West Midlands Air Quality Report from Birmingham Air Quality Supersite (BAQS): *Spring 2024 (March 2024 – May 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 March to May 2024, as measured at the Birmingham Air Quality Supersite (BAQS):

- Compared with long-term mean for spring (2019-2023), low levels of $PM_{2.5}$ concentrations were observed, well below the (annual) air quality objectives. NO2 levels were below the national annual mean objective and were consistent with the long-term record.
- 14% higher O_3 were observed compared to the long-term records in 2019 to 2023. The max concentration is up to 128.4 µg m^{-3}, with exceedances of the 100 µg m^{-3} 8-hour mean target observed 7 times.
- Four main components contributed to the $PM_{2.5}$ mass concentration at BAQS: organic carbon (mean contribution of 36%), inorganic elements (35%), inorganic aerosol (22%) and black carbon (6%). The formation and accumulation of inorganic aerosol was the dominant cause of the observed increase in PM concentration observed during the period.
- inorganic aerosols (mainly from secondary gas-particle formations) were mainly formed locally, while organic carbon, black carbon and inorganic compounds were 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 five 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): 01/03/2024 to 31/05/2024

Parameter	Mean value	Peak value	Previous mean value (2019-2023)*	National (England) air quality objectives
Temperature (T)	10.6 °C	24.7 °C (12/05 14:00)	9.5 °C	
Wind speed (ws)	3.8 m s^{-1}	10.8 m s^{-1} (19/04 12:00)	3.6 m s^{-1}	
Nitrogen dioxide (NO_2)	11.5 µg m^{-3}	79.2 µg m^{-3} (05/03 19:00)	11.4 µg m^{-3}	40 µg m^{-3} (annual mean)
Ozone (O_3)	65.6 µg m^{-3}	128.4 µg m^{-3} (12/05 14:00)	57.5 µg m^{-3}	100 µg m^{-3} (8-hour mean)
Fine particulate matter ($PM_{2.5}$)	8.1 µg m^{-3}	41.2 µg m^{-3} (11/03 00:00)	10.3 µg m^{-3}	20 µg m^{-3} (annual mean)

**Previous mean calculated from measurements at BAQS in March, April, May 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

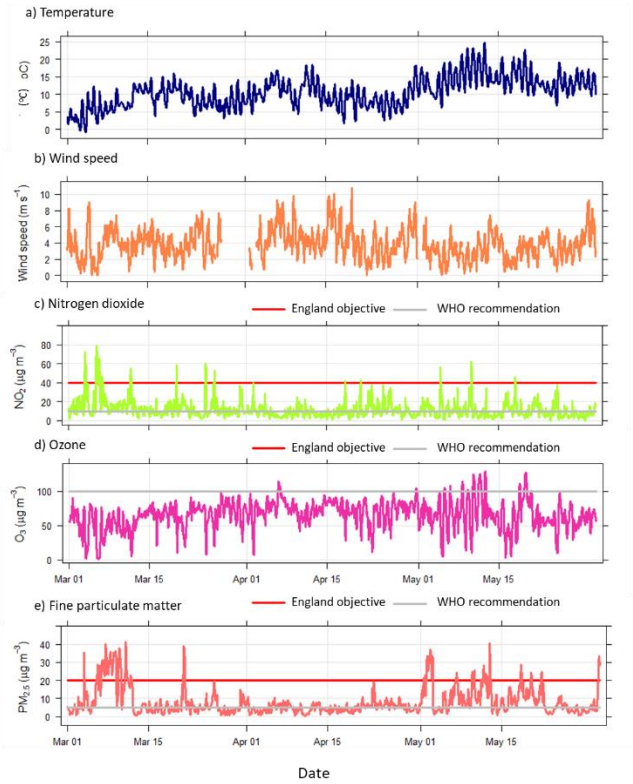

Figure B1: Time series of (a) Temperature, (b) wind speed, (c) provisional ozone concentrations, (d) provisional nitrogen dioxide and (e) provisional fine particulate matter ($PM_{2.5}$) recorded at BAQS from March to May 2024.

Figure B1 illustrates the changes in temperature, wind speed, concentrations of ozone, nitrogen dioxide, and $PM_{2.5}$ from March to May 2024. The average temperature was 10.6 °C, with the maximum

and minimum 24.7 °C and -0.8 °C, respectively. This is 1.1 °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 10.8 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 $PM_{2.5}$ were 11.5 µg m^{-3}, 65.6 µg m^{-3}, and 8.1 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. Comparing these values with the Daily Air Quality Index (DAQI) defined by DEFRA, the observed values of NO_2 and $PM_{2.5}$ from BAQS fall within the "low" level (Please refer to the appendix for detailed information on the classification of DAQI levels). Additionally, when compared to the same period from 2019 to 2023, the concentration of $PM_{2.5}$ is lower by 2.2 µg m^{-3} (21%), while the concentration of NO_2 has remained effectively unchanged. For O_3, the target is for an 8-hour mean of 100 µg m^{-3} not to be exceeded more than 10 times a year. The maximum concentration recorded at BAQS from March to May was 128.4 µg m^{-3}. During this period, values exceeding the 100 µg m^{-3} 8-hour mean were recorded 7 times, which accounts for 0.7% of the measurements and falls within the moderate level of the DAQI.

By exploring the data in more detail, it can be seen that the concentration of NO_2 reached a maximum of 79.2 µg m^{-3}, which is 6.9 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.

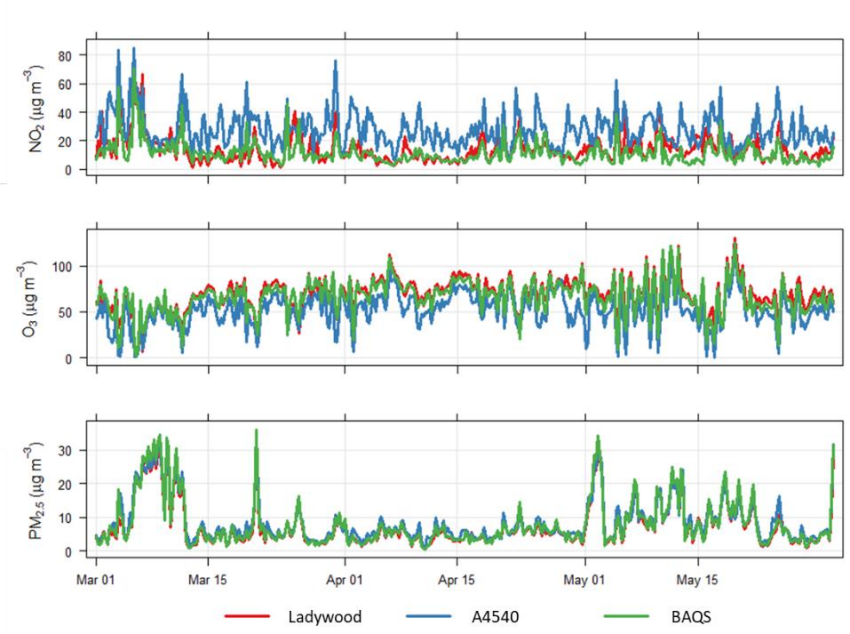

Figure B2: time series of (a) Nitrogen dioxides, (b) Ozone and (c) fine particulate matter ($PM_{2.5}$) from March to May 2024, the red, blue and green line refer to data measured at A4540 site, Ladywood site and BAQS site, respectively. For detailed information of A4540 site and Ladywood site please 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. Air quality at BAQS showed similar levels and trends to those at the Ladywood site (both are urban background sites in Birmingham. The concentration differences of NO_2, O_3 and $PM_{2.5}$ range between 3% and 24%. "A4540" is an air quality monitoring site situated on the A4540 ring road around Birmingham city centre, it is an urban traffic site and hence records higher NO_2 and thus

lower O_3. Nonetheless, the differences observed in $PM_{2.5}$ concentrations between BAQS and those at A4540 are not significant (5% in average).

Table B1: summary of concentrations measured at a4540 site, Ladywood site and BAQS site, respectively

Air pollutant	Site	Mean value ± SD (μg m^{-3})	Range (μg m^{-3})
NO_2	A4540	27.7±14.7	4.3-98.5
	lady wood	14.3±11.4	0.1-80.6
	BAQS	11.5±9.3	0.1-79.2
O_3	A4540	51.9±21.0	-2.5-121.9
	lady wood	67.8±21.4	1.8-134.0
	BAQS	65.6±20.8	1.1-128.4
$PM_{2.5}$	A4540	8.5±6.9	0.4-37.9
	lady wood	7.5±6.8	0.3-37.3
	BAQS	8.1±7.6	0.3-41.2

SD: standard deviation
Data at a4540 and Ladywood site were download from https://uk-air.defra.gov.uk/data/ .

2. Where did the air come from? Back trajectory analysis

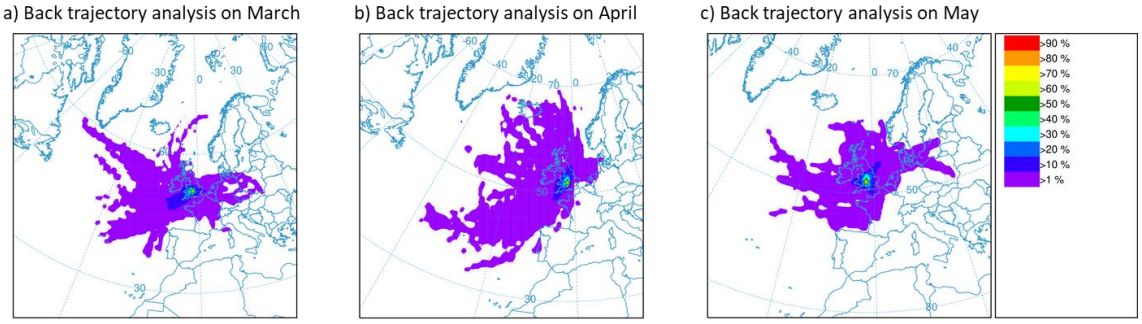

Figure B3: 48h back trajectory frequency analysis on (a) March, (b) April, and (c) May in 2024

Back trajectory modelling is an approach used to trace the movement of air "masses", the volumes of air which move around the atmosphere together. For a detailed explanation of the model, please refer to the appendix. Figure B3 shows the trajectory frequencies of air masses movements ending at BAQS simulated by the HYSPLIT Trajectory Model (https://www.arl.noaa.gov/hysplit/) over a period of 48 hours prior to their arrival in the West Midlands (at BAQS). As shown in the figure, the light blue areas represent the trajectory frequencies where more than 30% of air masses during March to May have travelled in the 48 hours prior to arriving in the WM, predominantly originating from the northeast and the southwest. This provides insight into the sources and pathways of air pollutants impacting the West Midlands and the influence of regional transport patterns on local air quality.

3. What is in the air – composition of fine particles ($PM_{2.5}$)

The composition of $PM_{2.5}$ observed at BAQS is shown in Figure B4. Generally, the components of $PM_{2.5}$ can be roughly divided into: organic carbon, elemental carbon (or black carbon), inorganic aerosols, and inorganic elements. Based on the observation methods used in BAQS, $PM_{2.5}$ components here are

categorized into four groups: black carbon, organic carbon, inorganic elements, and inorganic aerosols. For detailed information on the observation methods, please refer to the appendix.

Figure B4 also summarizes the average composition of $PM_{2.5}$ observed over the past three months. Specifically, the most abundant component is organic carbon, accounting for over 36% of the total, following by inorganic elements (35%) and inorganic aerosols (22%), with black carbon being the least abundant (5.8%). 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 third 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.

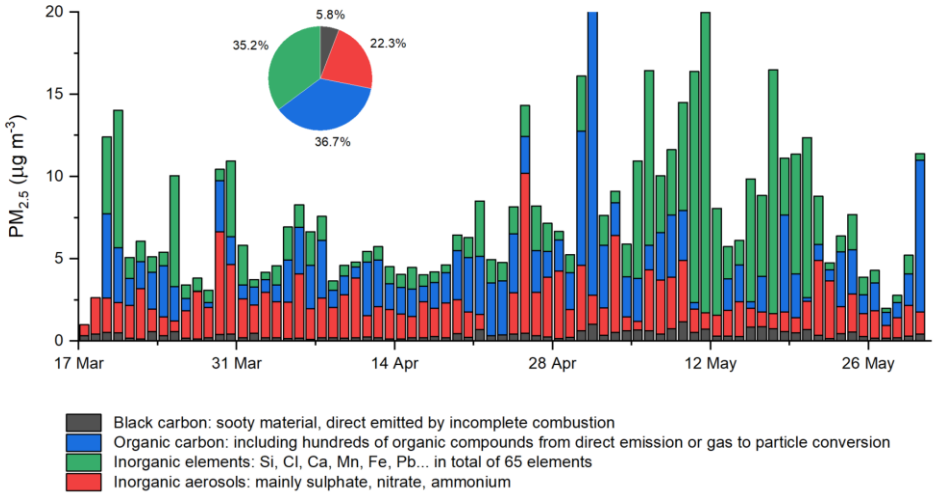

Figure B4: Daily variations in the composition of $PM_{2.5}$ resolved from December 2023 to February 2024. The pie chart shows the mean proportions of each composition (Please note that this data is very preliminary and should be used with caution for reference purposes only).

By plotting the concentration variations of the four components against wind direction and speed, wind polar plots were obtained (see Figure B6). $PM_{2.5}$, black carbon, and inorganic elements showed both high observed concentrations in the north-east part of the circle, increasing towards the edge. This suggests a source for these three pollutants to the north-east of BAQS. This source aligns with the air mass origins mentioned in the second section, indicating that the source is likely transported from distant regions with the air mass. Additionally, black carbon and inorganic aerosols both show high concentrations around BAQS (the centre of the circle), indicating that this portion of black carbon and inorganic aerosols is locally emitted or formed. Organic carbon exhibits darkening in the northeast and southwest as well, but it differs from the source of black carbon and inorganic elements, showing a potential transport from the north, and southwest 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.

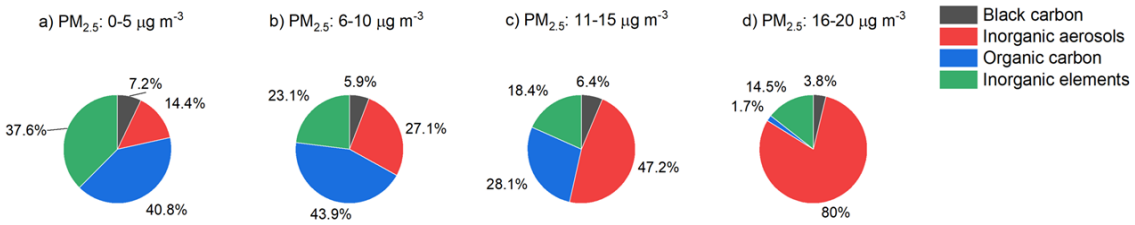

Figure B5: Pie charts of $PM_{2.5}$ composition under 4 different levels: a) $PM_{2.5}$ in range of 0-5 μg m^{-3}, b) $PM_{2.5}$ in range of 6-10 μg m^{-3}, c) $PM_{2.5}$ in range of 11-15 μg m^{-3}, d) $PM_{2.5}$ in range of 16-20 μg m^{-3}.

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.

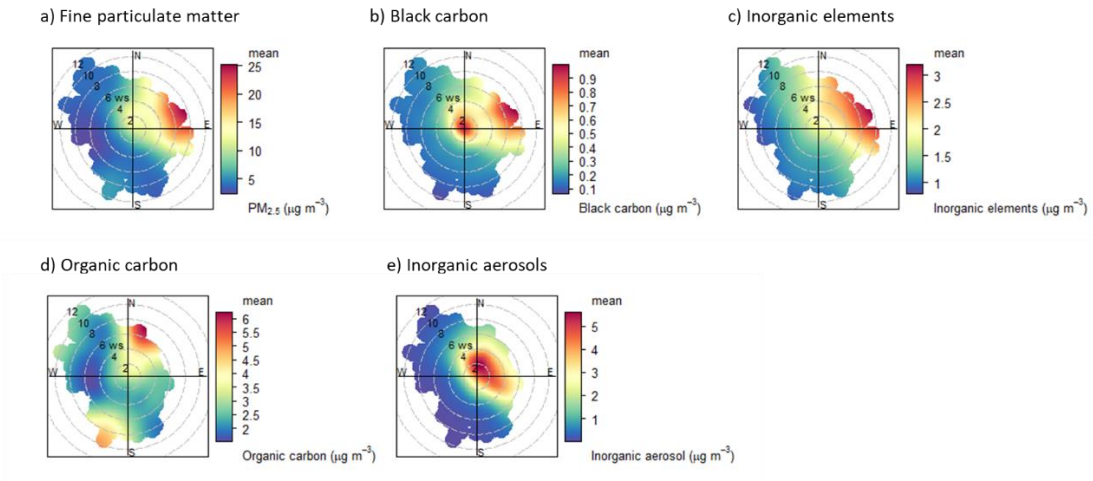

Figure B6: Wind polar plots depicting the distribution of various components of air pollutants measured at BAQS in January 2024. Panels (a) through (f) correspond to fine particulate matter, black carbon, inorganic elements, organic carbon, inorganic aerosols, and inorganic aerosols, respectively.

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).