West Midlands Air Quality Report from Birmingham Air Quality Supersite (BAQS): *Winter 2024/25 (December 2024 – February 2025)*

A report from the WM-Air project for WMCA

High level summary

Urban background air quality measured in winter 2024/25 from December 2024 to February 2025 at the Birmingham Air Quality Supersite (BAQS) located at the university of Birmingham.

- Compared to the long-term winter average of December, January and February 2019 to 2024, Fine Particulate Matter ($PM_{2.5}$) concentrations during Winter 2024/25 were greater than the previous average at 10.1 µg m^{-3} compared to the historical average of 7.9 µg m^{-3}. For reference the national (England) limit value for $PM_{2.5}$ concentration is an annual average of 20 µg m^{-3}, with an annual average of 10 µg m^{-3} to be achieved by 2040 (Environment Act).
- Nitrogen dioxide (NO_2) concentrations averaged 20.45 µg m^{-3} which is in line with the winter average from 2020 to 2024 of 19.6 µg m^{-3}. For reference, the national limit value for NO_2 concentrations is an annual average of 40 µg m^{-3}.
- Ozone (O_3) concentrations averaged 32.8 µg m^{-3} which is in line with the historical winter average from 2019 to 2024 of 35.6 µg m^{-3}, however, it is important to note that the O_3 concentrations for this period are preliminary. For reader information, the current national limit value for ozone concentrations is that 8-hour mean concentrations should not exceed 100 µg m^{-3} more than 10 times a year.
- Black carbon (BC) concentrations as measured at 880nm which is representative of the total BC in the atmosphere averaged 0.54 µg $m^{=3}$ which is lower than the previous winter average from 2019 to 2024 at 0.71 µg $m^{=3}$. The Aethalometer model developed by Sandradewi *et al.* (2008) showed that biomass burning dominated the BC concentrations during winter 2024/25.

Summary of air quality and meteorology at the Birmingham Air Quality Supersite (BAQS) from December 2024 to February 2025

Parameter	Mean value	Peak value	Previous winter average	National (England) air quality objectives
Temperature (T)	5.16°C	14.52°C	5.68°C (2020-2024)	
Wind speed (ws)	2.06 m s^{-1}	18.10 m s^{-1}	1.98 m s^{-1} (2020-2024)	
Fine particulate matter ($PM_{2.5}$)	10.07 µg m^{-3}	79.57 µg m^{-3}	7.86 µg m^{-3} (2019-2024)	20 µg m^{-3} (annual mean)
Nitrogen dioxide (NO_2)	20.45 µg m^{-3}	95.76 µg m^{-3}	19.62 µg m^{-3} (2020-2024)	40 µg m^{-3} (annual mean)
Ozone (O_3)	32.83 µg m^{-3}	78.49 µg m^{-3}	35.63 µg m^{-3} (2019-2024)	100 µg m^{-3} (8-hour average)

1. Introduction

The Birmingham Air Quality Supersite (BAQS) is a highly instrumented air quality monitoring station located at the University of Birmingham in Edgbaston, Birmingham (52°27'19.8"N 1°55'44.3"W). BAQS is part of the UK Air Quality Supersite Triplet (UK-AQST) with sister sites in Manchester and London both of which were set up at the same time as BAQS. The site serves as a typical urban background monitoring station.

In contrast to other automatic monitoring stations such as those run by Defra, not only does BAQS monitor conventional air pollutants such as nitrogen dioxide (NO_2), sulphur dioxide (SO_2), ozone (O_3), and particulate matter (PM_{10} and $PM_{2.5}$), it also monitors a large range of other pollutants such as carbon monoxide (CO), methane (CH_4), Volatile Organic Compounds (VOCs), Black Carbon (BC), particle number concentration and size distribution as well as particle composition.

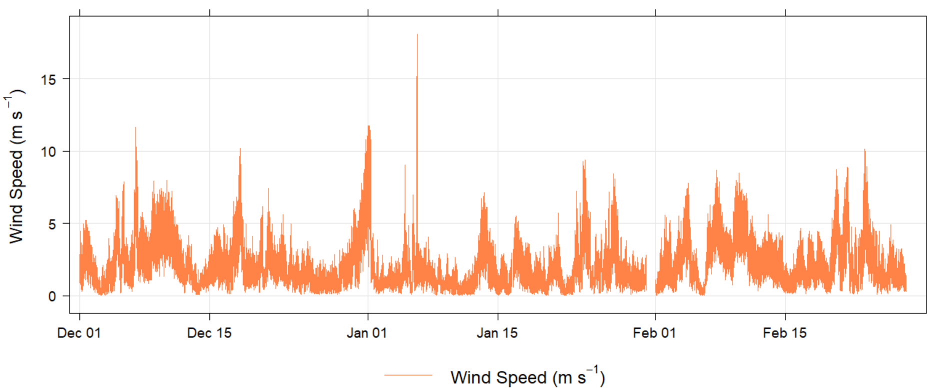
This air quality report provides a quarterly overview of the meteorological parameters (temperature and wind speed) and key pollutants (O_3, NO_2, $PM_{2.5}$) observed at BAQS over the past three months. Additionally, the report provides information on the concentrations and potential sources of BC.

Information on the chemical composition of $PM_{2.5}$ measured at BAQS has had to be excluded from this report as a recent routine servicing and calibration check of the instrument (which is performed once every 6 months) revealed that the x-ray tube has likely failed resulting in a significant degradation of the measurement accuracy. Since the last time the instrument was serviced and fully calibrated in November, the actual rate of performance degradation is unknown and as such the data has had to be flagged as being of low confidence, thus this data has been excluded from this report.

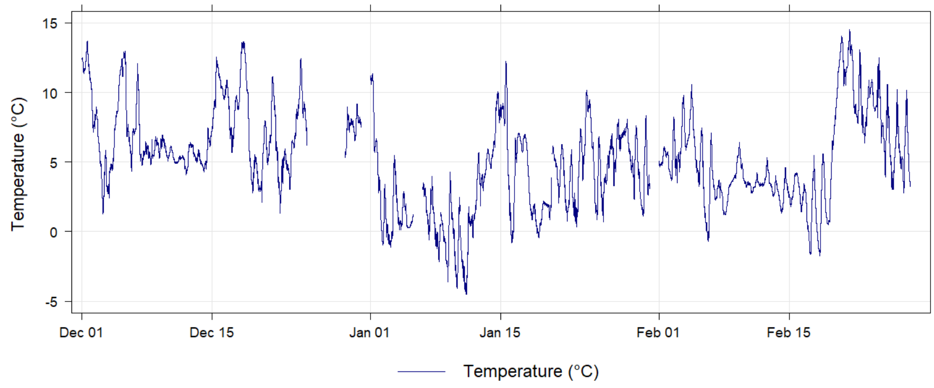
2. Meteorology and key pollutants

2.a. Time series

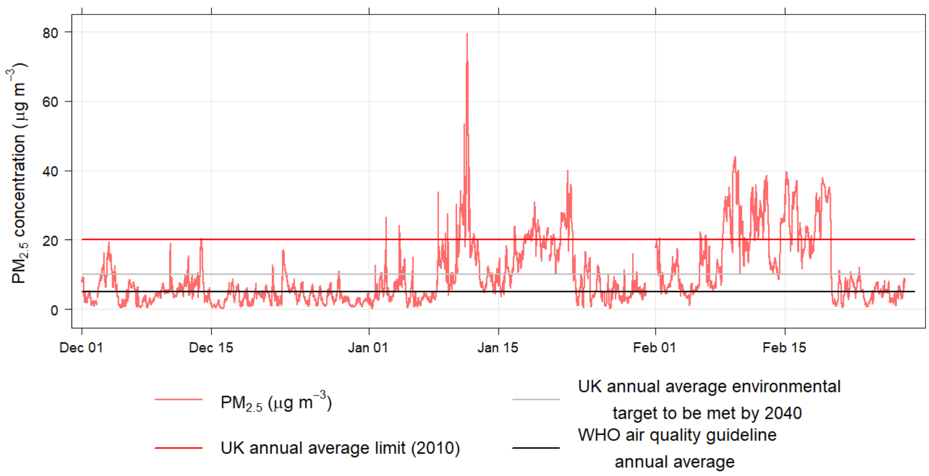
a. Wind speed



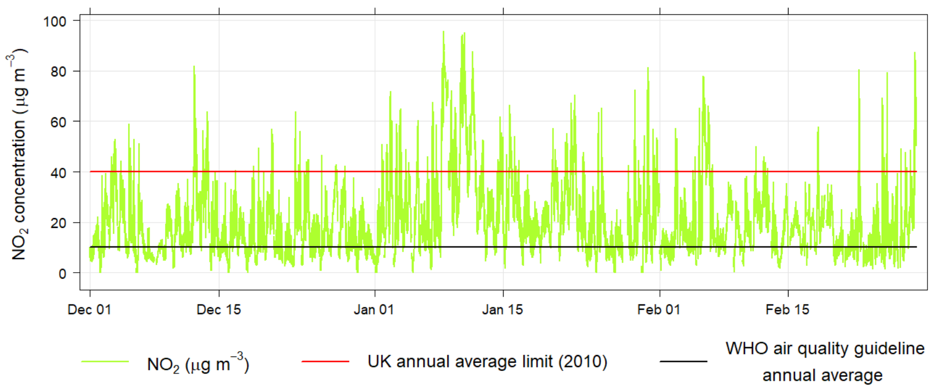
b. Temperature (dry bulb)



c. $PM_{2.5}$



d. NO_2



e. O_3

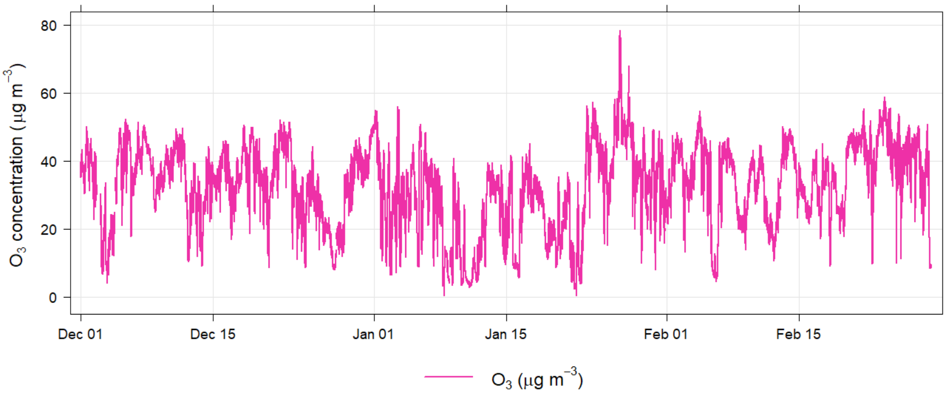


Figure 1: Time series of minute data for a. wind speed, b. dry bulb temperature, c. $PM_{2.5}$ concentrations, d. NO_2 concentrations and e. O_3 concentrations recorded at the Birmingham Air Quality Supersite (BAQS) located at the University of Birmingham from December 2024 to February 2025. Shown on plots c, d and e is the concentration limit for the 3 pollutants as stated in the UK's Air Quality Standards Regulations (2010), the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023), and as recommended by the WHO in the WHO global air quality guidelines (2021). Please note that these concentrations are preliminary, particularly the ozone concentrations.

Winter 2024/25 spans from December 2024 to February 2025. Wind speeds averaged 2.06 m s^{-1}, with a minimum of 0.03 m s^{-1} and a maximum of 18.10 m s^{-1}, the median wind speed was 1.69 m s^{-1}. The average speed recorded during this winter season is in line with the previous winter average recorded at the site from 2020 to 2024 at 1.98 m s^{-1}. Winter 2024/25 saw higher peak wind speeds than all previous winters at the site (2020 to 2024), with winds peaking at 18.10 m s^{-1} on 6 January 2025. Outside of this winter period, the previous highest winter wind speed (from 2020 to 2024) was 10.93 m s^{-1} occurring on 21 January 2024.

The dry bulb temperature recorded at BAQS averaged 5.16°C, with a minimum of -4.51°C, a max of 14.52°C and a median of 5.10°C. This average temperature is in line with the winter average from 2020 to 2024 at 5.68°C. Minimum and maximum temperature during this winter did not set any new records at BAQS and were within the range previously observed at the site. The greatest maximum winter temperature occurred on 15 February 2024 with a temperature of 17.09°C. The greatest minimum winter temperature occurred on 16 December 2022 with a temperature of -5.17°C.

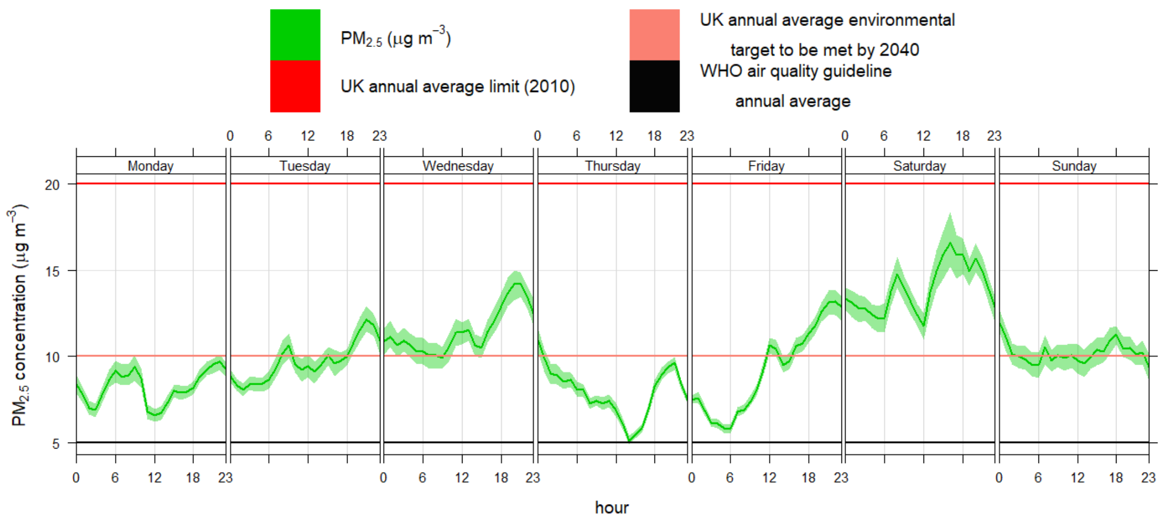
$PM_{2.5}$ concentrations averaged 10.07 µg m^{-3}, with a minimum of 0.23 µg m^{-3}, a maximum of 79.57 µg m^{-3} and a median of 6.35 µg m^{-3}. The average concentrations recorded during this winter season were greater than the winter average from 2019 to 2024 at 7.86 µg m^{-3}. For reference, the limit for $PM_{2.5}$ is an annual average concentration of 20 µg m^{-3} as stipulated in the UK's Air Quality Standards Regulations (2010). The new annual average limit which must be met by 2040 as stipulated in the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) is 10 µg m^{-3}, and the WHO air quality guideline recommends an annual average $PM_{2.5}$ concentration of 5 µg m^{-3}.

NO_2 concentrations averaged 20.45 µg m^{-3}, with minimum 0.01 µg m^{-3} and maximum 95.76 µg m^{-3}, with a median of 16.65 µg m^{-3}. The average during this winter period was in line with the winter average from 2020 to 2024 at 19.62 µg m^{-3}. For reference, the legal annual concentration limit stipulated in the Air Quality Standards Regulations (2010) requires that annual concentrations must not exceed 40 µg m^{-3}. The WHO's air quality guidelines say that concentrations should not exceed an annual average of 10 µg m^{-3}.

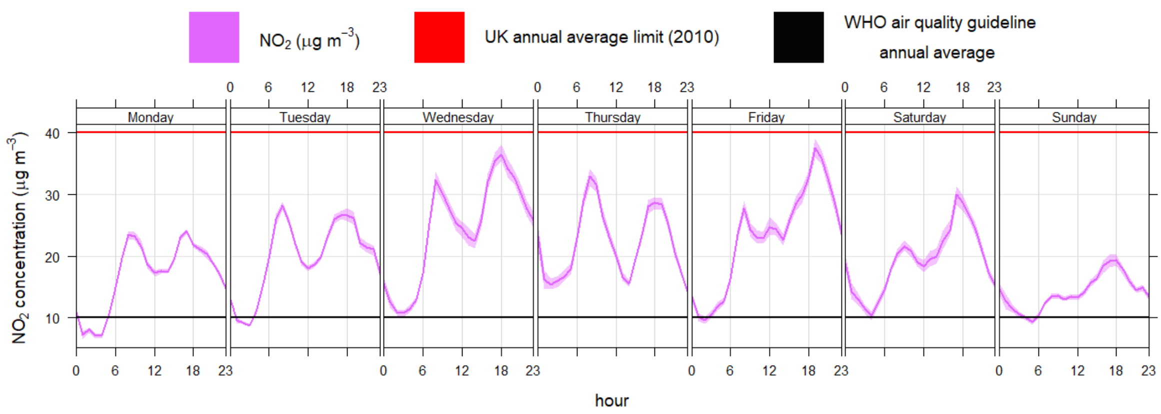
O_3 concentrations averaged 32.83 μg m^{-3}, with minimum of 0.38 μg m^{-3}, maximum of 78.49 μg m^{-3} and median 34.59 μg m^{-3}. The winter average during this winter is in line with the historical winter average from 2019 to 2024 at 35.63 μg m^{-3}. It is important to note that the O_3 concentrations for this period are preliminary so can only be used to show the trends and not give absolute values nor can it be used to show whether concentrations were within the legal or recommended limits. For reader information, the current limit for ozone concentrations stipulated in the Air Quality Standards Regulations (2010) are that a three-year average of 8-hour mean concentrations of O_3 should not exceed 120 μg m^{-3} more than 25 times. The WHO's air quality guideline is a limit of 100 μg m^{-3} as an 8-hour average.

2.b. Diurnal variation by day of the week

a. $PM_{2.5}$



b. NO_2



c. O_3

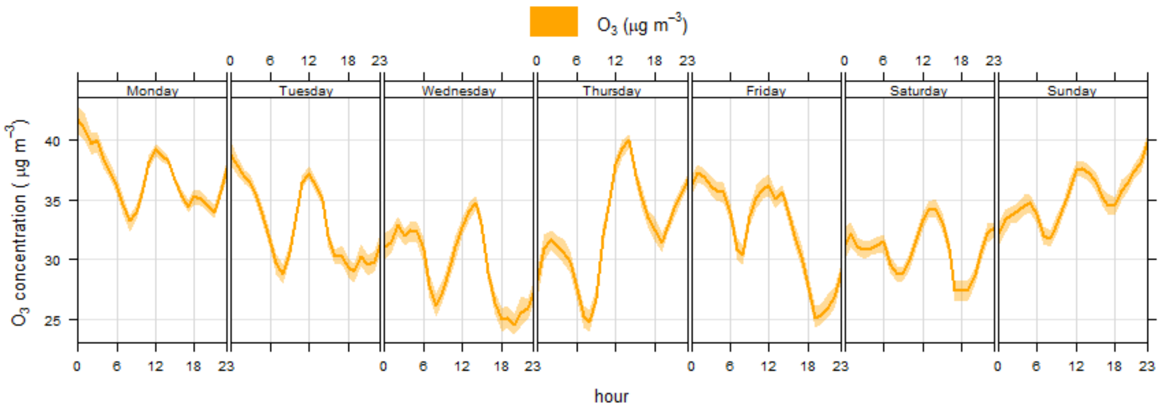


Figure 3: The average diurnal variation by day of the week between December 2024 to February 2025 for a.$PM_{2.5}$ concentrations, b. NO_2 concentrations and c. O_3 concentrations. Data was recorded at the Birmingham Air Quality Supersite (BAQS) located at the University of Birmingham. The shading shows the 95% confidence intervals of the mean.

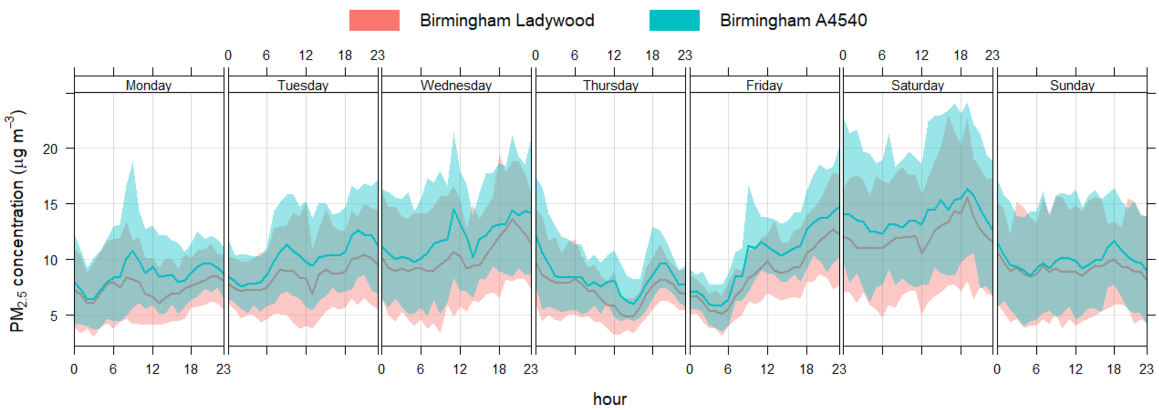


Figure 4: The average diurnal variation by day of the week between December 2024 to February 2025 for $PM_{2.5}$ concentrations recorded at the two AURN stations in Birmingham, the A4540 Roadside site and the urban background site Birmingham Ladywood. The shading shows the 95% confidence intervals of the mean.

Figure 3 shows the average diurnal variation by day of the week for the key meteorological variables and the key air pollutions recorded at BAQS during winter 2024/25.

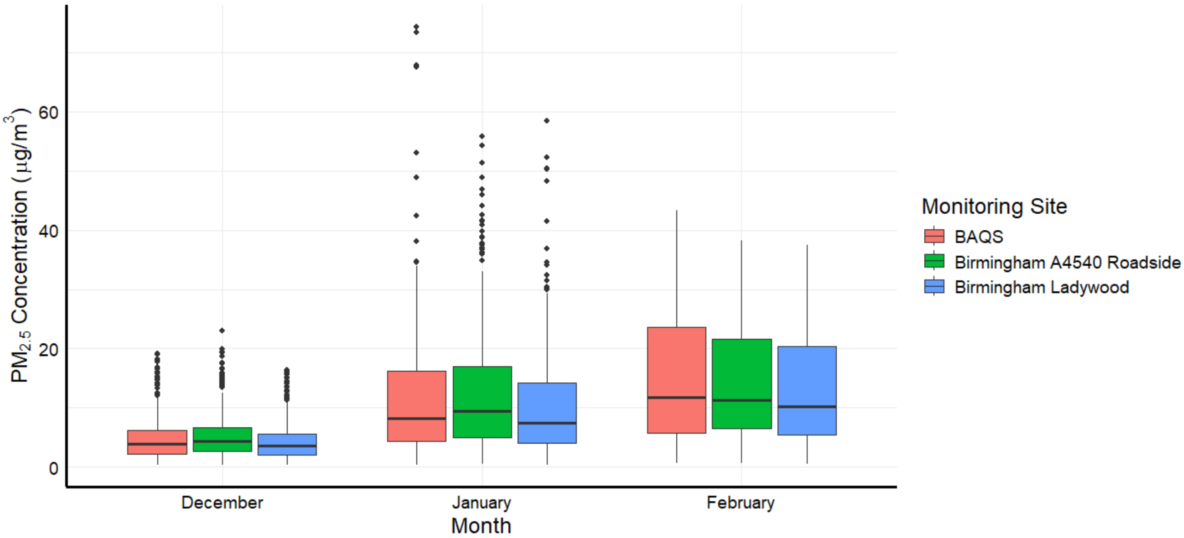
$PM_{2.5}$ concentrations at BAQS showed no significant diurnal trends across the week except for a clear decrease in concentrations on Thursdays and Fridays, as shown in figure 3.a. This is the same result seen in the concentrations measured at the two AURN stations in Birmingham, the A4540 roadside side and Birmingham Ladywood which is an urban background. The $PM_{2.5}$ concentrations from these sites are shown in figure 4. No clear diurnal trend can be seen. The only day of the week trend which can be observed is the drop in concentrations on Thursdays and Fridays.

NO_2 which is a very typical traffic dominated pollutant formed during high temperature combustion such as in internal combustion engines shows two clear peaks during Monday to Friday which coincides with morning and evening rush hour. Two peaks are still visible on both Saturday and Sunday, albeit with a lower magnitude, particularly on Sunday.

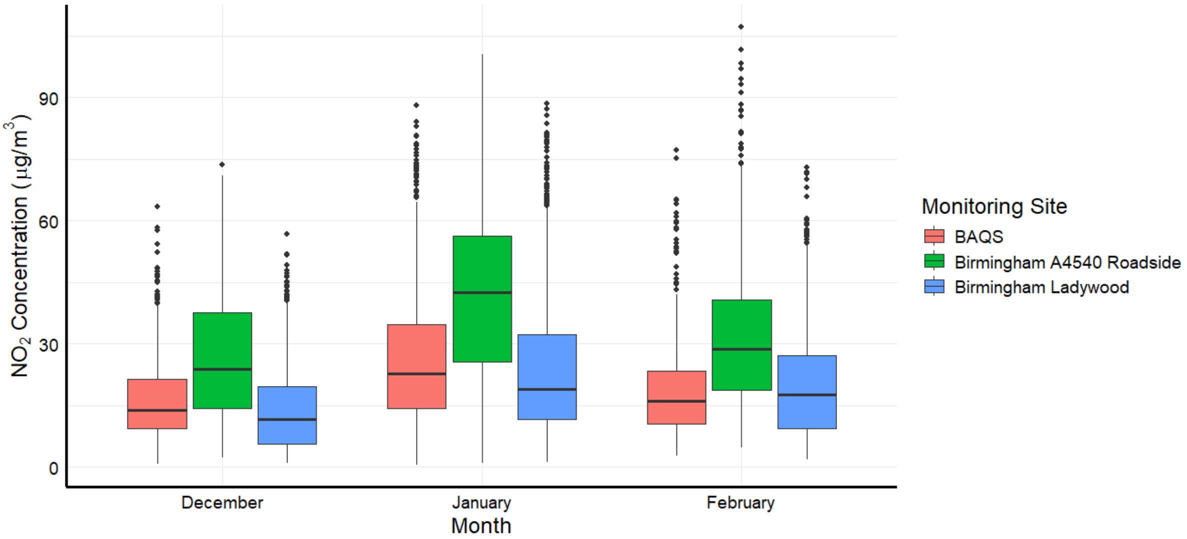
Ozone exhibits a decrease in concentrations during rush hour, particularly morning rush hour which is likely due to the sharp increase in NO concentrations being emitted from internal combustion engines during this time. Although NO_x is emitted from internal combustion engines as a result of high temperature combustion, the majority of it is emitted in the form NO which then reacts with ozone to form NO_2. This reaction depletes the ozone in the atmosphere causing the drop in concentrations seen during rush hour, so higher NO concentrations reduce O_3 concentrations (de Souza *et al.*, 2025).

2.c. Comparison to Birmingham AURN stations

a. $PM_{2.5}$



b. NO_2



c. O_3

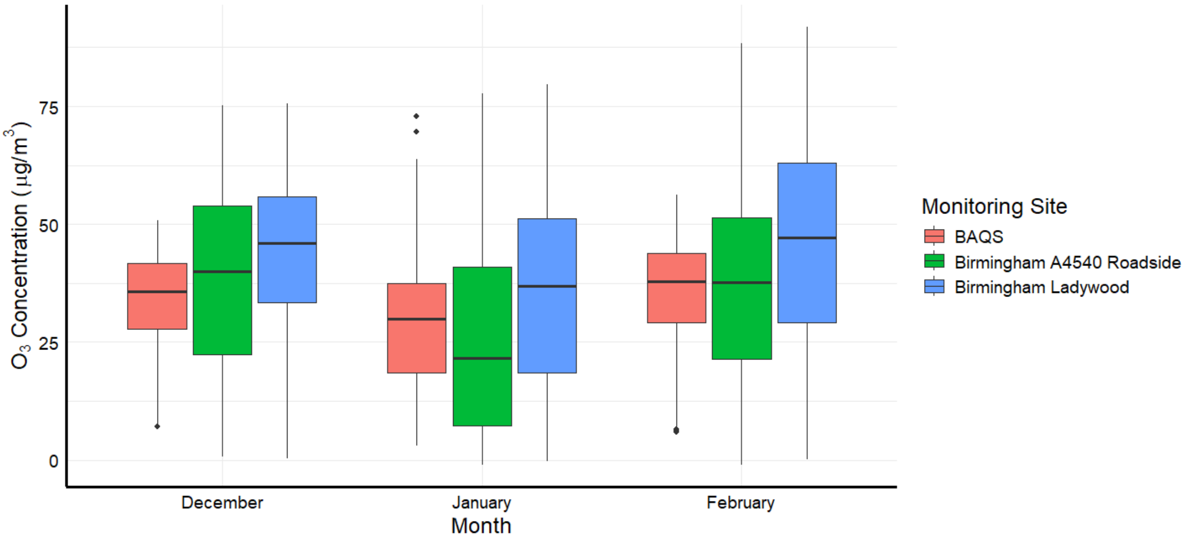


Figure 5: The distribution and variation of a. $PM_{2.5}$, b. NO_2 and c. O_3 concentrations by month. Concentrations were measured at the Birmingham Air Quality Supersite (BAQS), and the two AURN stations in Birmingham: the A4540 roadside site and Birmingham Ladywood which is an urban background site between December 2024 and February 2025. All data used for this plot was averaged to an hourly time resolution as the AURN reports concentrations at a 1 hour time resolution.

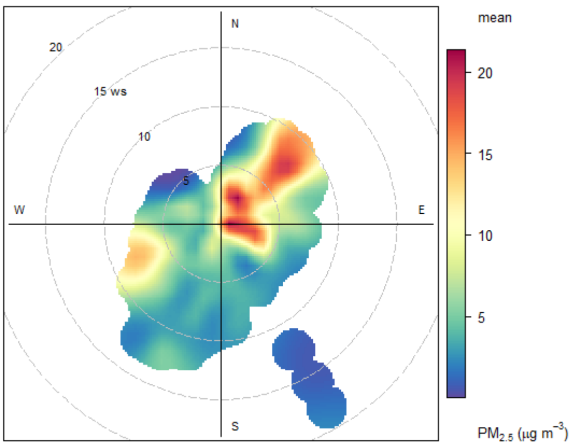
Median $PM_{2.5}$ concentrations are very similar in all 3 months across all sites. Interquartile ranges are very similar across all three sites, notably, February saw a slightly larger interquartile range at BAQS in comparison to the two AURN stations.

Median NO_2 concentrations were the highest in all three months at the A4540 site which is expected because this site is a roadside site so its concentrations will be dominated by traffic emissions from the adjacent road. As BAQS and Birmingham Ladywood sites are urban background locations it is expected that NO_2 concentrations would be lower at these two sites compared to the roadside, and this is the result clearly shown in figure 5b. Concentrations at BAQS span a smaller range than those measured at the two AURN stations, shown by the smaller interquartile range in figure 5b.

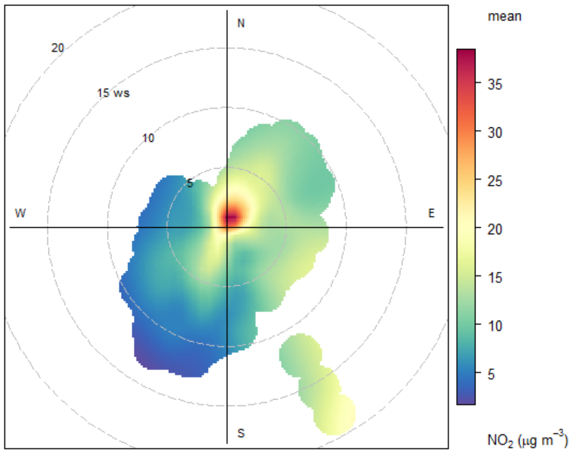
Median ozone concentrations were highest in all three months at Birmingham Ladywood, with the lowest at the A4540 roadside site in December and January, with BAQS being the lowest in February. It is expected that the roadside site would see lower ozone concentrations compared to the urban background sites as NO is the dominate form of NO_x emitted from vehicles. Ozone rapidly reacts with NO in the atmosphere to convert it into NO_2, 'consuming' the atmospheric ozone and thus depleting its concentrations.

2.d. Polar plots

a. $PM_{2.5}$



b. NO_2



c. O_3

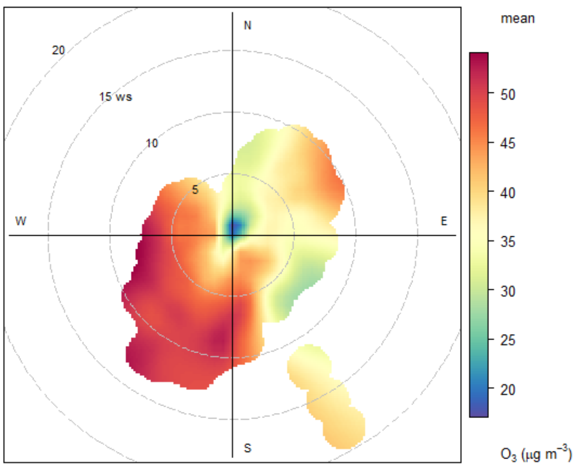


Figure 6: Polar plots of a. $PM_{2.5}$, b. NO_2 and c. O_3. Plots are of mean concentration by wind speed and direction. Wind speeds are measured in m/s. Concentrations were at the Birmingham Air Quality Supersite (BAQS) between December 2024 and February 2025.

$PM_{2.5}$ concentrations are highest when the wind is from the North East, as is shown in figure 6.a. which shows this PM is being transported from an easterly, north easterly source. The results suggest that traffic on the nearby Edgbaston Park Road could be playing a role in these concentrations as this runs north east of BAQS. This is backed up by the figure showing that low wind speeds from the north east and east result in the highest $PM_{2.5}$ concentrations demonstrating that it is likely not long range transport bringing this $PM_{2.5}$ to BAQS, it is coming from a local source when the wind speeds are low.

Wind direction lacks a clear influence upon NO_2 concentrations recorded at BAQS during this winter period. Lower wind speeds result in the highest concentrations, with a very marginal influence of northly winds resulting in the highest concentrations but this effect is incredibly small as is shown in figure 6.b.

The polar plot for O_3 concentrations shows a clear westerly, south westerly and southerly dominance upon its concentrations, with wind speeds greater than 5m/s showing that the O_3 is being transported downwind to BAQS. When wind speed are very low ozone concentrations are their lowest, this could indicate that in BAQS and the near vicinity there is a sink for ozone resulting in lower concentrations. This sink could be the traffic emissions from the nearby road as NO_2 concentrations are also highest when wind speeds are very low suggesting that the O_3 is being depleted through reacting with NO from vehicles to form NO_2 resulting in an NO_2 source and O_3 sink.

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

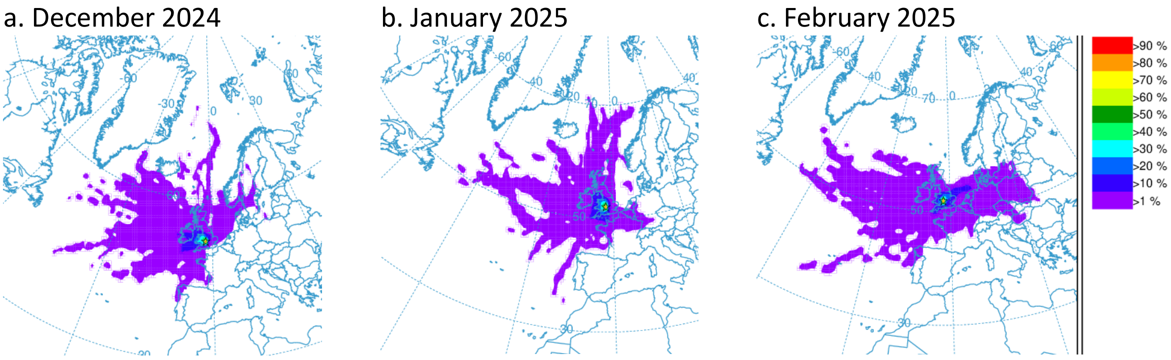


Figure 7: 48 hour back trajectory frequencies originating from the West Midlands (BAQS) in a. December 2024, b. January 2025 and c. February 2025. The maps show the trajectory frequencies which are back trajectories run from the starting location every 6 hours at an altitude of 500m above ground level, after which the back trajectories are summed to give a frequency for the number of times the trajectories have passed over each grid cell. This is then normalised using the following formula: 100 * number of trajectories passing though each grid square / number of trajectories - No residence time in grid cell (each trajectory is only counted once per grid cell)

Back trajectory modelling is an approach used to trace the movement of air masses to understand where the air mass has originated. An air mass is a body of air with uniform weather conditions such as similar temperature and humidity. Figure 7 shows the trajectory frequencies of air mass movements ending in the West Midland (BAQS) as simulated by the HYSPLIT Trajectory Model (Stein *et al.*, 2015; Rolph *et al.*, 2017) over a period of 48 hours prior to the air mass arrival at BAQS. The HYSPLIT model simulates the dispersion and trajectory of substances transported and dispersed through the atmosphere. The figure is of trajectory frequencies which start a trajectory from a single location and height every 6 hours. As is shown in figure 7, in all three months frequencies greater than 50% occurred in the West Midlands and wider Midlands region showing that in the 48 hours prior to arrival at BAQS the air masses spent the majority of their time in the Midlands. In December, frequencies greater than 30% were seen extending into east Wales. In January, frequencies greater than 30% were seen extending even further into Wales than was observed in December, stretching across to the West coast of Wales. In February, this trend differed and frequencies greater than 30% were much more clustered in the Midlands region showing the air masses travelled much shorter distances in these months in the 48 hours prior to arrival at BAQS. 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.

4. Black carbon

4.a. What is it?

Black carbon is defined as the carbonaceous component of particulate matter that absorbs all wavelengths of solar radiation present in the troposphere, i.e., 280-2500 nm (US-EPA, 2012, EPA-450/R-12-001). It is emitted from the incomplete combustion of biomass and fossil fuels (Yang *et al.*, 2021; Zhang *et al.*, 2021; Blanco-Donado *et al.*, 2022).BC can be used as "an indicator of combustion sources since its physical properties, and airborne concentration varies depending on the type of fuel used, combustion characteristics, and meteorology" (Blanco-Donado *et al.*, 2022).

Black carbon absorbs much more light than it reflects and subsequently warms the atmosphere through its interaction with sunlight, it also influences cloud processes, and alters the melting of snow and ice cover(Bond *et al.*, 2013). BC is regarded as the second significant anthropogenic contributor to the forcing of climate after CO_2 (Zhang *et al.*, 2021)

Additionally, BC is known to cause adverse health effects. A cohort study in France which looked at a population of 20,000 individuals between 1989 to 2017 found there was a positive association between long-term exposure to BC and increased mortality risk concluding that exposure to BC is a significant risk factor for mortality (Yang *et al.*, 2021).

The most commonly used instrument to measure real-time BC concentrations is an Aethalometer, specifically model AE33. This instrument measures the BC concentration at 7 different wavelengths from 370 to 950nm. The concentrations measured at 880nm are reported to be representative of the total BC in the atmosphere. The concentrations measured at 370nm are also of interest as this can be used in the Aethalometer model in order to estimate the amount of BC coming from fossil fuel combustion and the amount coming from biomass burning. This will be discussed in more detail shortly.

4.b. Concentrations at BAQS

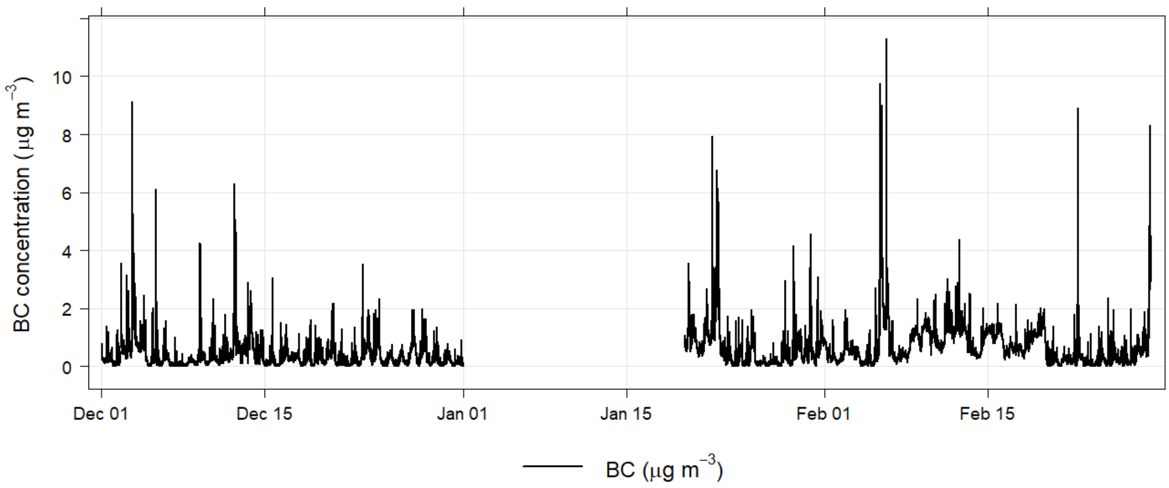


Figure 8: Black carbon concentrations measured at 880nm at the Birmingham Air Quality Supersite (BAQS) from December 2024 to February 2025. Due to an instrument fault, there is no data for the first three weeks of January.

During winter 2024/25 BC concentrations, measured at 880nm as this is representative of the total BC in the atmosphere, concentrations averaged 0.54 µg m^{-3} with a minimum of 0 µg m^{-3}, a maximum of 11.31 µg m^{-3} and a median of 0.35 µg m^{-3}. The average concentrations during this winter are lower than the previous winter average from 2019 to 2024 at 0.71 µg m^{-3}. There is currently no specific regulations limiting black carbon concentrations, however, in urban areas black carbon is in the $PM_{2.5}$ size fraction therefore it falls under the $PM_{2.5}$ concentration regulations. For reference, the annual average limit for $PM_{2.5}$ concentrations is 20 µg m^{-3} as stipulated in the UK's Air Quality Standards Regulations (2010). The new annual average limit which must be met by 2040 as stipulated in the Environmental Targets (Fine Particulate Matter) (England) Regulations (2023) is 10 µg m^{-3}, and the WHO air quality guideline recommends an annual average $PM_{2.5}$ concentration of 5 µg m^{-3}.

4.c. Diurnal variation by day of the week

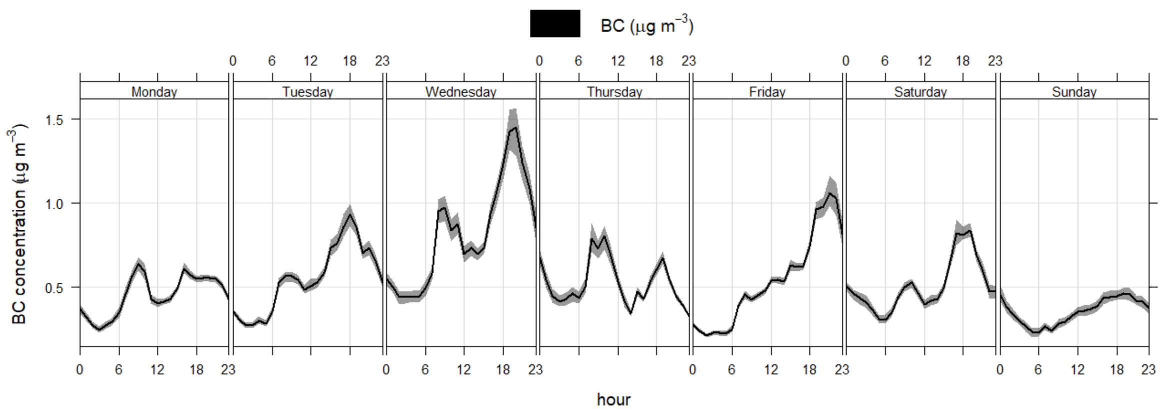


Figure 9: The average diurnal profile by day of the week of Black Carbon measured at 880nm at the Birmingham Air Quality Supersite (BAQS) from December 2024 to February 2025. The shading shows the 95% confidence intervals of the mean.

BC shows two clear peaks during weekdays, except for Friday when only 1 clear peak is seen in the evening. The first peak occurs approximately around morning rush hour, the second spike occurs after evening rush hour late in the evening. Both of these spikes are likely related to vehicle emissions from fossil fuel combustion. The spike in the evening, particularly on Tuesday, Wednesday, Friday and Saturday is of a greater magnitude, the concentrations during this period are likely dominated by biomass burning particularly for heating given these concentrations were measured during winter. A recent paper found that biomass burning was the major contributor (25%) to $PM_{2.5}$ mass in Birmingham (Srivastava *et al.*, 2025) An evening spike in BC concentrations is observed on both weekend days, although the spike on Sunday is of a much lower magnitude compared to the rest of the week.

4.d. Source apportionment of BC

The Aethalometer model developed by Sandradewi *et al.* (2008) is one of the most widely used methods for estimating the contribution of fossil fuel combustion and biomass burning to BC concentrations. This method is based upon the assumption that the main sources of BC are fossil fuel combustion (traffic) and biomass burning. This method takes the concentrations measured at a pair of wavelengths, typically 880nm and 370nm and then uses 4 equations alongside two constants called Ångström Absorption Exponent (AAE) values, one for traffic and one for biomass burning. AAE values are an aerosol optical property describing the spectral dependence of light absorption by aerosols. Putting the BC data into these equations you get an output which is the concentration of BC from fossil fuel and the concentration from biomass burning. This method of source apportionment has several known limitations however it is widely used in the literature and serves as a general indicator for the contribution of biomass burning and fossil fuel combustion upon BC.

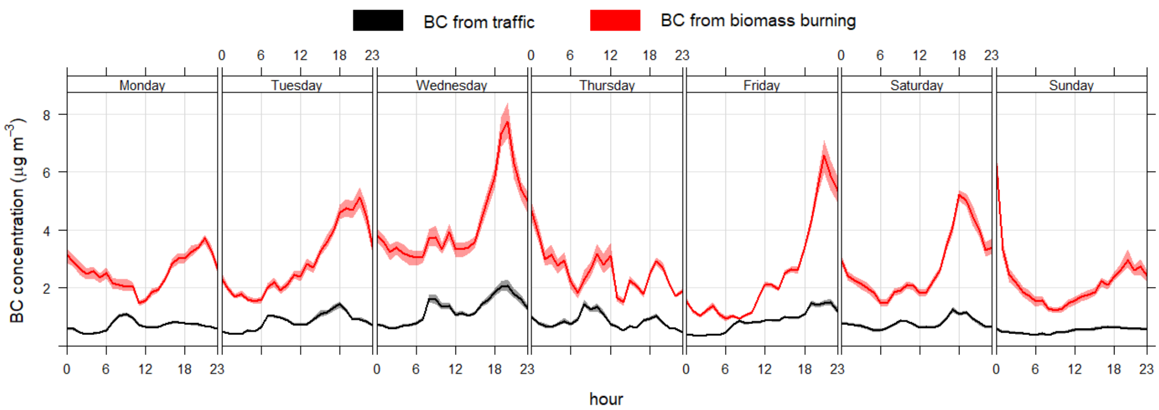


Figure 10: The average diurnal profile by day of the week for the concentration of BC coming from biomass burning and the concentration coming from fossil fuel combustion (traffic). Source apportionment was done using the Aethalometer model which serves as a general indicator for the concentration from biomass burning and from traffic. These concentrations are not absolute values due to the limitations of the Aethalometer model but are a good indicator of the impact of these two sources. The shading shows the 95% confidence intervals of the mean.

Biomass burning dominated the BC concentrations during winter 2024/25 as is shown in figure 10. This result is expected as biomass burning has become increasingly popular in the UK with the widespread use of wood burning stoves for heating, and particularly because these concentrations were measured during winter when there is the need for heating of homes due to low ambient temperatures. The evening spikes in BC seen in figure 9 clearly are as a result of biomass burning, demonstrated in figure 10 where it is shown to be the main source of BC resulting in the highest concentrations out of the two sources. In the BC concentrations from traffic we can see two peaks during weekdays, albeit of a small magnitude, both of which coincide with rush hour. No significant diurnal trends can be seen on Sundays in the BC coming from traffic.

5. References

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