Public Health 211 (2022) 66–71

Contents lists available at ScienceDirect

Public Health

journal homepage: www.elsevier.com/locate/puhe

Original Research

Ambient air pollutant concentrations and asthma-related hospital admissions during COVID-19 transport restrictions

C. Kelly [a], P. Kenny [b], M. O'Dwyer [b], K.I. Quintyne [a, c, *]

[a] Department of Public Health, HSE North East, Kells, Co Meath, Ireland
[b] National Ambient Air Quality Unit (NAAQU), Environmental Protection Agency (EPA), Clonskeagh Road, Co Dublin, Ireland
[c] School of Public Health, University College Cork, College Road, Co Cork, Ireland

ARTICLE INFO

Article history:
Received 26 April 2022
Received in revised form
6 July 2022
Accepted 8 July 2022
Available online 18 July 2022

Keywords:
Air pollution
Asthma
Particulate matter
Nitrogen dioxide
COVID-19 restrictions

ABSTRACT

Objectives: Exposure to air pollution is a known risk factor for asthma exacerbations and hospitalisations. This study aimed to identify if COVID-19 transport restrictions led to improvements in air quality in Dublin and if this had an impact on asthma-related hospital admissions.
Study design: This was a population-based retrospective cohort study.
Methods: Daily concentration levels of particulate matter ($PM_{2.5}$ and PM_{10}) and nitrogen dioxide (NO_2) were obtained from the Environmental Protection Agency (EPA). The Hospital In-Patient Enquiry (HIPE) system provided the daily number of asthma-related hospital admissions in Dublin. The figures for 2018–2019 were compared with the period of transport restrictions (from March 2020).
Results: During the period of transport restrictions, there was a significant decrease in mean daily concentrations in both $PM_{2.5}$ (8.9 vs 7.8 μg/m^3, $P = 0.002$) and NO_2 (24.0 vs 16.7 μg/m^3, $P < 0.001$). There was also a significant reduction in the mean number of daily asthma admissions (4.5 vs 2.8 admissions, $P < 0.001$). Only NO_2 showed a statistically significant correlation with asthma admissions ($r = 0.132$, $P < 0.001$).
Conclusion: Transport restrictions introduced to mitigate against COVID-19 led to lower pollutant levels and improved air quality. Previously described associations between pollutants and asthma would indicate that these improvements in air quality contributed to the reduction in asthma-related admissions. The complex nature of PM is the likely explanation for the lack of correlation between its concentration and asthma admissions, unlike NO_2 whose primary source is vehicular emissions. Public Health needs to advocate for transport policies, which can improve air quality and hence improve human health.

Introduction

Air pollution is a major international public health concern; the burden of disease attributable to air pollution is now similar to that caused by other significant public health issues – tobacco smoking and unhealthy diets – and is the most important environmental threat to health.[1] It is defined as chemical, physical, or biological contamination of both indoor and outdoor (ambient) air.[2] In Europe, one of the main sources of ambient air pollutants is the transport sector,[3,4] the term 'traffic-related air pollution' (TRAP) describes such emissions.[5] These pollutants include nitrogen dioxide (NO_2) and particulate matter (PM);[2] PM being atmospheric solid and liquid particles, categorised based on their diameter – PM_{10} having a diameter <10 μm and $PM_{2.5}$ having a diameter <2.5 μm.[6]

Exposure to ambient air pollutants has been shown to be associated with respiratory conditions, including asthma. A 2015 systematic review found that increases in air pollutant levels, including NO_2 and PM, were significantly associated with increased risk of asthma-related emergency department (ED) attendances and hospital admissions, on the same day and subsequent days.[7] Previous studies conducted in Ireland have shown a significant association between NO_2 and respiratory admissions, including chronic obstructive pulmonary disease (COPD),[8] as well as an association between the air quality index overall and respiratory hospital admissions.[9]

* Corresponding author. Department of Public Health, HSE North-East, Kells Business Park, Cavan Road, Kells, Co. Meath, Ireland. Tel.: +353 (0) 46 928 2700.
E-mail address: keithi.quintyne@hse.ie (K.I. Quintyne).

https://doi.org/10.1016/j.puhe.2022.07.009
0033-3506/

In March 2020, the World Health Organization (WHO) declared a global pandemic following the emergence of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).[10] Part of the mitigation measures implemented in Ireland included transport restrictions; non-essential services were closed, people were asked to work from home, and travel was restricted to a 2 km radius.[11] Compliance with these restrictions was estimated between 60 and 80% from April to November 2020,[12] with vehicular traffic demonstrably reduced.[13]

Similar restrictions were introduced internationally and, as a result, air pollutant concentrations were noted to be reduced in several studies.[14–16] The trends in air pollution concentration seen as a result of COVID-19 mitigation measures have allowed for exploration of the relationship between air pollutants and certain diseases. Although acknowledging that these restrictions were not sustainable long-term, recent studies have highlighted that these improvements in air quality may have had a positive impact on morbidity and mortality.[15,17] Such studies add to existing evidence on the association between air pollution and asthma, and may provide the impetus for governments to implement transport-related policy changes in order to meet the 2021 WHO air quality guidelines, recommending more stringent levels for several air pollutants.[1]

The aim of this study was to determine if the transport restrictions introduced during the COVID-19 pandemic had any impact on the concentrations of pollutants contributing to TRAP in Dublin, and to determine if this in turn had any impact on asthma-related hospital admissions.

Methods

This study was conducted using routinely collected data from January 2018 to February 2021. This period covers the COVID-19 pandemic, declared in early 2020, as well as the two preceding years acting as control years.

Data on asthma admissions were obtained from the Health Service Executive (HSE) Hospital In-patient Enquiry (HIPE) system, a national system that collects data on discharges from, and deaths in, acute public hospitals. Each HIPE record represents an episode of care, meaning that an individual patient may have multiple HIPE entries over the study period. Without a unique patient identification number, the data is analysed in terms of episodes rather than individuals, allowing for analysis of hospital activity rather than incidence of disease. Primary diagnoses of asthma (International Classification of Disease (ICD) 10AM codes J45, J46) were included in the study. Daily counts of the asthma-related hospital admissions for all ages with an address in Dublin (city and county) were obtained, along with average age of the patients, average length of stay, and number of bed days.

The Environmental Protection Agency (EPA) provided the daily average PM and NO_2 concentrations for the 15 monitoring stations across Dublin city and county during the study period. Some monitors are roadside, and others are located in suburban areas. A number of the stations did not come on-line until 2020/21, and so the mean concentration for each pollutant was calculated from the available readings for each 24-h period during the study period.

Data were analysed in IBM Statistical Package for Social Sciences (SPSS) version 26. Descriptive analysis was performed, to describe the patients admitted for asthma-related diagnoses during the study period, and to describe trends in pollutant concentration over the same period. Comparative analysis was performed, using the independent t, Wilcoxon Rank-Sum and Chi-squared tests, to examine the relationship between asthma admissions and pollutant concentrations during the study period. Spearman's rank order was used to assess the correlation between pollutant concentration and asthma-related hospital admissions. Results were considered significant at $P < 0.05$ (two-tailed).

During the COVID-19 pandemic, there was an overall reduction in hospital presentations and admissions. To ensure that any change in asthma-related admissions was not due to patients avoiding hospitals due to the pandemic, chronic liver disease (CLD) was chosen to act as a control, given that it has no association with air pollution. The HIPE system was used as the source of data on CLD admissions (ICD 10AM codes K70.3, K74.4, K74.5, K74.6). The average number of daily CLD admissions over the same periods was compared using the independent *t*-test.

Results

Taking March 2020 as the start of the global COVID-19 pandemic, 802 days of the study period were prepandemic, and the remaining 353 days were during the pandemic. Over the whole study period, there were a total of 4551 admissions to hospital with a primary diagnosis of asthma and an address in Dublin, equating to 12,673 in-patient bed days (see Table 1). Of these admissions, 2792 (61.3%) were women; the mean age was 40.9 years (standard deviation (SD) 20.3 years). The average daily concentration of each pollutant over the study period is in Table 1 and for each month of the study period is displayed in Fig. 1.

The first objective was to determine if there was any change in the concentrations of air pollutants during the pandemic period when compared to the previous few years. Table 1 shows the comparison of mean daily pollutant concentrations in the pre-pandemic and the pandemic periods. There was a significant decrease in the concentration of both $PM_{2.5}$ and NO_2 ($P = 0.002$ and $P < 0.001$, respectively). Although there was a decrease in mean PM_{10} concentrations, this was not statistically significant.

The second objective was to determine if there was any change in asthma admissions during the pandemic period, and as shown in Table 1, there was a statistically significant reduction in the average daily admissions for asthma in Dublin (mean daily asthma admissions 4.5 (3.4) vs 2.8 (SD 2.5); $P < 0.001$). There was also a statistically significant reduction in the average in-patient bed days (median 6.0 bed days (2.0–14.0) vs 3.5 bed days (IQR 0.5–9.0); $P < 0.001$). There was no significant difference in the average age or the proportions of males and females being admitted during the pandemic when compared with the pre-pandemic period.

There was no statistically significant difference in the average daily hospital admission for CLD in Dublin during the pandemic period when compared with the pre-pandemic study period (mean daily liver admissions 2.8 (SD 1.9) vs 2.6 (SD 1.8); $P = 0.202$), as seen in Table 1. Average daily hospital admissions for asthma and CLD for each month of the study period are shown in Fig. 2, with a marked drop-off in asthma admissions seen at the introduction of transport restrictions.

Spearman's correlation coefficients (r, see Table 2) were calculated to examine the relationship between the daily concentration of pollutants and the number of asthma admissions during the study period. The concentration of NO_2 was significantly positively correlated with the number of daily asthma admissions. There was no statistically significant correlation between either $PM_{2.5}$ or PM_{10} concentration and number of daily asthma admissions.

Discussion

The COVID-19 pandemic led governments worldwide to take unprecedented measures in a bid to control the spread of the virus. In many countries, this included the introduction of transport restrictions. These restrictions offered researchers the opportunity to conduct large-scale quasi-natural experiments that would not have

Table 1
Pollutant concentrations and hospital admissions during the whole study period and comparison between the prepandemic period and during the COVID-19 pandemic.

Variable	Valid denominator[a]	Total study period	Prepandemic	Pandemic	*P*-value
Pollutants (μg/m^3; mean (SD))					
$PM_{2.5}$	1152	8.6 (6.6)	8.9 (7.2)	7.8 (5.2)	0.002[b]
PM_{10}	1152	13.4 (7.9)	13.5 (8.5)	13.1 (6.5)	ns
NO_2	1135	22.2 (11.0)	24.0 (11.5)	16.7 (8.2)	<0.001[b]
Hospital admissions					
Asthma admissions (*n*)		4551	3573	978	
In-patient bed days (*n*)		12,673	9222.5	3450.5	
Asthma admissions per day (mean (SD))	1155		4.5 (3.4)	2.8 (2.5)	<0.001[b]
Average in-patient bed days (median (IQR))			6.0 (2.0–14.0)	3.5 (0.5–9.0)	<0.001[c]
Asthma admissions by sex					
Female (*n* (%))		2792 (61.3%)	2177 (60.9)	615 (62.9)	ns[d]
Male (*n* (%))		1759 (38.7%)	1396 (39.1)	363 (37.1)	
Age in years (mean (SD))		40.9 (20.3)	41.6 (19.7)	39.4 (21.8)	Ns[b]
Liver admissions per day (mean (SD))	1155		2.8 (1.9)	2.6 (1.8)	Ns[b]

SD: standard deviation; PM: particulate matter; NO_2: nitrogen dioxide; IQR: inter-quartile range.
Significance taken at alpha level <0.05.
[a] Number of days for which data available.
[b] Independent *t*-test.
[c] Mann Whitney U test.
[d] Chi-squared test.

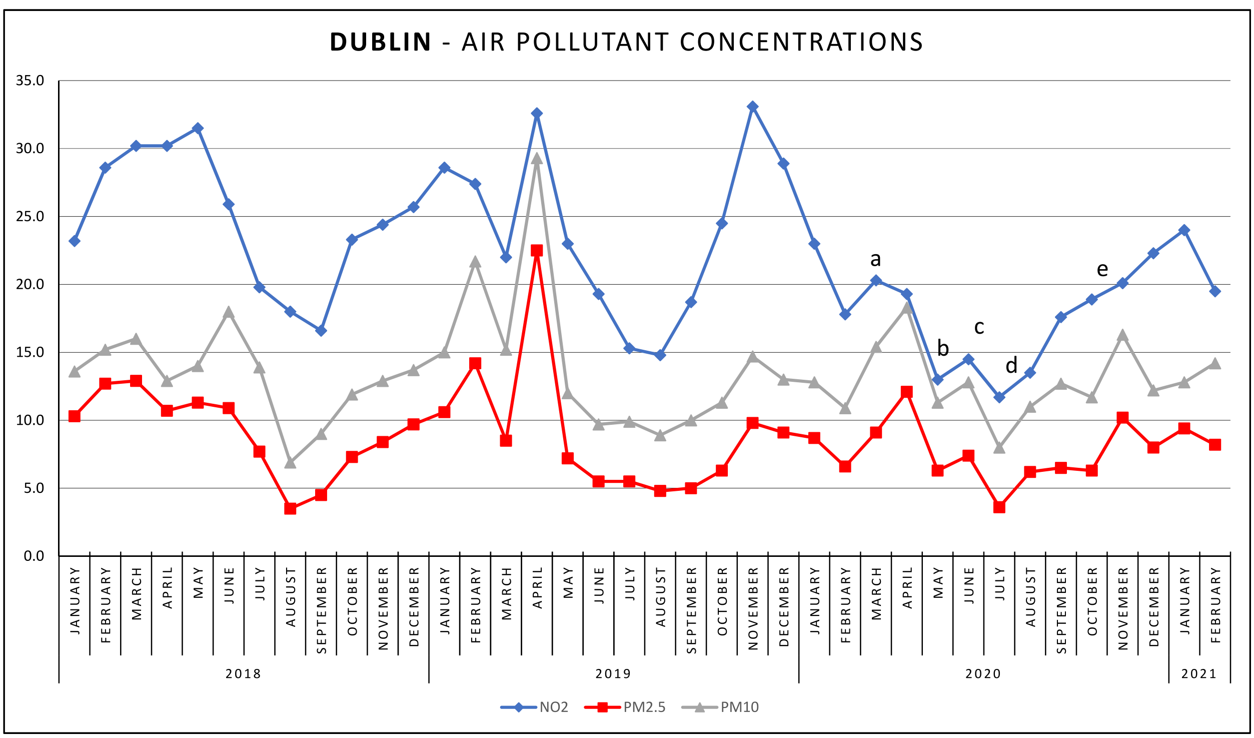

Fig. 1. Graph of average concentration of NO_2, $PM_{2.5}$ and PM_{10} for each month of the study period; a: 2 km restrictions introduced, b: 5 km restrictions introduced, c: 20 km restrictions introduced, d: cross-country travel allowed, e: cross-country restrictions re-imposed.

been feasible to conduct in prepandemic times. This study set out to use the transport restrictions imposed in Ireland, to examine whether the reduction in traffic, as seen by a reduction in motorised vehicle journeys,[18] would lead to a reduction in transport-related air pollution in Dublin, and whether this could potentially have a positive impact on asthma morbidity.

The reduction in traffic during the initial pandemic period from March 2020, as measured by Transport Infrastructure Ireland (TII),[18] did lead to a significant reduction in NO_2 and $PM_{2.5}$ concentrations in Dublin, although not in PM_{10}. This finding was similar to the picture seen nationally; there was a significant decrease in NO_2 levels across Ireland, related to the decrease in vehicle emissions, but no significant change in PM_{10} levels; the study authors attributing this to alternate non-transport sources of PM.[3] PM is a complex pollutant, produced from numerous sources, so although vehicle emissions decreased, alternate sources, such as home energy use and heating, are likely to have contributed to a greater extent in Dublin during the lockdown period, resulting in no significant change in its concentration.

Internationally, studies have demonstrated significant decreases in NO_2 and PM in many countries,[14,15,19,20] largely attributed to reductions in vehicle and industry emissions. A study from New York City, however, found no significant difference in PM concentration, the authors suggesting that countries with greater levels of

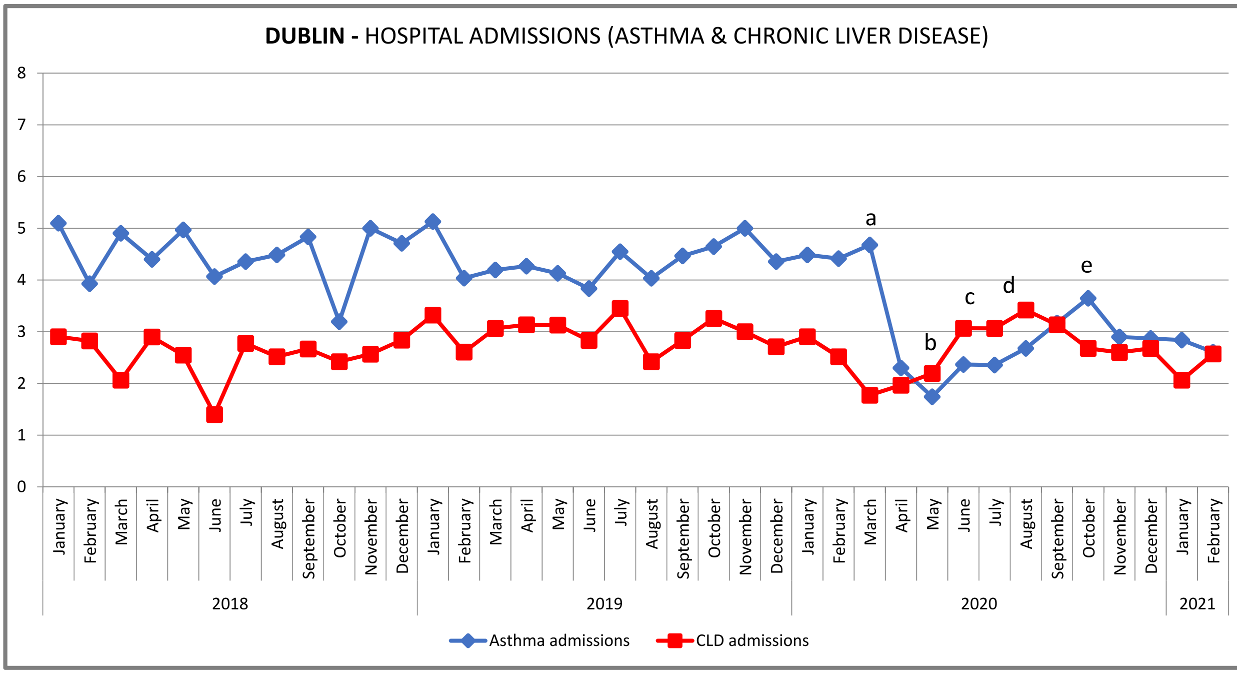

Fig. 2. Graph of average daily hospital admissions for asthma and chronic liver disease for each month of the study period; a: 2 km restrictions introduced, b: 5 km restrictions introduced, c: 20 km restrictions introduced, d: cross-country travel allowed, e: cross-country restrictions re-imposed.

pollutants before the pandemic would have a greater capacity to experience improvements compared with countries with lower baseline levels.[21] This may also explain the PM_{10} findings in Dublin.

The second objective was to determine if there was a change in asthma admissions during the pandemic period. In Dublin, there was a statistically significant decrease in the average number of asthma admissions. This is in keeping with international findings.[17,22–25] This study chose to focus on asthma admissions, rather than other markers of morbidity, such as ED attendances or systemic steroid use. This is because data on hospital admissions are easily accessible through HIPE, whereas data on prescriptions and ED attendances are not as readily available.

There are several factors, in addition to improved air quality, which may have contributed to the reduction seen in asthma admissions, such as improved adherence to baseline medications, and lower levels of respiratory viruses and pollen. Adherence to treatment was not included in this study as it is too difficult to adequately quantify. Other studies had previously concluded there was no significant change in pollen levels during the pandemic period and so had no impact on the reduction in asthma admissions.[17,24]

In Europe, levels of non-COVID respiratory viral pathogens, such as Respiratory Syncytial Virus (RSV)[26] and influenza,[27] were substantially lower in 2020, likely due to the restrictions and non-pharmacological interventions (NPIs) introduced as pandemic mitigation measures.[27] Viruses are an important cause of asthma exacerbations; with rhinovirus being the most commonly identified pathogen.[28] Although it is likely that the NPIs introduced for SARS-CoV-2 would have reduced the incidence of rhinovirus infections, these data were not available as rhinoviruses are not notifiable in Ireland. Also, it is important to note that asthma admissions were lower even over the summer period, which is not the traditional respiratory pathogen season.

Another factor which may have had an impact on asthma admissions was the idea that fear of COVID-19 may have resulted in fewer people attending hospitals. To acknowledge this, a disease entity that is not associated with air pollution was chosen to act as control in this study. Daily admissions numbers for CLD were compared between the pandemic period and the preceding two years, and no difference was found. This means that those patients who warranted admission were still attending the hospital and receiving appropriate treatment, suggesting that the number of people requiring hospital admission for asthma was actually lower during the pandemic period.

The final objective was to identify if there was an association between air pollutant concentration and the number of asthma admissions. The pandemic period saw a significant reduction in daily asthma admissions in parallel with a significant reduction in NO_2 and $PM_{2.5}$ concentrations. Beyond that, however, this study has also shown that daily NO_2 concentration is significantly positively correlated with daily asthma admissions, similar to the findings of Sigala et al.[25] The primary source of NO_2 is vehicle emissions.[3] Therefore, the travel restrictions imposed as part of the Irish government's pandemic response resulted in a reduction in NO_2 levels, and this improvement in air quality likely had a positive effect on asthma morbidity, as measured in hospital admissions. However, whilst NO_2 is a ‘key indicator of traffic-related changes in pollution,’ particulate matter is more complex, coming numerous sources.[3] Hence, whilst the link between traffic restrictions, reduced NO_2 concentration and fewer asthma admissions is apparent, it is not unexpected that there was no significant correlation between PM concentration and asthma admissions.

There are several strengths to this study. All asthma-related admissions to public hospitals of individuals with an address in Dublin during the study period were included in the analysis. These

Table 2
Spearman's correlation co-efficients for air pollutant concentrations and asthma admissions.

	$PM_{2.5}$	PM_{10}	NO_2
r	−0.004	0.035	0.132
P-value	0.882	0.242	**<0.001**

PM: particulate matter; NO_2: nitrogen dioxide.
r: Spearman's correlation co-efficient with significance taken at alpha level <0.05 (highlighted bold).

data were collected from HIPE, a national system which undertakes audits to enhance its data quality. The environmental data was provided by the EPA, from 15 monitoring stations around Dublin. Only stations with certified equivalent instruments were included, meaning the data are comparable between stations, allowing for an average daily concentration for each pollutant to be calculated that was representative of the Dublin region.

Another strength of this study was the inclusion of another disease entity as a control factor. By finding no reduction in CLD-related admissions during the study period suggests that people requiring admission were still presenting to hospital, lending weight to the idea that there were actually fewer people requiring admission for asthma-related reasons.

There are, however, several limitations. This is an observational study using ecological data and so it is not appropriate to draw causal conclusions from the data analysis. The findings of lower concentrations of common air pollutants are presented alongside the finding of reduced number of asthma admissions; however, it would be inappropriate to say conclusively that the reduction in asthma-related admissions was due to the improvement in air quality. Given what is known about air pollution and its link with asthma exacerbations, it stands to reason that the improvements seen in NO_2 and $PM_{2.5}$ levels likely did contribute to a reduction in asthma exacerbations, which in turn would have led to a decrease in asthma admissions. However, as discussed, there are several additional factors that may also have had an impact on the reduction in admissions, which were not included in this analysis.

HIPE data does not include admissions to private hospitals, so they were not included in this study, and the HIPE output is dependent on the data input, meaning that errors or omissions by the clinical team in documenting the diagnosis or errors made by the HIPE team in coding may result in the numbers of asthma admissions being either under- or over-reported. Many of the air quality monitoring stations did not have readings on all of the dates in this study, with several stations only commencing data collection in 2020. This means that the average concentrations used, particularly in 2018/19, may not be as truly representative of the average air quality in Dublin as compared with 2020.

Nonetheless, the results in this study are in keeping with similar international studies published in recent months. Therefore, when taken into the wider context, this study adds to the existing body of evidence that during the period of pandemic transport restrictions, there was a significant reduction in asthma hospital admissions and this corresponded with the significant reduction in air pollutants seen in many countries around the world. Although not possible to draw causal association, it is likely that an improvement in air quality contributed to this reduction in asthma morbidity.

Air pollution is a major public health issue, causing substantial morbidity and mortality each year.[1] The findings of this study suggest that significant air quality improvements can be made through more stringent transport policies aimed at significantly reducing the number of cars on the road. This improvement in air quality would have a substantial impact on public health; contributing to fewer asthma exacerbations and hospitalisations, as well as reducing healthy life years lost and premature deaths.

Author statements

Acknowledgements

The authors are grateful to Healthcare Pricing Office (HPO) for allowing access to the HIPE data that were used in this study.

Ethical approval

This research uses routinely collected data at the population level rather than the individual level; it conforms to the Helsinki Declaration and does not require approval from a research ethics committee.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Competing interests

The authors declare no conflict of interests.

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