Cheltenham Schools Air Quality Report

16th May 2021

Version 1.2

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Executive Summary

Air quality at three schools has been monitored for three weeks between the 12th April and the 2nd May. This allowed pollutants to be measured during the Easter holidays and term-time so that the influence of the school run on air quality could be explored. All Saints Academy, Bournside School and Gloucester Road Primary School all expressed an interest in taking part in the study, with temporary monitors being placed outside of All Saints and Bournside, whilst a permanent air quality monitor has been in place outside Gloucester Road Primary for several years. The two main pollutants of concern are NO_2 and particulate matter. All sites show a distinct morning peak in NO_2 concentration, but this occurs too early to be the result of the school run. There may be a stronger relationship between the afternoon school run and NO_2 though, with concentrations being higher at school closing time during term-time compared to holiday-term. One school recorded an average NO_2 concentration during the three-week period of 44.6 μgm^{-3} which is above the annual average limit set by the Air Quality Standards Regulations of 40 μgm^{-3}. Due to seasonal variations in air quality, a direct comparison should not be made between the recorded average and the annual average limit, and further monitoring is necessary to determine if the regulation limit is exceeded. Particulate matter has the same profile at all three sites, suggesting that a Cheltenham-wide factor, such as the atmospheric conditions, are the main control. Particulate matter does not correlate with NO_2 so is unlikely to be from the same source.

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Introduction

Static air quality monitors allow long-term variability in pollution to be measured in high temporal resolution. This study will focus on NO_2 and particulate matter (PM_{10}) pollution outside three schools in the Cheltenham Borough Council Area that all expressed an interest in taking part: All Saints Academy, Bournside School and Gloucester Road Primary. Comparisons will be made between term-time and holiday-time air quality, which will allow the influence of the school run to be explored, and levels of pollutants at the three sites will be identified.

Nitrogen dioxide

Nitrogen dioxide (NO_2) is produced through the burning of fuels, such as petrol and diesel in combustion engines. High levels of NO_2 can cause inflammation in the lungs and airways and long-term exposure can reduce the effectiveness of the respiratory system [1] and can lead to an increased susceptibility to infection[2]. This is especially true for people with asthma, although the relationship between NO_2 exposure and childhood asthma is stronger for indoor exposure (from poorly ventilated gas heating, for example)[3] compared to outdoor exposure from traffic[4]. Travelling within vehicles can lead to a higher exposure to NO_2, as the cabin can retain the gas[5].

NO_2 concentration is measured in micrograms per metre cubed (μgm^{-3}). A microgram is one millionth of a gram. There are 2 air quality limit values for NO_2 set out by the Air Quality Standards Regulations 2010[6]. The annual mean concentration of NO_2 must not exceed 40 μgm^{-3} and there must be no more than 18 exceedances of the hourly limit of 200 μgm^{-3} in a year. Within Cheltenham Borough Council's air quality monitoring program, 2 sites were found to exceed the annual limit in 2018, with another 4 sites recording values within 10% of the limit.

Particulate Matter

Particulate matter (PM) is used to describe any airborne particles with a mean aerodynamic diameter falling within a certain limit. Usually within the field of air quality this limit is 10 microns, referred to as PM_{10}, although $PM_{2.5}$ is also used for particles under 2.5 microns. PM can be released directly from a source into the air or can be formed from chemical reactions in the atmosphere[7]. Components of PM include sea salt, black carbon (formed through combustion of fossil fuels or wood), trace metals (from industrial process, fuel additives and mechanical abrasion such as brake pads) and minerals (from construction and quarrying). Components formed by chemical reactions in the atmosphere include sulphates, nitrates and water. PM can be transported long distances, and it is not uncommon for dust blown from the Saharan desert to cause elevated levels of PM in the UK[8]. Smaller particulates are thought to cause the most harm to humans, with those formed through fuel combustion having the strongest effect. The most vulnerable groups are those with pre-existing conditions, the elderly and children[7]. Health issues that can arise from exposure to high levels of PM include decreased lung function and elevated rates of cardiovascular disease, heart disease, strokes, chronic cough, bronchitis and conjunctivitis[9]. This can lead to an increased mortality rate for those exposed to high PM levels[10–12].

PM is also measured in micrograms per metre cubed (μgm^{-3}). There are 2 air quality objectives for PM_{10} levels in England. The annual mean limit is 40 μgm^{-3} and the 24 hour limit of 50 μgm^{-3} is not to be exceeded more than 35 times per year[13]. An annual average of 25 μgm^{-3} for $PM_{2.5}$ was set out in the Air Quality Standards Regulations 2010[6].

Previous studies

In 2017, a study[14] was performed on air quality around 7 schools in Gloucestershire, including 4 in Cheltenham. A mobile air quality monitoring vehicle, nicknamed the Smogmobile, was used to collect data from the sites. Only 2 days were monitored for each site, one during half-term and one during term time. 30 minutes of static measurements were recorded from 8:30, before data was collected on the move over the course of a pre-determined route. Time constraints limited consistency of measurements for some sites, resulting in comparisons between rush-hour and non-rush-hour data. During the sampling period, a particulate pollution episode occurred, where particulates were transported from an external source to cover a large area of the SW of England.

The study concluded that NO_2 levels were lower during term time compared to half-term along the route that the Smogmobile travelled but were significantly higher immediately outside the school gates. The high levels outside the schools were attributed to school traffic, as NO_2 concentrations fell sharply after the school run. There was no consistent relationship between distance from the town centre and NO_2 levels between the sites. PM_{10} levels were not correlated with NO_2 and changing wind direction and pollution episodes had a larger effect on PM_{10} concentration than traffic associated with the school run. Weather conditions, shelter and precursor pollutants were the main factors affecting O_3 around schools. As NO_2 was the only pollutant that reached its hourly threshold limit, the study recommended that it should be the focus of future air quality management plans.

Objectives

The objectives of this report are:

- Carry out in-depth analysis of pollution levels outside three schools in Cheltenham Borough Council
- Identify the impact of the school run on air quality by comparing term-time and holiday-time pollution levels
- Assess term-time pollution levels against legal guidelines and recommendations for child exposure

Method

Figure 1: Map of the three schools. Locations of monitoring pods are marked with the red dot, and the school grounds outlined in orange.

Three AQMesh Pods were used to monitor levels of NO_2, PM_{10} and $PM_{2.5}$. AQMesh Pods are certified air quality monitoring systems that have been used by local authorities, researchers and industry since 2012[15]. Over that period, sensor technology and data processing has improved to increase accuracy and allow air quality and local weather conditions to be measured continuously. The monitors also collect local meteorological data, including air pressure and temperature and are located at main entry points to school grounds. Occasionally the monitors produce negative results when pollutant levels drop below their limit of detection. The monitors outside All Saints Academy and Bournside School are temporary, having been installed in the week commencing 5th April and were left for several days to stabilise before data was downloaded. The monitor at Gloucester Road Primary School has been on location for several years, with data available going back to January 2018.

The monitoring schedule for this project covered the period 12th April to the 2nd May. This allowed term-time and holiday-time weeks to be compared, as schools were closed for the Easter holidays from the 12th-18th April. Term resumed on the 19th for All Saints Academy and Bournside School, and the 20th for Gloucester Road Primary due to an inset day.

Data was downloaded daily using both 15 minute and 1-hour averages from the Acoem airmonitors.net website. Readings were scaled and absolute units were used. The complete datasets were compiled into a master spreadsheet for analysis.

All Saints School

All Saints School is an academy situated in the northwest of Cheltenham. The student body consists of 900 11-16 year-olds, with an additional 220 sixth form places. The school day starts at 8:40 and finishes at 15:10[16]. Entrances to the school grounds are found at the roundabout between Blaisdon Way and Pilgrove Way, with both pedestrian and vehicle access, and Howell Road to the south of the site. The AQMesh Pod is located at the Blaisdon Way entrance.

Bournside School

Bournside School is in the southwest of Cheltenham and has 1750 students. The school day starts at 8:40 for Year 12 students, and 9:00 for all other year groups. Years 7-10 finish at 15:00, whilst Years 11-13 finish at 15:15[17]. There are two additional schools located within the grounds of Bournside. Belmont School is a community special school with approximately 150 pupils. The school day starts at 8:40 and finishes at 14:45[18]. The other school located on the Bournside site is Bettridge School. Another special school, it also has approximately 150 students. Some pupils at the additional schools on the Bournside site rely on minibuses and wheelchair-accessible vehicles to travel to and from school. These vehicles are often larger than non-accessible vehicles and many use diesel engines. Due to pandemic precautions, only one student was allowed per vehicle, which would raise traffic levels above those of non-pandemic times. Access to the Bournside School grounds is from Warden Hill Road to the northwest of the site. Bournside School was closed on Tuesday 27th due to a power supply issue. Roadworks took place close to the monitor during the study, which will influence the measurements of NO_2 and particulates and may have impacted traffic in the area.

Gloucester Road Primary School

Gloucester Road Primary School is in the centre of Cheltenham and has around 200 pupils from nursery to Year 6. The school day starts at 8:55 and finishes at 15:05[19] and the site is accessed from Gloucester Road (B4633). An inset day occurred at Gloucester Road Primary on Monday 19th April. The monitoring station is located opposite the school gates on Gloucester Road. Roadworks took place outside the school from the 26th April, which will impact pollutant measurements.

Weather Conditions During Data Collection

Cheltenham experienced cooler-than-average nights and average day-time temperatures throughout the monitoring period[20]. Week 2 was on average 3°C warmer than weeks 1 and 3. Air pressure was much lower in week 3 compared to the earlier weeks.

Wind speed was lower during the first week of the study period, with an average speed of 1.6 mph[21]. The following two weeks had average wind speeds of 3.75 mph and 3.21 mph respectively. It was common for wind speeds to drop during the night in Cheltenham.

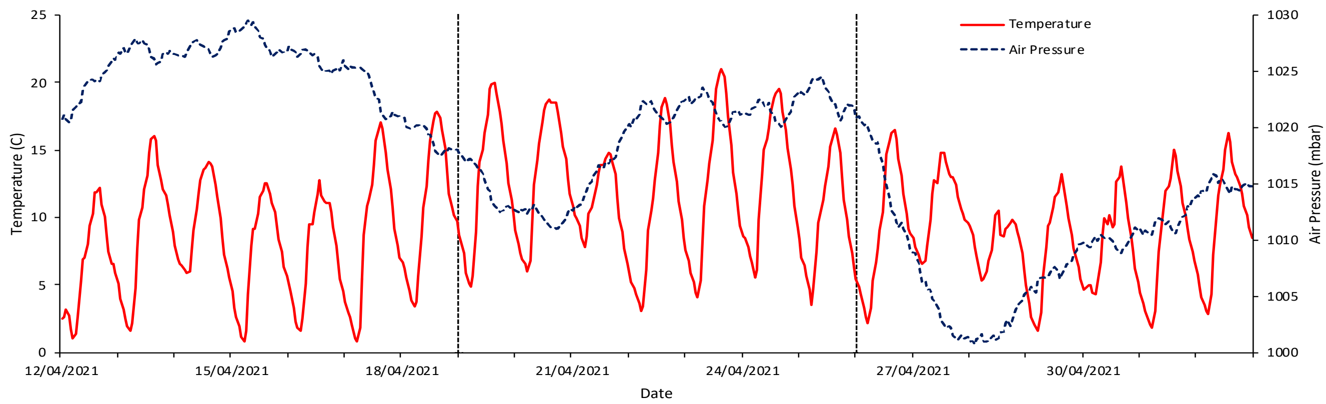


Figure 2: Temperature and air pressure data from Gloucester Road monitoring pod. All three monitoring pods showed very close alignment with their climate data. The start of each week is marked by a black dashed line.

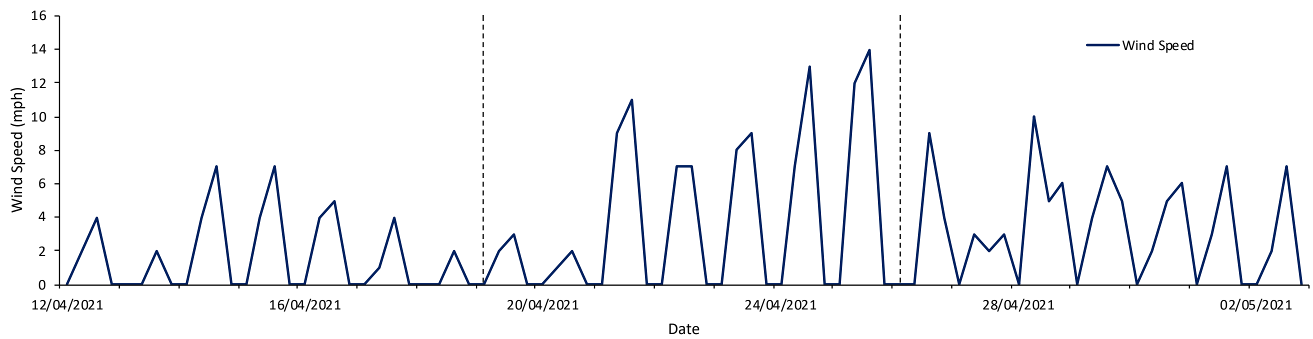


Figure 3: Wind speed data for Cheltenham, obtained from timeanddate.com. Data is 4-hourly. The start of each week is marked with a dashed black line.

Results

Results of NO_2 and PM_{10} will be discussed for each site. $PM_{2.5}$ was very strongly correlated with PM_{10}, so only PM_{10} is explored here.

All Saints – NO_2

NO_2 levels at All Saints did not exceed the 200 μgm^{-3} hourly limit, and the average NO_2 level for the three-week study period was 16.9 μgm^{-3}. The highest levels occurred on Monday and Tuesday of week 2, the first days back after Easter (Figure 4). These days had low wind speeds and were relatively warm. During these three peaks, the hourly NO_2 level exceeded 60 μgm^{-3}, but none of them occur during normal school run hours (2 of the peaks at 08:00 and one at

21:00). Values again dropped to around 30 μgm^{-3} by 09:00. Early morning peaks can be seen in both term-time and Easter holiday weeks. For example, on the Friday of week 1, there is a peak of 57 μgm^{-3} at 07:00, and on the Thursday of weeks 1 and 3 there is another 07:00 peak. As they occur before the school run, it is likely that there is no relationship between the morning peaks of NO_2 and school opening times.

Afternoon NO_2 levels may be occasionally influenced by school traffic. These can be more

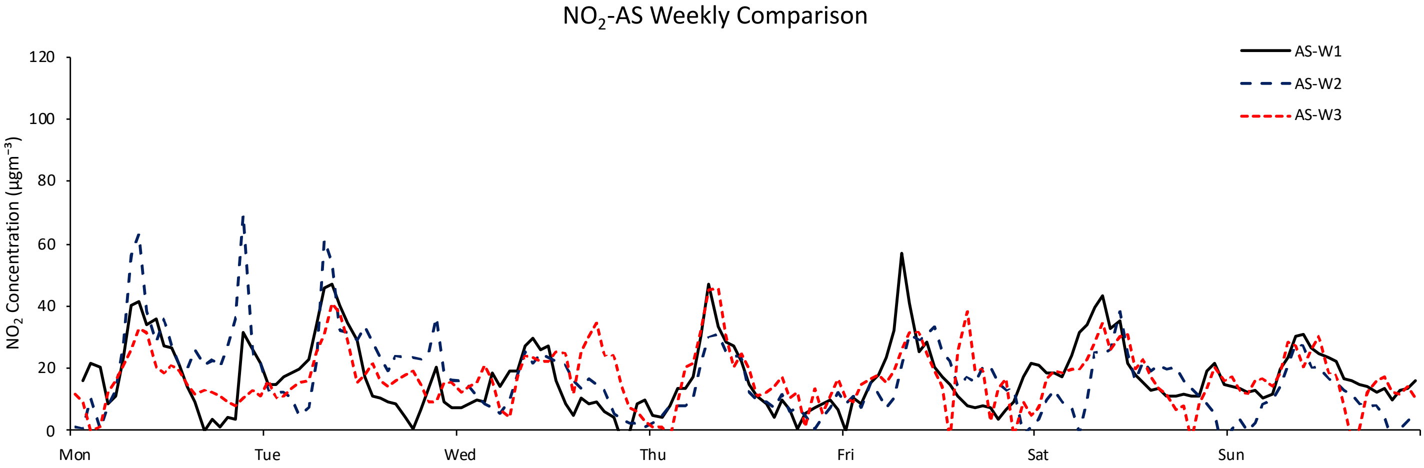


Figure 4: Hourly NO2 concentration for the three weeks during the study period. Week 1 (in black) covers the Easter holidays, whilst weeks 2 (in dashed blue) and 3 (in dashed red) are the first 2 weeks of term. Morning peaks often occur between 06:00 and 08:00, and there are some evening peaks at around 20:00, although these are much smaller and are infrequent.

easily seen when the 15-minute resolution data is plotted. In Figure 5, the daily profile of NO_2 can be seen, with the morning peak just before 08:00, and the gradual decline throughout the day. In week 1, there are no peaks or sudden increases between 11:00 and 18:00 on any day, but there is an evening peak visible on some days at around 21:00 (Monday and Tuesday, both relatively cold days). During week 2, the morning peak is more pronounced on Monday and Tuesday, but not during the rest of the week. These days were relatively still, but the rest of the week was much windier. There is a peak on Monday of week 2 at 13:30, which coincides with the end of the school day. The evening peaks are again visible on the still days. Week 3 has the lowest morning peaks, but the values are similar to those of week 2 when the still days are removed. On Wednesday and Friday of week 3, NO_2 levels at 15:30 are higher than the general trend and could be the result of increased traffic at those times. In general, afternoon peaks only occur sporadically throughout the study period.

There does not appear to be a strong relationship between NO_2 and school hours at All Saints. Morning peaks occur too early to be caused by school traffic and may be the result of the rush-hour in the wider area. During the morning school run, average NO_2 levels do not exceed the 40 μgm^{-3} limit (. It is therefore unlikely that the annual average of the site will breach the AQS regulations. The highest hourly value measured in this study at All Saints was 69 μgm^{-3}, far below the Air Quality Standards Regulation hourly limit of 200 μgm^{-3}.

Week 1	35.9
Week 2	32.2
Week 3	28.1

Table 1: Average NO_2 concentrations 07:00-10:00 (Mon-Fri) at All Saints.

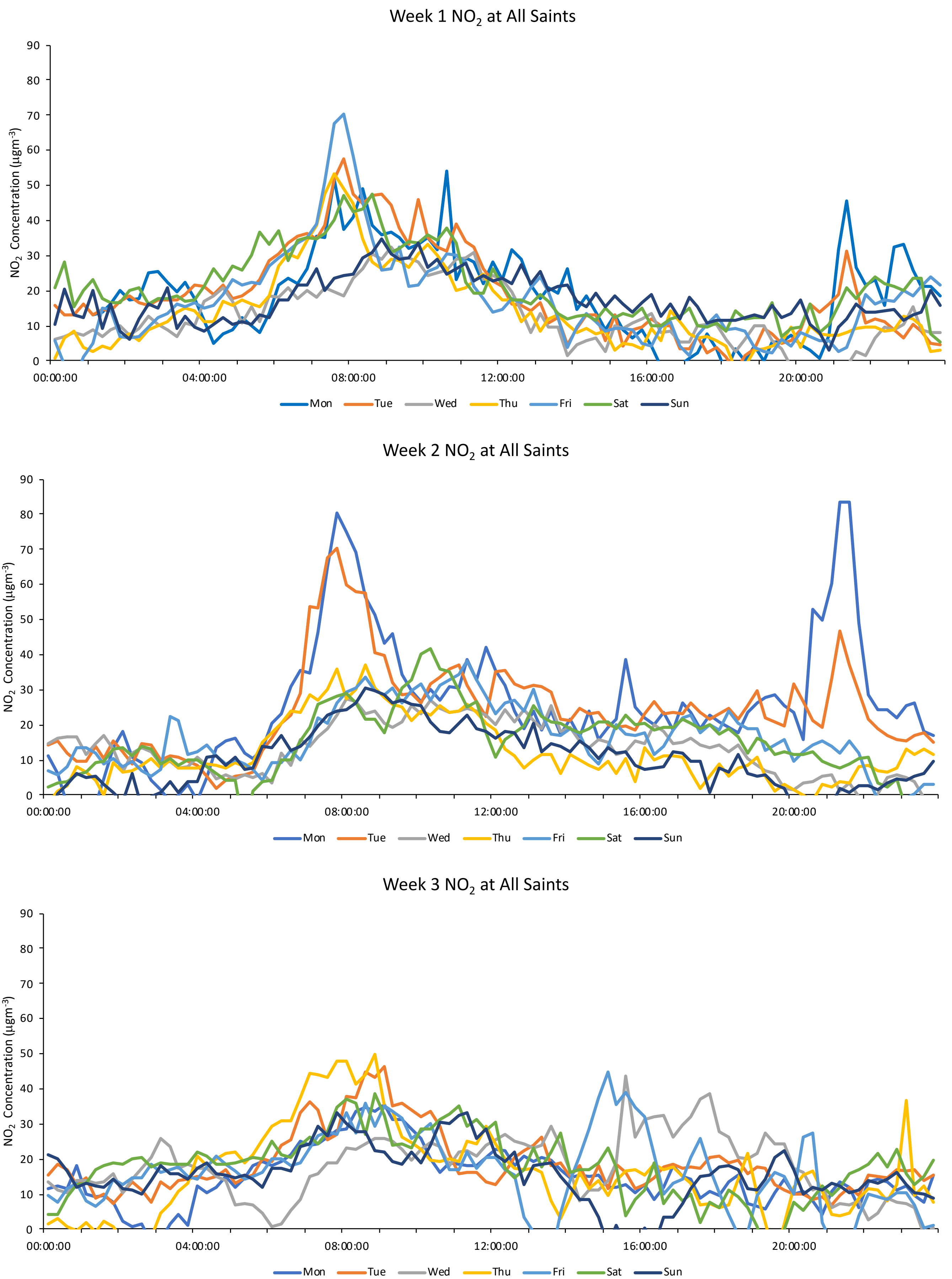


Figure 5: 15-minute resolution NO2 data from All Saints for all three weeks observed. Week 1 was the Easter holiday week.

All Saints – Particulate Matter

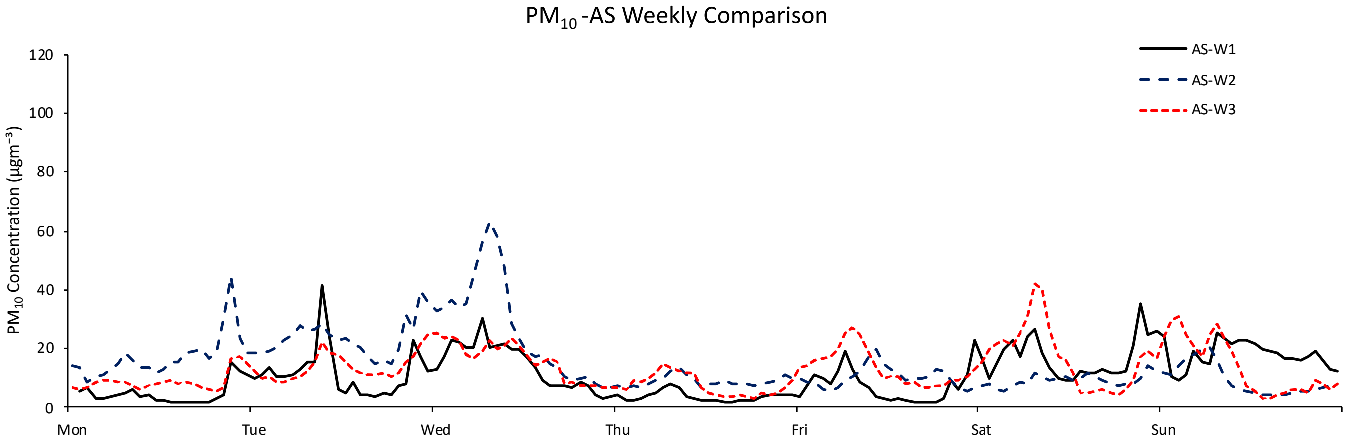


Figure 6: Hourly PM10 concentration at All Saints. Week 1 (in black) was recorded during the Easter holidays. Weeks 2 (dashed blue) and 3 (dashed red) during the first 2 weeks of term. Scale is same as other PM10 graphs for other sites.

PM_{10} does not show a consistent morning-peak pattern like NO_2. Instead, there are occasional morning peaks that occur on some days and not others. There are some evening peaks (Monday of week 2 and Saturday of week 3), but they do not occur regularly. The most notable peak occurs on Wednesday of week 2, where PM_{10} reach 63 μgm^{-3} at 06:00. This peak is also visible in Bournside and Gloucester Road data, so is unlikely to be a result of a local emission source. In fact, the entire profile of PM_{10} at All Saints is very strongly correlated with those at the other two sites (Table 2). It is likely, then, that the largest influence on changes in PM_{10} is not from a site-specific source, like road traffic, but a wide-scale source that influences the whole of Cheltenham, such as the atmosphere.

Correlation of sites		
AS+BS	AS+GR	BS+GR
0.91	0.91	0.96

Table 2: Correlation coefficient values of hourly PM10 at all three sites. A value of 1 would suggest that as on series increases, the other increases. 0 would suggest no relationship between the series. Values above 0.9 suggest that there is a very strong relationship between the sites.

The average concentration for the whole study period was 13 μgm^{-3}. When average values are broken down by week, the holiday week does have a lower average concentration than the term time weeks (Table 3). However, the differences are small and are likely to be influenced by the larger peaks, such as on Wednesday of week 2. It is therefore difficult to draw conclusions from the average values without more weeks of term-time and holiday-time data.

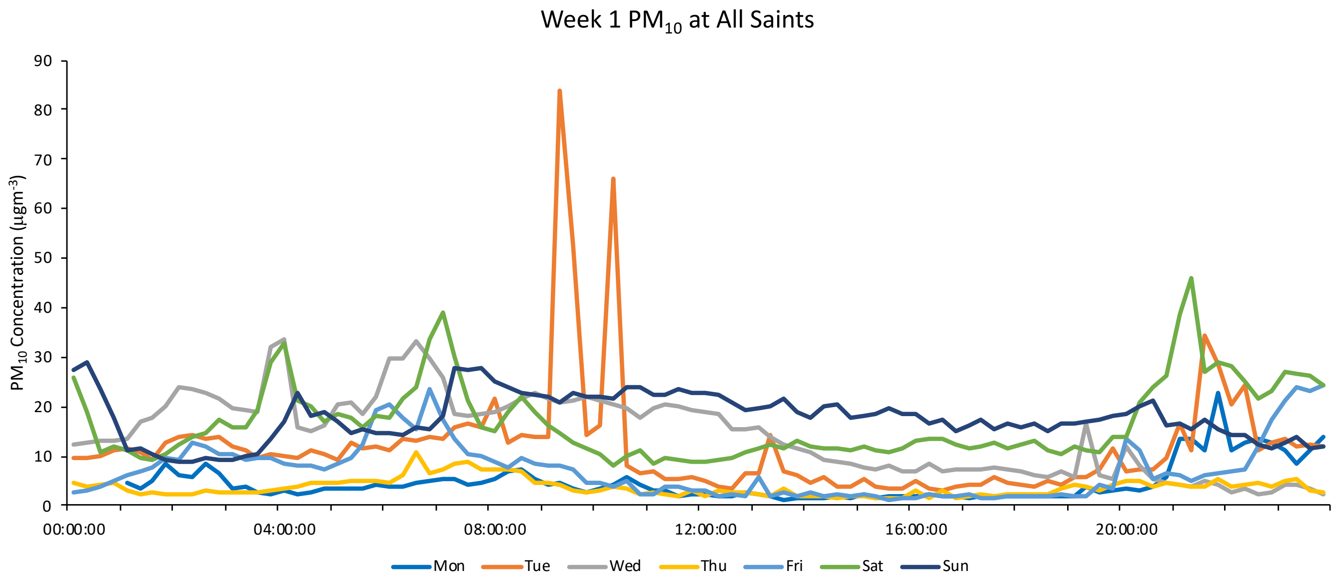
Whole	13.0
Week 1	11.0
Week 2	14.9
Week 3	13.0

Table 3: Average PM10 concentrations for each week at All Saints ($\mu g/m^{-3}$).

The Air Quality Standards Regulations set the limits of PM_{10} at 40 μgm^{-3} for the annual average and 50 μgm^{-3} for the 24-hour limit. These are both far higher than the values recorded at All Saints. The annual average limit for $PM_{2.5}$ is 25 μgm^{-3}. At All Saints, the $PM_{2.5}$ average over the three-week period was 9.6 μgm^{-3}, again much lower than the limit.

There are points in the 15-minute resolution data where values above 50 μgm^{-3} are recorded (Figure 7). These peaks are often very short, lasting less than 30 minutes in most cases. During winter, it is common for passing gritters to leave a large spike in particulate measurements and it is possible that another influence of similar effect has caused the same effect, such as roadworks or local smoke from a fire. There are six of these spikes and there is no evidence to suggest that school traffic has any influence on their occurrence.

$PM_{2.5}$ has also been explored, but closely resembles PM_{10}. For this reason, analysis has focussed on PM_{10}.



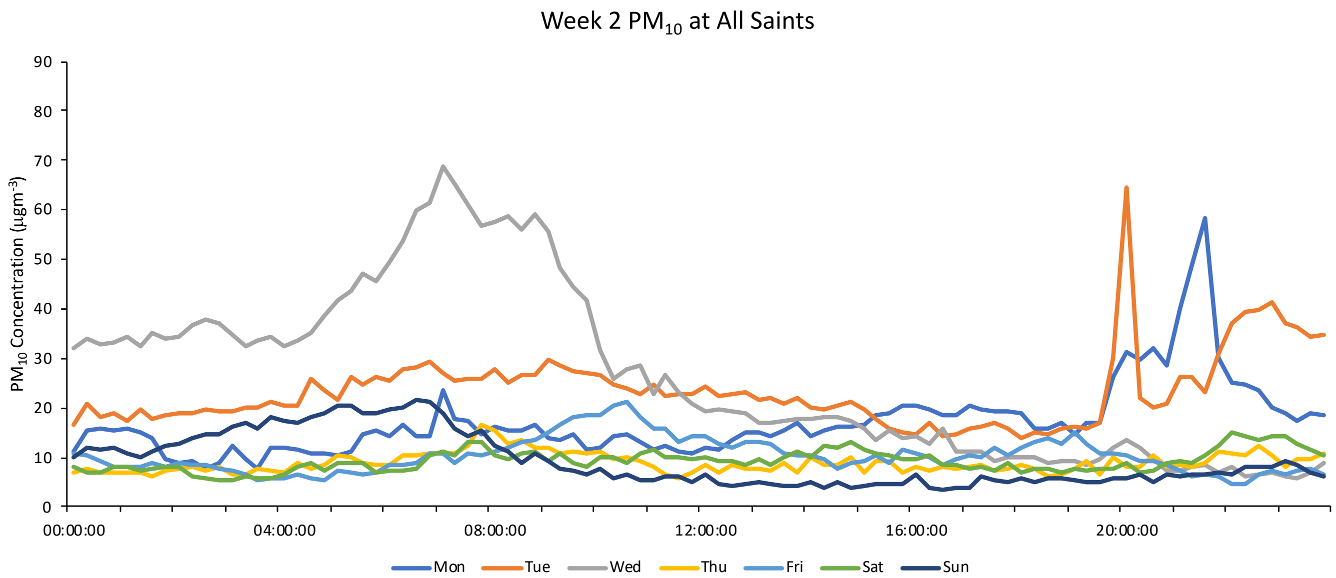


Figure 7a: 15-minute PM_{10} concentrations for weeks 1 and 2 at All Saints.

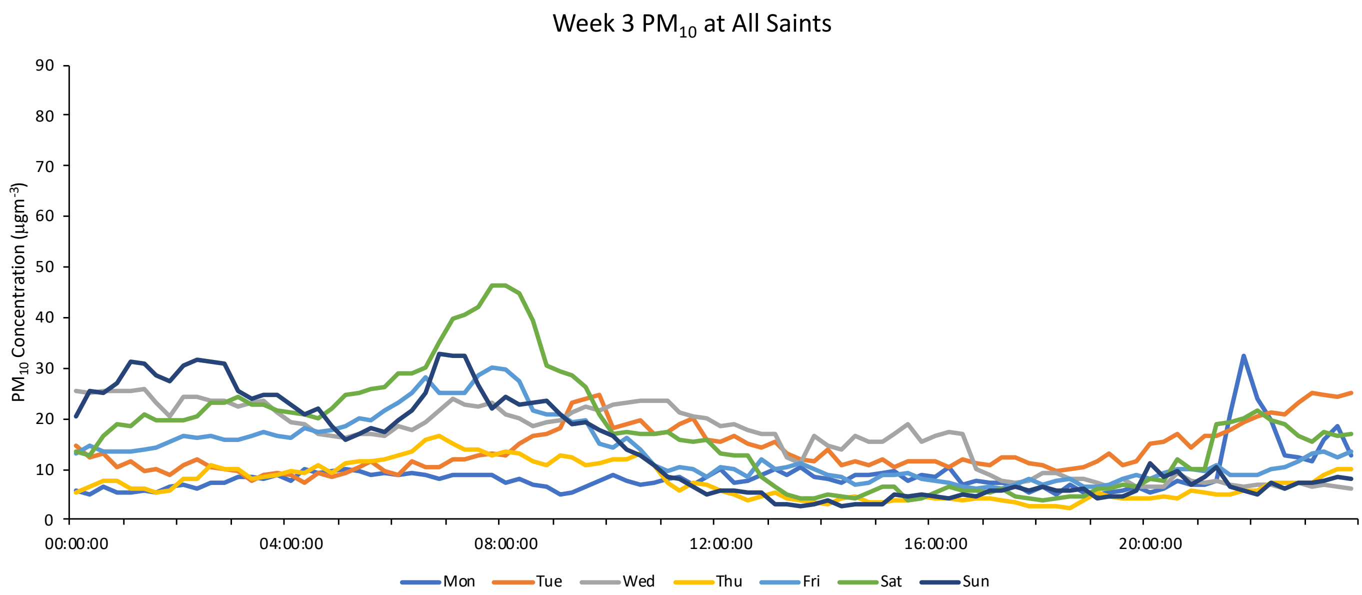


Figure 7b: 15-minute PM_{10} concentrations for week 3 at All Saints.

Bournside – NO_2

Average NO_2 concentration for the whole 3-week study period at Bournside was 44.6 μgm^{-3}. This is above the annual average limit set by the AQS Regulations of 40 μgm^{-3}. Therefore, continued exploration of NO_2 in the area is required to determine if the limit is exceeded year-round or if this study coincided with uncharacteristically high pollution. The hourly limit of 200 μgm^{-3} is not reached at any time during the study period; the highest recorded hourly value was 104.9 μgm^{-3} (the highest 15-minute value was higher but occurred when measurements from the AQMesh Pod were very erratic (Figure 9).

Similar to All Saints, Monday and Tuesday of week 2 had high NO_2 concentrations, both occurring at 08:00. By the time the school run would have started NO_2 was already beginning to fall. For all but 3 days during the study period, the daily 15-minute peak NO_2 concentration

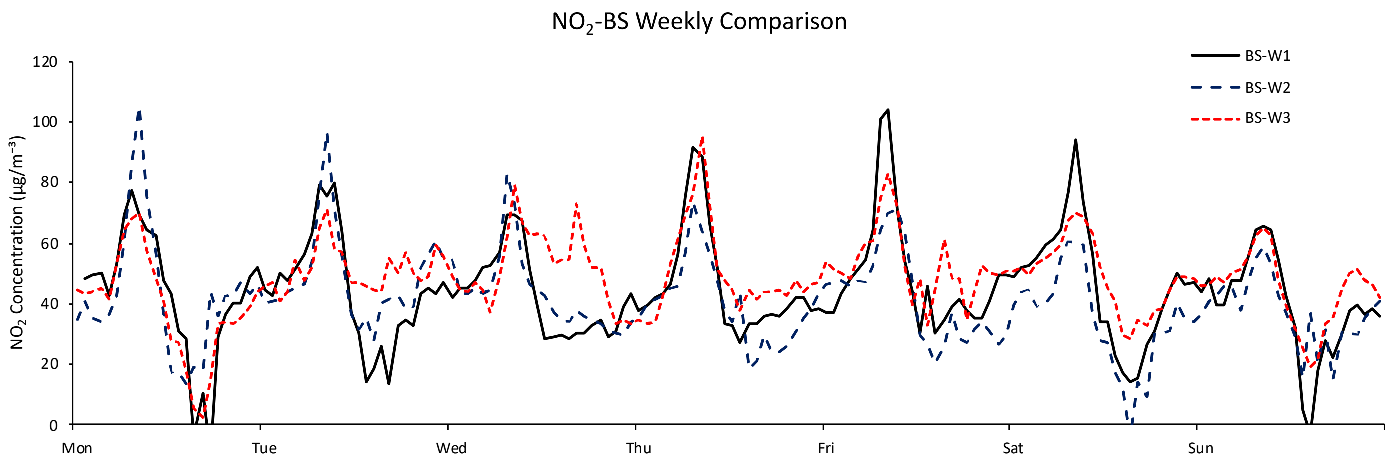


Figure 8: Hourly NO2 concentrations at Bournside. Week 1 (in black) was measured during the Easter holidays, and weeks 2 (dashed blue) and 3 (dashed red) were during the first 2 weeks of term.

occurred between 07:00 and 09:00. Two of those three days had peaks when the AQMesh Pods were returning very volatile readings (Figure 9) and Wednesday of week 3 had its peak at 16:30, which is likely to be too late to be caused by the afternoon school run.
During term-time, there are four days when peak NO_2 levels occur within 30 minutes of the start of the school day (excluding weekends). During the Easter holiday week, there is one day where the peak occurs within this same window. Three of the six weekend days in the study have their peak between 08:15 and 09:00. It is therefore possible that the school run contributes to the morning peak, but it is difficult to justify that it is the only cause, as non-school days also have peaks at the same time. There does not appear to be a strong relationship between the height of the peaks and whether the school is open.

Average NO_2 levels were calculated for the school morning and afternoon runs(Table 4). At all sites, the morning averages are consistently higher than in the afternoon. Also, week 1 always has the highest morning average. This could be down to the weather that occurred during that week or a change in driving habits during the holidays. All Saints and Bournside have similar morning averages in all three weeks, whereas Gloucester Road has a large drop in morning NO_2 from week 2.

	Week	Morning	Afternoon
AS	1	37.08	7.94
	2	39.05	16.24
	3	35.06	20.59
BS	1	80.26	24.23
	2	79.57	27.04
	3	79.25	42.57
GR	1	54.54	12.58
	2	39.05	17.64
	3	35.06	30.73

Table 4: Average NO_2 concentrations during the morning (08:00-09:14) and afternoon (14:45-15:59) school runs for all sites (Mon-Fri). Morning averages are always higher than afternoon averages as NO_2 levels are still declining from the pre-school run peak. At all sites, week 1 has the highest morning NO_2 average. In the afternoon, All Saints and Bournside have higher averages during term-time.

Afternoon averages behave very differently, visible perhaps because the impact of school traffic on air quality is not being masked by another peak, such as the case with the morning averages and the pre-school run peak. The weeks where schools are open generally have higher afternoon NO_2, especially when comparing weeks 1 and 3, when temperatures and wind speeds were more closely matched. This suggests that there may be an influence from the afternoon school run, but ideally more weeks, both holiday and term-time, would need to be observed to verify this.

On several days there is extreme variability recorded between 12:00 and 18:00 (Figure 9). This may be down to an error in the AQMesh Pod or in the processing of the data and will be investigated. Although more common in the term-time weeks, it does not appear to be linked to school opening as the variability was also be observed at weekends.

Apart from the extreme variability, the profile of NO_2 concentrations is relatively similar between the 3 weeks. If the large peaks caused by the erratic measurements are removed, the daily maximum values recorded are very similar (about 90 μgm^{-3}), all starting before the morning school run.

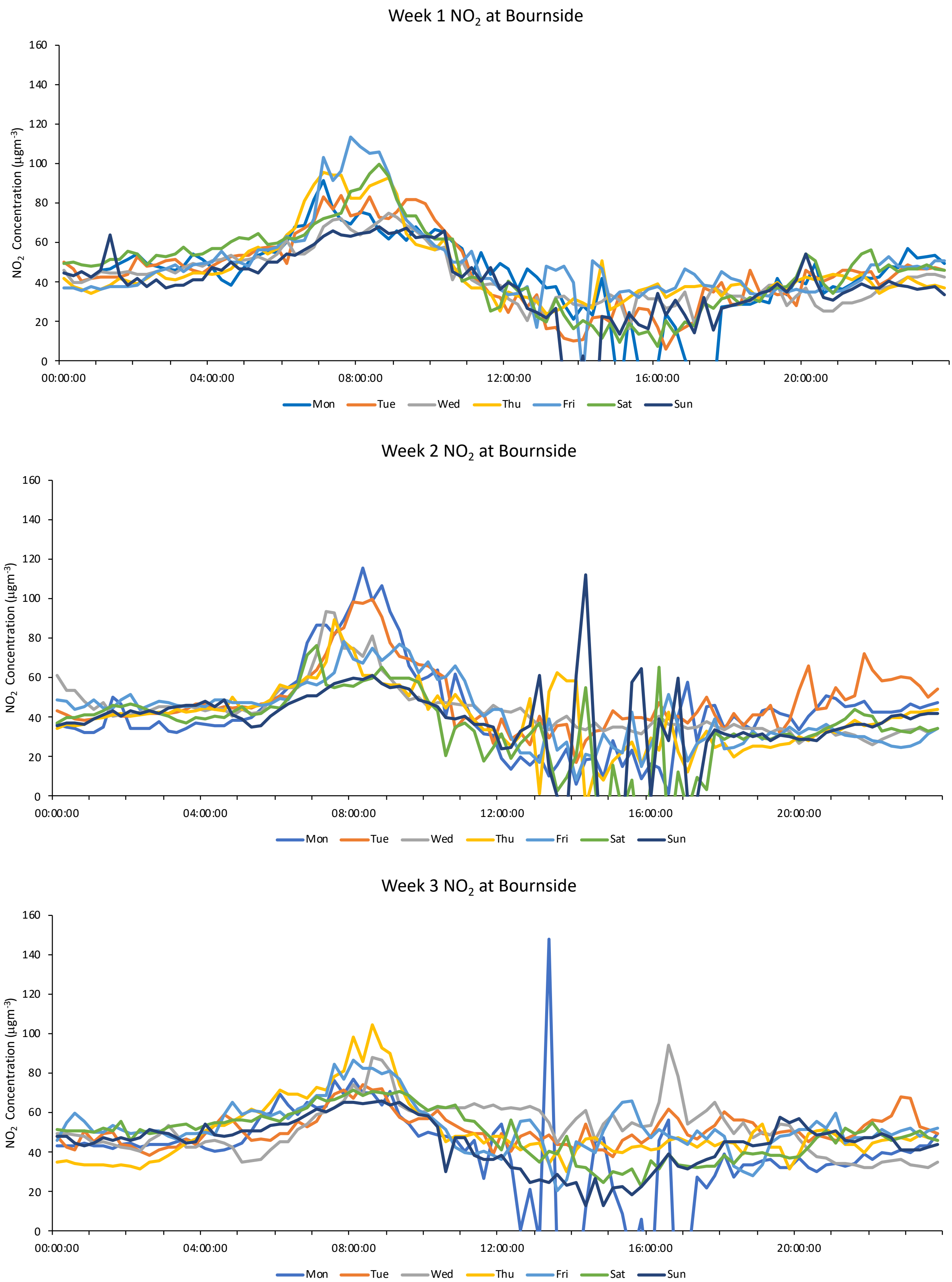


Figure 9: 15-minute NO2 concentration for all 3 weeks at Bournside.

Bournside - Particulate Matter

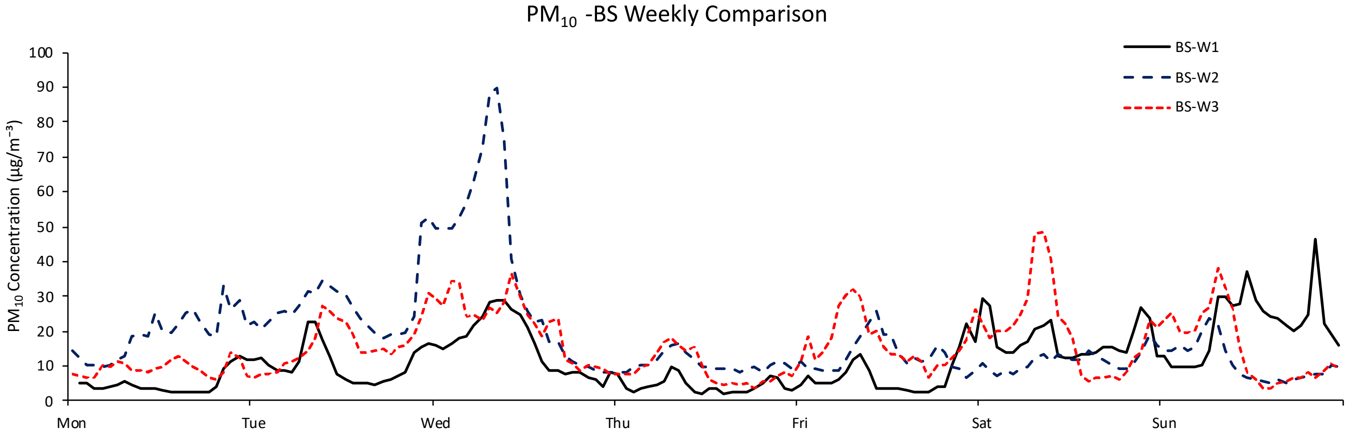


Figure 10: Hourly PM10 at Bournside for all three weeks.

Particulate matter shows a very similar profile between the three sites, with the only difference being the magnitude of the peaks, suggesting that a Cheltenham-wide source is responsible for PM_{10}, such as the atmosphere. The largest peak at Bournside occurs on Wednesday of week 2 at 07:00, reaching 90 µgm^{-3}, with another short, high peak occurring on Sunday of week 1 at 20:00.

If particulate matter and NO_2 originated from the same source, it would be expected that they would rise and fall together and change in similar magnitude between the sites. As this is not the case, it is unlikely that they share a source.

Average PM_{10} concentration at Bournside over the 3-week period is 9.2 µgm^{-3}. This is far below the annual average limit of 40 µgm^{-3}. 50 µgm^{-3} is exceeded during the large peak on Wednesday of week 2 and briefly on Saturday of week 3.

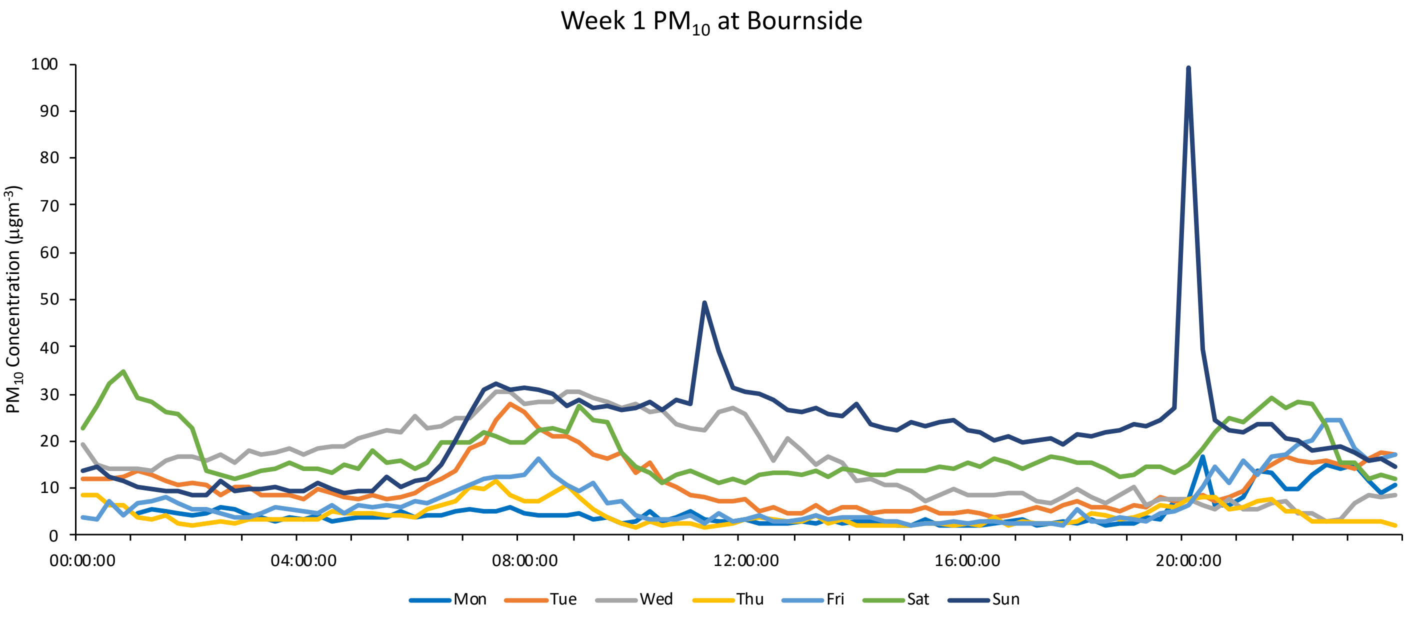
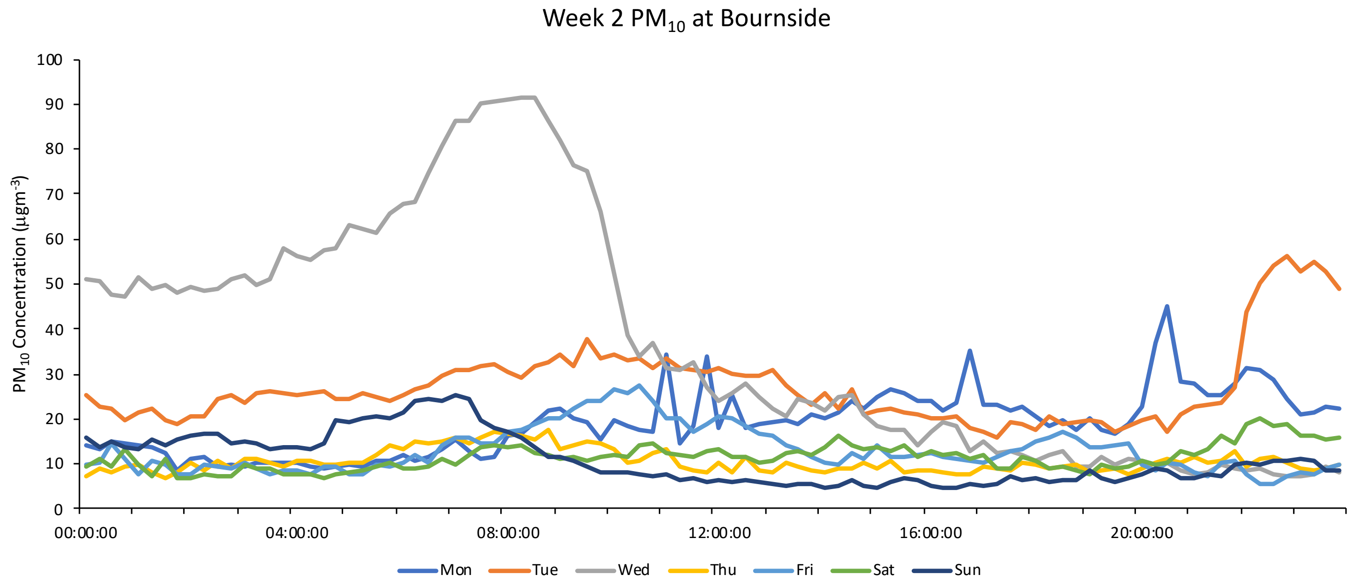


Figure 11a: 15-minute PM_{10} concentrations at Bournside for week 1.



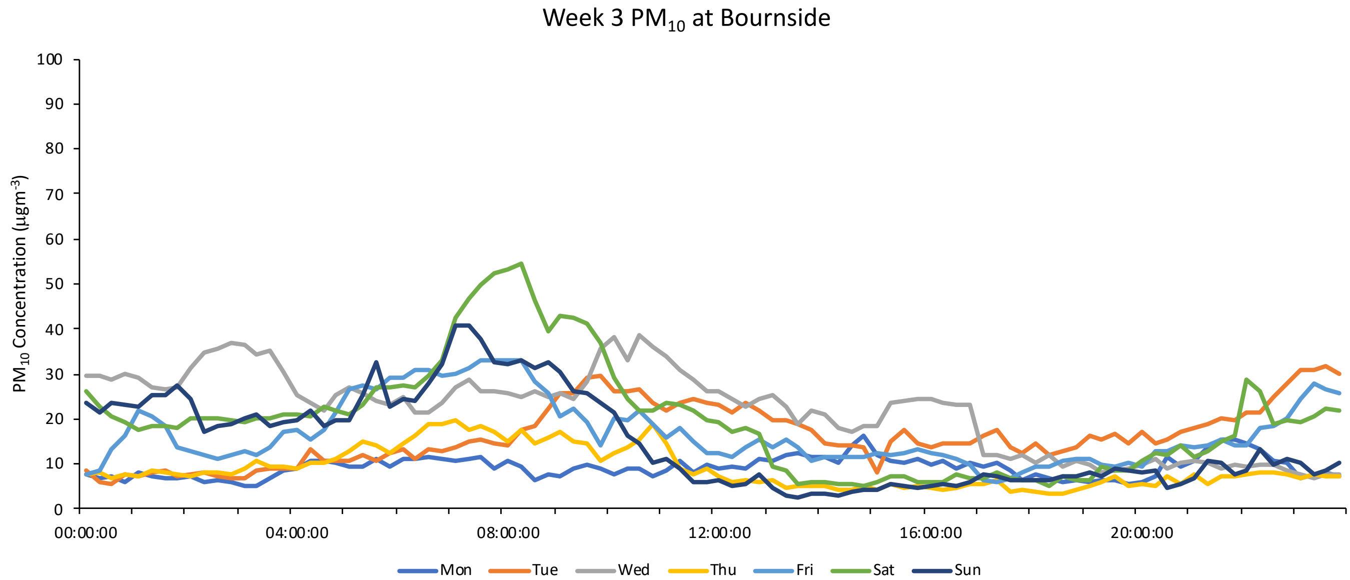


Figure 11b: 15-minute PM_{10} concentrations at Bournside for weeks 2 and 3.

Gloucester Road – NO_2

Gloucester Road exhibits the same morning peak pattern as the other sites. The average NO_2 concentration for the whole 3-week period was 14.8 μgm^{-3}. The highest hourly average value recorded was 82 μgm^{-3} on Monday of week 2 at 08:00. This is part of a very sharp peak and by 10:00 NO_2 had dropped to 14.2 μgm^{-3}. Gloucester Road School was closed on this day as it was an inset day, so the peak is not related to school traffic for Gloucester Road Primary but may be caused by car journeys to other schools.

Afternoon peaks are the most prominent at Gloucester Road, especially in the week 3 data (see also Table 4). As weekday afternoon peaks did not occur during the holidays, it is likely that that one of the main drivers for this is school traffic. Changes in the habits of parents

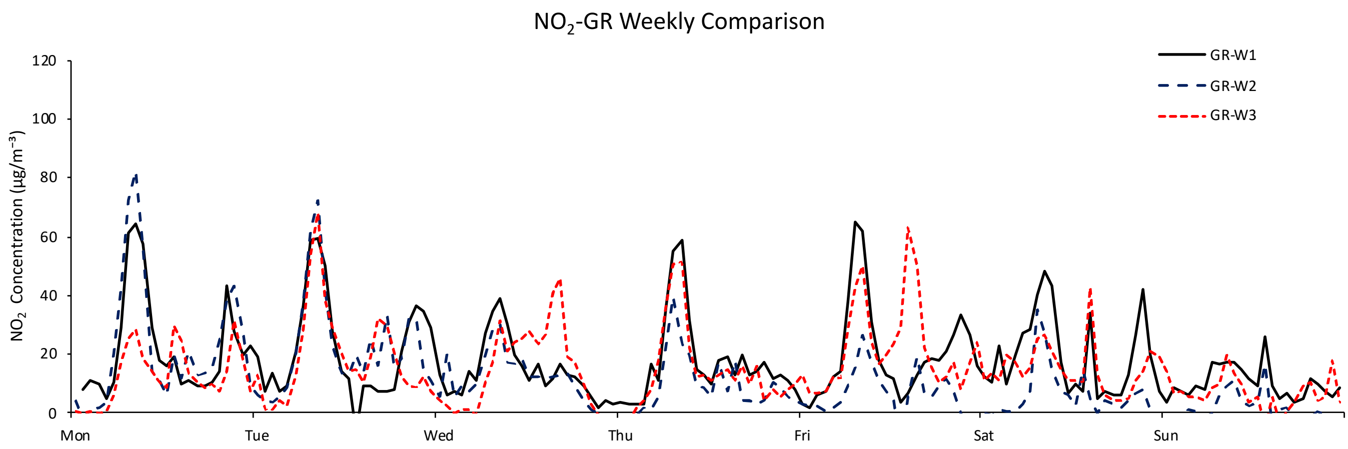


Figure 12: Hourly NO_2 concentration for all three weeks at Gloucester Road.

between primary and secondary school may result in more car traffic at pick-up times at Gloucester Road, increasing NO_2 emissions. The road itself is relatively narrow with terraced houses opposite the school, which may result in slower dispersal of exhaust gases compared to the other schools. Roadworks that occurred on Gloucester Road in the latter half of the study period will have resulted in increased emissions and congestion outside the school.

Morning peaks do not appear to be affected by school traffic. The peak starts to rise at around 06:00 and usually peaks at around 08:00. By the time school starts at 08:55, NO_2 is often beginning to decline. During week 3, morning peaks are more subdued and several days have their maximum NO_2 concentrations later in the day. During the morning school run of week 3, average NO_2 concentrations are lower than the concentrations recorded at the same time during the Easter holidays (Table 4). Afternoon school run NO_2 concentrations are higher in that same week compared to holiday-time levels, matching the pattern of the other sites in this study. This may support the argument that afternoon NO_2 is more strongly influenced by school traffic than in the morning, where another source, such as general commuting, has a greater impact.

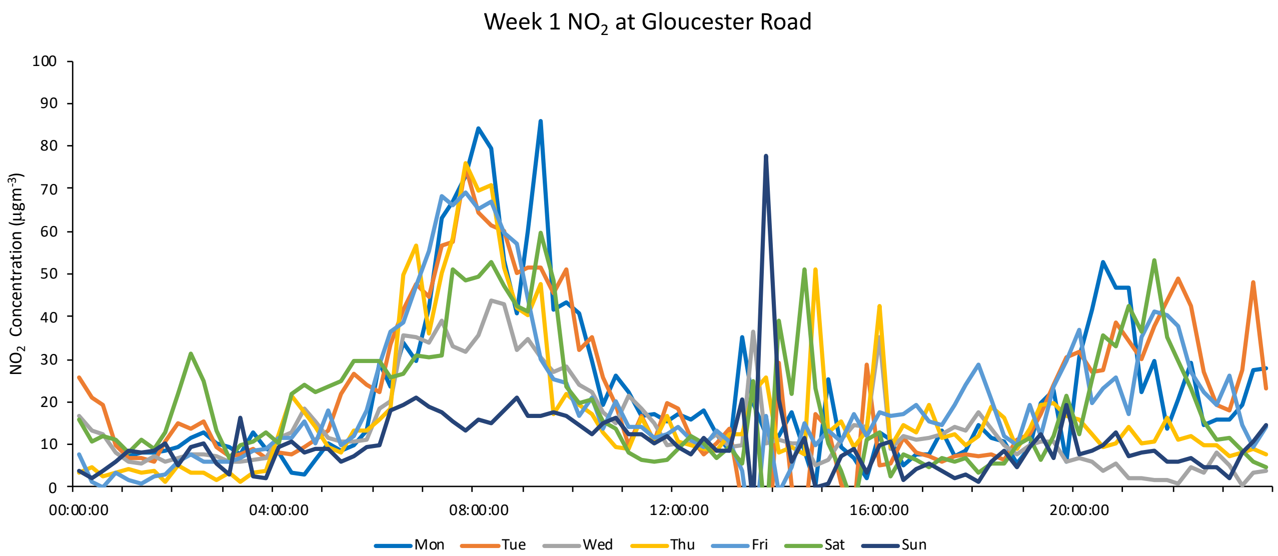


Figure 13a: 15-minute NO_2 concentrations at Gloucester Road for Week 1.

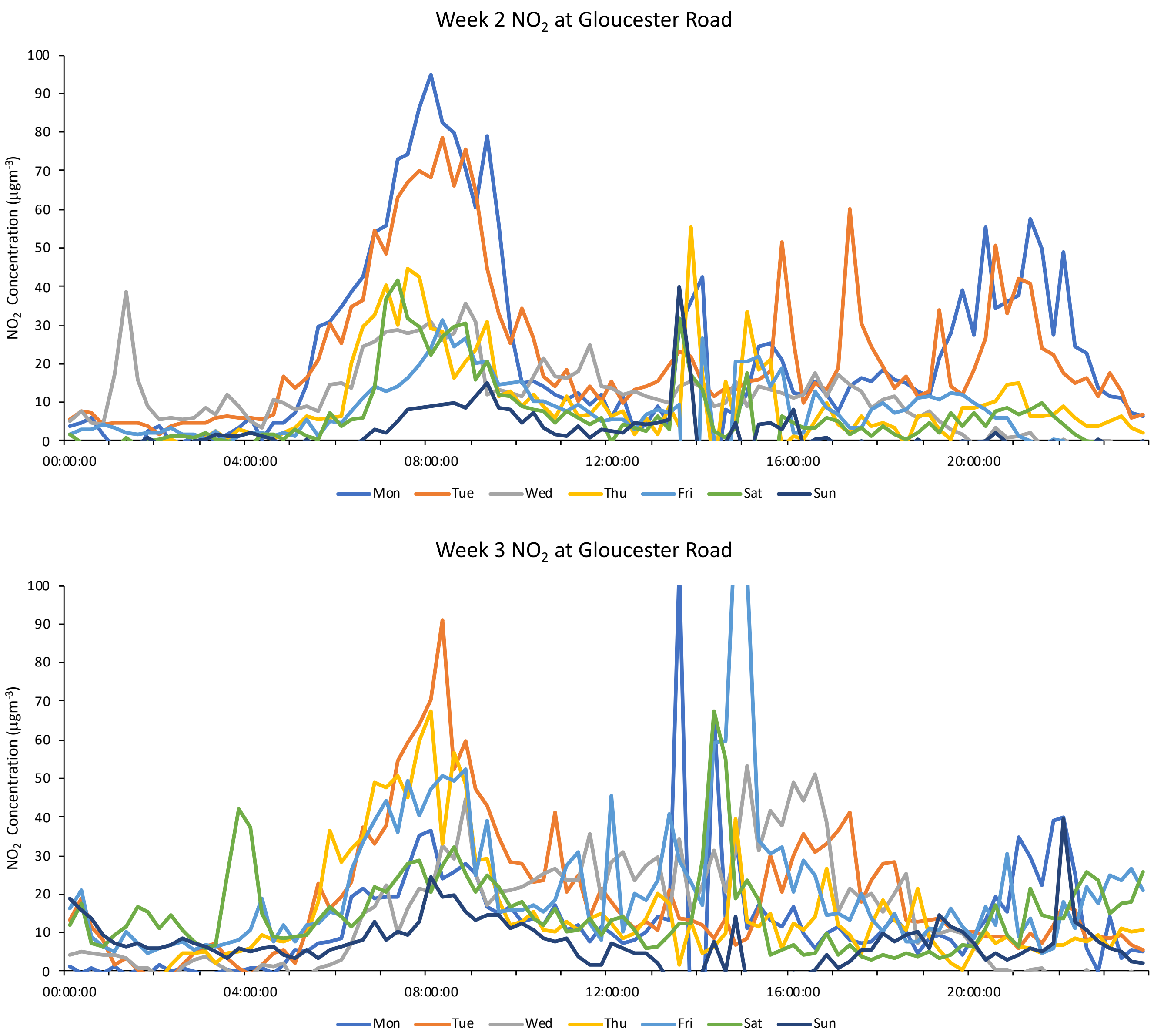


Figure 13b: 15-minute NO_2 concentrations at Gloucester Road for weeks 2 and 3.

Gloucester Road – Particulate Matter

The PM_{10} profile closely matches those of the other sites. The highest PM_{10} concentration recorded was 158 µgm^{-3} and was part of the large peak that occurred at all sites. The lower amount of open space near the monitor could reduce ventilation in the area to a higher degree compared to the other schools. All Saints and Bournside both have large playing fields, unlike Gloucester Road which only has a small playground and is surrounded by terraced houses. The higher particulate levels found in week 3 could have been caused by the roadworks on Gloucester Road and the increased congestion it will have caused. Times of peak PM_{10} levels vary widely across the three weeks and there is no reliable pattern as to when they occur.

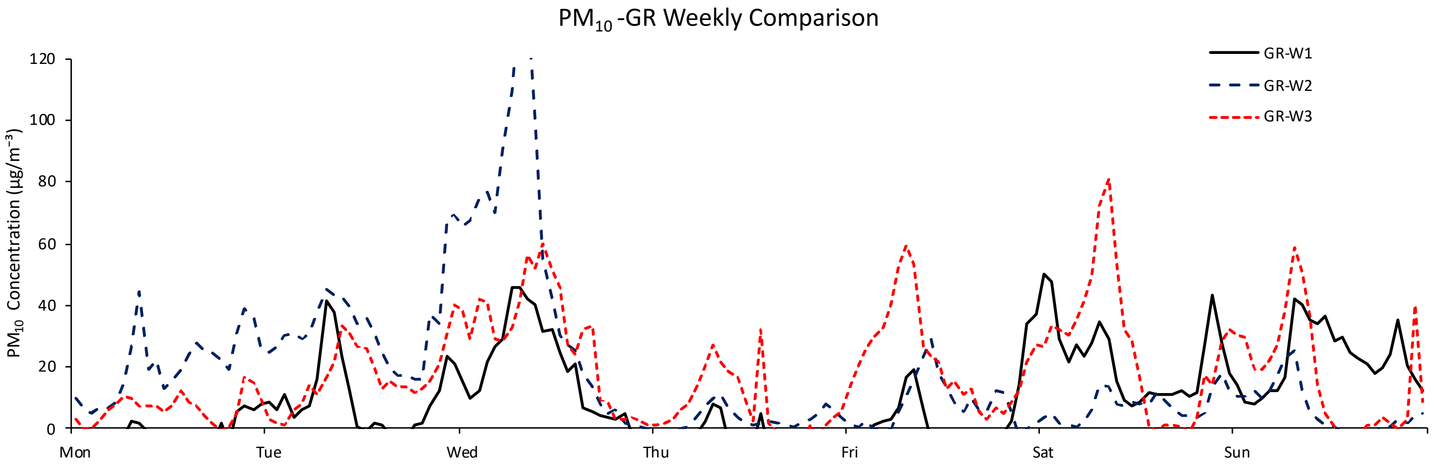


Figure 14: Hourly PM10 concentration at Gloucester Road

The daily PM_{10} concentrations are similar to those from the other sites and can be seen in Figure 15. During week 1 it was common for the monitor to register negative values, caused when PM_{10} concentrations are below the limit of detection of the Mesh Pods. The negative values will skew the average PM_{10} calculations. When average PM_{10} for each week is calculated (with the negative values being replaced with 0), there is a significant difference between the holiday week and term weeks. This is the only site where this pattern is observed. School traffic may have a greater influence on PM_{10} here, although as Gloucester Road is a major road in Cheltenham, especially compared to roads outside the other two schools, other changes in driving habits between holiday and term-time may also influence traffic (eg. not having to stay at home to look after children).

Whole	16.10
Week 1	11.80
Week 2	18.32
Week 3	18.15

Table 5: Average PM_{10} concentrations for each week at Gloucester Road, with negative values replaced with 0.

The large peak on Wednesday of week 2 can be seen in the 15-minute data, along with short spikes on Thursday and Sunday of week 3.

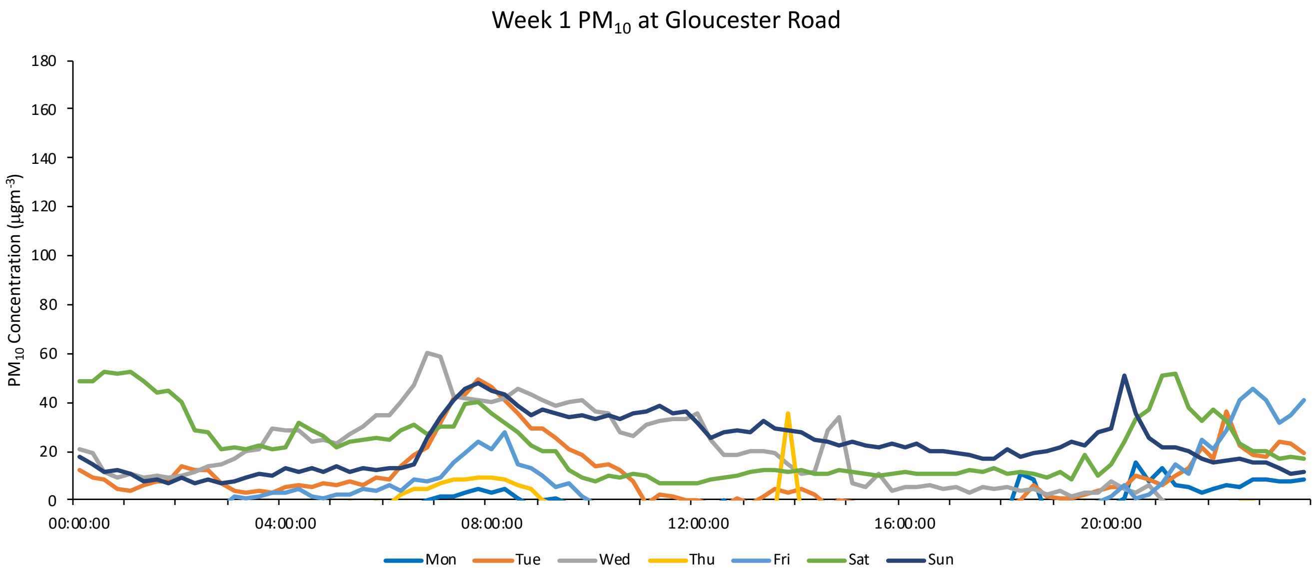
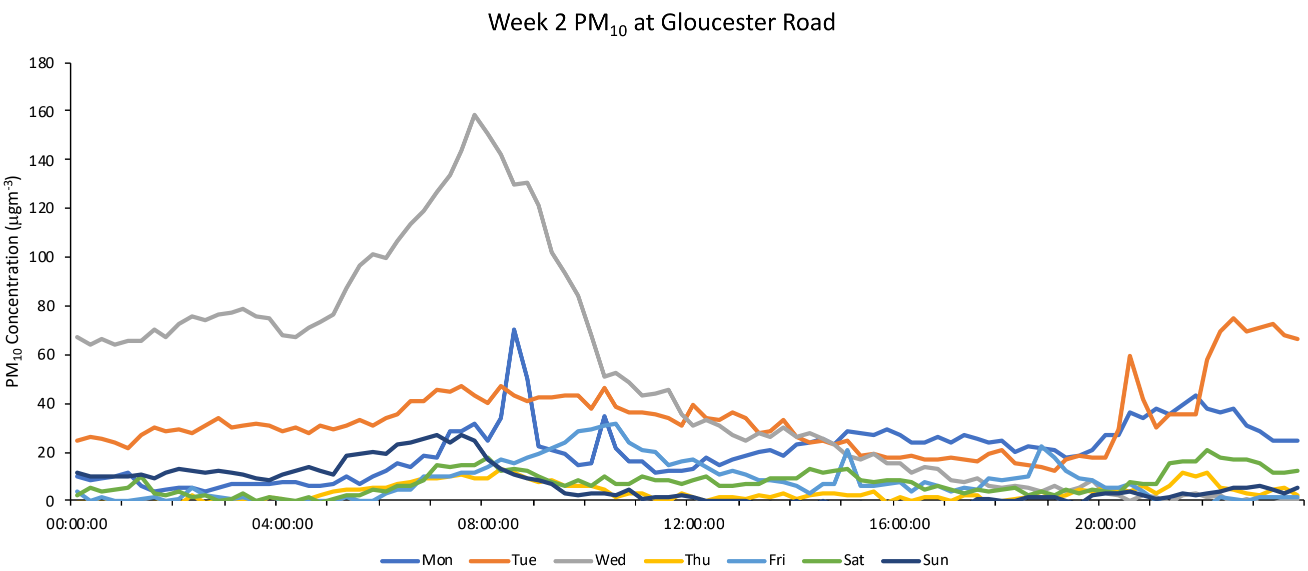


Figure 15a: 15-minute PM_{10} concentrations at Gloucester Road for week 1.



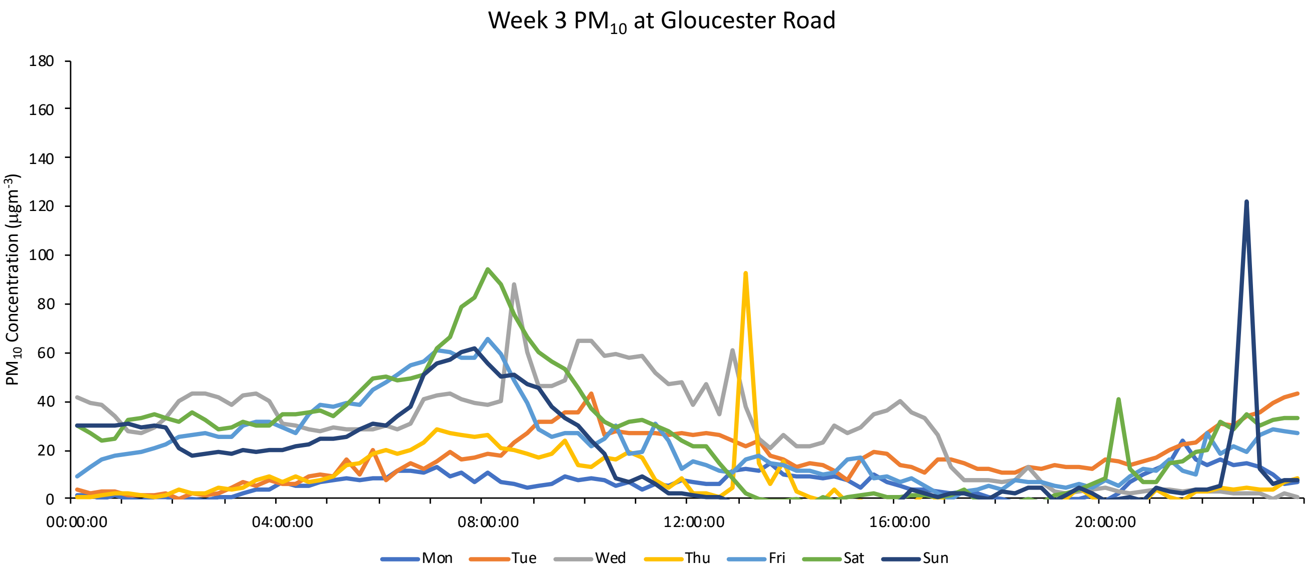


Figure 15b: 15-minute PM_{10} concentrations at Gloucester Road for weeks 2 and 3.

Conclusion

- Morning NO_2 peaks are generally not correlated to school traffic as they start too early and are on the decline by the time the school run occurs.
- The influence of afternoon school traffic on NO_2 is stronger, with average concentrations during pick-up time being higher during term-time compared to the Easter holidays
- School traffic does not cause levels of air pollution that breach Air Quality Standards.
- Particulate matter is not influenced by school traffic and Cheltenham-wide factors are its main driver.
- During this three-week study period, Bournside School had an average NO_2 concentration of 44.6 μgm^{-3}. Further monitoring is required to see if these levels are

maintained throughout the year or if the study period coincided with elevated NO_2 in the area.

- Borough-wide strategies to reduce air quality will have a stronger effect in reducing air pollution at schools compared to school-targeted strategies, as school traffic does not appear to be the main driver in pollution.

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Appendix

Daily max values							
		AS-1h		BS-1h		GR-1h	
Date		NO_2	Time	NO_2	Time	NO_2	Time
Mon	12	41.2	08:00	77.4	07:00	64.3	08:00
Tue	13	46.7	08:00	79.6	09:00	59.1	08:00
Wed	14	29.7	09:00	69.4	07:00	38.7	08:00
Thu	15	47.2	07:00	91.5	07:00	58.6	08:00
Fri	16	57	07:00	103.7	08:00	64.7	07:00
Sat	17	43.1	08:00	93.8	08:00	48	08:00
Sun	18	30.7	09:00	65.6	08:00	25.7	13:00
Wk1 Mon-Fri average max		44.36		84.32		57.08	
Mon	19	69	21:00	104.9	08:00	82	08:00
Tue	20	61.3	07:00	96.5	08:00	72.2	08:00
Wed	21	25.3	08:00	83.2	07:00	30.2	08:00
Thu	22	31.2	08:00	73.8	07:00	39.3	07:00
Fri	23	33.4	11:00	71.1	09:00	26.7	08:00
Sat	24	38.3	10:00	60.8	07:00	35	07:00
Sun	25	27.8	08:00	59	08:00	16.7	13:00
Wk2 Mon-Fri average max		44.04		85.9		50.08	
Mon	26	32.6	08:00	70.1	08:00	31.4	21:00
Tue	27	40.7	08:00	71.2	08:00	68.3	08:00
Wed	28	34.4	17:00	79.2	08:00	45.8	16:00
Thu	29	45.8	08:00	95.3	08:00	51.4	08:00
Fri	30	38.5	15:00	82.7	08:00	63.3	14:00
Sat	1	34.7	08:00	70.2	08:00	42.6	14:00
Sun	2	30	11:00	65.1	08:00	19.7	08:00
Wk3 Mon-Fri average max		38.4		79.7		52.04	

Appendix Figure A: Time and magnitude of maximum NO_2 levels (hourly) for each day at each site. The average of the weekday peak levels is also shown.

Average NO2		
AS	BS	GR
16.95	44.66	14.79

Appendix Figure B: Average NO_2 concentration for each site for the whole three-week period (using hourly values).

Daily max values (15 Minute)							
		AS-1h		BS-1h		GR-1h	
Date		NO_2	Time	NO_2	Time	NO_2	Time
Mon	12	54.2	10:30	91.4	07:00	85.8	09:15
Tue	13	57.7	07:45	83.6	07:30	75.3	07:45
Wed	14	32.3	09:00	75.1	08:45	43.9	08:15
Thu	15	53.3	07:30	95.4	07:00	76.2	07:45
Fri	16	70.5	07:45	113.2	07:45	69.3	07:45
Sat	17	47.5	08:30	99.4	08:30	59.7	09:15
Sun	18	34.7	08:45	68	08:30	77.9	13:45
Wk1 Mon-Fri average max		53.6		91.74		70.1	
Mon	19	83.4	21:30	115.1	08:15	95	08:00
Tue	20	70.4	07:45	99.5	08:30	78.7	08:15
Wed	21	27.6	08:00	93.3	07:15	38.6	01:15
Thu	22	36.9	08:30	89.2	07:30	55.2	13:45
Fri	23	38.2	11:15	78.4	07:45	31.2	08:15
Sat	24	41.7	10:15	76.2	07:00	41.6	07:15
Sun	25	30.5	08:30	111.9	14:15	39.7	13:30
Wk2 Mon-Fri average max		51.3		95.1		59.74	
Mon	26	35.4	09:00	147.6	13:15	104.8	13:30
Tue	27	46.4	09:00	74.2	08:15	91.1	08:15
Wed	28	43.5	15:30	94.2	16:30	53.2	15:00
Thu	29	50	08:45	104.1	08:30	67.4	08:00
Fri	30	44.9	15:00	86.5	08:00	117.1	14:45
Sat	1	38.6	08:45	71.4	08:00	67.4	14:15
Sun	2	33.2	23:30	65.9	08:45	39.5	22:00
Wk3 Mon-Fri average max		44.04		101.32		86.72	

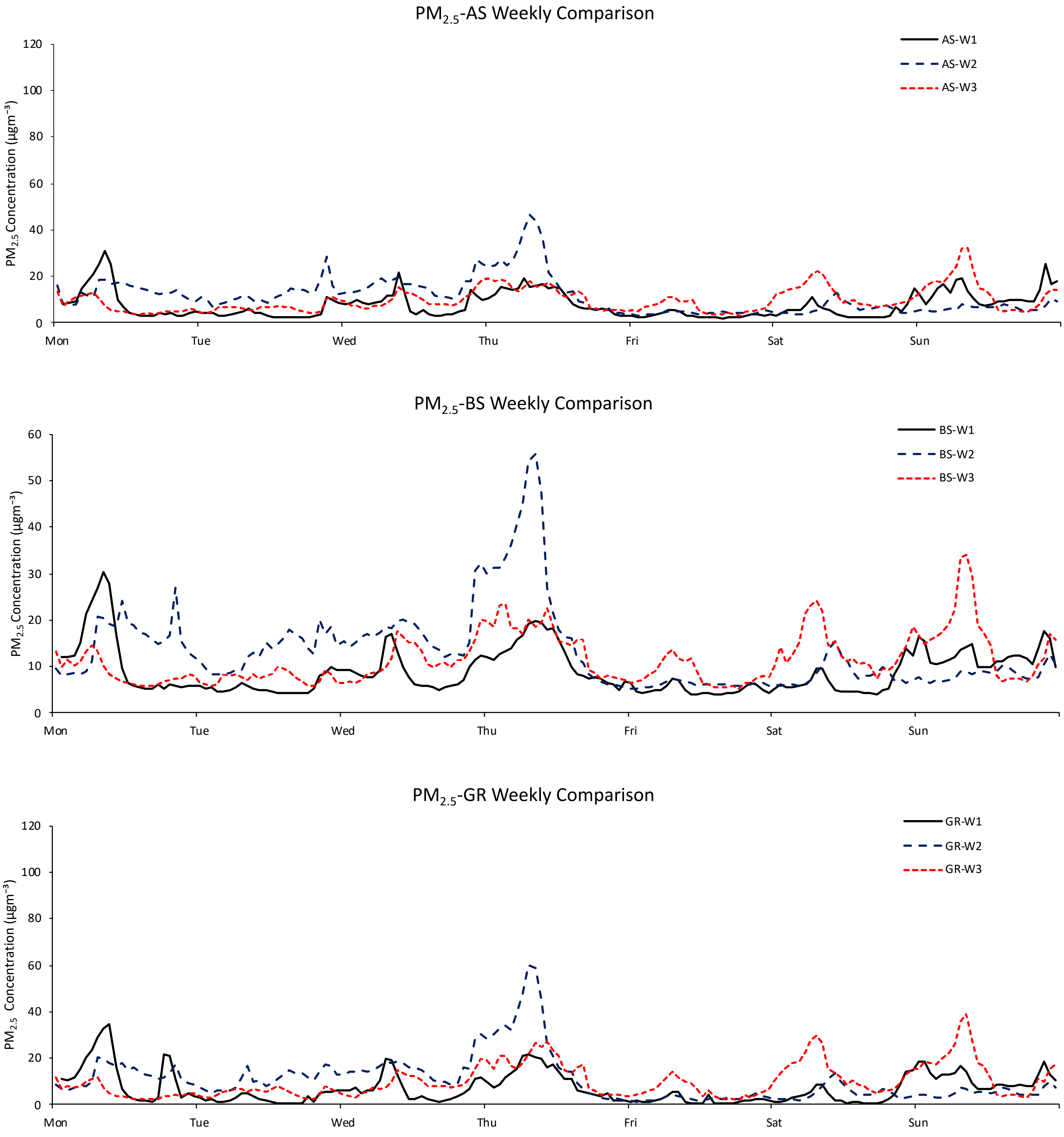
Appendix Figure C: Time and magnitude of maximum NO_2 levels (15-minute) for each day at each site. The average of the weekday peak levels is also shown.

Daily max values (1 hour)							
		AS-1h		BS-1h		GR-1h	
Date		PM_{10}	Time	PM_{10}	Time	PM_{10}	Time
Mon	12	15.21	21:00	13.03	22:00	8.67	00:00
Tue	13	41.21	09:00	22.72	08:00	41.52	07:00
Wed	14	30.54	06:00	28.78	09:00	45.81	07:00
Thu	15	7.91	07:00	9.95	07:00	8.25	07:00
Fri	16	23.14	23:00	29.22	00:00	50.28	00:00
Sat	17	35.13	21:00	27.39	01:00	47.60	01:00
Sun	18	25.28	07:00	46.23	20:00	42.00	07:00
Wk1 Mon-Fri average max		23.60		25.33		34.87	
Mon	19	44.27	21:00	33.17	20:00	44.65	08:00
Tue	20	39.41	22:00	52.37	23:00	69.47	23:00
Wed	21	63.03	07:00	89.95	08:00	140.64	07:00
Thu	22	13.53	08:00	16.40	08:00	10.87	08:00
Fri	23	19.67	10:00	25.95	10:00	28.97	10:00
Sat	24	14.33	22:00	19.15	22:00	18.08	22:00
Sun	25	20.62	06:00	23.49	06:00	25.55	07:00
Wk2 Mon-Fri average max		30.70		37.21		48.32	
Mon	26	17.20	22:00	13.79	21:00	16.89	21:00
Tue	27	25.44	00:00	30.84	23:00	39.99	23:00
Wed	28	23.94	02:00	36.50	10:00	60.13	10:00
Thu	29	14.72	06:00	18.19	07:00	32.21	13:00
Fri	30	27.21	07:00	31.81	07:00	59.27	07:00
Sat	1	42.21	07:00	48.36	08:00	81.26	08:00
Sun	2	31.18	02:00	37.94	07:00	58.60	07:00
Wk3 Mon-Fri average max		21.70		26.22		41.70	

Appendix Figure D: Time and magnitude of maximum PM_{10} levels for each day at all sites (1 hour).

Daily max values (15-minute)							
		AS-1h		BS-1h		GR-1h	
Date		PM_{10}	Time	PM_{10}	Time	PM_{10}	Time
Mon	12	22.682	21:45	16.679	20:15	15.445	20:30
Tue	13	83.94	09:15	27.744	07:45	49.498	07:45
Wed	14	33.542	04:00	30.659	08:45	60.089	06:45
Thu	15	10.729	06:30	11.358	07:30	35.844	13:45
Fri	16	25.937	00:00	34.593	00:45	52.895	00:30
Sat	17	45.829	21:15	29.159	01:00	52.319	01:00
Sun	18	27.811	07:45	99.06	20:00	51.011	20:15
Wk1 Mon-Fri average max		35.366		24.2066		42.7542	
Mon	19	58.161	21:30	44.979	20:30	70.09	08:30
Tue	20	64.494	20:00	56.214	22:45	74.992	22:30
Wed	21	68.686	07:00	91.363	08:30	158.466	07:45
Thu	22	16.438	07:45	17.386	08:45	12.786	08:15
Fri	23	21.232	10:30	27.405	10:30	31.502	10:30
Sat	24	14.899	22:00	20.301	22:15	20.619	22:00
Sun	25	21.455	06:30	25.169	07:00	27.2	07:00
Wk2 Mon-Fri average max		45.8022		47.4694		69.5672	
Mon	26	32.337	21:45	16.113	14:45	24.289	21:30
Tue	27	25.625	00:00	31.791	23:30	43.625	23:45
Wed	28	25.781	01:15	38.668	10:30	87.893	08:30
Thu	29	16.75	06:45	19.764	07:00	92.491	13:00
Fri	30	29.974	07:45	33.121	07:45	65.819	08:00
Sat	1	46.52	07:45	54.516	08:15	94.516	08:00
Sun	2	32.895	06:45	40.932	07:15	121.966	22:45
Wk3 Mon-Fri average max		26.0934		27.8914		62.8234	

Appendix Figure E: Time and magnitude of maximum PM_{10} levels for each day at all sites (15 minute)



Appendix Figure F: $PM_{2.5}$ data for all sites