West Midlands Air Quality Report from Birmingham Air Quality Supersite (BAQS): *Winter 2024 (December 2023 – February 2024)*

A report from the WM-Air project for WMCA

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A) High-level Summary

Background Air Quality across the West Midlands from December 2023 to February 2024, as measured at the Birmingham Air Quality Supersite (BAQS):

- Compared with the long-term (2019-2023) mean, low levels of NO_2, O_3 and $PM_{2.5}$ concentrations were observed during the winter period, well below the (annual) air quality objectives
- Four main components contributed to the $PM_{2.5}$ mass concentration at BAQS: black carbon (mean contribution of 40.2%), inorganic elements (30%), inorganic aerosol (22.5%) and organic carbon (7.7%). The formation and accumulation of inorganic aerosol was the dominant cause of the higher PM concentrations observed during the period.
- Black carbon (from combustion sources) was mainly formed locally, while organic carbon, inorganic aerosol and inorganic elements were partly influenced by long-range transport from outside of the region, as seen in the back trajectories and wind polar plots.
- Using modelling tools the PM composition can be analysed to estimate the PM sources and the contribution of these sources to PM concentrations - at least four sources contribute to the PM during the winter period: biomass burning, sea salt, dust and traffic, and industrial emissions.

Summary of provisional air quality at Birmingham air quality supersite (BAQS): 01/12/2023 to 29/02/2024

Parameter	Mean value	Peak value	Previous mean value (2019-2023)*	National (England) air quality objectives
Temperature (T)	6.7 °C	16.8 °C (2/01 14:00)	5.5 °C	
Wind speed (ws)	3.8 m s^{-1}	13.9 m s^{-1} (2/01 16:00)	3.7 m s^{-1}	
Nitrogen dioxide (NO_2)	16.5 µg m^{-3}	77.1 µg m^{-3} (17/01 19:00)	16.8 µg m^{-3}	40 µg m^{-3} (annual mean)
Ozone (O_3)	41.8 µg m^{-3}	70.4 µg m^{-3} (9/01 13:00)	43.8 µg m^{-3}	100 µg m^{-3} (8-hour mean)
Fine particulate matter ($PM_{2.5}$)	6.3 µg m^{-3}	34.6 µg m^{-3} (13/01 00:00)	8.3 µg m^{-3}	20 µg m^{-3} (annual mean)

**Previous mean calculated from measurements at BAQS in December, January, February in 2019-2023*

(B) Full Report

1. introduction

The Birmingham air quality supersite (BAQS), located on the University of Birmingham campus (52.46 N, 1.93 W), serves as a typical urban background station. In contrast to other automated high-resolution stations, it not only monitors conventional pollutants such as nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), inhalable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) but also records additional pollutants including ammonia (NH_3), methane (CH_4), Volatile organic compounds (VOCs), and Black Carbon, as well as particle number concentration, size distribution, and chemical composition. Based on these comprehensive data, a thorough assessment of atmospheric pollution can be conducted, whilst combining these data with model analysis enables the extraction of source information for different components, providing essential data support for the air quality situation in Birmingham and the wider West Midlands region. For more information about BAQS, including a detailed list of instruments installed at the site, definitions of term used, and break down of the analysis, please refer to the Appendix and Supplementary Information.

This air quality report provides a quarterly overview of the meteorological parameters (temperature and wind speed) and key pollutants (O_3, NO_2, $PM_{2.5}$) observed at BAQS over the past three months. It also offers a brief summary of the changes observed during this period. Additionally, the report includes a preliminary discussion on the potential sources of $PM_{2.5}$ based on its temporal and spatial distribution, along with air mass movement trajectory modelling.

2. Meteorological parameters and key air pollutants

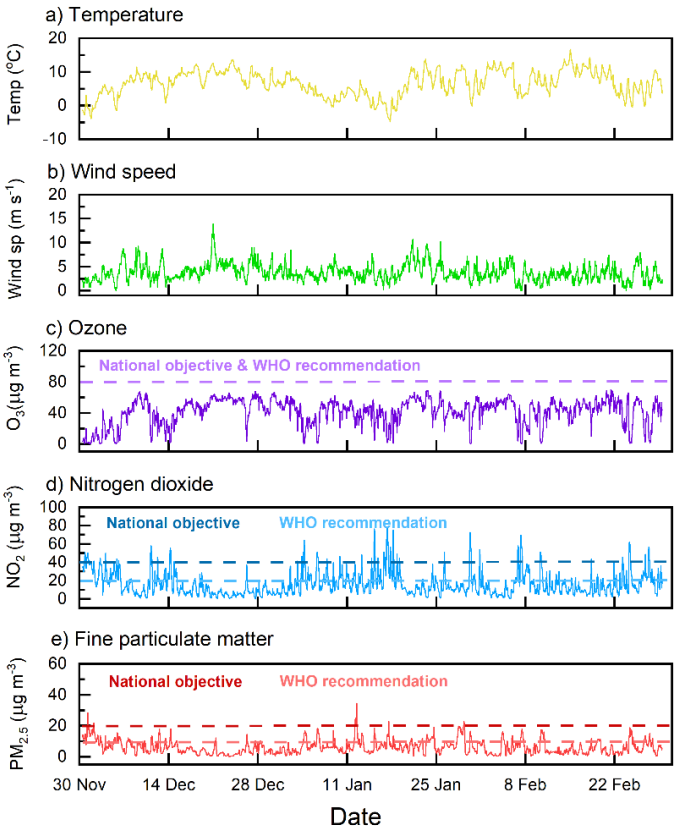

Figure B1: Time series of (a) Temperature, (b) wind speed, (c) provisional ozone concentrations, (d) provisional nitrogen dioxide and (e) provisional fine particulate matter ($PM_{2.5}$) recorded at BAQS from December 2023 to February 2024.

Figure B1 illustrates the changes in temperature, wind speed, concentrations of ozone, nitrogen dioxide, and $PM_{2.5}$ from December 2023 to February 2024. The average temperature was 6.7 °C, with the maximum and minimum 16.8 °C and -4.8 °C, respectively. This is 1.2 °C higher on average compared to the same period from 2019 to 2023. The average wind speed was 3.8 m s^{-1}, with the highest recorded wind speed being 13.9 m s^{-1}. The average wind speed corresponds to a level 2 "Light breeze" on the Beaufort scale (https://www.metoffice.gov.uk/weather/guides/coast-and-sea/beaufort-scale), and it remains relatively unchanged compared to the same period from 2019 to 2023.

The observed average concentrations of NO_2, O_3, and $PM_{2.5}$ are 16.5 µg m^{-3}, 41.8 µg m^{-3}, and 6.3 µg m^{-3}, respectively. For context the national (England) air quality objectives for NO_2 and $PM_{2.5}$ are annual means of 40 µg m^{-3} and 20 µg m^{-3} respectively. For O_3 the objective is for 100 µg m^{-3} (8-hour mean) not to be exceeded more than 10 times a year. Comparing these values with the Daily Air Quality Index (DAQI) defined by DEFRA, all observed values from BAQS fall within the low level (Please refer to the appendix for detailed information on the classification of DAQI levels). Furthermore, compared to the same period from 2019 to 2023, the concentrations of these three pollutants are slightly lower, especially $PM_{2.5}$, which has decreased by 2 µg m^{-3} (24%).

By exploring the data in more detail, it can be seen that the concentration of NO_2 reached a maximum of 77.1 µg m^{-3}, which is 4.7 times higher than the average. Analysis of the daily variation of NO_2 (see Supplementary Material Figure S1) shows that NO_2 levels are higher during morning and evening traffic peaks, indicating that traffic is the primary source of NO_2.

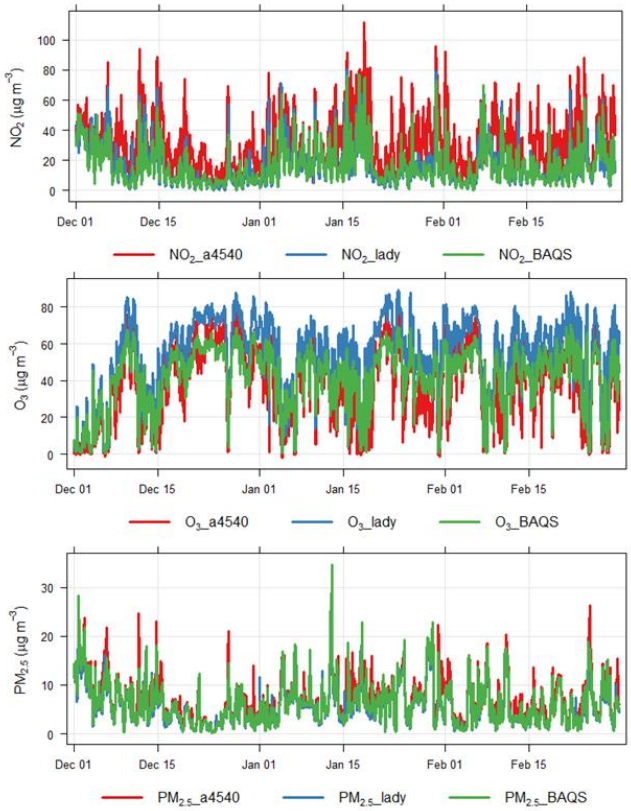

Figure B2: time series of (a) Nitrogen dioxides, (b) Ozone and (c) fine particulate matter ($PM_{2.5}$) from December 2023 to February 2024, the red, blue and green line refer to data measured at a4540 site, Ladywood site and BAQS site, respectively. For detailed information of a4540 site and Ladywood site please see the appendix. Data at a4540 and Ladywood site were download from https://uk-air.defra.gov.uk/data/ .

BAQS represents a typical urban background site, making it a representative of air quality across the Birmingham urban area(30%) and organic carbon (27%), with black carbon being the least abundant (7.8%). This is consistent with the results obtained previously in BAQS (for previous offline observation results, please refer to the Appendix). Although inorganic aerosol is the second largest component, its contribution increases with $PM_{2.5}$ (Figure B5), suggesting that the accumulation of $PM_{2.5}$ is inevitably linked to the formation of inorganic aerosol.

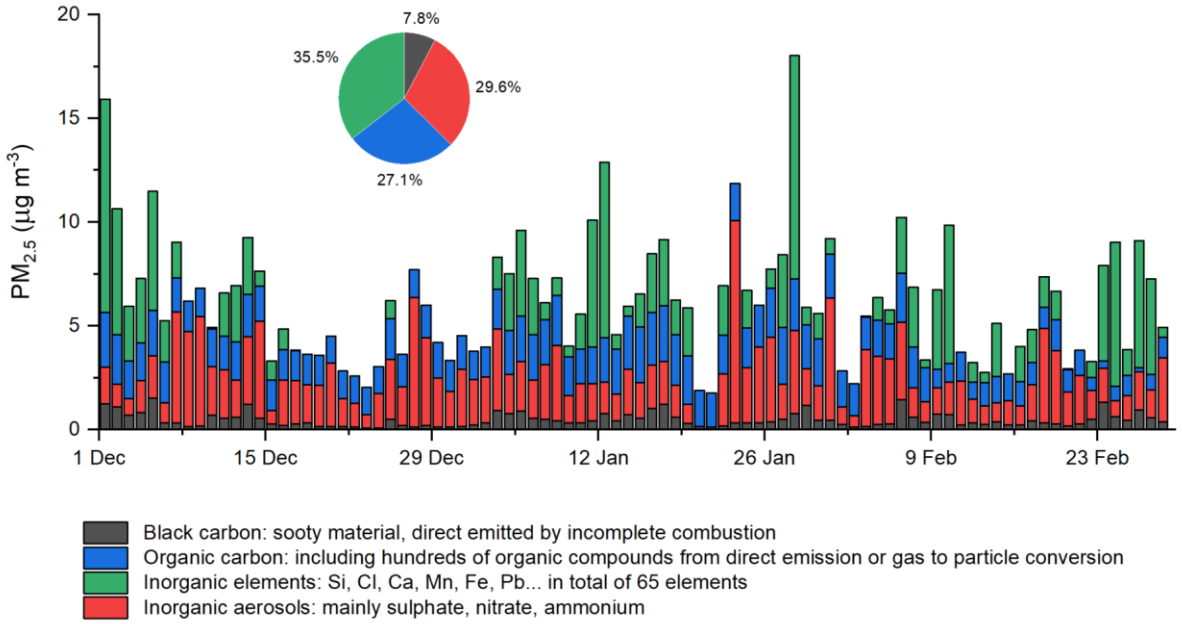

Figure B4: Daily variations in the composition of $PM_{2.5}$ resolved from December 2023 to February 2024. The pie chart shows the mean proportions of each composition.

By plotting the concentration variations of the four components against wind direction and speed, wind polar plots were obtained (see Figure B6). Taking black carbon as an example, its distribution shows higher concentrations concentrated around BAQS (the centre of the circle, representing lower wind speeds), gradually decreasing towards the edges, suggesting local emission of black carbon. Similarly, inorganic elements exhibit low concentrations around BAQS but higher concentrations in the west with concentrations increasing towards the edges, indicating potential transport in to the WM from other areas. This may be originating from the west, as suggested by air mass trajectories shown in the second part. Additionally, organic carbon not only exhibits darkening in the central area but also shows transport from the north, east, and southeast regions. Overall, the observed increase in PM composition levels may be attributed to the influence of long-range transport from neighbouring and distant sources, emphasizing the critical role of regional and global-scale influences on air quality.

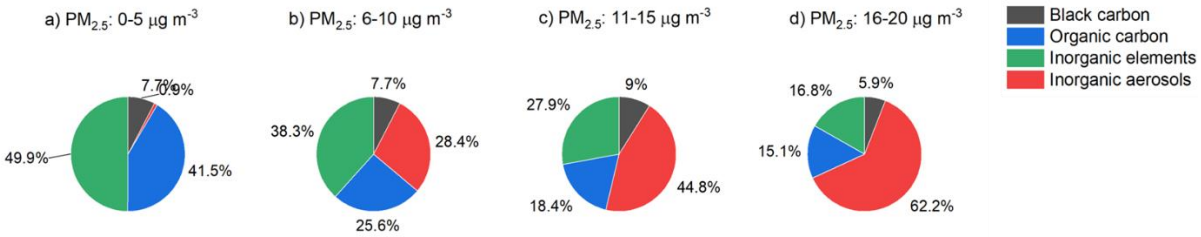

Figure B5: Pie charts of $PM_{2.5}$ composition under 4 different levels: a) $PM_{2.5}$ in range of 0-5 μg m^{-3}, b) $PM_{2.5}$ in range of 6-10 μg m^{-3}, c) $PM_{2.5}$ in range of 11-15 μg m^{-3}, d) $PM_{2.5}$ in range of 16-20 μg m^{-3}.

After obtaining the composition data of $PM_{2.5}$ and then combining it with model analysis, it is possible to analyse the specific sources of $PM_{2.5}$ and the contribution of each source. Common methods can be found in the appendix. However, since only very preliminary results are provided in this report, and there is no detailed detection of components such as Semi-volatile Organic Compounds (SVOCs), which can be seen as individual organic molecular marker compounds to identify pollution sources, source apportionment models cannot be used. Hence, a limited discussion of the sources is conducted.

Previous literature has utilized measured elements as tracers for certain sources to conduct $PM_{2.5}$ source apportionment. For instance, potassium (K) is indicative of biomass burning, while chlorine (Cl) mainly originates from sea salt. Elements such as calcium (Ca), manganese (Mn), iron (Fe), titanium (Ti), zinc (Zn), copper (Cu), and lead (Pb) may stem from vehicle emissions or mineral dust, while lead (Pb), copper (Cu), and selenium (Se) can act as tracers for industrial emissions.

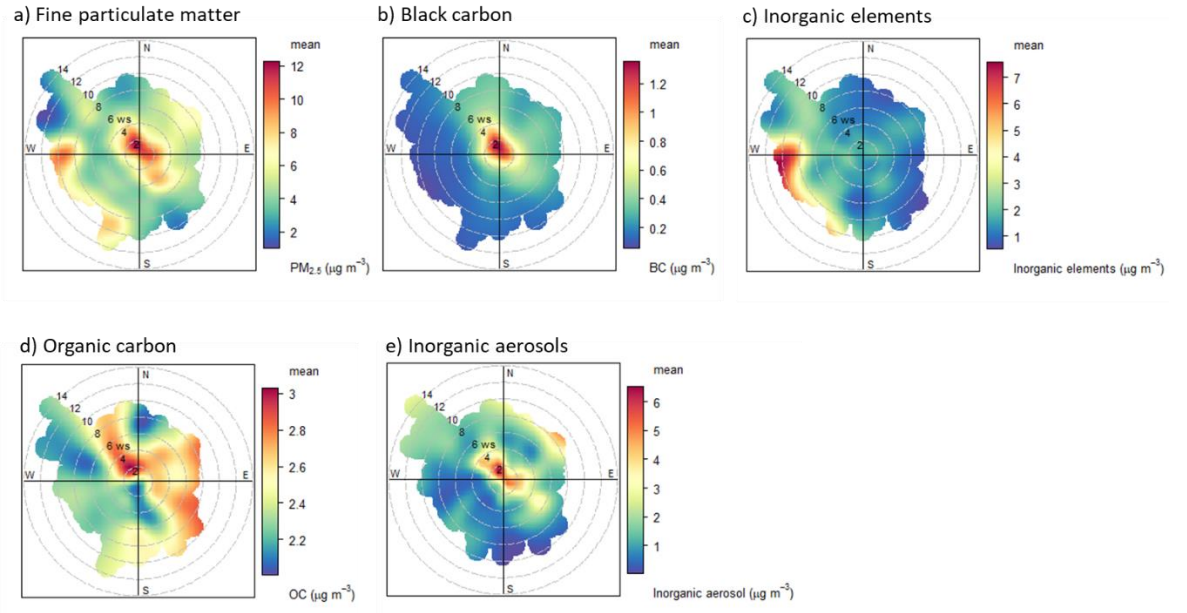

Figure B6: Wind polar plots depicting the distribution of various components of air pollutants measured at BAQS in January 2024. Panels (a) through (f) correspond to fine particulate matter, black carbon, inorganic elements, organic carbon, inorganic aerosols, and inorganic aerosols, respectively.

Based on the diurnal variations, spatial distribution, and correlation analysis of the measured elements (see Supplementary Material), they can be classified into four categories, representing possible sources: biomass burning, sea salt, dust and traffic, and industrial emissions. However, due to the lack of SVOCs analysis as mentioned, some sources such as secondary aerosols, biogenic aerosols, and agricultural emissions cannot be identified solely through elemental analysis.

In 2021, an alternative measurement approach - filter sampling - was conducted at the BAQS site, and source apportionment was performed using a PMF model. This resulted in the identification of six $PM_{2.5}$ sources: biomass burning, resuspended dust and traffic-related emissions, fuel oil combustion, sea salt, secondary aerosols from power generation and agriculture, and biogenic aerosols. Their contributions were estimated at 25%, 22%, 9%, 9%, 25%, and 10%, respectively (see Appendix for details).