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Monitoring the effect of air pollution episodes on health care consultations and ambulance call-outs in England during March/April 2014: A retrospective observational analysis☆

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ABSTRACT

There is an increasing body of evidence illustrating the negative health effects of air pollution including increased risk of respiratory, cardiac and other morbid conditions. During March and April 2014 there were two air pollution episodes in England that occurred in close succession. We used national real-time syndromic surveillance systems, including general practitioner (GP) consultations, emergency department attendances, telehealth calls and ambulance dispatch calls to further understand the impact of these short term acute air pollution periods on the health seeking behaviour of the general public. Each air pollution period was comparable with respect to particulate matter concentrations (PM_{10} and $PM_{2.5}$), however, the second period was longer in duration (6 days vs 3 days) and meteorologically driven 'Sahara dust' contributed to the pollution. Health surveillance data revealed a greater impact during the second period, with GP consultations, emergency department attendances and telehealth (NHS 111) calls increasing for asthma, wheeze and difficulty breathing indicators, particularly in patients aged 15–64 years. Across regions of England there was good agreement between air quality levels and health care seeking behaviour. The results further demonstrate the acute impact of short term air pollution episodes on public health and also illustrate the potential role of mass media reporting in escalating health care seeking behaviour.

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1. Introduction

The effect of ambient air pollution on human health is well documented. Short term exposure to pollutants can exacerbate underlying respiratory conditions e.g. asthma (Samoli et al., 2011), have a negative effect on lung function (Chen et al., 2015), and cause excess hospital admissions for respiratory and cardiovascular conditions (Atkinson et al., 2014).

In the United Kingdom (UK) there are occurrences of moderate air pollution episodes, and infrequent incidents when air pollution reaches high levels over one or more regions. During spring 2014, there were two short periods of widespread poor air quality across the UK, starting mid-March and lasting to early April. The meteorological driver behind these episodes was a high pressure system, which slowed the circulation of air across North West Europe (Dawson, 2014). This situation resulted in several days where high to very high levels of particulate air pollution were experienced across most regions of the UK. The breakdown of the pollutants comprised a combination of UK emissions, emissions from continental Europe and, during the second episode, 'Sahara dust'.

During these two air pollution episodes, Public Health England (PHE) used syndromic surveillance to monitor the impact of the pollution on health care service utilisation by the public, using

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primary care (general practitioner in hours and out of hours) consultations, emergency department (ED) attendances and telehealth (NHS 111) calls. These prospective surveillance data were used during the incident to provide situational awareness, and to inform media statements and public facing messages.

Here, we present a retrospective observational analysis of syndromic surveillance data monitored during the 2014 air pollution episodes, including regional and age breakdowns, augmenting the initial preliminary findings (Smith et al., 2015). We also present ambulance dispatch call data collected during the incident to assess the potential utility for these additional health data for syndromic surveillance during future air pollution episodes.

2. Methods

2.1. Study period

Two periods of poor air quality were included in the analysis when levels of air pollution were high or very high (7 or above on the 1–10 scale of the Daily Air Quality Index (Department for Environment Food and Rural Affairs, 2015b)). The first episode occurred from 12 to 14 March 2014 and the second two weeks later, from 29 March to 3 April 2014. Syndromic surveillance data were selected covering a period from 1 March to 30 April 2014.

2.2. Air quality data

Daily mean concentrations for particulate matter (PM_{10} and $PM_{2.5}$) were obtained from the UK Automatic Urban and Rural Network (AURN) air quality monitoring network of the Department for Environment, Food and Rural Affairs (DEFRA) for March and April 2014 (Department for Environment Food and Rural Affairs, 2015a; Muir et al., 2006). Data from nine urban background monitoring stations representative of population exposure to air pollution in England were included (Supplementary Table 1). Data for PM_{10} and $PM_{2.5}$ were not continuously available from all monitoring stations during the entire study period, however the data were included for the air pollution episodes.

The daily air quality index is divided into 4 bands (low, moderate, high and very high), with the boundaries between bands determined by the health effects following short-term exposure to air pollutants (Table 1).

2.3. Syndromic surveillance systems

Syndromic surveillance is the near real-time collection, analysis, interpretation and dissemination of health-related data to enable the early identification of the impact (or absence of impact) of potential health threats which require effective public health action (Triple S Project, 2012). PHE coordinates a suite of national syndromic surveillance systems and delivers a real-time syndromic surveillance service that has been described in detail elsewhere (Elliot et al., 2013). In brief, daily data are collected from a number of healthcare provider sources and analysed, interpreted and assessed using statistical algorithms incorporating a multi-level hierarchical mixed effects model that compares contemporaneous data to historical data to identify statistically significant activity (Morbey et al., 2014, 2015). These data are aggregated into a number of ‘syndromic indicators’ based upon symptoms and/or clinical diagnosis of disease.

Four national syndromic surveillance systems were used in this study (Table 2); general practitioner (GP) in hours (GPIH) and GP out of hours (GPOOH) consultations, sentinel ED attendances (EDSSS) and calls to the national NHS 111 telephone health line. The methods of data capture, analysis and statistical interpretation of daily syndromic surveillance data have been described in detail elsewhere (Elliot et al., 2013; Morbey et al., 2015). When analysing syndromic surveillance data at regional level, it is important to consider the population coverage of each system. The PHE syndromic surveillance systems had varying levels of national population coverage (Table 2) and this was further broken down by PHE Centre (region) to assess the regional coverage (Table 3). Certain systems e.g. EDSSS were sentinel in nature and therefore there was limited or no coverage in certain areas of the country.

2.4. Syndromic surveillance indicator data

A number of ‘syndromic indicators’ monitored by syndromic surveillance systems were selected based upon their potential sensitivity to exposure to air pollution. These indicators included respiratory symptoms, severe asthma, wheeze and difficulty breathing (Table 2). Daily syndromic surveillance data were obtained from each system broken down by age group (age groups 0–4, 5–14, 15–64, 65–74, and ≥75 years) and also by region. GPIH data were calculated as incidence rates per 100,000 registered patient population. It was difficult to calculate accurate patient denominators for the EDSSS and GPOOH systems due to problems defining the patient ‘catchment population’ for individual hospitals/EDs, and individual GPOOH service providers. Therefore, for the EDSSS and GPOOH syndromic indicator activity was calculated as a daily percentage of all the total activity (ED attendances/GPOOH consultations). NHS 111 calls were also presented as a percentage of total calls to compensate for call fluctuations at weekends and public holidays.

2.5. Ambulance dispatch call data

Daily ambulance call dispatch data were obtained from the London Ambulance Service (LAS) for March and April 2014. LAS provides emergency ambulance services to approximately 8 million people who live and work in the London area (London Ambulance Service, 2015). When a 999 ambulance call is received it is evaluated to determine whether or not an ambulance is required. Where an ambulance is dispatched the call is termed a ‘999 incident’, of which a smaller number are assigned as ‘category A’ (life threatening), that require the most urgent response. Calls are initially triaged to a provisional illness category (chief complaint) that alerts the ambulance crew to what they might expect. The crew assign the incident to a more detailed category once they have arrived at the scene of the emergency.

Table 1
Bandings for PM_{10} and $PM_{2.5}$ in daily air quality index.

Pollutant	Averaging period	Units	Low	Moderate	High	Very high
PM_{10}	24-h mean	$\mu g/m^3$	0–50	51–75	76–100	101 or more
$PM_{2.5}$	24-h mean	$\mu g/m^3$	0–35	36–53	54–70	71 or more

Table 2
PHE syndromic surveillance systems and associated reporting statistics.

Syndromic surveillance system	Reporting statistic	Population coverage	Indicators
NHS 111	Daily telehealth calls; calls for syndromic indicators as % of total calls	~54 million (100% England pop)	Difficulty breathing
GP in hours (GPIH)	Daily in hours (week days, daytime) GP consultation rates per 100,000 population	35 million (~60% England pop)	Severe asthma; wheeze
GP out of hours (GPOOH)	Daily out of hours and unscheduled care (weekends, evenings/nights, public holidays) GP consultations for syndrome as % of total consultations	~70% coverage of GPOOH activity across England	Asthma/wheeze/ difficulty breathing
Emergency department (EDSSS)	Daily emergency department attendances; attendances coded to indicator as % of total attendances	36 EDs across England and Northern Ireland	Asthma/wheeze/ difficulty breathing

Table 3
Approximate regional population coverage for each national syndromic surveillance system across England.

Region[a]	Approximate regional coverage			
	NHS 111	GPIH	GPOOH	EDSSS[b]
North West	100%	71%	–	8 (11%)
North East	100%	56%	–	0
Yorkshire and Humber	100%	52%	–	5 (18%)
East Midlands	100%	42%	–	0
West Midlands	100%	68%	–	0
East of England	100%	46%	–	4 (12%)
London	100%	68%	–	7 (22%)
South East	100%	58%	–	7
South West	100%	51%	–	2 (4%)

[a] Region is defined as a Public Health England Centre.
[b] Regional coverage for EDSSS is defined as number of participating emergency departments within that PHE Centre and the EDSSS total attendances as a percent of total ED attendances in that PHE Centre (England, 2015). –: Regional coverage for GPOOH is not available due to difficulties in calculating accurate denominators.

2.6. Trend analysis

Time series graphs were plotted for the rates/percentages of selected indicators (daily data including seven day moving average) by age group and region for each of the EDSSS, GPOOH, GPIH (where seven day moving averages were calculated to exclude weekend zero activity) and NHS111 surveillance systems. Ambulance dispatch calls were plotted as numbers of calls for total dispatches and also for respiratory symptoms (chief complaints).

2.7. Regional syndromic surveillance data analysis

Daily syndromic surveillance data were stratified by region across England (based upon PHE Centre boundaries). Selected indicators for the GPIH and NHS 111 systems were plotted by region and examined graphically against regional air pollution data. Regional analysis for the GPOOH and EDSSS systems were not undertaken due to insufficient and non-representative coverage across England.

2.8. Statistical analysis

Each PHE syndromic surveillance system is underpinned by a statistical algorithm that determines whether current activity is higher than expected. These statistical methods were based upon existing methodologies developed to provide multi-level mixed effects models to enable the detection of unusual syndromic activity across a wide range of syndromes, both nationally and locally (Morbey et al., 2015). The statistical algorithms also accounted for a range of variables including day of the week (accounting for increased activity at weekends), public holidays (resulting in increases in counts in GPOOH systems) and increases in total counts which could potentially affect the resulting indicator rates or proportions. Initially, retrospective statistical exceedances (alarms) generated prospectively during the air pollution period were noted. Additionally, an interrupted time series approach was taken to assess the probability of these statistical alarms occurring during the second air pollution period (29 March to 3 April 2014) compared to the periods surrounding the pollution period (7 days before and after) for each system and selected indicators. The ambulance dispatch data were a new data source and therefore there were no statistical tests underpinning these routine data.

3. Results

3.1. Air pollution

During the study period all regions (Defra Regions Representative sites) showed elevated levels of PM_{10} and $PM_{2.5}$ during the air pollution episodes (Fig. 1). There was a singular spike in daily levels of PM_{10} and $PM_{2.5}$ during the first episode, peaking on 13/14 March, and a double spike in the second, peaking on the 29 of March and 3 of April.

3.2. Syndromic surveillance by age group (England)

There were fluctuations in the trend of daily ED attendances for asthma/wheeze/difficulty breathing over the study period (Fig. 2). Attendances in the 0–4 and 5–14 years age groups increased before the first air pollution period (12–14 March). During the second episode (29 March – 3 April) ED attendances for the 5–14 age group increased, peaking on 6 April (n = 15 cases, 4.7% of attendances, 95% CI 2.8–7.5%). Older age groups appeared to be more affected during the second episode, in particular the 15–64 age group which increased sharply on 7 April (n = 38 cases, 1.3% of attendances, 95% CI 1.0–1.8%).

Analysing the daily trend for GPOOH daily consultations for difficulty breathing/asthma/wheeze illustrated that there were no obvious peaks in children corresponding to the first air pollution incident; increases in the 0–4 and 5–14 years age groups started in advance of the pollution episode. There was no trend in the 15–64 years age group during the first episode, however there was an increase in consultations during the second episode (Fig. 3). The highest percentage of GPOOH consultations for difficulty breathing/asthma/wheeze in this age group was recorded on 3 April, remaining high until 6 April, then returning to normal levels.

The analysis of daily NHS 111 difficulty breathing calls illustrated similar trends to GPOOH difficulty breathing/asthma/wheeze (Fig. 4). During the first pollution episode, calls in the 0–4 and 5–14 years age groups had increased in advance of the first episode. There was an increase in calls across all age groups during the second episode with the percentage of cases remaining high until 6

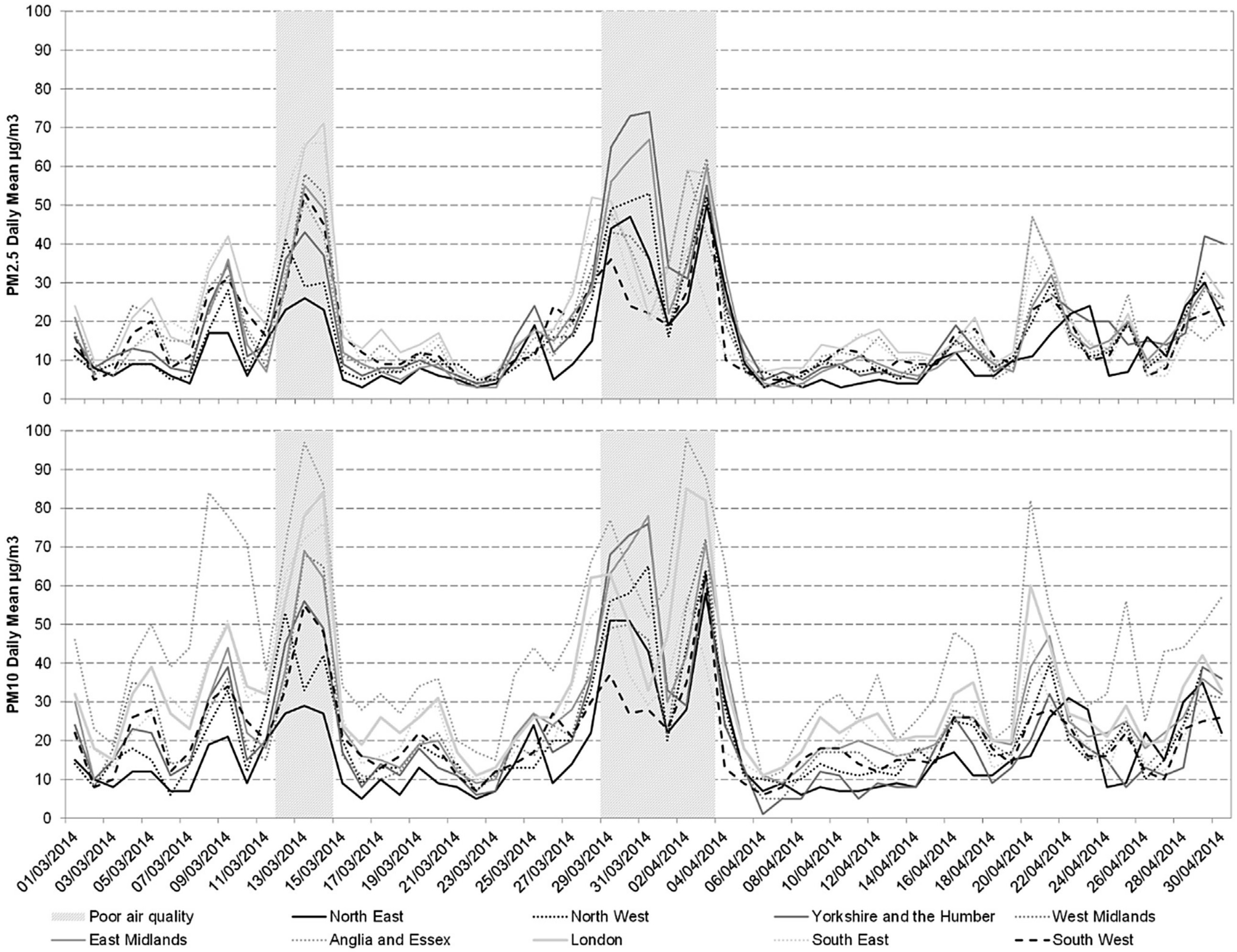

Fig. 1. $PM_{2.5}$ and PM_{10} daily mean levels (μg/m^3) over Defra regional sites during the study period (see Supplementary Table 1).

April after which they returned to normal levels. Compared to the first episode, the 15–64 years age group demonstrated the greatest difference in trend.

Daily GPIH consultation rates for severe asthma showed little change during the first episode, however, all age groups (excluding 0–4 years) showed an increase in consultations during the second episode (Fig. 5). Consultation rates peaked on Monday 7 April when GP surgeries reopened after the weekend closures following the incident.

3.3. Ambulance dispatch calls

During the first air pollution episode there was no gross changes in the total ambulance calls in London, although there was a peak two days later on 16 March (Fig. 6). At the start of the second air pollution episode (29 March – 3 April) there was a sharp increase in total calls that continued during the following week (Fig. 6).

In line with other syndromic surveillance systems, in general, respiratory calls to the ambulance service did not increase during the initial air pollution episode, however there were increases during the second. Dyspnoea (difficulty breathing) accounted for the highest number of respiratory calls to the ambulance service. There was an increase in dyspnoea calls during the second pollution episode with a peak 3 April (n = 166 calls). There was a similar pattern for respiratory/chest infection calls (n = 86 calls), and asthma calls (n = 35 calls).

3.4. Regional syndromic consultations

Daily plots of selected syndromic indicators (GPIH severe asthma, wheeze and NHS 111 difficulty breathing calls) were plotted against daily $PM_{2.5}$ and PM_{10} air quality data at the regional level. In the North of England (North East, North West, Yorkshire and Humber) there were clear differences in air pollution levels between the first and second episodes, e.g. $PM_{2.5}$ levels peaked in Yorkshire and Humber at 40 and 75 μg/m^3 in the first and second episodes, respectively. There were no gross differences in GPIH syndromic indicators, however NHS 111 calls for difficulty breathing illustrated heightened activity during the second episode (Fig. 7). The East Midlands region also experienced differential air pollution peaks; similarly, only the NHS 111 calls mirrored these data. In the South regions, the $PM_{2.5}$ and PM_{10} levels were lower during the second episode, however, GPIH wheeze consultations and NHS 111 calls for difficulty breathing were higher.

The statistical alarms underpinning the routine surveillance and generated during the incidents (Morbey et al.) were retrospectively assessed for each indicator (Supplementary Table 2). Across all regions there were statistical alarms for GPIH wheeze consultations during the second air pollution period. A similar increase was seen in statistical alarms for NHS 111 difficulty breathing calls. These daily statistical alarms were assessed using an interrupted time series methodology: results for GPIH wheeze consultations by PHE

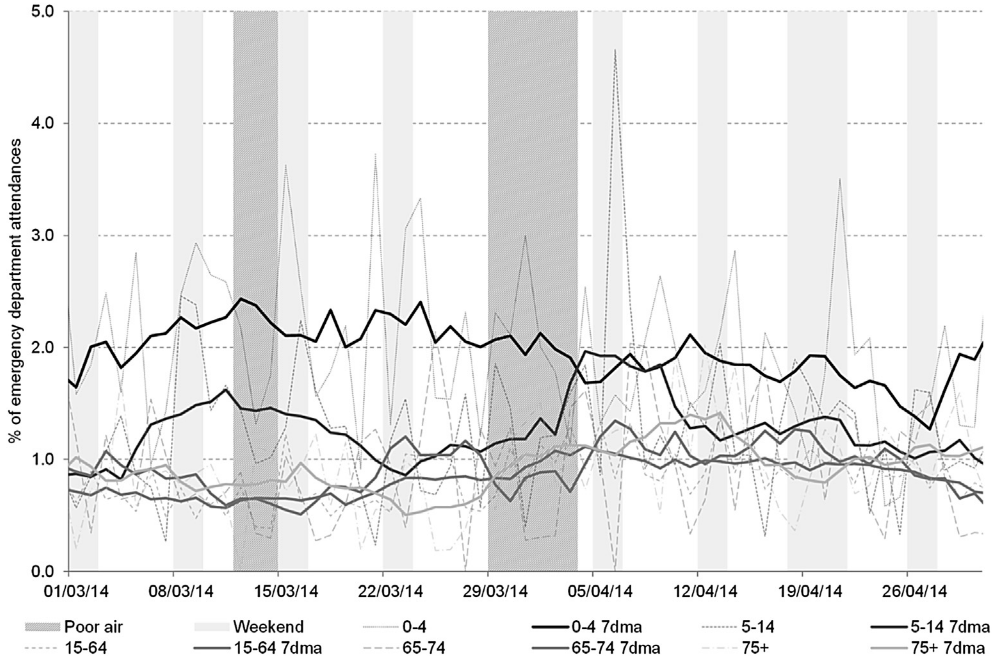

Fig. 2. Daily emergency department (ED) attendances for asthma/wheeze/difficulty breathing by age group over the study period: daily incidence and seven day moving average (7 dma) are presented.

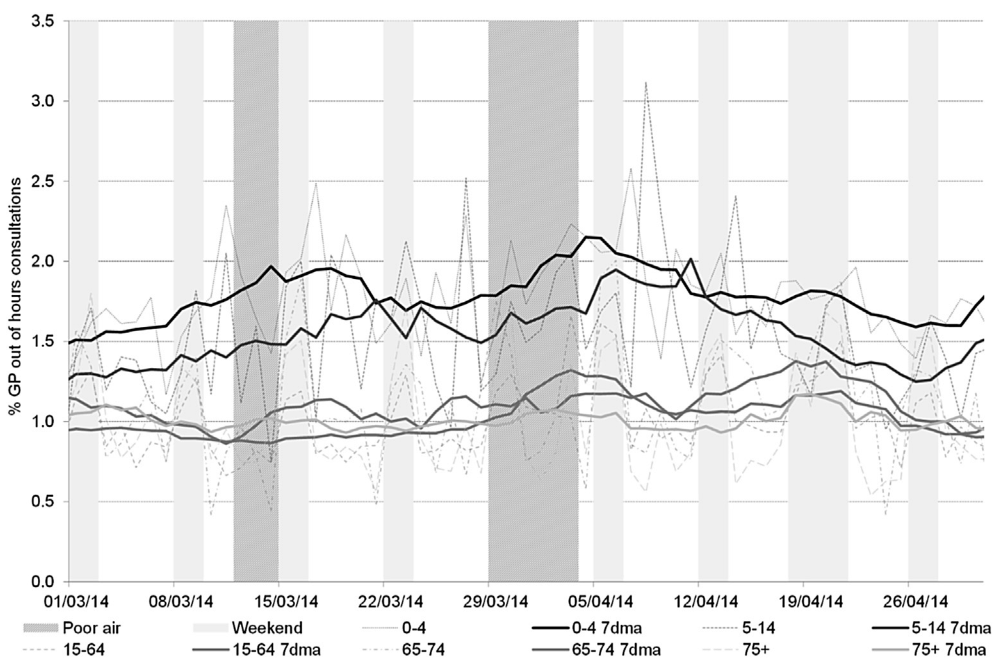

Fig. 3. Daily general practitioner out of hours (GPOOH) difficulty breathing/asthma/wheeze consultations by age group over the study period: daily percentage of consultations and seven day moving average (7 dma) are presented.

centre gave an odds ratio (OR) of 10.7, i.e. a statistical alarm at regional level was 10 times more likely to occur during the week of the second air pollution episode (29 March – 4 April) than during the weeks before and after. This was statistically significant at the 99% confidence level. This was repeated for NHS 111 difficulty breathing calls (OR = 33) and was similarly found to be statistically significant at the 99% confidence level.

GPIH severe asthma, GPOOH asthma, GPOOH asthma/wheeze/difficulty breathing, and EDSSS asthma/wheeze/difficulty breathing did not show a statistically significant increase in the chance of an alarm during the second air pollution period.

4. Discussion

We present an analysis of syndromic surveillance and air pollution data during a period of poor air quality that affected large parts of England during March/April 2014, further expanding the initial surveillance findings (Smith et al., 2015). During the

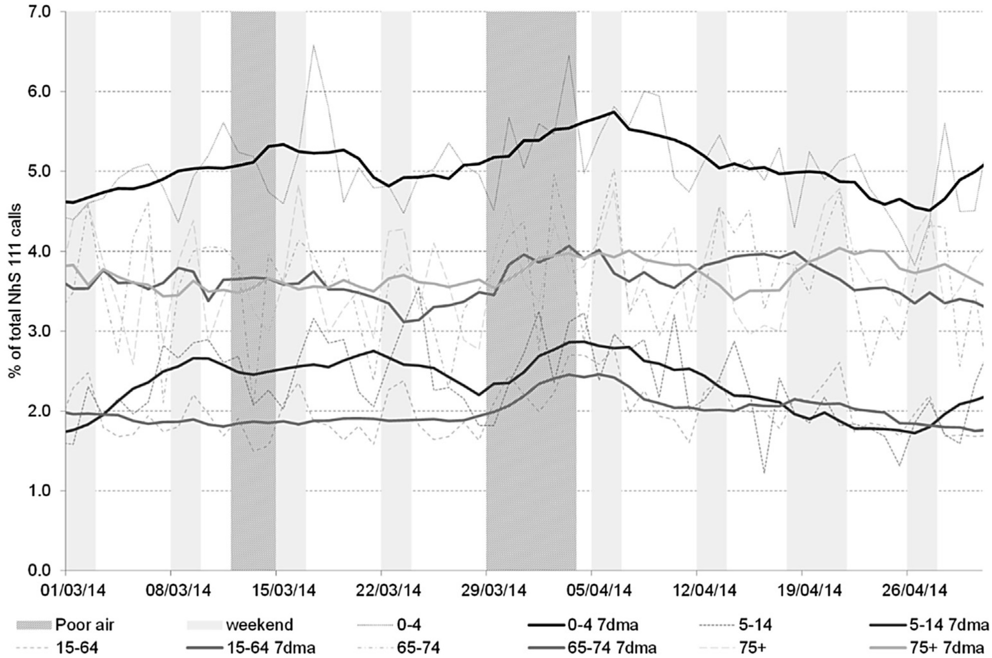

Fig. 4. Daily NHS 111 difficulty breathing calls by age group over the study period: daily calls (as a percentage of total calls) and seven day moving average (7 dma) are presented.

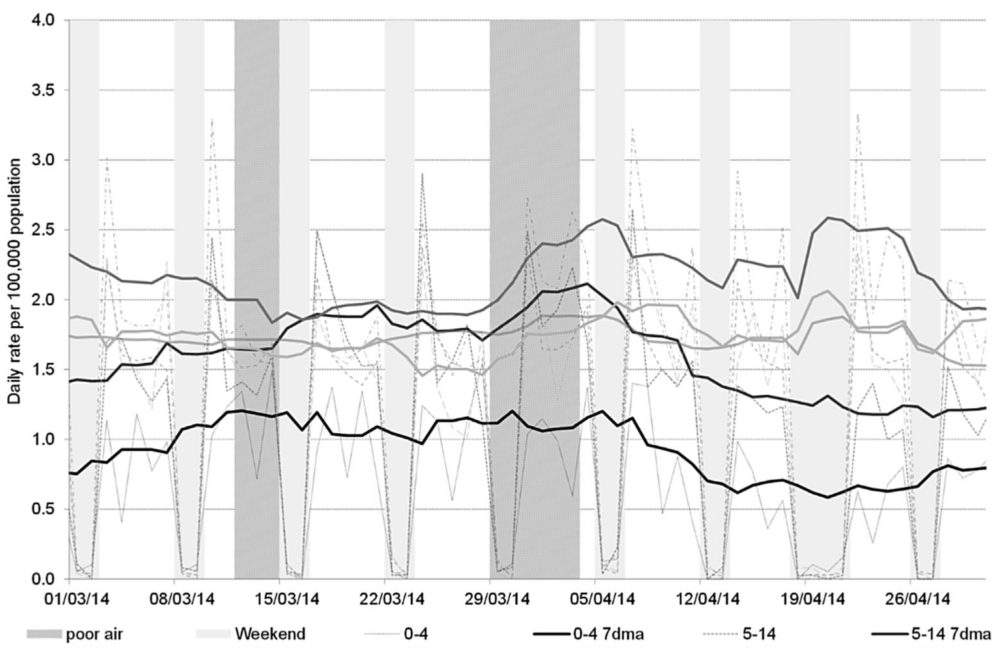

Fig. 5. Daily general practitioner in hours (GPIH) severe asthma consultation rate by age group over the study period: daily incidence and seven day moving average (dma) are presented.

incidents, syndromic surveillance systems were prospectively used to assess the impact of air pollution on health care seeking behaviour, providing situational awareness to support public health risk assessments of the potential risk to the population, and media messages. The enhanced analysis presented here provides a further insight into the surveillance data available to support response to future incidents, and explores the potential for using additional sources of data, such as ambulance dispatch activity, to enhance this response at regional level.

The air quality data illustrated that the levels of particulate air pollution ($PM_{2.5}$ and PM_{10}) recorded between the two periods in March and April 2014 were similar in magnitude, albeit however of different duration (3 days vs 6 days respectively). GP consultations, NHS 111 calls and sentinel ED attendances for selected indicators were in general higher during the second period. It was also interesting that when broken down by age group, certain ages were more likely to present during the second period: the 15–64 years age group was consistently higher during the second period across all systems for respiratory indicators. It is possible that the duration of the second episode had an increased impact: the length of

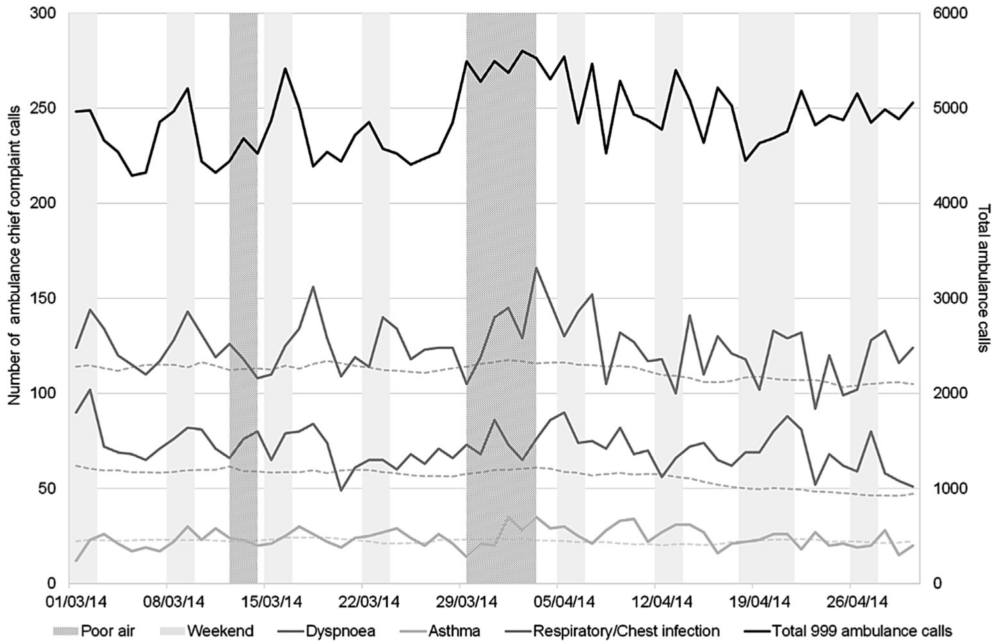

Fig. 6. Daily ambulance dispatch activity for total calls and selected 'syndromic' calls. Historical baselines (based upon 5 years of data) are included for each syndromic indicator as a broken line.

exposure has previously been shown to increase the impact on health outcomes at population level (Beverland et al., 2012) and this might explain these findings. Secondly, the addition of 'Saharan dust' to the composition of the pollutants during the second episode might have caused more health problems (Perez et al., 2008), or, due to the visible nature of the dust might have promoted more worry amongst the public about the health risks. Finally, anecdotally there was much greater media exposure during the second period, with significant national media coverage. This may have changed the public's propensity to consult with a health care practitioner, thereby increasing the numbers of patients consulting. This latter point has previously been reported as a potential bias in public health surveillance as the reporting of outbreaks or public health incidents in the media can influence the consulting behaviour of clinicians and patients (Olowokure et al., 2007, 2012). This is also supported by the age stratified analysis: patients aged 15–64 are more likely to be the age group using traditional media and social media and therefore potentially more likely to be influenced in their health seeking behaviour.

The analysis of regional syndromic and air pollution data further illustrated the different pollution and health data trends during the two periods. Actual air pollution levels ($PM_{2.5}$ and PM_{10}) in the North of England were higher during the second episode, similar in the Midlands, but higher in the first episode in the South of England. Despite this, syndromic surveillance data activity was higher in the South during the second period: this is again potential evidence of the impact of the media on the health care seeking behaviour of the public. Furthermore, the composition of airborne particles between the periods was different, with Saharan dust contributing to the poor air quality during the second period. However, the ratio of $PM_{2.5}$ to PM_{10} concentrations revealed no significant difference between the two periods (data not shown). Poor visibility due to the higher contribution of Saharan dust particles during the second episode, and the evidence of dust settling on surfaces may have also influenced the consulting behaviour of patients. The contribution of Saharan dust, both as a direct and indirect effect on health and health seeking behaviour requires further exploration to improve future public health responses to these episodes.

Analysing the routine statistical alarms (by indicator and region) that were prospectively generated during the air pollution episodes provided evidence that the GPIH wheeze and NHS 111 difficulty breathing indicators were most useful for monitoring the short-term health impact of the air pollution episodes. These findings were supported by the regional analysis which showed that these indicators appeared more sensitive to the regional air pollution levels.

We utilised a novel source of health data (ambulance dispatch calls) in this study, a data source that is not currently used routinely and systematically within England for syndromic surveillance, but one that has been utilised in other countries (Coory et al., 2009; Greenko et al., 2003; Hefferman et al., 2004; Rosenkotter et al., 2013; Ziemann et al., 2014). During the second air pollution episode there were anecdotal reports of increases in ambulance call outs in London due to the health effects of air pollution (London Ambulance Service, 2014). The results presented here support these anecdotal reports: total call numbers increased during the second period with immediate effect with respiratory calls increasing also. PHE are currently exploring the potential for using ambulance dispatch data for routine syndromic surveillance and the results presented here further support the use of ambulance data, adding to the situation awareness during an air pollution episode.

Syndromic surveillance systems are able to monitor signs and symptoms of disease across large populations. During a widespread air pollution episode, these systems are able to monitor surveillance data systematically, and due to their routine nature, it is possible to compare findings with historically expected values to determine whether there are significant changes in disease presentation or health care seeking behaviour linked to increased air pollution. In addition, smaller more localised air pollution episodes can also be supported as large syndromic surveillance systems can deliver data at local levels (Smith et al., 2010, 2011). However, in the event of an incident that attracts wide scale media attention, one limitation of syndromic surveillance is the potential that bias will be introduced when patients are more likely to

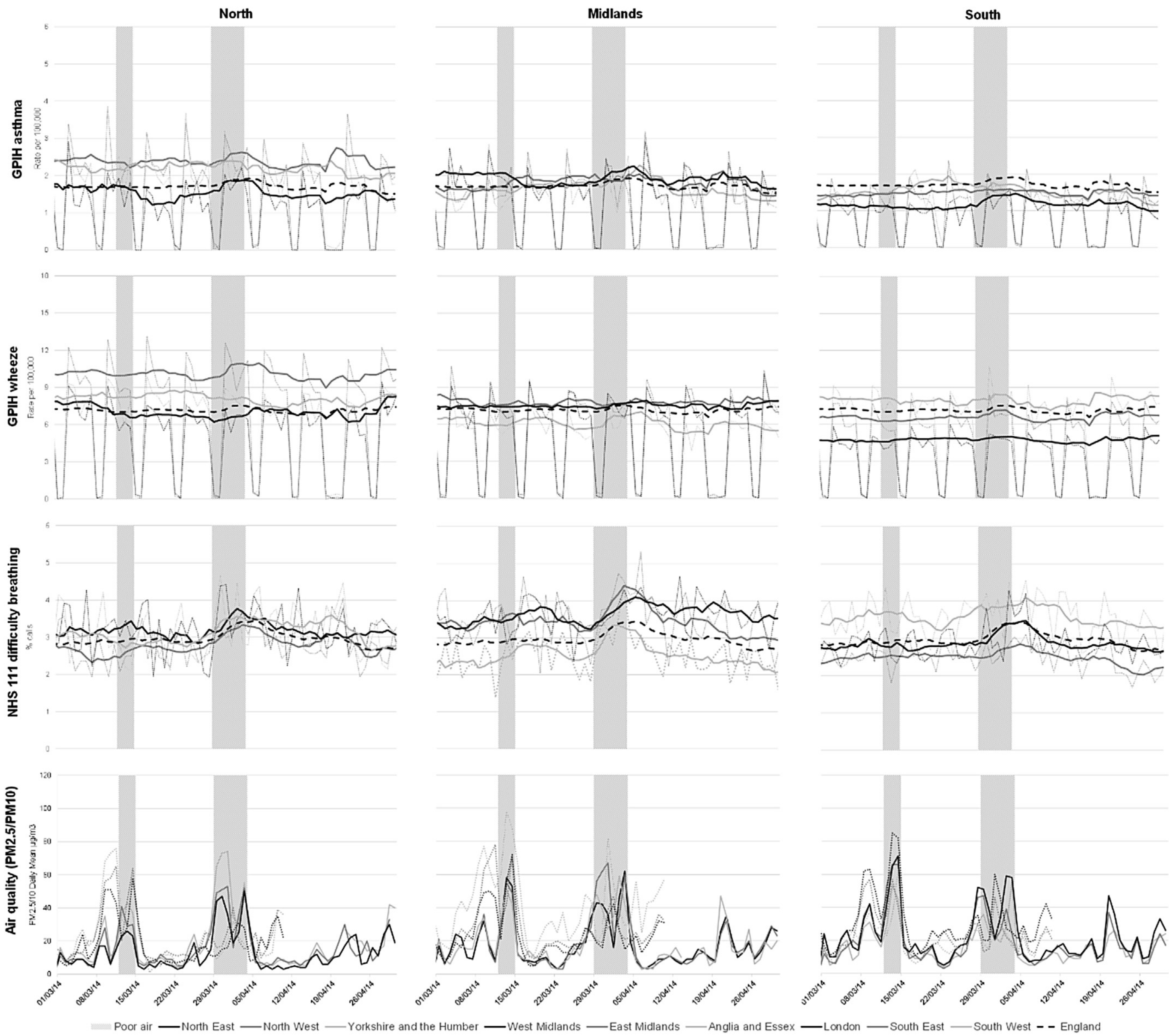

Fig. 7. Daily analysis of GPIH severe asthma and wheeze consultations, NHS 111 difficulty breathing calls and air quality $PM_{2.5}/PM_{10}$ concentrations across regions of England (North: North East, North West, Yorkshire and the Humber; Midlands: West Midlands, East Midlands, Anglia and Essex; South: London, South East, South West). Vertical grey bars indicate the air pollution episodes; solid lines represent daily syndromic values and $PM_{2.5}$ concentrations, broken lines indicate 7 day moving averages and PM_{10} concentrations.

present to a health care professional following exposure to messages through the media reporting potential health risks. There also appeared to be some limitations to the usefulness of GPIH consultation data: in the event of an air pollution episode occurring over a weekend or public holiday, the GPIH services (and therefore surveillance data) are not available. Results presented here suggest that on the first routine service day following GP closures, there might be a surge of patients presenting, causing an over-estimation of cases. However, an advantage of having a suite of national syndromic surveillance systems, many of which operate during the periods of closure of GPIH services, provides triangulation of data and reassurance that activity will not be missed.

We limited our analysis by comparing the period of the air pollution episodes ($n = 9$ days) with a relative short period surrounding the episodes ($n = 52$ days). Although this potentially limited the power of our analysis, it was our aim to avoid using longer comparator periods which may have contained additional significant air pollution episodes. The population coverage of syndromic surveillance systems can also fluctuate as a result of underlying changes in service provider systems and therefore we aimed to limit the potential effect of these changes occurring over time.

A further limitation of our approach was the varying regional population coverage of the syndromic surveillance systems. Although the NHS 111 system had 100% coverage both nationally and regionally, the EDSSS did not have coverage across each of the ten PHE Centres in England due to its sentinel nature. The implication of this is that the effectiveness of monitoring data during the acute phase of an air pollution episode will be dependent on the geographical extent of the impact. If the air pollution episode is only seen on a regional basis then it would be necessary to assess the coverage afforded by each syndromic surveillance system to provide effective monitoring during the incident.

These findings have provided a further insight into the usefulness of syndromic surveillance for monitoring the public health impact of air pollution episodes. One of the key outcomes is the refinement of the syndromic indicators sensitive to air pollution. GPIH consultations for wheeze and NHS 111 difficulty breathing calls were more likely to produce statistical alarms during the second air pollution episode thus suggesting that these indicators could comprise the front line surveillance during future incidents. Results also illustrated the usefulness in monitoring syndromic surveillance data stratified by age group and region.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.envpol.2016.04.026.

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Contributors

All authors contributed to the concept and design of the study. SS undertook the analysis of syndromic surveillance data. AJE and SS drafted the initial manuscript, all authors contributed to subsequent drafts and have seen and approved the final version.

Conflict of interest

No authors declare a conflict of interest.

Ethical approval

Not required.

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