Read/ICD-10 code	Notes
Respiratory Read code recorded in primary care data	H%*, 1712.-1717., 1719., 171A. - 171Z., 1761., 1732.-1739., 173A.-173D., 173F., 173G., 173I.-173L., 173N.-173Y., 173Z., 173a.-173c., 17ZZ., 1822.-1829., 182A.-182C., 182B0, 182Z.	During period being considered
Cardiovascular Read code recorded in primary care data	G%*	During period being considered
Patient is in their last year of life	-	Based on date of death
History of a respiratory diagnosis in secondary care	J%	Emergency admission. Primary diagnosis on admitting episode
History of a cardiovascular diagnosis in secondary care	I%	Emergency admission. Primary diagnosis on admitting episode
History of respiratory Read code recorded in primary care data	H%*, 1712.-1717., 1719., 171A. - 171Z., 1761., 1732.-1739., 173A.-173D., 173F., 173G., 173I.-173L., 173N.-173Y., 173Z., 173a.-173c., 17ZZ., 1822.-1829., 182A.-182C., 182B0, 182Z.	Within 12 month period prior to study period
History of cardiovascular Read code recorded in primary care data	G%*	Within 12 month period prior to study period
Patient is on QOF register for COPD	QOF Definitions	Business definition v25
Patient is on QOF register for asthma	QOF Definitions	Business definition v25
Patient is on QOF register for atrial fibliration	QOF Definitions	Business definition v25
Patient is on QOF register for heart failure	QOF Definitions	Business definition v25
Patient is on QOF register for hypertention	QOF Definitions	Business definition v25
Patient is on QOF register for stroke	QOF Definitions	Business definition v25
Patient is on QOF register for coronary heart disease	QOF Definitions	Business definition v25
Sex of patient	0= male 1 = female	

Produced by Public Health Wales Observatory

*excludes known invalid Read codes

5 Results

5.1 Summary of modelled exposure to PM10

It is estimated that 23,328 individuals (56.9%) within the study area had no days of above-threshold exposure to PM^{10} (defined as days where 24-hour mean exposure exceeded of $50 \mu g/m^3$). However, 10,384 (25.3%) experienced 1 or 2 days of above-threshold exposure to PM^{10}, and 7,314 individuals (17.8%) experienced 3 or more days of above-threshold exposure to PM^{10}. Within this population, 869 patients registered with asthma and 248 patients registered with COPD experienced 1 or 2 days of above-threshold exposure to PM^{10}, and 639 patients registered with asthma and 220 patients registered with COPD experienced 3 or more days of above-threshold exposure to PM^{10}.

Tables 5.1a, 5.1b and 5.1c describe the distribution of age and sex across the 3 estimated exposure categories. 5.1a considers the entire cohort, 5.1b considers those with asthma and 5.1c considers those with COPD.

Table 5.1a. Summary of exposure to PM_{10}, entire cohort, 16 June 2011 - 7 July 2011

		Number of days that PM_{10} concentrations exceeded 50 $\mu g/m^3$ (24-hour mean)		
Variable		**0 days (%)**	**1-2 days (%)**	**3+ days (%)**
Age group	0-14	4567 (57.2)	2113 (26.5)	1307 (16.4)
	15-24	3205 (57.6)	1383 (24.9)	977 (17.6)
	25-34	3231 (56.7)	1478 (25.9)	988 (17.3)
	35-44	3167 (57.0)	1413 (25.4)	980 (17.6)
	45-54	3305 (58.2)	1334 (23.5)	1042 (18.3)
	55-64	2559 (56.6)	1182 (26.1)	783 (17.3)
	65-74	1702 (55.1)	755 (24.4)	632 (20.5)
	75+	1592 (54.5)	726 (24.8)	605 (20.7)
Average age		37.6	37.4	39.3
Sex	Males	11577 (57.0)	5117 (25.2)	3619 (17.8)
	Females	11751 (56.7)	5267 (25.4)	3695 (17.8)
Total		23328 (56.9)	10384 (25.3)	7314 (17.8)

Produced by Public Health Wales Observatory using WDS (NWIS) and exposure data (Met Office) accessed via the SAIL databank

Table 5.1b. Summary of exposure to PM_{10}: patients appearing on the QOF asthma register, 16 June 2011 - 7 July 2011

		Number of days that PM_{10} concentrations exceeded 50 µg/m³ (24-hour mean)		
Variable		**0 days (%)**	**1-2 days (%)**	**3+ days (%)**
Age group	0-14	252 (60.3)	105 (25.1)	61 (14.6)
	15-24	258 (62.0)	97 (23.3)	61 (14.7)
	25-34	239 (53.8)	122 (27.5)	83 (18.7)
	35-44	292 (58.5)	127 (25.5)	80 (16.0)
	45-54	323 (59.2)	123 (22.5)	100 (18.3)
	55-64	277 (57.1)	123 (25.4)	85 (17.5)
	65-74	197 (52.8)	96 (25.7)	80 (21.4)
	75+	185 (52.9)	76 (21.7)	89 (25.4)
Average age		42.9	43.5	47.0
Sex	Males	894 (58.7)	377 (24.8)	252 (16.5)
	Females	1129 (56.2)	492 (24.5)	387 (19.3)
Total		2023 (57.3)	869 (24.6)	639 (18.1)

Produced by Public Health Wales Observatory using WDS (NWIS) and exposure data (Met Office) accessed via the SAIL databank

Table 5.1c. Summary of exposure to PM_{10}: patients appearing on the QOF COPD register, 16 June 2011 - 7 July 2011

		Number of days that PM_{10} concentrations exceeded 50 µg/m³ (24-hour mean)		
Variable		**0 days (%)**	**1-2 days (%)**	**3+ days (%)**
Age group	0-44	28 (53.8)	15 (28.8)	9 (17.3)
	45-54	58 (53.2)	32 (29.4)	19 (17.4)
	55-64	157 (56.3)	75 (26.9)	47 (16.8)
	65-74	158 (55.8)	59 (20.8)	66 (23.3)
	75+	162 (52.6)	67 (21.8)	79 (25.6)
Average age		66.2	65.4	68.7
Sex	Males	282 (57.0)	111 (22.4)	102 (20.6)
	Females	281 (52.4)	137 (25.6)	118 (22.0)
Total		563 (54.6)	248 (24.1)	220 (21.3)

Produced by Public Health Wales Observatory using WDS (NWIS) and exposure data (Met Office) accessed via the SAIL databank

5.2 Patients with a recorded respiratory Read code in General Practice data (total GP-registered population)

5.2.1 Direct standardised rates

Direct standardised rates allow a comparison of rates between the two periods having accounted for any potential differences in age structure of the population at the two different time periods. This measure does not account for other factors which could influence a change in healthcare use, such as changes in service provision, circulating infections or temperature fluctuations.

The rate of patients with a respiratory Read code appearing in their patient record was higher in the study period than the reference period for both males and females. However, only the rates for females and Persons were statistically significantly higher using the Breslow and Day significance method (1987) which assesses the confidence intervals around the relative rate rather than the two individual rates. The rate in males was statistically significantly lower than that of females in both periods.

Table 5.2a: Patients with a recorded respiratory Read code(s), European age standardised rates per 1,000, all ages, Fforestfach residents, Selected periods**

	Females		Males		Persons	
	Crude rate (n)	EASR (95% CI*)	Crude rate (n)	EASR (95% CI*)	Crude rate (n)	EASR (95% CI*)
Reference period	42.7 (884)	42.3 (39.5 - 45.2)	32.7 (666)	33.2 (30.6 - 35.9)	37.8 (1550)	37.6 (35.7 - 39.6)
Study period	47.7 (988)	47.3 (44.4 - 50.4)	34.4 (699)	34.6 (32.0 - 37.4)	41.1 (1687)	41.0 (39.0 - 43.0)

Produced by Public Health Wales Observatory, using GP data and WDS (SAIL databank)
*CI = confidence interval
**Reference period (16 June - 11 August 2010), study period (16 June - 11 August 2011)

5.2.2 Logistic regression model

Table 5.2b describes the potential confounding variables that were considered in the logistic regression model.

Table 5.2b. Descriptive analysis of independent variables and their univariate association with the outcome (presence of a General Practice respiratory Read code)

Variable Description		General Practice respiratory Read code	
		No (%)	Yes (%)
Number of days that exposure to PM_{10} exceeds 50 $\mu g/m^3$ (24-hour average)	0	22,349 (95.8)	979 (4.2)
	1-2	9,974 (96.1)	410 (3.9)
	3+	7,016 (95.9)	298 (4.1)
Age group	0-54	29,317 (96.2)	1,173 (3.8)
	55-64	4,324 (95.6)	200 (4.4)
	65-74	2,926 (94.7)	163 (5.3)
	75+	2,772 (94.8)	151 (5.2)
Sex	Male	19,614 (96.6)	699 (3.4)
	Female	19,725 (95.2)	988 (4.8)
Patient in last year of life	No	39,040 (95.9)	1,653 (4.1)
	Yes	299 (89.8)	34 (10.2)
History of an emergency admission for a respiratory condition*	No	38,907 (96.0)	1,602 (4.0)
	Yes	432 (83.6)	85 (16.4)
History of an emergency admission for a cardiovascular condition*	No	39,030 (95.9)	1,666 (4.1)
	Yes	309 (93.6)	21 (6.4)
History of respiratory Read code in General Practice	No	30,907 (97.5)	783 (2.5)
	Yes	8,432 (90.3)	904 (9.7)
History of cardiovascular Read code in General Practice	No	37,958 (96.0)	1,593 (4.0)
	Yes	1,381 (93.6)	94 (6.4)
Patient on QOF register for COPD	No	38,550 (96.4)	1,445 (3.6)
	Yes	789 (76.5)	242 (23.5)
Patient on QOF register for asthma	No	36,201 (96.5)	1,294 (3.5)
	Yes	3,138 (88.9)	393 (11.1)
Patient on QOF register for atrial fibrillation	No	38,769 (95.9)	1,649 (4.1)
	Yes	570 (93.8)	38 (6.3)
Patient on QOF register for heart failure	No	38,468 (95.9)	1,639 (4.1)
	Yes	871 (94.8)	48 (5.2)
Patient on QOF register for hypertension	No	34,186 (96.0)	1,442 (4.0)
	Yes	5,153 (95.5)	245 (4.5)
Patient on QOF register for stroke	No	38,565 (95.9)	1,633 (4.1)
	Yes	774 (93.5)	54 (6.5)
Patient on QOF register for CHD	No	37,848 (96.0)	1,577 (4.0)
	Yes	1,491 (93.1)	110 (6.9)
	Total	39339 (95.9)	1687 (4.1)

Produced by Public Health Wales Observatory, using GP data, WDS (NWIS), PEDW (NWIS), ADDE (ONS) and exposure data (Met Office) via the SAIL databank

*Primary diagnosis on the admitting episode of care

Of the 15 independent variables considered in the model, 11 were significantly associated with the outcome of interest (General Practice respiratory Read code) (table 5.2c). However, there was no significant association between above-threshold exposure to PM_{10} and the occurrence of a respiratory Read code in General Practice (p=0.559) and this lack of association remained throughout the model building process. Four significant main effects remained in the final model along with four interaction terms.

Table 5.2c. Final logistic regression model, patients with a respiratory Read code recorded in General Practice data, entire cohort, 16 June 2011 - 11 August 2011

		Odds Ratio	P-value	95% CI*
Main effects				
Sex	Male	1.00	-	-
	Female	1.47	0.000	(1.27 - 1.70)
History of respiratory Read code in General Practice	No	1.00	-	-
	Yes	4.08	0.000	(3.46 - 4.83)
History of an emergency admission for a respiratory condition**	No	1.00	-	
	Yes	2.03	0.000	(1.57 - 2.61)
Patient on QOF register for asthma	No	1.00	-	
	Yes	2.64	0.000	(2.12 - 3.28)
Patient on QOF register for COPD	No	1.00	-	
	Yes	9.55	0.000	(6.96 - 13.10)
Interactions				
Patient on QOF register for asthma and patient on QOF register for COPD		13.86	0.000	(9.42 - 20.42)
Patient on QOF register for asthma and history of respiratory Read code in General Practice		7.77	0.000	(6.31 - 9.55)
Patient on QOF register for COPD and history of respiratory Read code in General Practice		16.39	0.000	(12.69 - 21.16)
History of respiratory Read code in General Practice and sex		4.48	0.000	(3.83 - 5.23)

Produced by Public Health Wales Observatory, using GP data, WDS (NWIS), PEDW (NWIS), ADDE (ONS) and exposure data (Met Office) via the SAIL databank

* CI = confidence interval
**Primary diagnosis on the admitting episode of care

5.3 Patients with a recorded cardiovascular Read code in General Practice data (total GP-registered population)

5.3.1 Direct standardised rates

Table 5.3a describes the direct age standardised rates of patients with a cardiovascular Read code appearing in their patient record. This analysis considers the entire GP-registered cohort. Rates were higher in the reference period compared to the study period for both males and females although not statistically significantly higher. The rates of events in males and females in both periods were comparable.

Table 5.3a: Patients with a recorded cardiovascular Read code(s), European age standardised rates per 1,000, all ages, Fforestfach residents, Selected periods**

	Females		Males		Persons	
	Crude rate (n)	EASR (95% CI*)	Crude rate (n)	EASR (95% CI*)	Crude rate (n)	EASR (95% CI*)
Reference period	7.6 (158)	8.5 (7.2 - 10.0)	6.3 (129)	7.9 (6.5 - 9.4)	7.0 (287)	8.2 (7.3 - 9.2)
Study period	6.7 (138)	7.2 (6.1 - 8.6)	5.8 (118)	7.2 (5.9 - 8.6)	6.2 (256)	7.1 (6.3 - 8.1)

Produced by Public Health Wales Observatory, using GP data and WDS (SAIL databank)
*CI = confidence interval
**Reference period (16 June - 11 August 2010), study period (16 June - 11 August 2011)

5.3.2 Logistic regression model

Table 5.3b describe the variables considered in the logistic regression model.

Having a General Practice cardiovascular Read code was associated with all variables except above-threshold exposure to PM_{10}, sex and history of an emergency admission for a respiratory condition. Above-threshold exposure to PM_{10} did not contribute significantly to the final logistic regression model, however, five main effects and four interaction terms remained significant (table 5.3c). The odds ratios for some main effects and interaction terms are large due to the small cohort, particularly when considering the interaction between age group and the presence of a cardiovascular Read code. The confidence intervals associated with these odds ratios indicate a high level of uncertainty in the estimate and caution should be exercise when interpreting the results.

Table 5.3b. Descriptive analysis of independent variables and their univariate association with the outcome (presence of a General Practice cardiovascular Read code)

Variable description		General Practice cardiovascular Read code			
		No	**%**	**Yes**	**%**
Number of days that exposure to PM_{10} exceeds 50 µg/m^3 (24-hour average)	0	23,175	(99.3)	153	(0.7)
	1-2	10,323	(99.4)	61	(0.6)
	3+	7,272	(99.4)	42	(0.6)
Age group	0-24†	13,541	(99.9)	11	(0.1)
	25-34	5,680	(99.7)	17	(0.3)
	35-44	5,527	(99.4)	33	(0.6)
	45-54	5,636	(99.2)	45	(0.8)
	55-64	4,479	(99.0)	45	(1.0)
	65-74	3,048	(98.7)	41	(1.3)
	75+	2,859	(97.8)	64	(2.2)
Sex	Male	20,195	(99.4)	118	(0.6)
	Female	20,575	(99.3)	138	(0.7)
Patient in last year of life	No	40,446	(99.4)	247	(0.6)
	Yes	324	(97.3)	9	(2.7)
History of an emergency admission for a respiratory condition*	No	40,258	(99.4)	251	(0.6)
	Yes	512	(99.0)	5	(1.0)
History of an emergency admission for a cardiovascular condition*	No	40,461	(99.4)	235	(0.6)
	Yes	309	(93.6)	21	(6.4)
History of respiratory Read code in General Practice	No	31,507	(99.4)	183	(0.6)
	Yes	9,263	(99.2)	73	(0.8)
History of cardiovascular Read code in General Practice	No	39,347	(99.5)	204	(0.5)
	Yes	1,423	(96.5)	52	(3.5)
Patient on QOF register for COPD	No	39,757	(99.4)	238	(0.6)
	Yes	1,013	(98.3)	18	(1.7)
Patient on QOF register for asthma	No	37,272	(99.4)	223	(0.6)
	Yes	3,498	(99.1)	33	(0.9)
Patient on QOF register for atrial fibrillation	No	40,185	(99.4)	233	(0.6)
	Yes	585	(96.2)	23	(3.8)
Patient on QOF register for heart failure	No	39,871	(99.4)	236	(0.6)
	Yes	899	(97.8)	20	(2.2)
Patient on QOF register for hypertension	No	35,470	(99.6)	158	(0.4)
	Yes	5,300	(98.2)	98	(1.8)
Patient on QOF register for stroke	No	39,962	(99.4)	236	(0.6)
	Yes	808	(97.6)	20	(2.4)
Patient on QOF register for CHD	No	39,218	(99.5)	207	(0.5)
	Yes	1,552	(96.9)	49	(3.1)
	Total	**40,770**	(99.4)	**256**	(0.6)

Produced by Public Health Wales Observatory, using GP data, WDS (NWIS), PEDW (NWIS), ADDE (ONS) and exposure data (Met Office) via the SAIL databank

*Primary diagnosis on the admitting episode of care

† age groups have been combined to suppress small values for extraction from the SAIL gateway

Table 5.3c. Final logistic regression model, patients with a cardiovascular Read code recorded in General Practice data, entire cohort, 16 June 2011 - 11 August 2011

		Odds Ratio	P-value	95% CI*
Main effects				
Age group	0-14	1.00	-	-
	15-24	5.05	0.043	(1.05 - 24.31)
	25-34	8.47	0.005	(1.89 - 37.86)
	35-44	22.03	0.000	(5.27 - 92.10)
	45-54	22.36	0.000	(5.36 - 93.27)
	55-64	25.30	0.000	(6.04 - 106.03)
	65-74	25.93	0.000	(6.08 - 110.56)
	75+	49.77	0.000	(11.86 - 208.85)
History of cardiovascular Read code in General Practice	No	1.00	-	-
	Yes	502.18	0.000	(41.28 - 6,109.17)
History of an emergency admission for a cardiovascular condition**	No	1.00	-	
	Yes	12.04	0.000	(5.29 - 27.38)
Patient on QOF register for coronary heart disease	No	1.00	-	
	Yes	2.23	0.000	(1.54 - 3.23)
Patient on QOF register for hypertension	No	1.00	-	
	Yes	1.64	0.004	(1.17 - 2.29)
Interactions				
Age group and history of cardiovascular Read code in General Practice	0-14	-	-	-
	15-24	65.23	0.001	(5.82 - 731.43)
	25-34	196.86	0.000	(37.55 - 1,032.04)
	35-44	54.00	0.000	(7.46 - 390.85)
	45-54	185.50	0.000	(39.68 - 867.13)
	55-64	142.15	0.000	(29.91 - 675.49)
	65-74	146.82	0.000	(31.11 - 692.94)
	75+	67.94	0.000	(13.42 - 344.01)
Patient on QOF register for CHD and history of an emergency admission for a cardiovascular condition		6.17	0.000	(2.32 - 16.42)
Patient on QOF register for hypertension and history of cardiovascular Read code in General Practice		379.96	0.000	(29.14 - 4,954.83)
History of cardiovascular Read code in General Practice and history of an emergency admission for a cardiovascular condition		1576.54	0.000	(116.29 - 21,372.32)

Produced by Public Health Wales Observatory, using GP data, WDS (NWIS), PEDW (NWIS), ADDE (ONS) and exposure data (Met Office) via the SAIL databank

*CI = confidence interval
**Primary diagnosis on admitting episode

5.4 Patients with a recorded respiratory Read code in General Practice data (patients with asthma)

5.4.1 Direct standardised rates

Table 5.4a describes the direct age standardised rates of respiratory Read codes occurring in the records of patients with asthma in the two selected periods. Males and females that were on the QOF register for asthma had a higher rate of a respiratory Read code appearing in their patient record during the study period than in the reference period; however, neither were statistically significantly higher. As with the total GP-registered population, females with asthma had a higher rate of recorded respiratory Read codes than males in both periods; however, this was not statistically significantly higher.

Table 5.4a: Patients with a recorded respiratory Read code(s), asthma patients, European age standardised rates per 1,000, all ages, Fforestfach residents, Selected periods**

	Females		Males		Persons	
	Crude rate (n)	**EASR (95% CI*)**	**Crude rate (n)**	**EASR (95% CI*)**	**Crude rate (n)**	**EASR (95% CI*)**
Reference period	113.9 (234)	113.2 (97.9 - 130.1)	87.7 (140)	95.1 (79.2 - 113.0)	102.4 (374)	106.0 (95.1 - 117.8)
Study period	124.0 (249)	118.0 (102.3 - 135.2)	94.6 (144)	104.8 (85.8 - 126.3)	111.3 (393)	113.5 (101.9 - 126.0)

Produced by Public Health Wales Observatory, using GP data and WDS (SAIL databank)
*CI = confidence interval
**Reference period (16 June - 11 August 2010), study period (16 June - 11 August 2011)

5.4.2 Logistic regression model

Table 5.4b describes the variables considered in the regression model for asthma patients.

Table 5.4b. Descriptive analysis of independent variables and their univariate association with the outcome (presence of a General Practice respiratory Read code: patients on QOF register for asthma only)

Variable Description		**General Practice respiratory Read code**	
		No (%)	**Yes (%)**
Number of days that exposure to PM_{10} exceeds 50 $\mu g/m^3$ (24-hour average)	0	1,825 (90.2)	198 (9.8)
	1-2	765 (88.0)	104 (12.0)
	3+	548 (85.8)	91 (14.2)
Age group	0-14	371 (88.8)	47 (11.2)
	15-24	385 (92.5)	31 (7.5)
	25-34	412 (92.8)	32 (7.2)
	35-44	461 (92.4)	38 (7.6)
	45-54	483 (88.5)	63 (11.5)
	55-64	425 (87.6)	60 (12.4)
	65-74	315 (84.5)	58 (15.5)
	75+	286 (81.7)	64 (18.3)
Sex	Male	1,379 (90.5)	144 (9.5)
	Female	1,759 (87.6)	249 (12.4)
Patient in last year of life	No	3,101 (89.1)	381 (10.9)
	Yes	37 (75.5)	12 (24.5)
History of an emergency admission for a respiratory condition*	No	3,045 (89.3)	366 (10.7)
	Yes	93 (77.5)	27 (22.5)
History of an emergency admission for a cardiovascular condition*	No	3,092 (88.9)	385 (11.1)
	Yes	46 (85.2)	8 (14.8)
History of respiratory Read code in General Practice	No	1,579 (93.5)	110 (6.5)
	Yes	1,559 (84.6)	283 (15.4)
History of cardiovascular Read code in General Practice	No	2,993 (89.4)	355 (10.6)
	Yes	145 (79.2)	38 (20.8)
Patient on QOF register for COPD	No	2,844 (90.7)	290 (9.3)
	Yes	294 (74.1)	103 (25.9)
Patient on QOF register for atrial fibrillation	No	3,077 (89.1)	378 (10.9)
	Yes	61 (80.3)	15 (19.7)
Patient on QOF register for heart failure	No	3,040 (89.0)	374 (11.0)
	Yes	98 (83.8)	19 (16.2)
Patient on QOF register for hypertension	No	2,543 (89.5)	297 (10.5)
	Yes	595 (86.1)	96 (13.9)
Patient on QOF register for stroke	No	3,044 (89.0)	375 (11.0)
	Yes	94 (83.9)	18 (16.1)
Patient on QOF register for CHD	No	2,955 (89.6)	344 (10.4)
	Yes	183 (78.9)	49 (21.1)
Total		**3,138 (88.9)**	**393 (11.1)**

Produced by Public Health Wales Observatory, using GP data, WDS (NWIS), PEDW (NWIS), ADDE (ONS) and exposure data (Met Office) via the SAIL databank

*Primary diagnosis on the admitting episode of care

For patients on the QOF register for asthma, having a General Practice respiratory Read code recorded was associated with 11 of the 14 variables considered in our model, including above-threshold exposure to PM_{10} (p=0.006). Above-threshold exposure to PM_{10} remained significant throughout the modelling process and remained in the final model (table 5.4c). It can be seen that whilst adjusting for the confounding effects of the other variables in our model, asthma patients exposed to above-threshold concentrations of PM_{10} for 3 or more days had 38% increased odds of a General Practice respiratory Read code compared to asthma patients not exposed to any days of above-threshold concentrations of PM_{10} (OR=1.38, 95% CI (1.05-1.82), p=0.021). There was an apparent dose-response relationship with increasing days of above-threshold exposure to PM_{10}; although the increased odds in asthma patients with 1 to 2 days above-threshold exposure to PM_{10} concentrations was not statistically significantly different when compared to asthma patients not exposed to any days of above-threshold concentrations of PM_{10} (OR=1.23, p=0.121).

Table 5.4c. Final logistic regression model, patients with a respiratory Read code recorded in General Practice data, asthma patients, 16 June 2011 - 11 August 2011

		Odds Ratio	P-value	95% CI*
Main effects				
Number of days that exposure to PM_{10} exceeds 50 $\mu g/m^3$ (24-hour average)	0	1.00	-	-
	1-2	1.23	0.121	(0.95 - 1.59)
	3+	1.38	0.021	(1.05 - 1.82)
Sex	Male	1.00	-	-
	Female	1.27	0.038	(1.01 - 1.58)
History of respiratory Read code in General Practice	No	1.00	-	-
	Yes	2.46	0.000	(1.89 - 3.19)
History of cardiovascular Read code in General Practice	No	1.00	-	-
	Yes	1.64	0.015	(1.10 - 2.44)
Patient on QOF register for COPD	No	1.00	-	-
	Yes	4.56	0.000	(2.63 - 7.90)
Patient on QOF register for CHD	No	1.00	-	-
	Yes	1.53	0.022	(1.06 - 2.20)
Interactions				
Patient on QOF register for COPD and history of respiratory Read code in General Practice		5.29	0.000	(3.77 - 7.42)

Produced by Public Health Wales Observatory, using GP data, WDS (NWIS), PEDW (NWIS), ADDE (ONS) and exposure data (Met Office) via the SAIL databank

* CI = confidence interval

Other variables identified as important in predicting the occurrence of a General Practice respiratory Read code in asthma patients along with above-threshold exposure were sex, history of respiratory Read code in General Practice, history of cardiovascular Read code in General Practice and being on the QOF register for COPD and CHD.

5.5 Patients with a recorded respiratory Read code in General Practice data (patients with COPD)

5.5.1 Direct standardised rates

Table 5.5a describes the direct age standardised rates in COPD patients in the two selected periods. The analysis was restricted to patients aged over 50 due to very small number of patients with COPD who were under 50 years of age. Females on the QOF register for COPD had a higher rate of respiratory Read code recorded on their patient records than males on the register, for both time periods. For males on the QOF register for COPD, there was a statistically significantly higher rate of respiratory Read code recorded on their patient records during the study period compared to the reference period. The same was true for females but the difference was not statistically significant.

Table 5.5a: Patients with a recorded respiratory Read code(s), COPD patients, European age standardised rates per 1,000, all ages, Fforestfach residents, Selected periods**

	Females		Males		Persons	
	Crude rate (n)	EASR (95% CI*)	Crude rate (n)	EASR (95% CI*)	Crude rate (n)	EASR (95% CI*)
Reference period	207.0 (100)	205.9 (165.2 - 253.1)	204.0 (92)	181.2 (142.8 - 226.0)	205.6 (192)	199.9 (170.1 - 233.0)
Study period	243.4 (120)	232.4 (190.2 - 280.7)	241.7 (109)	252.6 (198.7 - 314.7)	242.6 (229)	236.7 (204.1 - 272.7)

Produced by Public Health Wales Observatory, using GP data and WDS (SAIL databank)
*CI = confidence interval
**Reference period (16 June - 11 August 2010), study period (16 June - 11 August 2011)

5.5.2 Logistic regression model

Table 5.5b describes the variables considered in the regression model for COPD patients.

Table 5.5b. Descriptive analysis of independent variables and their univariate association with the outcome (presence of a General Practice respiratory Read code: patients on QOF register for COPD only)

Variable description		General Practice respiratory Read code	
		No (%)	Yes (%)
Number of days that exposure to PM_{10} exceeds 50 $\mu g/m^3$ (24-hour average)	0	436 (77.4)	127 (22.6)
	1-2	188 (75.8)	60 (24.2)
	3+	165 (75.0)	55 (25.0)
Age group	0-54†	131 (81.4)	30 (18.6)
	55-64	219 (78.5)	60 (21.5)
	65-74	214 (75.6)	69 (24.4)
	75+	225 (73.1)	83 (26.9)
Sex	Male	381 (77.0)	114 (23.0)
	Female	408 (76.1)	128 (23.9)
Patient in last year of life	No	745 (77.0)	223 (23.0)
	Yes	44 (69.8)	19 (30.2)
History of an emergency admission for a respiratory condition*	No	739 (77.4)	216 (22.6)
	Yes	50 (65.8)	26 (34.2)
History of an emergency admission for a cardiovascular condition*	No	762 (76.6)	233 (23.4)
	Yes	27 (75.0)	9 (25.0)
History of respiratory Read code in General Practice	No	244 (80.5)	59 (19.5)
	Yes	545 (74.9)	183 (25.1)
History of cardiovascular Read code in General Practice	No	709 (77.7)	203 (22.3)
	Yes	80 (67.2)	39 (32.8)
Patient on QOF register for asthma	No	495 (78.1)	139 (21.9)
	Yes	294 (74.1)	103 (25.9)
Patient on QOF register for atrial fibrillation	No	739 (76.6)	226 (23.4)
	Yes	50 (75.8)	16 (24.2)
Patient on QOF register for heart failure	No	713 (76.3)	221 (23.7)
	Yes	76 (78.4)	21 (21.6)
Patient on QOF register for hypertension	No	502 (77.2)	148 (22.8)
	Yes	287 (75.3)	94 (24.7)
Patient on QOF register for stroke	No	714 (76.9)	214 (23.1)
	Yes	75 (72.8)	28 (27.2)
Patient on QOF register for CHD	No	647 (77.1)	192 (22.9)
	Yes	142 (74.0)	50 (26.0)
	Total	**789 (76.5)**	**242 (23.5)**

Produced by Public Health Wales Observatory, using GP data, WDS (NWIS), PEDW (NWIS), ADDE (ONS) and exposure data (Met Office) via the SAIL databank

*Primary diagnosis on the admitting episode of care

† age groups have been combined to suppress small values for extraction from the SAIL gateway

Ten of the 14 variables considered in the model were not statistically significantly associated with the occurrence of a General Practice respiratory Read code for patients on the QOF register for COPD in the univariate analysis. One of those found to not to be statistically significantly associated was above-threshold exposure to PM_{10} (p=0.734). Only two significant main effects remained in the final logistic regression model, age group and history of cardiovascular Read code in General Practice (table 5.5c). It can be seen that COPD patients aged 75 and over had over 5.8 times the odds of a General Practice respiratory Read code compared to COPD patients aged under 45 (OR=5.81, p=0.004).

Table 5.5c. Final logistic regression model, patients with a respiratory Read code recorded in General Practice data, COPD patients, 16 June 2011 - 11 August 2011

		Odds Ratio	P-value	95% CI*
Main effects				
Age group	0-44	1.00	-	-
	45-54	5.38	0.008	(1.55 - 18.68)
	55-64	4.37	0.016	(1.32 - 14.54)
	65-74	5.06	0.008	(1.53 - 16.76)
	75+	5.81	0.004	(1.76 - 19.15)
History of cardiovascular Read code in General Practice	No	1.00	-	-
	Yes	2.35	0.019	(1.09 - 2.50)

Produced by Public Health Wales Observatory, using GP data, WDS (NWIS), PEDW (NWIS), ADDE (ONS) and exposure data (Met Office) via the SAIL databank

*CI = confidence interval

6 Discussion

This report documents the change in the number of patients that had a respiratory or cardiovascular Read code recorded in their General Practice patient record in the eight weeks following the Fforestfach fire. The analysis found no evidence of a significant association between above-threshold exposure to PM_{10} and recorded General Practice respiratory events or cardiovascular events in the total GP-registered population, after adjustment for other factors. The analysis also found no evidence of a significant association between above-threshold exposure to PM_{10} and recorded General Practice respiratory events in patients registered as having COPD. However, the limitations of the study must be considered when interpreting these results (see section 6.1).

The analysis did find a significant association between above-threshold exposure to PM_{10} and recorded General Practice respiratory events in patients on the asthma register. Patients with asthma that were exposed to a 24 hour mean concentrations of PM_{10} that exceeded 50µg/m^3 for 3 or more days experienced a 38% increase in odds of a General Practice respiratory Read code being recorded in the eight weeks following the fires ignition, compared to asthma patients that were not exposed to any days of above-threshold concentrations of PM_{10} (OR=1.38, 95% CI (1.05-1.82), p=0.021); meaning that patients with asthma who were exposed to 3 or more days of above threshold concentrations of PM_{10} were 38% more likely to have contacted their GP about a respiratory complaint during the study period than those patients with asthma that were estimated to have been exposed for zero days. The finding is consistent with the COMEAP advice presented in table 1.2b indicating those with chronic respiratory conditions are more vulnerable to the ill-effects of the exposure.

As might be expected, when considering General Practice respiratory complaints in the total GP-registered population, a diagnosis of COPD or asthma, or a history of a primary or secondary care event relating to a respiratory condition, were important predictors of the occurrence of a respiratory Read code in a patient's record, irrespective of the category of exposure (table 4.2c). Asthma patients with Coronary Heart Disease (CHD) or a history of a cardiovascular Read code recorded on their patient record were also more likely to experience the outcome. In COPD patients, a history of a cardiovascular Read code recorded on their patient record and age were strongly associated with the outcome. Those in the higher age category of 75+ were between 1.76 and 19.15 times more likely to have a respiratory Read code recorded on the patient record than those aged 0-44 (tables 5.3c and 5.4c). Due to small numbers it was not possible to examine the impact of above-threshold exposure in those patients with multiple chronic conditions.

The comparison of directly standardised rates (at the time of the fire and during the same period one year previously) demonstrated an increase in rates of General Practice respiratory events in the total GP-registered population, statistically significantly so for females. The comparison of rates also found a significant increase in General Practice respiratory events within males appearing on the QOF COPD register. Both males and females with asthma showed an increased rate but this was not statistically significant. The increase in the rate of respiratory conditions provides some evidence that people that were exposed to days of above-threshold concentrations of PM_{10} suffered an increase in ill health as a result, although this type of analysis carries a number of inherent limitations (discussed below).

When looking at the appearance of cardiovascular Read codes in General Practice patient records, no association with above-threshold exposure to PM_{10} was found. Unlike respiratory events, the number of cardiovascular events was too small to stratify the analysis into at risk groups so it was not possible to examine the effects on specific population sub-groups. Additionally, it is possible that patients with existing cardiovascular conditions might have experienced increased ill-health; however, it was not possible to perform the analysis on the relatively small study population with these conditions. Although evidence suggests that above-threshold exposure to PM_{10} is associated with cardiovascular complaints, it is thought that constituent particles towards the lower end of the size spectrum, particularly $PM_{2.5}$ and fine particulate matter, are responsible for the majority of cardiovascular complaints. Being on the QOF register for CHD or hypertension, or a history of an event relating to a cardiovascular condition in primary or secondary care were important variables for predicting the occurrence of a cardiovascular Read code appearing in a patients record within the study period, irrespective of the category of exposure (table 5.3c). As expected, increasing age showed a significant association with increasing risk of cardiovascular Read codes, irrespective of category of exposure.

6.1 Study strengths and limitations

This study provides a unique insight into the potential health impacts of real-life population-level exposure to a plume of smoke from a rubber tyre. Tyre fires are not unusual and acute population exposures of this nature are likely to occur again. The results of this natural experiment are therefore likely to be applicable to future public health emergencies.

The use of the SAIL databank proved a major strength for this study, and is unlikely to be replicated elsewhere. No other country has such a well-developed privacy protecting system that allows the impact of environmental incidence to be evaluated. Through the use of the SAIL databank this study was able to obtain individual level exposure and outcome data for the entire population of the study area, rather than a sample, greatly increasing the sample size and reducing the potential for bias from selected reporting. The power of the study was therefore maximised, although it remains constrained by the size of the exposed population.

The quality of the available General Practice data, obtained from the GP record system via the SAIL databank, is another strength of the study. Detailed, objective, individual-level health outcome data was available, covering a range of outcomes of interest as well as relevant medical history.

The duration and coverage of the data available allowed the study to benefit from the use of two separate study designs; a before and after design and a population cohort design. The combination of these provides a more comprehensive picture of the health impacts of the fire and reduces the potential that confounding factors, such as seasonality, and selection bias may have influenced the results.

As with all studies however, there are a number of limitations to consider with respect to this analysis. An important consideration is the eight week outcome period during which General Practice activity was examined. During the study design stage the length of the study period was discussed in some depth. The period needed to be long enough to capture the majority of health impacts feasibly associated with the fire and allow time for these to be reported to the GP, either through acute or planned appointments; this needed to be balanced against the possible dilution effect of an extended period on any association with the most acute impacts. It was anticipated that General Practice contact due to the psychological effects of exposure to the plume (e.g. anxiety, depression) would also be analysed and that these effects in particular may require a longer observation period; it was therefore felt that an 8 week study period would provide the most appropriate balance and allow time to capture both physical and mental health impacts. Unfortunately, due to very low uptake of a survey conducted to examine the psychological impacts of the fire, it was not possible to examine the impacts on mental health in the final study. It has been suggested that the majority of the physical health impacts of the fire were likely to occur during the period that the fire was burning and in the 3-5 days after it was extinguished; using the eight week study period for these more acute physical health outcomes may therefore have diluted any association between outcomes and exposure, increasing the likelihood of type 2 error.

It is important to recognise that there are a number of factors that influence healthcare use that it was not possible to account for in this analysis. Temperature, circulating infections and pollen count, for example, are considered important predictive factors as they are known to exacerbate respiratory illness, however it was not possible to include them in the analysis. These more temporal factors are more likely to have influenced the comparison of age standardised rates, where the control population was taken from the previous year, than the logistic regression analysis, where the controls were unexposed individuals from the same time period and therefore similar levels of these factors. Where possible, potentially influential chronic conditions, such as COPD, cardiovascular disease and asthma, were accounted for in the analysis.

There are some limitations with the estimated exposure measure used for this analysis. Firstly, the exposure data are based on complex plume modelling rather than actual measurements. However, during the time of the fire three air quality monitoring stations were distributed in the vicinity of the fire and data from these were used to assess the goodness of fit of the plume modelling. In general the modelling agreed with the monitoring stations, however there were some differences. This may have resulted in some under/over estimate of exposure.

The evidence suggests that fires involving rubber tyres are likely to produce a number of other toxic pollutants (Environment Agency 2009; Wakefield, 2010). The exposure model only considered the distribution of PM_{10}, however it is likely that any pollutants would be dispersed in a similar pattern albeit with differing geographical ranges due to particle size. Therefore the exposure boundaries generated by the Met Office are likely to reflect estimated exposure to the plume in general. The results of this analysis may therefore reflect exposure to a variety of pollutants and not just PM_{10}.

Exposure data are based on a person's home address which does not account for day to day movements. This would affect some groups more than others. For example, people in full time employment were likely to be away from their residence for a significant proportion of the working day; conversely, older or housebound residents would be less likely to be away from their homes. There are also likely to be other differences in population sub groups not accounted for in the regression models. People with chronic conditions would have been strongly advised to stay indoors and minimise their exposure and some may have sought alternative accommodation and potentially avoid exposure altogether; this misclassification may have resulted in an over-estimation of their true exposure levels, reducing the likelihood of finding a statistically significant link to the exposure. Additionally, there may be a proportion of the population that were not resident at their home address during the period of the fire. For example, given the time of year, the chance of a person being on holiday was higher than usual.

Estimated exposure was based on an outdoor 24-hour mean, but did not account for other factors, such as the insulating properties of each individual's house which would have potentially altered exposure during time spent indoors. Exposure days were based on a 24-hour mean, however in some cases a person may have been exposed to short periods where the concentrations of PM_{10} were much higher than this mean.

This analysis used the number of days that a person was likely to have been exposed to a mean concentrations of PM_{10} exceeding 50 μg/m^3 as its main exposure. Alternative measures of exposure, such as categorising exposure by the COMEAP bands, or maximum exposure concentration, were considered but would have reduced the population size in each exposure category and reduced the power of the study. For example, the population for which the 3 week mean concentration of PM_{10} exceeded guideline annual mean concentration levels of 40 μg/m^3 (World Health Organisation, 2013) was relatively small, and did not necessarily reflect the short sharp peaks in exposures that the population were likely to have been subjected to. Additionally, care needs to be taken when using modelled exposure data which may lack the precision needed for a more detailed breakdown of exposure. The method chosen yielded a larger population, increasing the likelihood of detecting any possible increase in General Practice respiratory complaints which could be attributed to the fire.

A number of studies have demonstrated an association between deprivation and negative health outcomes following an air pollution event; this may be due to a number of factors including health inequalities and smoking status. It is possible that those in the less deprived groups would have been in a better position to re-locate during the event, reducing their exposure, although it was not possible to examine this here. This study did not account for differences in deprivation status because there was no suitable individual-level measure for deprivation; the Welsh Index of Multiple Deprivation (WIMD) provides an area based measure of deprivation but due to the small geographic study area there would have been little variation. Many of the other factors considered, such as history of primary and secondary care use, would take account of deprivation effects resulting in healthcare activity.

The analysis considered permanent residents that fell within exposure boundaries that were currently registered to a GP practice submitting data to the SAIL databank. This did not included temporary residents and visitors, or at risk groups such as homeless people. Swansea is also a university city and therefore could potentially contain a number of residents that were not registered with their local GP. The study also did not account for exposures to non-residents who may have experienced ill health as a result of above-threshold exposure to PM_{10}. Carmarthen Road in the Fforestfach area is a busy main road which accommodates a large number of commuters who would have been exposed to above-threshold concentrations of PM_{10} during their commute. Additionally, Fforestfach is an industrial area and there will have been a large number of people working in the area that were exposed to above-threshold concentrations of PM_{10} that were also not classified as such. Being able to classify exposure based on residence only may have led to an under-estimation of the number of individual exposed to above-threshold concentrations of PM_{10} and therefore an underestimation of the true impact of the fire; where misclassified individuals resided within one of the lower exposure boundaries included in the study, this would also have had the effect of reducing the studies ability to detect a significant impact of exposure.

There were also a number of limitations in terms of capturing the outcomes of interest. This could occur if patients attend a GP practice not submitting data to the SAIL databank. However, this is unlikely as the GP practices nearest the fire were included within the dataset and the majority of the local population would be expected to access these GP practices. A number of people also moved in and out of the area during the study period and therefore had a partial exposure; these people were excluded from the study but may have suffered ill health from above-threshold exposure to PM_{10}.

The use of Read coding to identify events raises a number of important considerations. In some cases events may only have been captured in the free text fields, rather than through Read codes, which were not available for analysis. There would have been some variation between the Read codes used by different GP's; there are a number of potential Read codes available and it is entirely possible that each GP would record an acute respiratory event differently. To try and compensate for this a broad definition was used to identify outcomes but this may have introduced other difficulties. Read coding is often not standardised and it can be difficult to distinguish between different types of General Practice activity such as telephone consultations and nurse visits. However, GP systems are operational systems and as such the recording of a Read code should accurately represent activity that is related to the specific Read code that has been recorded.

Using General Practice Read codes also limits the impact that would be detectable. Above-threshold exposure to PM_{10} may have also induced minor symptoms that the patient did not feel warranted a visit to a GP practice and so would not have been captured in this analysis. Additionally, some patients, such as those with COPD, may also have access to medication which could ease symptoms and prevent the need for a GP consultation. Similarly, patients who visited secondary care services with more severe health impacts may not have been adequately recorded in the Read codes; however, the number emergency admissions for either a cardiovascular or respiratory complaint were too small for a meaningful analysis and so this report has been restricted to General Practice activity.

The SAIL databank has great potential for epidemiological studies. This is thanks to the ability to anonymously match records across a number of routinely collected data. However, occasionally records may be incorrectly matched during the anonymisation process, or the data may contain duplicates (Randall et al, 2013). The risk of incorrect matching is reduced in this analysis as the majority of data used comes from NHS systems which have the benefit of NHS numbers allowing easier matching of records.

7 Conclusions

Findings from this report support the current health advice which states that individuals with certain chronic conditions may be more likely to experience symptoms when exposed to 24-hour mean concentrations of PM_{10} exceeding 50µg/m^3; but the risk of significant symptoms as a result such exposure in the general population is likely to be minimal.

After accounting for confounding variables, this report found no association between days of above-threshold exposure to PM_{10} and respiratory or cardiovascular events recorded in General Practice for the total GP-registered population. An increased rate of contact for respiratory symptoms was found for males on the COPD register, but this was no longer present after adjustment for confounding variables in the logistic regression.

A significant association was found between above-threshold exposure to PM_{10} and respiratory events recorded in General Practice for patients on the asthma register. This suggests that people with asthma living in areas with above-threshold PM_{10} concentrations at the time of the fire had increased contacts with their General Practice relating to respiratory conditions than those residing in areas that were not above threshold.

Despite the study limitations described, this report adds to the body of evidence around the health impacts of above-threshold exposure to PM_{10}. This report also demonstrates the ability to use SAIL data for public health research. Linked data provides a more detailed picture of an individual's experiences and use of General Practice data is a valuable asset allowing more detailed investigations of events of this type, as well as a range of other potential studies.

A summary of the report will be produced to aid the communication of these findings to the public.

8 References

Breslow N.E. & Day N.E. (eds) 1987. Statistical methods in cancer research: Volume II - the design and analysis of cohort studies. IARC Scientific Publication No. 82, International Agency for Research on Cancer, Lyon, pp. 61-64.

Brunt H & Russell D. 2012. Public Health risk assessment and air quality cell for a tyre fire, Fforestfach Swansea. Chemical Hazards and Poisons Report. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/203631/CHaP_Report_21.pdf [Accessed: 25 January 2016]

Canova, C., Dunster, C., et al. 2012. *PM10-induced hospital admissions for asthma and chronic obstructive pulmonary disease: the modifying effect of individual characteristics*. *Epidemiology* 23(4), pp. 607-615.

Carracedo-Martinez, E, Taracido, M., et al. 2010. *Case-crossover analysis of air pollution health effects: a systematic review of methodology and application. Environ Health Perspect* 118(8), pp.1173-1182. Available at: http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2920078/ [Accessed: 13 July 2013]

Committee on Medical Effects of Air Pollutants. 2011. *Review of the UK Air Quality Index: A report by the Committee on Medical Effects of Air Pollutants.* Available at: https://www.gov.uk/government/publications/comeap-review-of-the-uk-air-quality-index> [Accessed: 27 June 2013]

Department for Food, Environment and Rural Affairs. 2007. *The air quality strategy for England, Scotland, Wales and Northern Ireland*. Vol 1. (Cm 7169; NIA61/06-07) Norwich: TSO. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69336/pb12654-air-quality-strategy-vol1-070712.pdf [Accessed: 21 August 2014]

Dobson, A.J., Kuulasmaa, E.E., et al. 1991. *Confidence intervals for weighted sums of poisson parameters. Stat Med* 10(3), pp. 457-462.

Environment Agency. 2009. Review if emission factors for incident fires. Science Report SC060037/SR3. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/291186/scho0809bqut-e-e.pdf [Accessed: 25 January 2016]

Ford, D.V., Jones, K.H., et al. 2009. *The SAIL databank: building a national architecture for e-health research and evaluation. BMC Health Serv Res* [Online] 9 pp.157. Available at: http://www.biomedcentral.com/1472-6963/9/157 [Accessed: 27 June 2013]

Hoek, M. R., Bracebridge, S., et al. 2007. *Health impact of the Buncefield oil depot fire, December 2005 Study of accident and emergency case records*. *J Public Health* 29(3), pp. 298-302. Available at: http://jpubhealth.oxfordjournals.org/content/29/3/298.long [Accessed: 13 July 2013]

Hosmer, D.W., Leneshow, S., et al. 2013. *Applied logistical regression*. 3rd ed. Wiley Interscience.

Jaakkola, J.J.K. 2003. *Case-crossover design in air pollution epidemiology*. *Eur Respir J* 21(40), pp. 81-85. Available at: http://erj.ersjournals.com/content/21/40_suppl/81s.full.pdf+html [Accessed: 13 July 2013]

Jones A.R., Thomson D.J., et al. 2007. *The U.K. Met Office's next-generation atmospheric dispersion model, NAME III.* In Borrego C. and Norman A.-L. Eds. *Air pollution modeling and its application* XVII:

Proceedings of the 27th NATO/CCMS International Technical Meeting on Air Pollution Modelling and its Application, Banff, 24-29 October, 2004. Canada. Springer, pp. 580-589.

Karakatsani, A., Analitis, A., et al. 2012. *Particulate matter air pollution and respiratory symptoms in individuals having either asthma or chronic obstructive pulmonary disease: a European multicentre panel study. Environ Health* 11 pp.75. Available at: http://www.ehjournal.net/content/11/1/75 [Accessed: 6 July 2013]

Lyons, R.A, Jones, K.H., et al. 2009. *The SAIL databank: linking multiple health and social care datasets. BMC Med Inform Decis Mak* [Online] 9 pp.3. Available at: http://www.biomedcentral.com/1472-6947/9/3 [Accessed: 27 June 2013]

Maclure, M. and Mittleman, M.A., 2000. *Should we use a case-crossover design? Annu Rev Public Health* 21, pp. 193-221. Available at: http://www.annualreviews.org/doi/full/10.1146/annurev.publhealth.21.1.193?url_ver=Z39.88-2003&rfr_id=ori:rid:crossref.org&rfr_dat=cr_pub%3dpubmed [Accessed: 13 July 2013]

Martin, K.L., Hanigan, I.C., et al. 2013. *Air pollution from bushfires and their association with hospital admissions in Sydney, Newcastle and Wollongong, Austrailia 1994-2007. Aust N Z J Public Health* 37(3) pp. 238-3.

Peled, R., 2011. *Air pollution exposure: Who is at high risk? Atmos Environ* 45(10) pp. 1781-1785*.*

Ponce de Leon, A., Anderson, H.R., et al. 1996. *Effects of air pollution on daily hospital admissions for respiratory disease in London between 1987-88 and 1991-92. J Epidemiol Community Health* 50(1) pp. S63-S70. Available at: <http://jech.bmj.com/content/50/Suppl_1/s63.full.pdf+html?sid=6cf85991-938f-41f4-9574-185d8ef6944b> [Accessed: 15 July 2013]

Public Health Wales. 2011. *Advice to Fforestfach residents.* [Online]. Available at: http://www.wales.nhs.uk/sitesplus/888/news/19443 [Accessed: 27 June 2013]

Qiu, H., Yu, I.T.S., et al. 2013. *Season and humidity dependence of the effects of air pollution on COPD hospitalizations in Hong Kong. Atmos Environ* 76, pp. 74-80.

QOF business rules V25. [Online]. Available at: http://www.nhsemployers.org/PayAndContracts/GeneralMedicalServicesContract/QOF/DevelopingQOFbusinessrules/Pages/DevelopingtheQOFbusinessrules.aspx [Accessed: 16 October 2013]

Randall, S.M., Ferrante, A.M., et al. 2013. *The effect of data cleaning on record linkage quality. BMC Med Inform Decis Mak* [Online] 13 pp.64. Available at: http://www.biomedcentral.com/1472-6947/13/64 [Accessed: 29 June 2013]

Rodgers, S.E., Lyons, R.A., et al. 2009. *Residential anonymous linking fields (RALFs): a novel information infrastructure to study the interaction between the environment and individuals' health. J Public Health* 31(4), pp. 582-588. Available at: http://jpubhealth.oxfordjournals.org/content/31/4/582.long [Accessed: 15 July 2013]

Wakefield JC. 2010. *A toxicological review of the products of combustions*. Didcot: HPA. Available at: http://cvoed.imss.gob.mx/COED/home/normativos/DPM/archivos/HDRM/health_topics/chemical_safety/a_toxicological_review.pdf [Accessed 25 January 2016]

Whitaker, H.J., Hocine, M.N., et al. 2007. *On case-crossover methods for environmental time series data. Environmetrics* 18(2), pp. 151-171.

World Health Organisation. 2013. *Air pollution*. [Online]. Available at: http://www.who.int/topics/air_pollution/en/ [Accessed: 27 June 2013]

World Health Organisation. 2013. *Review of evidence on health aspects of air pollution REVIHAAP project.* Copenhagen: WHO. Available at: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/review-of-evidence-on-health-aspects-of-air-pollution-revihaap-project-final-technical-report [Accessed: 21 August 2014]

Zhu, W., Wang, J., et al. 2012. *Short-term effects of air pollution on lower respiratory diseases and forecasting by group method of data handling. Atmos Environ* 51, pp. 29-38.

9 Appendix

Substance	Detection limit	Equipment
Acrolein	250 ppb	Gasmet DX4030 FTIR Spectrometer
Ammonia	130 ppb	Gasmet DX4030 FTIR Spectrometer
Arsine	20 ppb	Gasmet DX4030 FTIR Spectrometer
Benzene	130 ppb	Gasmet DX4030 FTIR Spectrometer
1,3 butadiene	50 ppm	Gasmet DX4030 FTIR Spectrometer
Carbon monoxide	250 ppb	QRAE Plus Gas Sensor
Chlorine	100 ppb	QRAE Plus Gas Sensor
Ethylbenzene	80 ppb	Gasmet DX4030 FTIR Spectrometer
Formaldehyde	90 ppb	Gasmet DX4030 FTIR Spectrometer
Hydrogen bromide	3000 ppb	Gasmet DX4030 FTIR Spectrometer
Hydrogen chloride	200 ppb	Gasmet DX4030 FTIR Spectrometer
Hydrogen cyanide	350 ppb	Gasmet DX4030 FTIR Spectrometer
Hydrogen fluoride	200 ppb	Gasmet DX4030 FTIR Spectrometer
Hydrogen sulphide	3 ppb	Jerome 631-X Gold Film Sensor
Methyl isocyanate	250 ppb	Gasmet DX4030 FTIR Spectrometer
Nitrogen dioxide	400 ppb	Gasmet DX4030 FTIR Spectrometer
Particulate Matter (TSP, PM_{10}, $PM_{2.5}$, $PM_{1.0}$)	5 microgram/m^3	Turnkey OSIRIS Nephelometer
Phosgene	200 ppb	Gasmet DX4030 FTIR Spectrometer
Phosphine	200 ppb	Gasmet DX4030 FTIR Spectrometer
Sulphur dioxide	300 ppb	Gasmet DX4030 FTIR Spectrometer
Toluene	130 ppb	Gasmet DX4030 FTIR Spectrometer
Xylene	120 ppb	Gasmet DX4030 FTIR Spectrometer