St Andrews Air Quality Report

By Sydney Piepgrass for Transition University of St Andrews, March 2024

Summary

Poor air quality can affect the health of anyone exposed to it. We did a survey of outdoor air quality in St Andrews, focusing specifically on nitrogen dioxide (NO_2) and particulate matter (PM), to identify potential hotspots of poor air quality and provide information for public information campaigns to support active travel. St Andrews is not currently designated as having poor air quality by the council, but we wanted to understand air quality across St Andrews. We collected data using personal air quality monitors over four years covering as much of St Andrews as possible and found that air quality is generally good. NO_2, PM_{10} and $PM_{2.5}$ are all below the Scottish Air Quality Objectives and PM_{10} and $PM_{2.5}$ are also below the WHO Air Quality Guidelines. However, there are some areas of concern are around some of the busier roads, specifically Abbey Walk, Canongate, Largo Road and Buchanan Gardens. Market Street and South Street also have slightly elevated pollution levels. The quieter residential neighbourhoods in the southeast and southwest of St Andrews are the least polluted areas in St Andrews. Though high pollution areas generally match up with busier roads, there is minimal correlation between areas of high NO_2 pollution and areas of high PM pollution, suggesting different sources or transmission mechanisms.

Background

Pollutants

Exposure to air pollution, in both the short and long term, can cause adverse health effects and disease, including the exacerbation of conditions like asthma. Long-term exposure can increase the risk of strokes, cancer and cardiovascular disease. Air pollution affects everyone from unborn foetuses, children, adults to the elderly and reduces life expectancy (Public Health England, 2018). Nitrogen dioxide (NO_2; representing all NOx species) and particulate matter (PM) are generally of the greatest concern for human health and the environment and consequently the focus of our study. See Table 1 for the Scottish Air Quality Objectives and WHO Air Quality Guidelines for NO_2 and PM. All measurements of the pollutants are presented in micrograms per cubic metre of air (µg/m³). One microgram is one millionth of a gram (10^{-6}) and a cubic meter is equivalent to one thousand litres. These are very small concentrations; for comparison, carbon dioxide, which makes up about 0.04% of the Earth's atmosphere, has a concentration of 756,000 µg/m³ in ambient air.

Nitrogen Dioxide

NO_2 is a gas produced by combustion processes. Nitric oxide (NO) is often also produced in these processes but is oxidised in the air to NO_2. It is estimated that 27% of NOx emissions in the UK are from road transport as it is produced in internal combustion engines (Defra, 2023). Short-term exposure to NO_2 can cause inflammation of the lungs and is most pertinent for people with existing lung or heart conditions like asthma. NOx gases can react with other gases in the air to form ground-level ozone, another dangerous pollutant for human and environmental health.

NO_2 emission forming ground-level ozone can trigger reactions that lead to the creation urban smog, which is not only dangerous for human health but also affects wildlife. NO_2 contributes to acid rain which has a negative impact on vegetation, including reduced growth which can affect crops. The deposition of NO_2 on oceans can cause harmful algal blooms (Pandey and Singh, 2021). Unlike PM,

NO_2 is quickly dispersed by wind and concentrations fall rapidly with distance from the source. For example, NO_2 concentrations are generally low during the night because of low traffic levels.

Particulate Matter

PM refers to any solid or liquid particles in the air. These particles can be of varying size, shape and composition and are formed in a diverse range of processes and activities. Some are naturally occurring (e.g. pollen and sea spray), many are anthropogenic (e.g. smoke from the combustion of fuel, dust from building works and tyre wear from road vehicles). PM can also travel long distances on the wind and about one third of PM in the UK has been transported from other European countries. But, similar to NO_2, road traffic is still a significant source of PM (Defra, 2023). They are often categorised by size with PM_{10} referring to particles less than 10 microns (µm) and $PM_{2.5}$ referring to particles less than 2.5 µm in diameter.

The size of the particles affects the health and pollution impacts of PM, $PM_{2.5}$ is generally considered the most dangerous to human health because the small size allows them to penetrate the lungs and possibly even pass into the bloodstream. Exposure to PM is linked to cancer, cardiovascular and respiratory diseases (Public Health England, 2018). To our current knowledge, there is no level of PM exposure without negative health effects, so any reduction in emission and exposure is beneficial (Hector *et al.*, 2023). PM effects vegetation depending on its composition but can have toxic effects on the plants directly or can affect the soil chemistry and affect nutrient uptake (Grantz, Garner and Johnson, 2003).

Table 1: Scottish Air Quality Objectives (Hector et al.*, 2023) and WHO Air Quality Guidelines (World Health Organization, 2021) for NO_2, PM_{10} and $PM_{2.5}$.*

Pollutant	Average period	Scottish Air Quality Objective	WHO Air Quality Guideline
NO_2	1-hour mean	200 µg/m³ not to be exceeded more than 18 times in a year	
	Annual mean	40 µg/m³	10 µg/m³
PM_{10}	24-hour mean	50 µg/m³ not to be exceeded more than 7 times in a year	45 µg/m³
	Annual mean	18 µg/m³	15 µg/m³
$PM_{2.5}$	Annual mean	10 µg/m³	5 µg/m³

Location

Air quality in St Andrews is generally good. It is not designated as an area of concern by Fife council. The principal pollutants of concern are NO_2 and PM with the most important source of these being road traffic. The council measures NO_2 by diffusion tube along City Road and recently added an additional monitor to measure PM. Further diffusion tubes are on Links Crescent, North Street and Bell Street. Across Fife, NO_2 has fallen since 2018, with 2020 being the lowest year for NO_2 pollution, likely due to low traffic during covid-19 lockdowns. In 2022, no monitoring by Fife Council indicated exceedances of NO_2 or PM air quality objectives anywhere in Fife[1]. However, roadside concentrations of $PM_{2.5}$ and NO_2 in Fife have consistently been exceeding the WHO Air Quality Guidelines since 2018 (Thomson, 2023). Our data covers the majority of St Andrews, including main roads and residential areas.

[1] For more details on Fife Council air quality monitoring, see https://www.fife.gov.uk/air-quality and real-time data can be found at https://www.scottishairquality.scot/

Data Collection

Data for this reported was collected by volunteers and Transition St Andrews staff using Plume Flow meters (1 and 2), personal air quality monitors that measure and record concentrations of PM (1, 2.5 and 10 µm), NO_2 and volatile organic compounds (VOCs). We disregarded VOC concentrations because this is of greater concern for indoor air quality, and we are focusing on outdoor air quality. This also better aligns with the pollutants already being monitored in St Andrews by the council.

Data was collected from March 2020 to February 2024 covering most of St Andrews, air quality data is recorded by the Flow meters and GPS data is collected by the mobile phone it is paired with. Interpolated maps were produced to indicate hotspots of poor air quality (see Appendix 3 for further details on methods used). There are seasonal trends in the different pollutant levels elsewhere in Fife (Thomson, 2023), but because our monitoring in St Andrews has not been continuous we cannot account for this probable effect on the data, but will infer the representativeness where possible.

Results

Our results confirm that air quality in St Andrews is generally good. The median values for each pollutant and 50.1% of all our data meet NO_2, PM_{10} and $PM_{2.5}$ the Scottish annual average Air Quality Objectives (AQOs). The median values for PM_{10} and $PM_{2.5}$ and 33.2% of all our data meet WHO annual average Air Quality Guidelines (AQGs). See Table A1.2 for summary of data and targets. It is unlikely that the air quality in St Andrews is of particular concern, though some specific areas appear to be hotspots for certain pollutants, details discussed below.

Nitrogen Dioxide

Both the mean (22.8 µg/m³) and median (11.5 µg/m³) values measured for NO_2 are well within the Scottish annual average AQO and only 0.52% of our data is in excess of the 1-hour average AQO of 200 µg/m³ (Figure 1a). There is a significant difference between the Scottish AQO for NO_2 and the WHO AQG so 51.5% of our data is in excess of the annual average AQG of 10 µg/m³. However, because road traffic is a principal source of NO_2 emissions in urban areas, it is higher during the day and falls significantly overnight. Additionally, NO_2 is generally higher in the winter months, as seen consistently elsewhere in Fife (Thomson, 2023). Our data represents daytime hours and is slightly biased towards Nov – Mar compared to Apr – Oct (Table A2.1 and Figure A2.1). It is therefore likely that, with the exception of busy roadside locations (mean = 15.8 µg/m³ from Thomson, 2023), for most locations in St Andrews, the annual average of NO_2 within the 10 µg/m³ AQG.

The mapping of the data confirms that the majority of St Andrews has low levels of NO_2 pollution, especially the south and southwestern areas that are mostly quiet, residential streets (Figure 2). Market Street, North Street and South Street see slightly elevated levels of NO_2 pollution, as does Canongate. This is to be expected from streets that see more traffic but have limited speed and are likely to see drivers need to brake often, for example at pedestrian crossings or mini roundabouts. Acceleration and deceleration increase the emission of NO_2 from internal combustion engines. The highest emissions were measured along Abbey Walk between the bridge over the Kinessburn and the intersection with Greenside Place. It can be inferred that this is because this is relatively high-traffic road, and this particular section is on a significant gradient and has a tall stone wall on the northern side. This combination would both increase the emission of NO_2 and reduce the dispersal by the wind. This section also has two light-operated pedestrian crossings which would increase the amount of braking, idling and acceleration.

The pockets of high NO_2 measured around North Haugh and the Kinessburn are due to a small number of data points that measured high pollution, so it is possible that these are also hotspots, but it cannot be reliably confirmed with the available information.

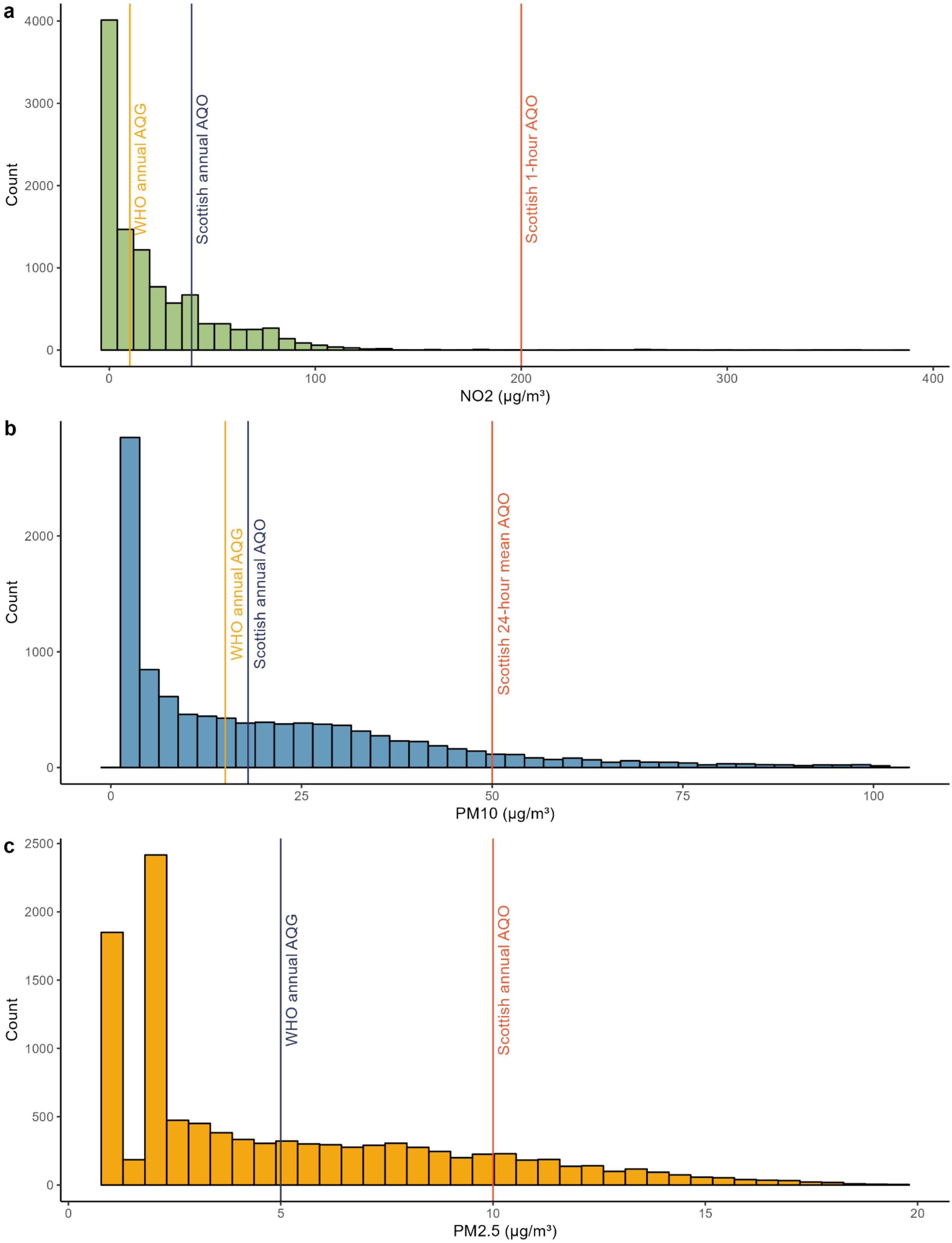

Figure 1: The distribution of concentrations of (a) NO_2, (b) PM_{10} and (c) $PM_{2.5}$ data. The labelled lines represent Scottish AQOs and WHO AQGs.

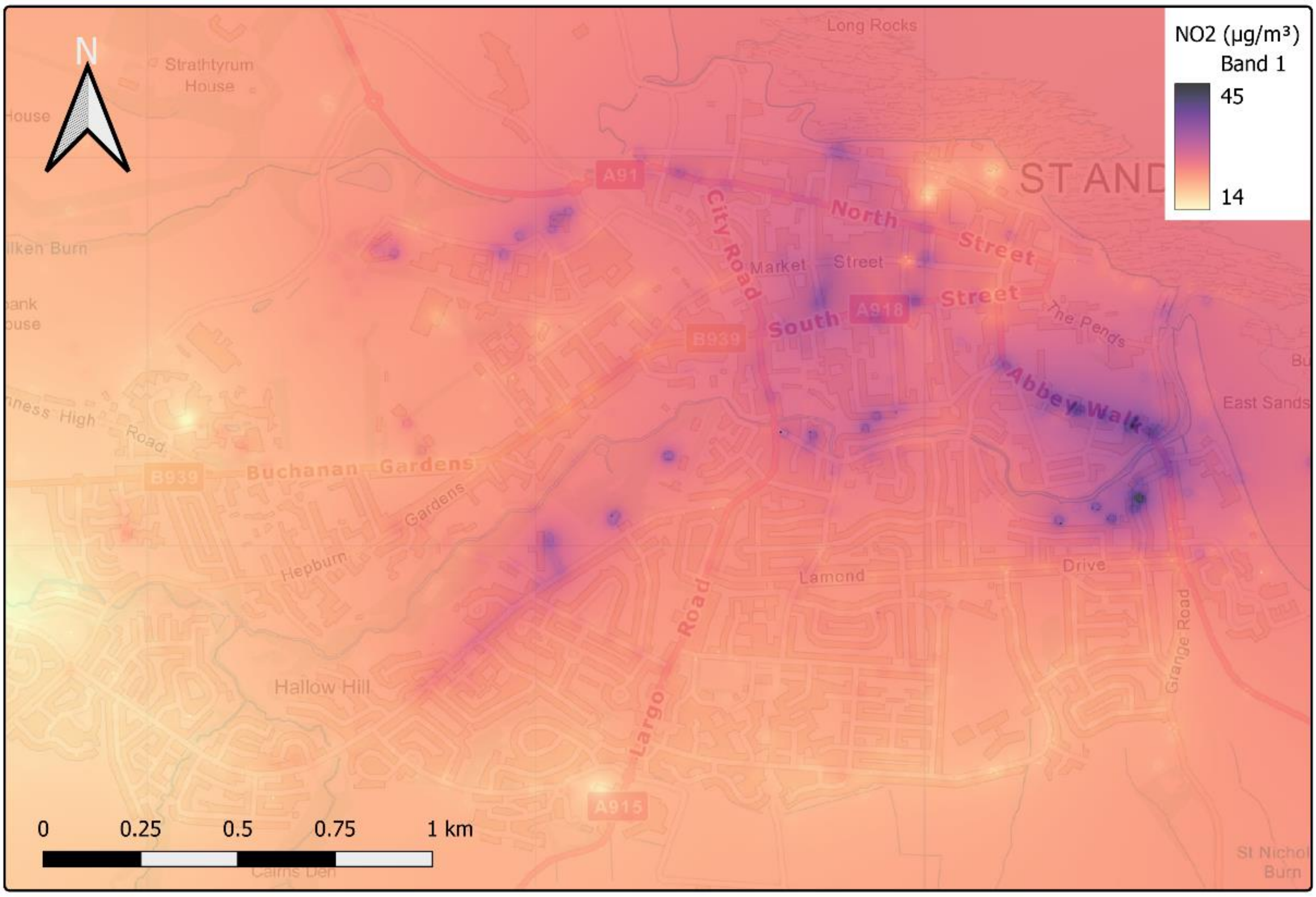

Figure 2: Map of NO_2 pollution in St Andrews, interpolated from point data. Contains Ordnance Survey data © Crown copyright database right 2024.

Particulate Matter

The annual mean AQO for PM_{10} is 18 µg/m³, and the median for our data is well within this (14.0 µg/m³) but the mean is slightly above (20.6 µg/m³). The WHO AQG for PM_{10} is only slightly lower than the Scottish AQO at 15 µg/m³ and only 48.4% of our data is in excess of this (Figure 1b). The Scottish 24-hour mean AQO that should not be exceeded more than 7 times in a year, is exceeded in only 9.0% of our data. Like NO_2, PM_{10} is higher during the day, which our data is biased to (Figure A2.1) and so it is reasonable to assume that the true annual mean of PM_{10} in St Andrews is below the Scottish AQO and likely also the WHO AQG since this is true for more than half of all PM_{10} measurements (Table A1.2).

$PM_{2.5}$ has much stricter guidelines because it is more harmful to human health. The mean (5.0 µg/m³) and median (3.3 µg/m³) $PM_{2.5}$ from our measurements are within the WHO AQG and only 14.6% of our data is over the Scottish annual mean AQO of 10 µg/m³ (Figure 1c). There is not a daily or hourly AQO for $PM_{2.5}$, but our data indicates that St Andrews is well within the annual objective, so is of little concern. However, ambient PM concentration (both PM_{10} and $PM_{2.5}$) is very dependent on weather and transport of PM from the rest of the UK and even Western Europe so can be more erratic than trends in NO_2, therefore our data is not only indicative of sources of PM from within St Andrews. Because of this, PM can be more difficult to trace and limit. It is also important to note that any decrease in PM is beneficial for human health (Hector *et al.*, 2023).

The mapping of PM_{10} and $PM_{2.5}$ show very similar spatial patterns (Figures 3 and 4) and show a high level of positive correlation ($\rho = 0.844$, $p < 0.01$). With high levels of PM pollution around the main roads Buchanan Gardens, Largo Road and Canongate, indicating that traffic is a significant source of PM pollution in St Andrews. The eastern side of St Andrews shows significantly lower levels of PM pollution and Market Street and South Street are also slightly elevated. The area surrounding Lade Braes is likely misrepresented due to interpolation from the higher pollution roads surrounding it and minimal data for the Lade Braes itself. It is also important to note that the southern sections of Largo Road and Canongate are also overrepresented in our data, especially at times of peak traffic and potential idling, for example, during pick-up and drop-off times around Canongate Primary School. Canongate also has speed limiting infrastructure, including speed humps and mini roundabouts that would increase the need for braking and accelerating on this stretch of road, increasing fuel consumption and therefore the emission of pollutants.

However, there must also be factors other than traffic influencing the distribution of PM in St Andrews because there is limited correlation between NO_2 and both PM_{10} and $PM_{2.5}$. There is minimal PM pollution along Abbey Walk where NO_2 pollution is highest. Therefore, even if traffic is a significant source of both NO_2 and PM, there are other factors (e.g., weather) and other sources (e.g., long-distance transport of PM) creating this difference in distribution.

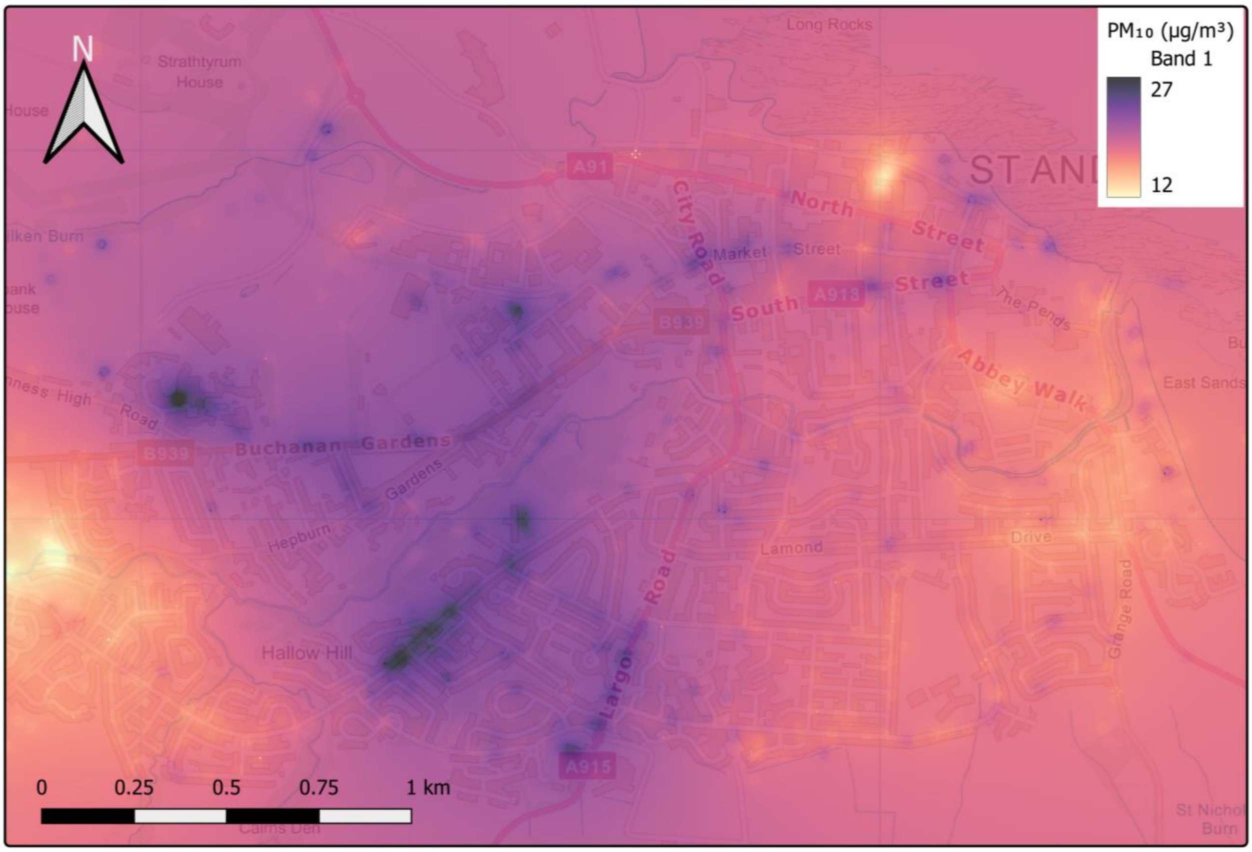

Figure 3: Map of PM_{10} pollution in St Andrews, interpolated from point data. Contains Ordnance Survey data © Crown copyright database right 2024.

Other apparent hotspots, for example at David Russel Apartments (north-western edge of St Andrews) could be a result of the burning of domestic fuels but are more likely a measure of indoor air quality, where the air quality monitors have accidentally left on inside and measured PM from cooking, cleaning or dust. Unlike NO_2, there can be significant sources of PM indoors as well as outdoors and therefore there is likely some error from these sources for which it is difficult to account.

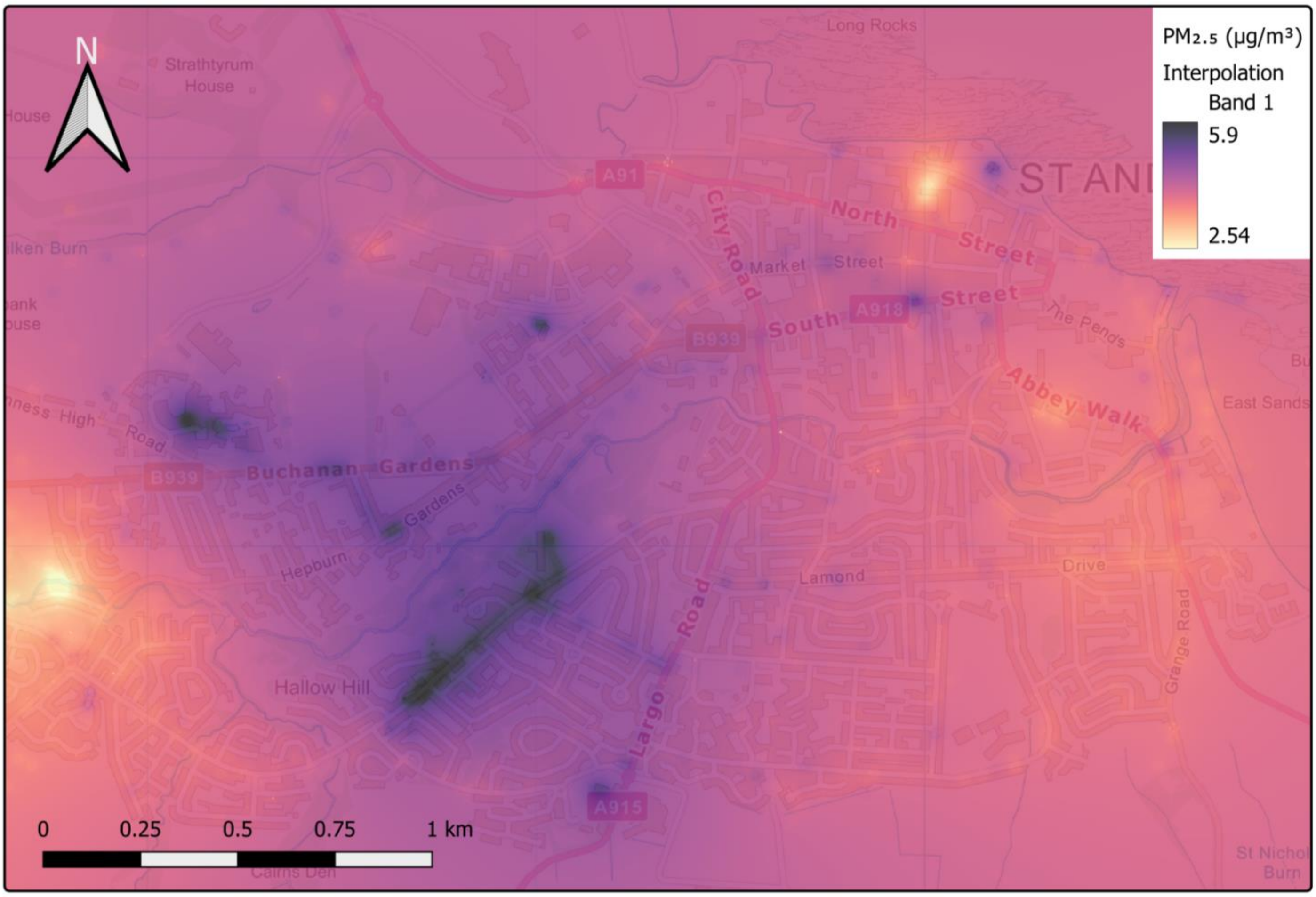

Figure 4: Map of $PM_{2.5}$ pollution in St Andrews, interpolated from point data. Contains Ordnance Survey data © Crown copyright database right 2024.

Air Quality Index

An Air Quality Index (AQI) combines multiple measures of air quality into one value to give a more cohesive picture of air quality. There are many different AQIs, which use different combinations of pollutants and use different methods of quantifying risk. Plume, the producer of the air quality monitors used in this study, have derived their own AQI in which each pollutant measured is given a value based on human health impacts at that concentration the overall AQI is determined by the highest of these values measured at any given time. For example, if the AQI values were measured to be NO_2 = 18, PM_{10} = 50 and $PM_{2.5}$ = 23, the AQI would be 50[2]; we again excluded VOCs from the calculation of the AQI. See Table 2 for how the Plume AQI corresponds with health impacts.

The vast majority of our measurements fall under ‘Excellent’ or ‘Fair’ air quality according to Plume’s AQI (Figure 5). Only 15.3% of our data corresponds to an AQI of 50 or more (i.e., ‘Poor’, ‘Unhealthy’ or ‘Very Unhealthy’). Mapping the AQI confirms that busier roads are where air quality is the worst in St Andrews, mirroring the maps of individual pollutants with high AQI around Abbey Walk, Canongate, Largo Road and the main three streets of the town centre (Figure 6). Similarly, air quality is better in the quieter residential areas, including the southeastern edge of town and the area around Bogward Road in the southwest. More than the individual pollutants, AQI also shows significant influence of anomalies from areas of low data density (e.g., North Haugh).

[2] https://air.plumelabs.com/learn/en/what-is-an-aqi

Table 2: Different Plume AQI levels and their meaning. Recreated from the Plume Labs website.

Air Quality	Plume AQI Range	Explanation
Excellent	0 - 20	The air quality is ideal for most individuals
Fair	21-50	The air quality is generally acceptable for most individuals. Sensitive groups may experience minor to moderate symptoms from long-term exposure.
Poor	51-100	The air has reached a high level of pollution and is unhealthy for sensitive groups.
Unhealthy	101-150	Health effects can be immediately felt by sensitive groups. Health individuals may experience difficulty breathing and throat irritation with prolonged activity.
Very Unhealthy	151-250	Health effects will be immediately felt by sensitive groups and should avoid outdoor activity. Healthy individuals are likely to experience difficulty breathing and throat irritation.
Dangerous	251 +	Any exposure to the air, even for a few minutes, can lead to serious health effects on everybody.

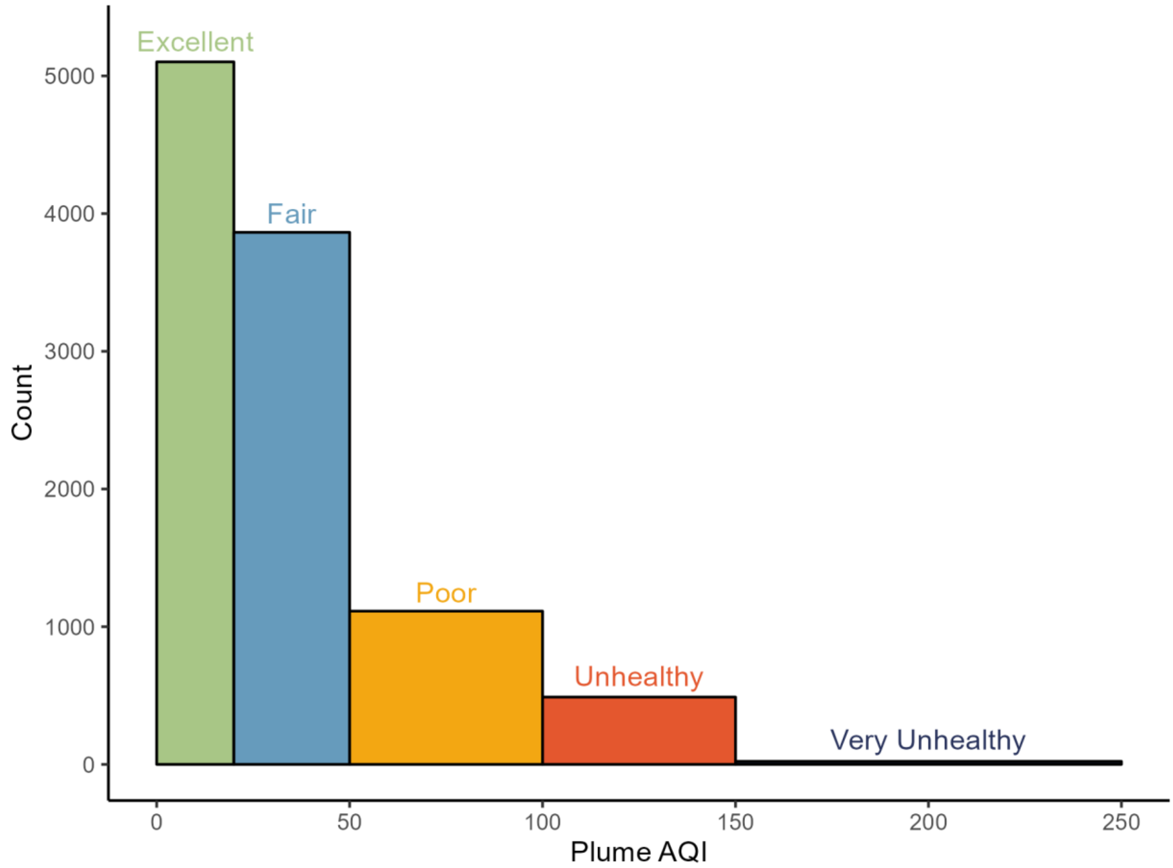

Figure 5: The distribution of different air quality levels using the Plume AQI. The levels correspond with the levels described in Table 2.

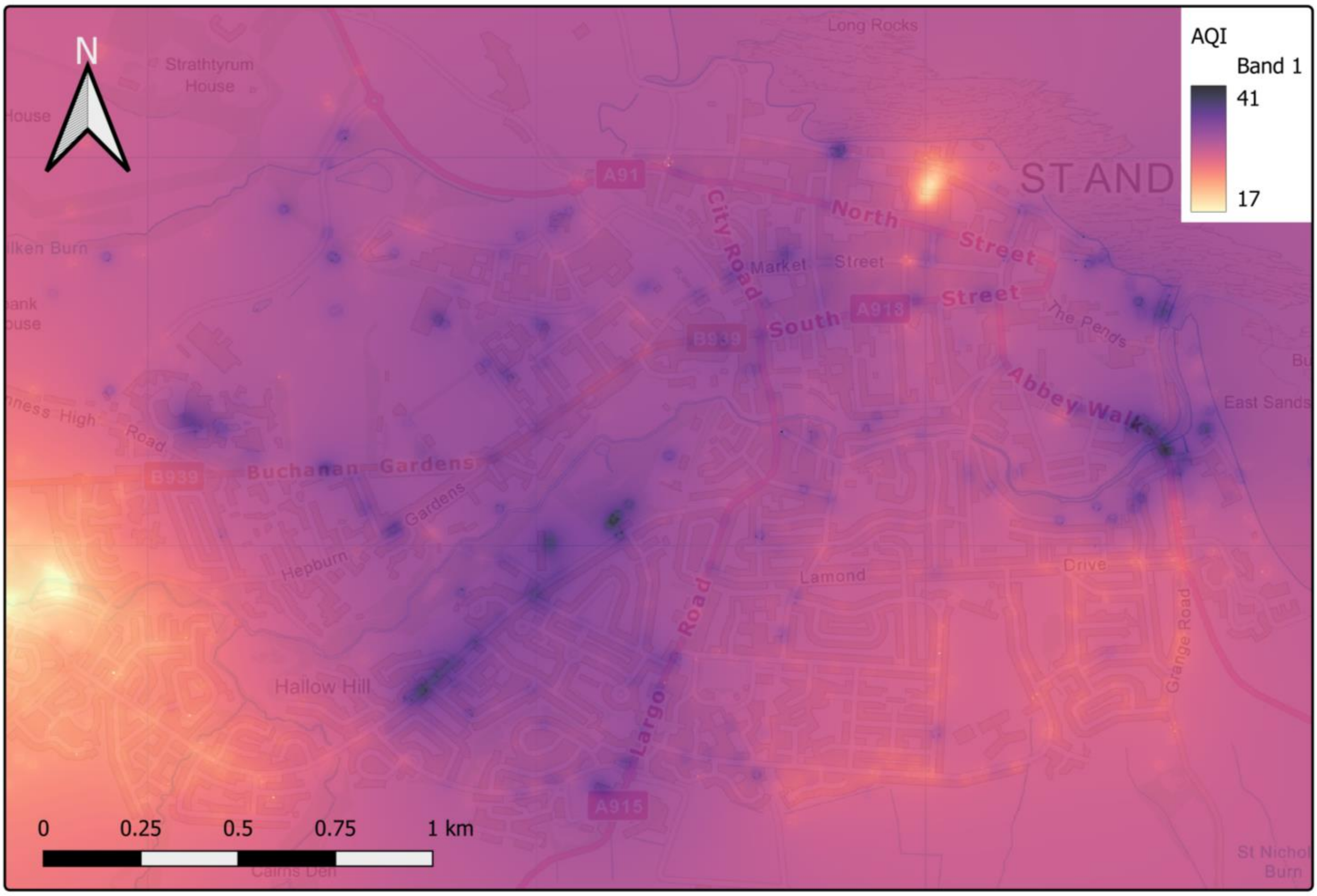

Figure 6: Map of Plume AQI in St Andrews, interpolated from point data. Contains Ordnance Survey data © Crown copyright database right 2024.

Reliability and bias

Our data is subject to bias due to its spatial and temporal distribution. Many areas of St Andrews are overrepresented where others are represented by just a few sparse data points. For example, the southern sections of Canongate and Largo Road and Abbey Walk were covered many times but several of the streets around Tom Morris Drive and Bogward Road were covered only once or twice. Therefore, some conclusions are more reliable than others. However, to the best of our ability, we covered each main section of St Andrews at least three separate times. This allowed us to establish a background level of pollution for comparison to the main roads that were sampled more heavily. Additionally, though majority of the data was collected between 8 am and 6 pm, the year is not evenly represented with June and September having no data at all over the four years of data collection (Appendix 2).

Additionally, despite best efforts to limit the measuring of indoor air quality, it is likely that the PM data especially is influenced by indoor air quality in specific locations. Where possible, this has been accounted for with spatial averages in areas of high data density (Appendix 3 – GIS).

The accuracy of the flow meters is very good for a personal air quality monitor, with 90 to 95% correlation with static monitors (Plume Labs, 2019). However, some days measured consistently anomalously high NO_2 (> 3 standard deviations from the mean) and these were removed from analysis. For all data, anomalies greater than 3 standard deviations from the mean were removed from analysis.

Improve your local air quality

Limit Car Journeys

Road traffic is one of the biggest polluters in urban areas so limiting the number of vehicles on the road is one of the best ways to improve air quality. This can be done by carpooling, taking public transport instead of personal vehicles and by swapping short journeys with walking or cycling. Active transport like walking and cycling has the additional benefit of getting you moving which is good for your health.

If you must drive somewhere, avoid busy routes and times where possible. Properly maintaining your vehicle, turning off your engine when stationary (and safe to do so) and driving efficiently (avoiding sudden stops/starts) also limits air pollution. Automatic Start-Stop systems are one of the best ways to do this, so make sure this is enabled on your vehicle if available. You could also consider switching to a low emission or electric vehicle.

Avoid Burning Household Solid Fuels

The domestic burning of solid fuels, including dried wood, manufactured solid fuels (e.g. briquettes and fire logs) and coal, releases very high levels of PM, especially $PM_{2.5}$ which can have a significant impact on your health and shorten your life expectancy. The best way to avoid this pollution is to not use wood-burning stoves and open fireplaces, using gas stoves and central heating instead to warm your home. If you use a wood-burning stove or fireplace, use fuel marked with the 'Ready to Burn' logo. This ensures the fuel is suitably dried and will burn more efficiently and with less smoke. You should also check and clean your fireplace or stove regularly to limit the build-up of soot, ash and tar.

Protect yourself from poor air quality

Avoid areas and times of poor air quality by avoiding busy roads and periods of peak traffic when travelling or exercising (air quality inside a car can also be worsened by traffic conditions). You can also set air quality alerts, so that you can be notified if the air quality in your area is expected to worsen[3] and plan your time outdoors accordingly. It is also important to note that some people are more sensitive to poor air quality. Children are closer to the ground and therefore breathe in higher concentrations of pollution from exhaust and people with existing lung and cardiovascular conditions may feel the negative effects of pollution at lower concentrations.

References

Defra (2023) *Emissions of air pollutants in the UK, GOV.UK*. Available at: https://www.gov.uk/government/statistics/emissions-of-air-pollutants/emissions-of-air-pollutants-in-the-uk-particulate-matter-pm10-and-pm25 (Accessed: 25 January 2024).

Grantz, D.A., Garner, J.H.B. and Johnson, D.W. (2003) 'Ecological effects of particulate matter', *Environment International*, 29(2–3), pp. 213–239. Available at: https://doi.org/10.1016/S0160-4120(02)00181-2.

Hector, D. *et al.* (2023) *Scottish Air Quality Database Annual Report 2022*. ED11194. Scottish Government.

Pandey, S.K. and Singh, J. (2021) 'Nitrogen dioxide: Risk assessment, environmental, and health hazard', in *Hazardous Gases*. Elsevier, pp. 273–288. Available at: https://doi.org/10.1016/B978-0-323-89857-7.00001-3.

[3] https://www.scottishairquality.scot/know-and-respond

Plume Labs (2019) 'Evaluation of Flow, a personal air quality sensor'. Available at: https://plumelabs.zendesk.com/hc/en-us/articles/360025092554-How-Accurate-is-Flow (Accessed: 29 February 2024).

Public Health England (2018) *Health matters: air pollution*, *GOV.UK*. Available at: https://www.gov.uk/government/publications/health-matters-air-pollution/health-matters-air-pollution (Accessed: 25 January 2024).

Thomson, V. (2023) *Fife Air Quality Annual Progress Report 2023*. ED14794. Fife Council.

World Health Organization (2021) *WHO global air quality guidelines. Particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.* Geneva.

Appendix 1 – Data in summary

Table A1.1: Summary statistics for each pollutant, all values given in µg/m³.

Statistic	NO_2	PM_{10}	$PM_{2.5}$
Minimum	0	1.0	1
Median	11.5	14.0	3.3
Maximum	384.4	102.5	19.7
Mean	22.8	20.6	5.0
IQR	34.4	27.6	5.7
SD	33.2	20.4	4.1

Table A1.2: Our data in accordance with WHO AQGs and Scottish AQOs.

Pollutant	Target (µg/m³)	Exceeding target (%)
NO2	10 (WHO annual AQG)	51.5
	40 (Scottish annual AQO)	20.1
	200 (Scottish 1-hour AQO)	0.52
PM10	15 (WHO annual AQG)	48.4
	18 (Scottish annual AQO)	43.8
	45 (WHO 24-hour AQG)	12.0
	50 (Scottish 24-hour AQO)	9.02
PM2.5	5 (WHO annual AQG)	39.3
	10 (Scottish annual AQO)	14.6
All three	WHO annual AQG – see above	66.8
	Scottish annual AQO – see above	49.8

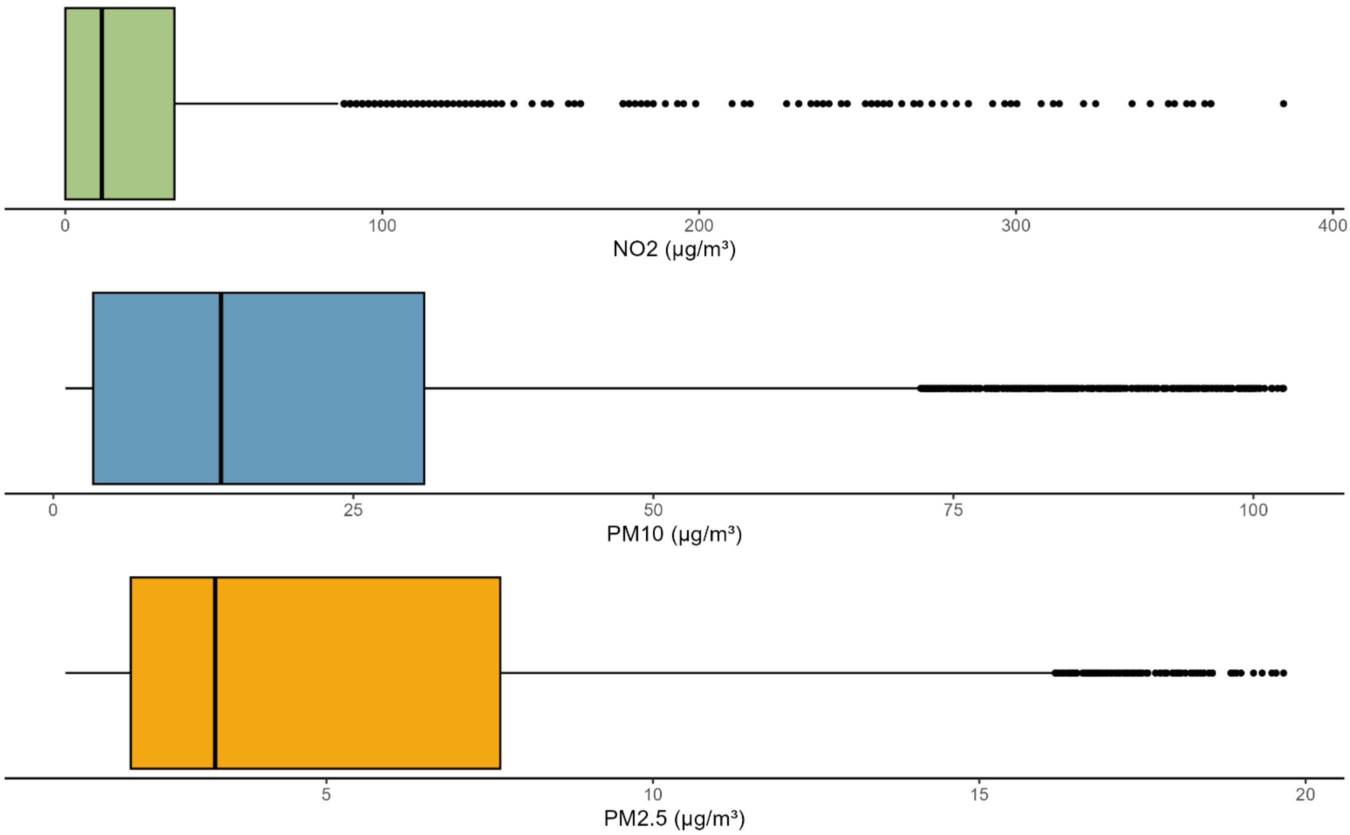

Figure A1.1: Boxplots showing the distribution of the data for NO_2 (top), PM_{10} (middle) and $PM_{2.5}$ (bottom). The black dots represent anomalies.

Appendix 2 – Time representativeness

Table A2.1: The distribution of our data by month.

Month	Number of data points
January	2592
February	595
March	668
April	1149
May	279
June	0
July	309
August	2502
September	0
October	138
November	981
December	1426

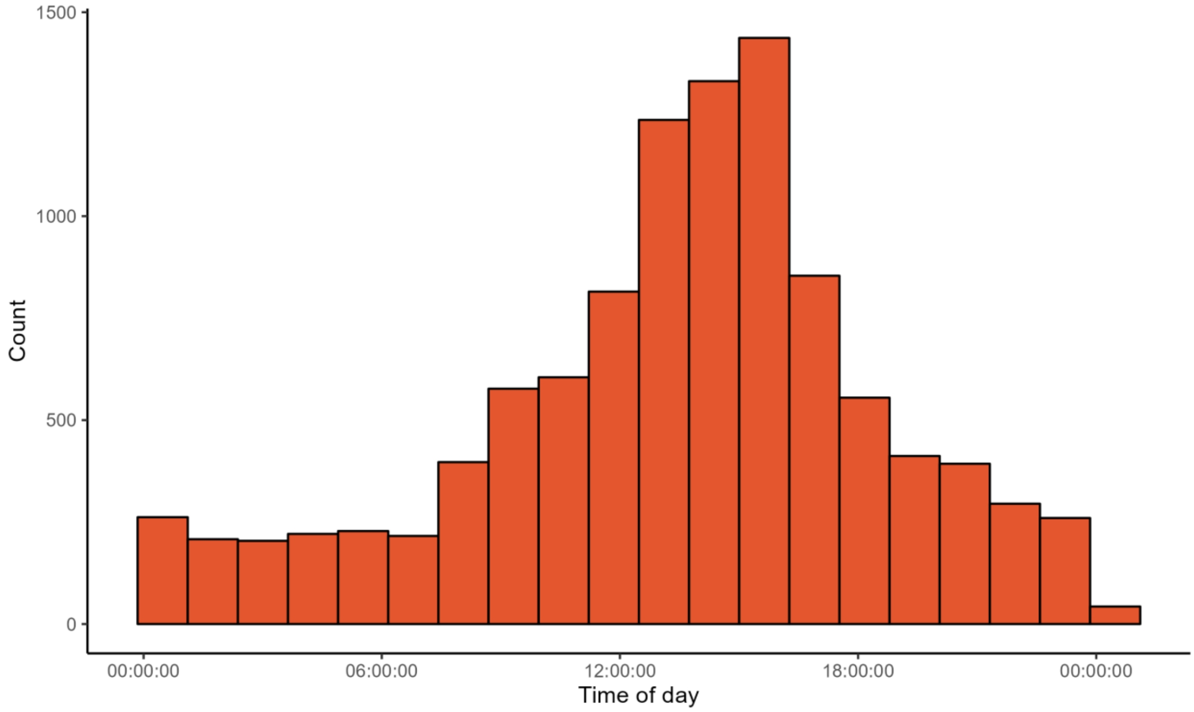

Figure A2.1: The distribution of our data by time of day.

Appendix 3 – Methods

Data Collection: Data was collected on foot or on bikes on the streets and paths of St Andrews. The Flow meters automatically measure all parameters every minute and while moving the mobile phone paired to the Flow meter records location data via GPS. The data was collected ad hoc so the time of day, week and year are not controlled for.

Data processing: Data was processed in R (open-access programming language for data analysis). Timestamps were used to link air quality data with GPS location. Only the smallest difference in timestamp for each air quality data point was kept and any differences of more than a minute were discarded. NO_2 data was converted from ppb to µg/m^3 with the conversion factor 1 ppb = 1.9125 µg/m^3 (correct for 20 °C and 1013 mb). Anomalies greater than 3 standard deviations above the mean were removed as well as 6 anomalously high days for the NO_2 dataset. Significant correlation was tested using Spearman's rank.

GIS: Data was mapped using QGIS (open-access geographical information system). The data was first reprojected to the British National Grid coordinate system from WGS 84. Then each point was given a 10 m buffer and the 'Join attributes by location (Summary)' tool used to calculate a mean for points that intersect. Then points with the same mean value were dissolved. Large clusters (>100 data points within a few tens of meters) were manually averaged and dissolved into one larger polygon. All points and polygons were then used as the input for an IDW interpolation (distance coefficient = 1) based on the mean concentration of the pollutant.