SHORT REPORT

# Changes in outdoor air pollution due to COVID-19 lockdowns differ by pollutant: evidence from Scotland

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## ABSTRACT

**Objectives** To examine the impact of COVID-19 lockdown restrictions in March/April 2020 on concentrations of nitrogen dioxide ($NO_2$) and ambient fine particulate matter ($PM_{2.5}$) air pollution measured at roadside monitors across Scotland by comparing data with previous years.

**Methods** Publicly available data of $PM_{2.5}$ concentrations from reference monitoring systems at sites across Scotland were extracted for the 31-day period immediately following the imposition of lockdown rules on 23 March 2020. Similar data for 2017, 2018 and 2019 were gathered for comparison. Mean period values were calculated from the hourly data and logged values compared using pairwise t-tests. Weather effects were corrected using meteorological normalisation.

**Results** $NO_2$ concentrations were significantly lower in the 2020 lockdown period than in the previous 3 years ($p<0.001$). Mean outdoor $PM_{2.5}$ concentrations in 2020 were much lower than during the same period in 2019 ($p<0.001$). However, despite UK motor vehicle journeys reducing by 65%, concentrations in 2020 were within 1 µg/m$^3$ of those measured in 2017 ($p=0.66$) and 2018 ($p<0.001$), suggesting that traffic-related emissions may not explain variability of $PM_{2.5}$ in outdoor air in Scotland.

**Conclusions** The impact of reductions in motor vehicle journeys during COVID-19 lockdown restrictions may not have reduced ambient $PM_{2.5}$ concentrations in some countries. There is also a need for work to better understand how movement restrictions may have impacted personal exposure to air pollutants generated within indoor environments.

## Key messages

**What is already known about this subject?**

- Road traffic has been significantly reduced in countries adopting lockdowns due to COVID-19. Research has shown that this has led to reductions in outdoor air pollution in some locations.

**What are the new findings?**

- Nitrogen dioxide concentrations declined in Scotland following the lockdown, but fine particulate matter did not despite the fall in vehicle use.

**How might this impact on policy or clinical practice in the foreseeable future?**

- Policymakers should take care not to overestimate improvements in outdoor air quality following COVID-19 lockdowns and should consider the impact of indoor air pollution on personal exposure during these periods.

## INTRODUCTION

In the wake of the COVID-19 pandemic, many countries introduced wide-ranging restrictions on individual movement and gathering, known as 'lockdowns' or 'stay-at-home orders'. In the UK, a lockdown was introduced at 20:30 on 23 March 2020.

These new regulations led to substantial falls in road traffic with UK data suggesting motor vehicle journeys reduced by around 65% between 16 March and 28 April 2020.[1] The result of movement restrictions and reduced traffic volumes has been widely reported in the media (and some scientific studies) to have resulted in improved air quality and lower concentrations of common pollutants, such as fine particulate matter ($PM_{2.5}$) and nitrogen dioxide ($NO_2$).[2,3] It has been suggested that this will result in positive health effects, due to lowered exposure to air pollution, and even that the net effect of the pandemic will be to improve health (due to the adverse health effects of exposure to air pollution, particularly $PM_{2.5}$[4]).

Analyses of this kind assume that road traffic-related $PM_{2.5}$ is a significant source of personal exposure to fine particles. This may not be true in all locations. Scotland's relatively low ambient $PM_{2.5}$ may be related more closely to natural and non-traffic sources and may not therefore have fallen following the introductions of the lockdown measures. If $PM_{2.5}$ in outdoor air has not declined, it is possible that net exposure to $PM_{2.5}$ will increase, as people spend more time in their homes where generation of fine particles from activities such as cooking and smoking may produce high concentrations within enclosed and poorly ventilated spaces.[5] $NO_2$ is specifically associated with vehicle exhaust emissions[6] and so provides a measure of relative traffic for use in this analysis.

## METHODS

Scottish local authorities maintain a network of automatic monitoring stations for $PM_{2.5}$ and other pollutants. The $PM_{2.5}$ monitors in use comprise gravimetric monitors (using tapered element oscillating microbalances, TEOMs) and high-precision optical monitors (optical aerosol spectrometers).

**Table 1** Geometric mean $PM_{2.5}$ and $NO_2$ in Scotland 24 March–23 April in years 2017–2020, including both observed and normalised data

| Pollutant | 2017 period geometric mean concentration (μg/m$^3$) | 2018 period geometric mean concentration (μg/m$^3$) | 2019 period geometric mean concentration (μg/m$^3$) | 2020 period geometric mean concentration (μg/m$^3$) |
|---|---|---|---|---|
| $PM_{2.5}$ (observed) | 6.7 | 7.4 | 12.8 | 6.6 |
| $PM_{2.5}$ (normalised) | 6.9 | 6.4 | 7.6 | 6.1 |
| $NO_2$ (observed) | 21.9 | 23.7 | 22.4 | 9.9 |
| $NO_2$ (normalised) | 25.8 | 25.4 | 24.4 | 15.1 |

$NO_2$, nitrogen dioxide; $PM_{2.5}$, fine particulate matter.

These monitors report $PM_{2.5}$ measurements hourly and data are made publicly available on the internet.

To examine the effect of the lockdown on Scotland's air, $PM_{2.5}$ and $NO_2$ data were extracted from the monitor network for the period from 24 March to 23 April in 2017, 2018, 2019 and 2020. Data from 2020 have only been provisionally validated by the Scottish Government. Data were downloaded using the openair R package.

To simulate the removal of weather effects on pollutant concentrations, meteorological normalisation using the random forest machine learning algorithm[7] was conducted using the rmweather R package. Individual models were calculated for both $PM_{2.5}$ and $NO_2$ at monitoring sites around Scotland. Models were based on daily mean pollutant concentrations and incorporated wind speed, wind direction, atmospheric pressure, air temperature and relative humidity at the nearest available weather station (downloaded using the worldmet R package). Models used 64 trees and 100 samples.

Arithmetic mean concentrations were calculated for each of 70 $PM_{2.5}$ monitoring stations and 89 $NO_2$ monitoring stations over this period in each year. Geometric means of these values were calculated for each local authority area where monitoring took place and for Scotland overall in each year.

To determine statistical significance in differences in 2020 $PM_{2.5}$ and $NO_2$ values for this month versus each other year, both observed and normalised data were log-transformed and compared using a pairwise t-test. Statistical analysis was performed in R V.4.0.2.[8]

## RESULTS

Across Scotland's air pollution monitoring network, observed and normalised $NO_2$ concentrations remained close to constant in 2017, 2018 and 2019 but fell substantially in 2020 (pairwise t-test $p<0.001$ for all years) (table 1).

By contrast, the observed geometric mean $PM_{2.5}$ concentration over the lockdown period in 2020 was 6.6 μg/m$^3$, very similar to the mean concentration over the same period in 2017 (6.7μg/m$^3$, pairwise t-test $p=0.66$). The 2020 value showed a modest decrease ($-0.8$ μg/m$^3$) in comparison with 2018 (7.4μg/m$^3$, $p<0.001$) but was substantially lower than the markedly high concentrations measured in 2019 (12.8μg/m$^3$, $p<0.001$). Geometric means of normalised data showed the same pattern, with the 2019 mean higher than the other 3 years (pairwise t-test $p<0.001$ for all comparisons) (table 1).

Year 2019 was a visible outlier in observed data across all local authority areas where $PM_{2.5}$ monitoring was conducted (figure 1). This is likely due to a sustained meteorological event that brought fine particulate dust from the Saharan desert to the UK atmosphere beginning on 15 April 2019 and persisting through the end of the analysis period on 23 April.[9] Removing that period from the 2019 analysis reduces the mean observed value to 7.8 μg/m$^3$, similar to overall values from the three other years in this analysis.

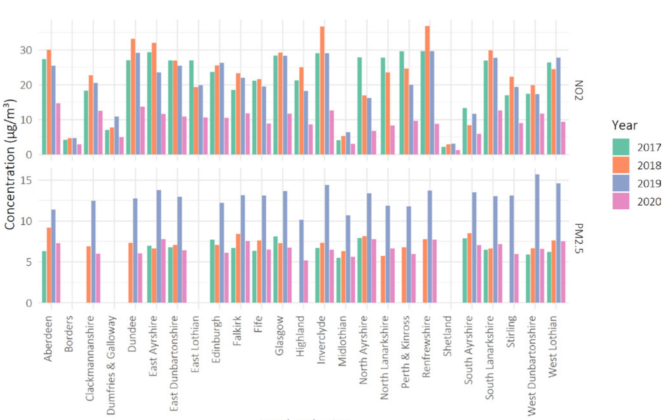


**Figure 1** Observed geometric mean $PM_{2.5}$ and $NO_2$ by local government divisions (council areas) in Scotland 24 March–23 April in years 2017–2020. Note that some local authorities have $NO_2$ monitors but not $PM_{2.5}$ monitors. $NO_2$, nitrogen dioxide; $PM_{2.5}$, fine particulate matter.

## DISCUSSION

The lockdown period has provided a natural experiment to examine the potential impact of reducing car journeys on air quality in Scotland. The $NO_2$ data suggest that car journeys have declined substantially during the lockdown compared with the same period in the previous 3 years. This may lead to significant health benefits, both from reduced exposure to harmful $NO_2$ and in reduced rates of traffic accidents and pedestrian collisions.

However, our results suggest that the decline in vehicle-related $NO_2$ has not coincided with significantly reduced $PM_{2.5}$ concentrations. The health risks of exposure to $PM_{2.5}$ are extremely well established, including cardiovascular disease, pulmonary illness and stroke. This research has established that reducing the number of vehicles on the road would not be an effective measure to reduce exposure to this pollutant in Scotland and consequently would not affect incidence of these illnesses.

Our analysis is limited by the data available from the monitoring network. Seven Scottish local authority areas have no $NO_2$ monitors, while nine have no $PM_{2.5}$ monitors, so these data do not cover the entirety of Scotland. Data from 2020 have been provisionally validated by the Scottish Government; while they have undergone screening to identify faulty or suspect data, they have not been ratified following detailed manual review. The later discovery of a fault or error associated with a monitor could change these results retroactively (if, for instance, a new calibration factor were applied). This is unlikely; in summer 2018, three faults were identified in particle monitors across the Scotland-wide network.[10] The use of data from a wide range of sources (70 $PM_{2.5}$ monitors and 90 $NO_2$ monitors) would limit the impact of a change to an individual monitor.

We have attributed the fall in normalised $NO_2$ concentrations in 2020 to the lockdown, but underlying effects, including a move towards less-polluting fuels and vehicles, could have contributed to this decline (though likely gradually over a period of years).

We believe these results have important policy and health implications in terms of the use of lockdowns to control future epidemics of infectious disease, and in considering how best to tackle outdoor air pollution in different countries in the future. Lockdowns are intended to result in people spending more time in their homes. This could increase population exposure to indoor air pollution such as cooking fumes and secondhand tobacco smoke (a particular concern given the high concentrations of $PM_{2.5}$ that can be generated by smoking indoors). Previous work suggests that living with a smoker can increase a person's daily dose of $PM_{2.5}$ by over 80%.[11]

In countries like Scotland where it appears that the lockdown has not led to reductions in outdoor fine particulate matter pollution, it is possible that personal exposure to $PM_{2.5}$ may actually have increased rather than declined due to higher concentrations from indoor sources of particulate within the home setting. This could increase adverse health effects overall and also health inequalities—lower income people are more likely to smoke and to smoke indoors[12] and are likely to have smaller homes leading to higher $PM_{2.5}$ concentrations from individual sources, due to smaller room volumes. If the severity of COVID-19 is related to air pollution exposure (as has been suggested in ref 13), increased exposure to $PM_{2.5}$ could potentially increase the death toll of that disease. Careful and balanced consideration of both outdoor and indoor sources of $PM_{2.5}$ is essential to tackling the health harm of air pollution effectively and equitably.

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**Data availability statement** Data are available in a public, open access repository. Data used in this study are available from the Scottish Government's air quality repository (www.scottishairquality.scot).



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