Road Traffic Impact on Pedestrian Exposure to Air Pollution and Noise: A Natural Experiment

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Abstract

Noise and air pollution pose health risks for active transportation users, yet the impact of traffic volume and roadway proximity remains underexplored. This study exploited an unusual circumstance, a natural experiment, to assess environmental changes from temporary road closures. On summer weekends, the National Capital Commission (NCC) of Canada closes a segment of Queen Elizabeth Driveway in Ottawa. To evaluate the environmental benefits of this intervention, measurements of A-weighted equivalent continuous sound levels (LAeq), particulate matter ($PM_{2.5}$), and ultrafine particles were taken at 12 fixed sites along a nearby multi-use pathway across 10 sampling sessions, over six days. All measured pollutants showed statistically significant reductions during closures. A composite noise–air pollution index indicated a 60% decrease in overall exposure, highlighting the effectiveness of the car-free policy in improving environmental quality for active transportation.

Keywords: Air pollution; noise; trafic; pedestrian and cyclist exposure

1 Introduction

1.1 Background

As of 2018, over half the world's population lives in urban environments, with a projected 68% by 2050 (United Nations, 2019). Urban settings are burdened with many environmental stressors and associated with rising pollutant trends, affecting the health and well-being of their citizens (Sicard et al., 2023). With increasing urban populations, city planners are facing increased pressure to design more sustainable environments. Among various sources of urban pollution, road traffic remains a dominant source of noise and air pollution in urban areas and is a primary hindrance for the development of healthier cities (Khan et al., 2018, Harrison et al., 2021).

Road traffic is known to increase urban particulate matter concentrations through vehicle exhaust, abrasion, and re-suspension. Fine particulate matter, particulate matter with diameters less than 2.5 µm ($PM_{2.5}$), is specifically attributed to vehicle exhaust emissions (Pant and Harrison, 2013) and is consistently used to measure traffic influence on air quality (Lopez-Vicente et al., 2025, Kim et al., 2024, Thi Khanh et al., 2025). $PM_{2.5}$ can penetrate the respiratory tract and enter the bloodstream, affecting major organs. High exposure levels can cause cardiovascular and respiratory diseases and increase mortality through inflammation and oxidative stress (Mayntz et al., 2024, Sangkham et al., 2024). A 2021 Health Canada report attributes an estimated 8.0% of nonaccidental mortality among Canadians over 25 to chronic

$PM_{2.5}$ exposure (from all sources, such as combustion, dust, and agriculture) based on 2014-2017 pollution data (Canada and Canada, 2021). Although WHO $PM_{2.5}$ guidelines exist, a 2024 study shows that even low-level pollution can significantly raise health risks, calling for updated $PM_{2.5}$ exposure recommendations and air quality guidelines (Valar et al., 2025).

Comparably, ultrafine particles (UFPs), particles with diameters less than 0.1 µm, are closely linked to traffic emissions with an estimated 50% of UFPs originating from combustion sources (Groma et al., 2022). In urban environments, UFP concentrations are dominated by traffic with motor vehicle emissions recognized as the most significant source of UFP emissions (Weichenthal et al., 2016, Abdillah et al., 2024). Though little research has been conducted on UFPs, current findings suggest a strong association with increased mortality and inflammation risk and increased oxidative and cardiovascular stress (Chen et al., 2025). Recent studies conducted in neighboring Canadian cities (Toronto, Montreal) attribute an estimated 1100 nonaccidental yearly deaths to UFPs (Lloyd et al., 2024b) and correlate the pollutant with the development of malignant brain tumors (Lloyd et al., 2024a). Given the lack of current research, outdoor UFPs do not have standardized guidelines or benchmarks and are not currently regulated, posing major health risk implications.

Noise in urban environments is a key pollutant and psychological stressor associated with many cardiovascular and neuropsychiatric diseases (Valar et al., 2025). Frequent exposure to environmental noise is known to disturb sleep, and induce annoyance and stress (Mayntz et al., 2024), and can significantly increase the risk of heart failure (Liu et al., 2025). In March 2022, Health Canada released results of a survey comparing self-reported health status from environmental noise of 6647 randomly selected Canadians. Results show that road traffic remains a top source of annoyance amongst Canadians, with urban dwellers reporting significantly higher annoyance levels (10.5%) compared to rural/remote dwellers (6.6%) (Michaud et al., 2022). Although specific levels vary, the World Health Organization (WHO) suggests elevated continuous sound pressure levels (LA_{eq}) greater than 55 dBA can cause annoyance, with adverse cardiovascular and psychophysiological occurring after long-term exposure of LA_{eq} levels of 65-70 dBA (World Health Organization, 1999).

1.2 Justification

Over summer months, the National Capital Commission of Canada (NCC) closes a 2.2 km section of Queen Elizabeth Driveway (QED), a two-lane road in Ottawa, Ontario, to vehicle traffic on weekends and holidays (National Capital Commission). This policy provides a safe and accessible space for active transportation users (i.e. pedestrians and cyclists) given the increasing demand for walking and cycling during summer weather. From herein, pedestrians refers to all active transportation users (all types are allowed according to the policy). Many cities have implemented similar strategies centered around pollution mitigation in various environments.

While some studies explore the environmental impacts of car-free day initiatives (Kalisa et al., 2025, Aida et al., 2019), research assessing their impact on pollution remains limited.

The current literature evaluating the effects of car-free days on pollution levels represent the area of implementation with limited spatial coverage. These studies have captured pollutant data to represent large study areas using only one or two monitoring sites (Masiol et al., 2014, Kalisa et al., 2025). To improve spatial resolution and balance feasibility, portable sensors and stationary spot check methods over numerous sampling sites are commonly used in urban pollution assessment studies. Portable sensors allow for efficient monitoring of multiple sites, offer more precise spatial resolution at locations of interest, and are relatively cost-effective. While they provide more limited temporal coverage and require more intensive calibration to account for environmental variability, their use is justified in studies constrained by logistical and financial considerations (Kerckhoffs et al., 2025). For example, King et al. (2016) utilizes portable stationary measurements to capture pollutant levels along a stretch of the New York City High Line and adjacent road. This approach enables a quantifiable comparison between two independent sampling populations while also providing detailed spatial characterization. However, it does not measure the impact of road closures.

Though traditionally measured separately, studies have also advocated for combined exposure assessments of noise and air pollution when pedestrians are simultaneously exposed to both pollutants (King et al., 2016, King et al., 2009, Silva and Mendes, 2012, Adza et al., 2022). To quantitatively incorporate both air and noise pollution exposure, an Air-Noise Pollutant Reduction Index (ANP_r) was developed alongside a study investigating the effect of a segregated boardwalk on pollution levels in Dublin, Ireland (King et al., 2009). The index was also used in a separate study to examine the effectiveness in pollution reduction of the High Line in New York City (King et al., 2016).

This paper leverages systematic longitudinal measurements to analyze the efficacy of car-free day initiatives and quantify traffic-based pollution trends in Ottawa, a clean and developed urban environment. The combined analysis presented using the ANP_r metric incorporates $PM_{2.5}$ and UFPs as primary air pollutants to better identify traffic-associated pollution, whereas the above-mentioned studies use $PM_{2.5}$ and benzene. A new framework is also presented to compare noise and air pollution levels in a defined study area across a time-based parameter.

1.3 Research Questions

We hypothesize that pollution levels (air and noise) will be significantly lower on the multi-use pathway when the adjacent road is closed to traffic. Therefore, the following research questions are addressed in this paper.

1. How is the traffic-associated pollution exposure level affected by the presence of vehicles on the adjacent roadway?

2. How do traffic-associated pollution levels compare between locations?
3. What is the correlation between traffic flow and measured pollutants?

2 Methodology

2.1 Measurement Procedure

QED is a frequently used road in downtown Ottawa running along the Rideau Canal. The road has an adjacent multi-use pathway (MUP) for active transportation users, shown in Figures 1 and 2. Active transportation users are herein referred to as pedestrians. The MUP is positioned between five and 55 meters from road traffic and is partially shielded by vegetative barriers in places. To assess pollution levels directly experienced by pedestrians, all measurements were taken along the MUP.

Figure 1: Closed Queen Elizabeth Driveway and adjacent multi-use pathway stretch for the study area. Figure was created using Google Maps from the base map Imagery ©2025 Map data ©2025 Google, accessed on August 1, 2025.

Figure 2: Queen Elizabeth Driveway and adjacent multi-use pathway during road closures. (Photo credit: William O'Brien)

Data were collected along the 2.2 km closed segment of QED. Spot measurements were taken at 12 predetermined locations three times of day (morning, midday, afternoon) to capture spatial and diurnal pollution trends. Measurements were taken on three days for each road condition (open, closed), with morning and afternoon measurements taken on two days and midday measurements on one day. All measurements were taken in a one-month span in June and July 2025.

Traffic counts, A-weighted sound pressure level, $PM_{2.5}$ mass concentration, and UFP number concentration (PNC) were all measured. At each location and time of day, all pollutants were simultaneously sampled for 5 minutes at 1-second log intervals (i.e., 300 samples at 1 Hz frequency). Traffic was manually measured along QED at each location and time of day, yielding the number of vehicles passing per 5-minute sampling interval.

To isolate source pollution, background levels were recorded at a control site at Brewer Park (Figure 1). Background samples were taken for 15 minutes at a 1-second sampling rate. Criteria used to select background environmental stations are established. For a source of interest in a study area, background locations are required to be uninfluenced by source emissions from the area; have similar air quality as the study area (except for air quality influenced by source emissions); have similar weather conditions; and be reasonably far away from the emission source. The background location should possess a similar terrain to the study area and must have necessary infrastructure and meet general sitting requirements for air sampling locations (Fritz et al., 2015). Brewer Park was selected as a background location due to its eligibility as per the outlined requirements and the feasibility of travelling to and from the location to QED in short time frames.

2.1.1 Site Selection

Past studies showed an exponential decrease in air pollution concentrations with greater distance from the source, as well as an added reduction from vegetation and other barriers (King et al., 2009, Sheng et al., 2025, Moronta-Sabad et al., 2025). Similarly, increased source distance and barriers also reduce noise levels (King et al., 2009, Barros et al., 2024). To account for spatial variation along QED, the 12 sampling locations were selected based on proximity to the road and nearby barriers and vegetation. The geographical placement of the selected sampling locations is shown in Figure 3. Approximate distances between sampling locations and each location's distance from the center of the road is shown in Table 1. GPS coordinates for each sampling location are provided in the Appendix (Table A1). The measurement height was 1.5 m above the ground.

Figure 3: Selected fixed monitoring locations along QED. Figure was created using Google Maps from the base map Imagery ©2025 Map data ©2025 Google, accessed on August 1, 2025.

Table 1: Approximate distances between sampling locations, and each location's distance to the center of the road, estimated using Google Maps. Note the road itself

is approximately 9 m wide. The vegetation level between the MUP and road was assessed and specified here to provide context for the data.

	Distance to next location (m)	Distance to center of road (m)	Vegetation
L1	170	5	Low
L2	200	55	Moderate
L3	250	15	Moderate
L4	190	20	High
L5	115	15	Moderate
L6	215	10	Low
L7	200	5	Low
L8	170	20	High
L9	210	15	Moderate
L10	190	30	High
L11	190	10	High
L12	-	5	Moderate

2.1.2 Time of Day Selection

Measurements were taken during mornings, midday, and afternoons to reflect diurnal variability related to traffic trends. Morning measurements began at 8:45am; midday measurements began at 12:45pm; afternoon measurements began at 3:45pm; and background measurements began at 11:45am. Times were primarily selected based on monitored rush hour periods for morning and afternoon, given that each measurement period along QED takes approximately 90-120 minutes. The timing of the background measurement was due to the practical constraints of field measurement.

2.1.3 Meteorological Controls

Meteorological variables such as temperature, relative humidity, precipitation, wind speed, and wind direction can have a significant effect on air pollutant concentrations (Rouse and McCutcheon, 1970, Zender-Świercz et al., 2024, Wang et al., 2023, Zheng et al., 2019), making it important to ensure samples are taken on days with similar weather conditions. As such, measurements were taken on days which had similar mean temperatures and relative humidities, and 0.0 mm of precipitation.

Although temperature and relative humidity fluctuate less during summer months, wind speed remains unpredictable, making it difficult to account for. A study analyzing the influence of wind speed and direction on roadway pollution found that vehicular emissions significantly decrease with wind speeds higher than 2.0 m/s (Kim et al., 2015). The study analyzed particle-bound polycyclic aromatic hydrocarbons to represent road pollution, which are more closely associated with vehicle exhaust emissions as opposed to $PM_{2.5}$; therefore, the wind speed associated with decreasing $PM_{2.5}$ concentrations may vary. For that reason, and for feasibility purposes, measurements were taken on days with similar wind directions and daily average wind speeds of less than 5 m/s.

Table 2 summarizes the meteorological conditions of each test day. Government of Canada's Ottawa CDA RCS weather station (45.38°, -75.72°) data were used (Canada, 2025), spaced approximately 4 km away from L1 (Google). The weather station is 10 m above ground and 79m above sea level. In the table, all variables were averaged for all hours of the test day.

Table 2: Daily average meteorological conditions recorded at Ottawa CDA RCS weather station.

Date	Road condition	Measurement times of Day	Temperature (^oC)	Relative humidity (%)	Precipitation (mm)	Wind speed (m/s)	Wind direction (^{o}CCW from N)
Wed, 06/11/2025	Open	Morning Afternoon	18.5	68.4	0.0	4.9	246.2
Thurs, 06/12/2025	Open	Midday	16.3	68.5	0.0	5.0	308.7
Tues, 06/17/2025	Open	Morning Afternoon	21.5	74.3	0.0	3.5	206.1
Sat, 06/21/2025	Closed	Midday	20.4	65.7	0.0	2.4	207.7
Sun, 06/29/2025	Closed	Morning Afternoon	20.7	69.1	0.0	3.3	269.3
Sat, 07/05/2025	Closed	Morning Afternoon	21.9	63.7	0.0	3.8	211.8

2.1.4 Equipment

A-weighted decibel measurements were recorded using the Danoplus Digital Sound Decibel Meter[1]. Air quality measurements for $PM_{2.5}$ mass concentrations (µg/m^3) were recorded using the Ultrasonic Personal Air Sampler (UPAS)[2] device's built-in Sensirion SPS30 sensor. PNC (#/cm^3) was measured using the Naneos Partector 2[3]. All sensors were calibrated prior to data collection. Details of each instrument are provided in the Appendix (Table A2).

The three devices were set up on two tripods at a height of 1.5 m; one tripod fixed the UPAS while the other fixed the Partector 2 and Decibel Meter. As illustrated in Figure 4, the UPAS was kept apart from the other two devices to ensure the Decibel Meter did not record noise made by the UPAS device. A windshield ball was attached to the Decibel Meter to reduce wind noise interference and protect the sensor from dust.

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[1] https://www.danoplus.com/products/dp-441/#user_manuals

[2] https://www.accsensors.com/upasv2.1

[3] https://www.naneos.ch/partector2.html

Figure 4: Equipment setup at a sampling location for noise (right side), PM2.5, and UFP (left side) measurements. (Photo credit: Farès Chéraitia)

2.2 Data Analysis

2.2.1 Data Processing

Raw data were collected for sound pressure level (noise), $PM_{2.5}$ concentration, and PNC. To account for varying noise intensity, A-weighted sound pressure levels are reported as A-weighted equivalent continuous sound levels (LA_{eq}). Five A-weighted measurements were converted to an energy-averaged LA_{eq} measurement. LA_{eq} measurements were used for all subsequent plots and statistical tests. Raw data for $PM_{2.5}$ concentration and PNC were used for respective plots and statistical tests.

2.2.2 Background Level Adjustment

Weekends tend to have lower background air pollution levels (less traffic, etc.). Because QED is closed to vehicles mainly on weekends, a correction needs to be made to isolate pollution directly caused by vehicular traffic for both weekdays and weekends. (Hilker et al., 2019) evaluated three methods to distinguish air pollution caused by local activity from background levels: average site differences (method 1 (DeWinter et al., 2018)), downwind-upwind analysis (method 2 (Galvis et al., 2013)), and time series background analysis (method 3 (Wang et al., 2018)). All three methods have been implemented in previous air pollution studies. Method 1 was applied in this paper, where each raw data measurement was subtracted by the mean background level for the corresponding day. Although method 3 was recommended, method 1 produced similar results when compared with method 3 and was employed for simplicity.

Background correction was only utilized for $PM_{2.5}$. Studies show that background UFP levels vary with wind direction and area, with UFPs decaying rapidly with increasing distance from the source. The literature suggests that the background correction method used for $PM_{2.5}$ would likely lead to errors in UFP exposure estimates (Jones et al., 2020, Weichenthal et al., 2024, Xiang et al., 2018). Since vehicle emissions dominate UFP emissions, no background adjustment method was used for UFP concentration. Similarly, noise measurements were not adjusted by background levels as sensor proximity is the dominant source of measurement variability.

3 Results

3.1 Traffic Volume

Figure 5 shows diurnal traffic profiles across QED with an average profile across all measurement periods. Traffic volumes fluctuated by location and time of day, peaking at L1 at 77 vehicles and L5 at 83 vehicles recorded during the 5-minute interval. From L6 onwards, traffic volumes decreased until location L10. L10 was observed to hold the lowest traffic volume at 29 vehicles, with traffic volume showing less variation between L8 and L12.

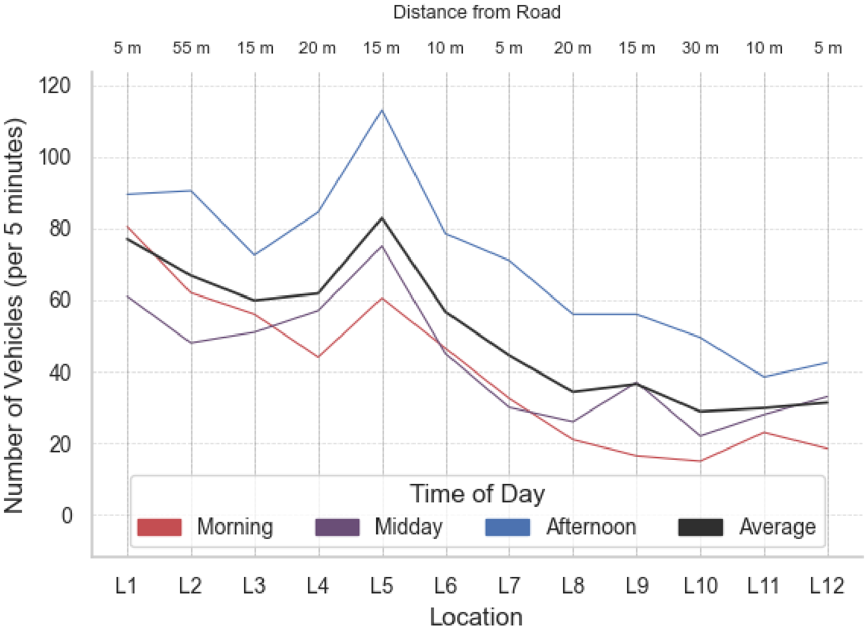

Figure 5: **Traffic volume diurnal profiles along QED across all locations, with distance between the MUP and centre of the road indicated at the top of the plot**

A stratified analysis for linear correlation between traffic volume and pollutant level is presented in Table 3. Data were stratified by date and time of day to exclude distortion from inconsistent traffic counts or weather conditions. $PM_{2.5}$ was found to have the most significant linear correlation with traffic levels, with a mean coefficient of determination of 0.532 across all strata and coefficients greater than 0.600 for 3 out of 5 strata. Both LA_{eq} and PNC exhibited weak linear correlations with traffic volume, yielding low coefficients of determination across all strata.

Table 3: **Stratified coefficients of determination coefficients assessing the correlation between pollutant levels and traffic volume. Note: Noise levels have been converted to Pascals to perform linear computations.**

		06-11-2025		**06-12-2025**	**06-17-2025**		
		Morning	**Afternoon**	**Midday**	**Morning**	**Afternoon**	**Average**
LA_{eq}	R^2	0.002	0.004	0.037	0.043	0.183	0.054
	p-value	0.901	0.845	0.547	0.518	0.165	
$PM_{2.5}$	R^2	0.874	0.002	0.743	0.643	0.398	0.532
	p-value	0.000	0.899	0.000	0.002	0.028	
PNC	R^2	0.063	0.138	0.002	0.119	0.133	0.091
	p-value	0.431	0.235	0.888	0.272	0.243	

3.2 LA_{eq} Results

LA_{eq} levels were consistently elevated across all locations when QED was open to traffic, as illustrated in Figure 6. L7, directly adjacent to QED, reported the maximum LA_{eq} mean of 64.50 dBA and showed high variability. In contrast, L2, separated by vegetation and located further away from QED, reported the minimum LA_{eq} mean of 53.75 dBA and showed low variability.

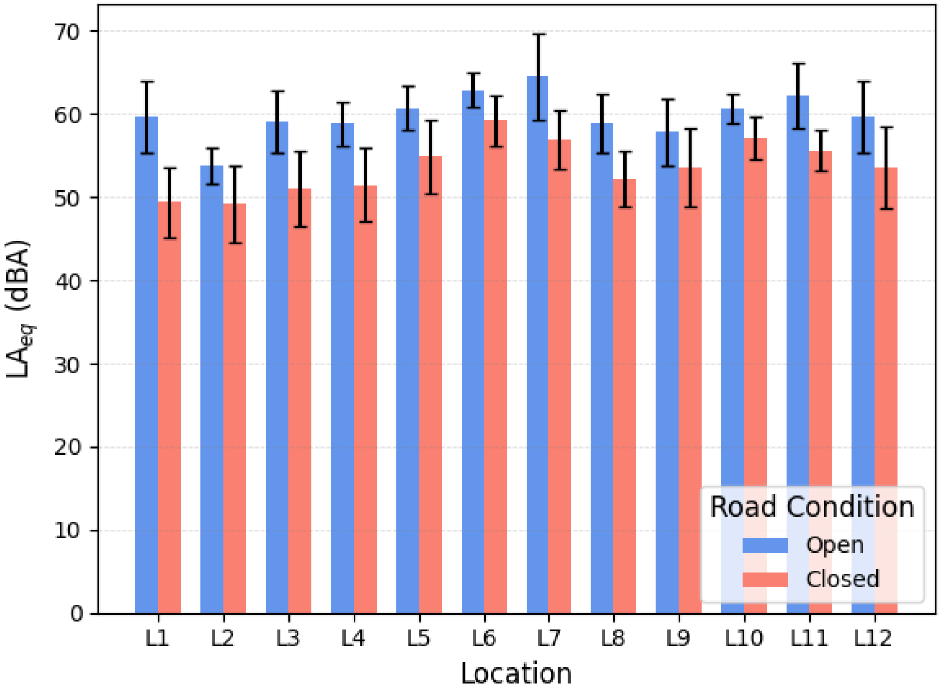

Figure 6: LAeq (dBA) level means and standard deviations for open and closed road conditions across all fixed monitoring locations.

Table 4 presents a statistical summary of LA_{eq} results, showing significantly higher levels when QED is open to vehicles, concluded by a one-sided t-test ($p < 0.01$). Pedestrians experience a 6.23 dBA increase on the MUP when QED is open, with a minimum increase of 6.01 dBA indicated by a 95% confidence interval. Though results show maximum exposure exceeded 85 dBA, only 1.2% of measurements exceeded 70 dBA, while 29.4% exceeded 60 dBA (Table 5).

Table 4: Statistical analysis of LAeq (dBA) level differences for open and closed road conditions (L1-L12).

	Population Statistics				One-sided t-test for Difference of Means (Open - Closed)			
	Mean (dBA)	Standard Deviation (dBA)	Maximum (dBA)	Minimum (dBA)	Mean Difference (dBA)	t	p-value	95% confidence interval (Open - Closed) (dBA)
Open	59.91	4.41	85.83	47.31	6.23	56.0	< 0.01	[6.01, 6.45]
Closed	53.68	5.01	75.75	35.96				

Table 5: Percentage of LAeq measurements (dBA) exceeded above various thresholds.

LA_{eq} threshold (dBA)	60	62.5	65	67.5	70	72.5
Percentage of measurements above limit	29.4%	14.8%	6.0%	2.6%	1.2%	0.3%

3.3 PM$_{2.5}$ Results

3.3.1 Background-Adjusted PM$_{2.5}$ Concentrations

Figure 7 displays background-adjusted PM$_{2.5}$ mass concentrations across all fixed monitoring locations, highlighting traffic-associated pollutant levels. Recall that the details on the background level adjustment are explained in Section 2.2.2. The maximum relative PM$_{2.5}$ concentration was observed at L1, at 2.31 µg/m^3, with spikes occurring at L2, L4, and L5. A steady decrease in pollutant level was observed from L6 onwards, with a minimum PM$_{2.5}$ concentration of -0.25 µg/m^3 observed at L8. Background-adjusted PM$_{2.5}$ trends are related to measured traffic volume, which similarly decreased after L5. Though concentrations are typically reduced when QED is closed to traffic, L9-L12 closed concentrations are greater than their open counterparts. Distributions for open and closed conditions are detailed in Figure 8.

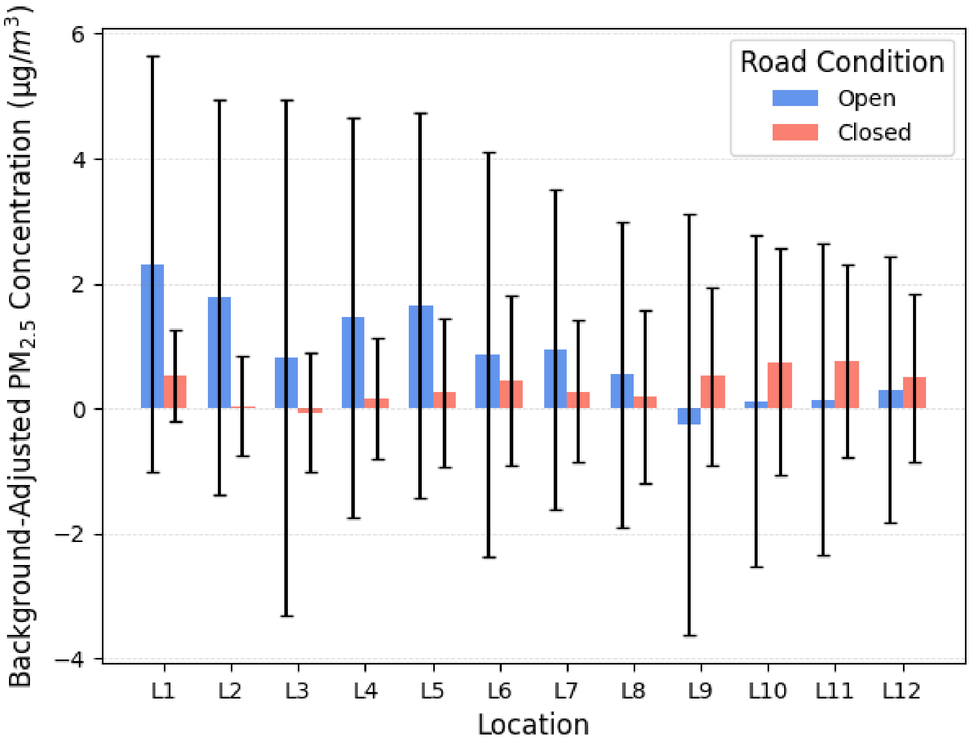

Figure 7: Background-adjusted PM2.5 mass concentration (µg/m^3) means and standard deviations for open and closed road conditions across all fixed monitoring locations.

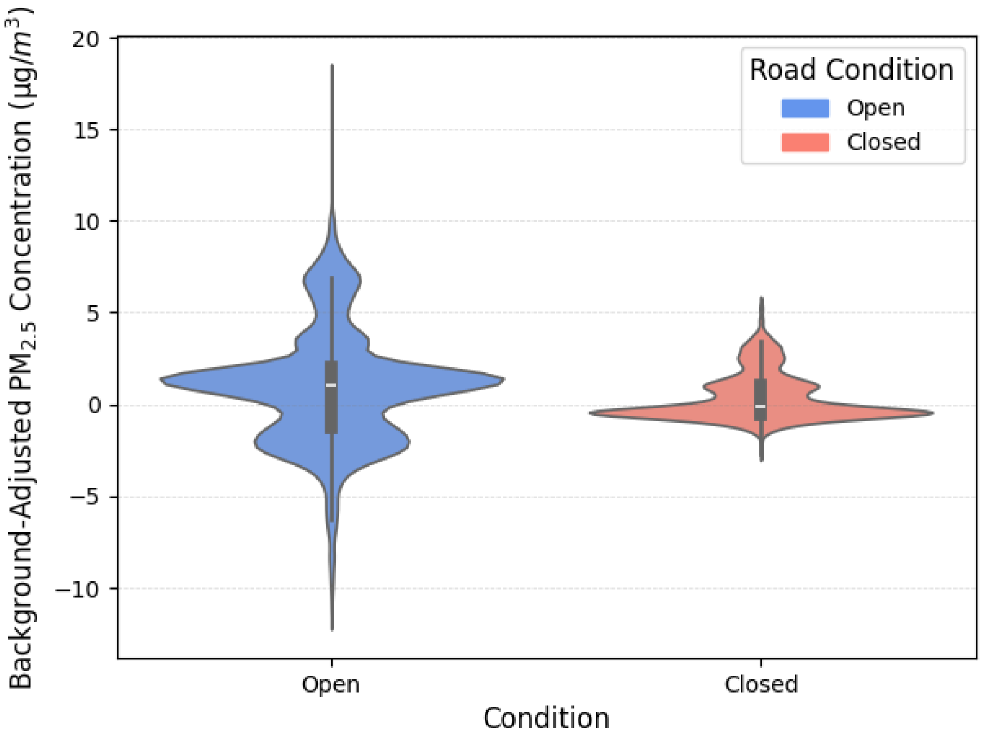

Figure 8: **Comparison of background-adjusted PM2.5 mass concentration (µg/m³) distributions for open and closed road conditions.**

Relative $PM_{2.5}$ concentrations adjusted by background levels were significantly greater when QED was open to traffic, concluded by a t-test ($p < 0.01$), shown in Table 6. A 0.52 µg/m³ increase, relative to background levels, in $PM_{2.5}$ pedestrian exposure was found when considering all fixed monitoring locations along QED. Table 7 presents the same statistical analysis omitting measurements taken at L9-L12, where closed levels observed to be greater. In this analysis, a 1.06 µg/m³ $PM_{2.5}$ concentration increase relative to background levels was found. Background $PM_{2.5}$ concentration means and standard deviations are shown in Table 8. It should be noted that locations L9-L12 showed lower traffic levels compared to L1-L8, as per Figure 6, with more nearby vegetation.

Table 6: **Statistical analysis of background-adjusted PM2.5 mass concentration (µg/m³) differences for open and closed road conditions (L1-L12).**

	Population Statistics				**One-sided t-test for Difference of Means (Open - Closed)**			
	Mean (µg/m³)	**Standard Deviation (µg/m³)**	**Maximum (µg/m³)**	**Minimum (µg/m³)**	**Mean Difference (µg/m³)**	**t**	**p-value**	**95% confidence interval (Open -**

								Closed) (µg/m³)
Open	0.89	3.12	17.64	-11.39	0.52	20.8	<0.01	[0.47, 0.57]
Closed	0.36	1.28	5.48	-2.70				

Table 7: **Statistical analysis of background-adjusted PM2.5 mass concentration (µg/m³) differences for open and closed road conditions (L1-L8).**

	Population Statistics				One-sided t-test for Difference of Means (Open - Closed)			
	Mean (µg/m³)	Standard Deviation (µg/m³)	Maximum (µg/m³)	Minimum (µg/m³)	Mean Difference (µg/m³)	t	p-value	95% confidence interval (Open - Closed) (µg/m³)
Open	1.29	3.23	17.64	-11.39	1.06	34.1	< 0.01	[1.00, 1.12]
Closed	0.23	1.11	5.46	-2.70				

Table 8: **Background PM2.5 mass concentration (µg/m³) means and standard deviations for all measurement days.**

	Open			Closed		
	06-11-2025	06-12-2025	06-17-2025	06-21-2025	06-29-2025	07-05-2025
Mean (µg/m³)	14.42	2.87	1.18	5.21	1.90	4.78
Standard deviation (µg/m³)	0.68	2.45	0.20	0.92	0.19	0.31

3.3.2 Absolute PM$_{2.5}$ Concentrations

PM$_{2.5}$ mass concentration exposure levels from all sources (without background-adjustment) were much greater than traffic-associated levels, shown in Figure 9. Unlike background-adjusted concentrations, open levels remained consistently greater for all monitoring sites. A statistical summary of the absolute PM$_{2.5}$ concentrations (Table 9) reports that pedestrians are exposed to a mean concentration of 7.70 µg/m³ when the road is open compared to 4.08 µg/m³ when closed, resulting in a 3.62 µg/m³ PM$_{2.5}$ exposure increase when QED is open to traffic.

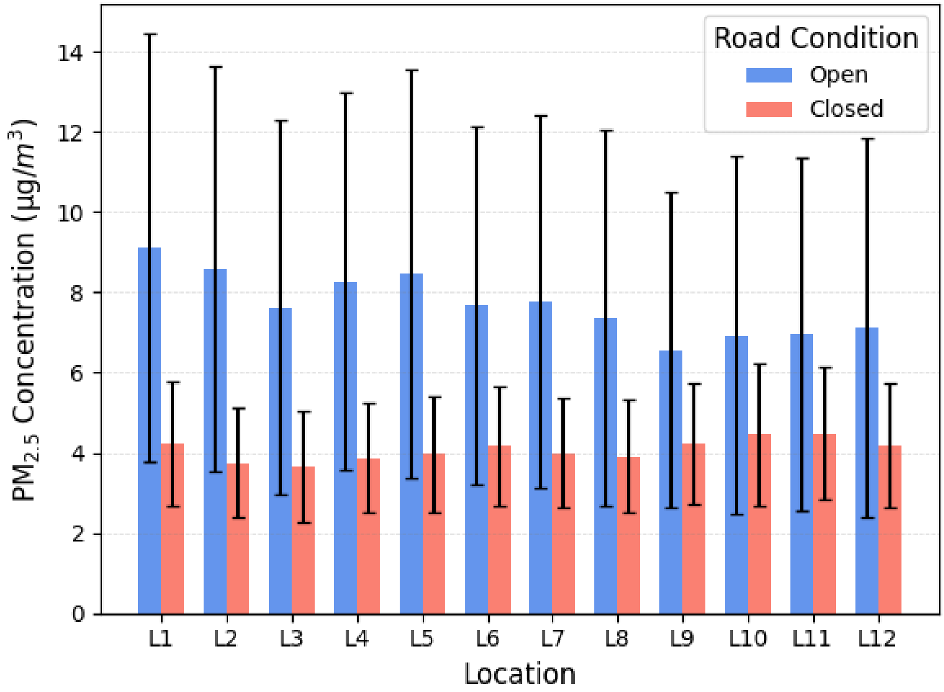

Figure 9: **Absolute PM2.5 mass concentration (μg/m^3) means and standard deviations for open and closed road conditions across all fixed monitoring locations.**

Table 9: **Statistical analysis of absolute PM2.5 mass concentration (μg/m3) differences for open and closed road conditions (L1-L12).**

	Population Statistics				**One-sided t-test for Difference of Means (Open - Closed)**			
	Mean (μg/m^3)	**Standard Deviation (μg/m^3)**	**Maximum (μg/m^3)**	**Minimum (μg/m^3)**	**Mean Difference (μg/m^3)**	**t**	**p-value**	**95% confidence interval (Open - Closed) (μg/m^3)**
Open	7.70	4.75	18.82	1.39	3.62	97.5	< 0.01	[3.55, 3.70
Closed	4.08	1.53	10.24	0.88				

A comparison of traffic contribution for absolute PM$_{2.5}$ exposure concentrations between spatial distributions L1-L8 and L1-L12 is provided in Table 10. Results suggest that traffic accounts for 14.4% of the PM$_{2.5}$ concentration increase when QED is open when considering all fixed monitoring locations, and 25.5% when only considering locations L1-L8. All mean differences reported in Table 10 are statistically significant by t-test ($p < 0.01$).

Table 10: Comparison of traffic emission contribution to absolute PM2.5 mass concentration (μg/m3) levels for spatial distributions L1-L8 and L1-L12.

	Background-adjusted $PM_{2.5}$ concentration mean difference (μg/m^3)	**Absolute $PM_{2.5}$ concentration mean difference (μg/m^3)**	**Traffic-attributed percentage for absolute levels**
L1-L12	0.52	3.62	14.4%
L1-L8	1.06	4.16	25.5%

3.4 UFP Results

In comparison, UFP concentrations showed sporadic and unpredictable behavior. PNC increases when QED is open to traffic at only three of 12 monitoring sites (L5, L6, L8), displayed in Figure 10. Locations L5 and L6 proved to be the only locations which showed substantial increases in PNC when QED was open to traffic, with mean differences of 3346.89 #/cm^3 and 3798.15 #/cm^3 respectively. Exceptionally large variability was observed for L1 (closed), and L5, L6, and L7 (open), where substantial concentrations were observed. Figure 11 compares distributions between open and closed measurements. While mean concentrations remain in the thousands, maximum recorded concentrations were much greater.

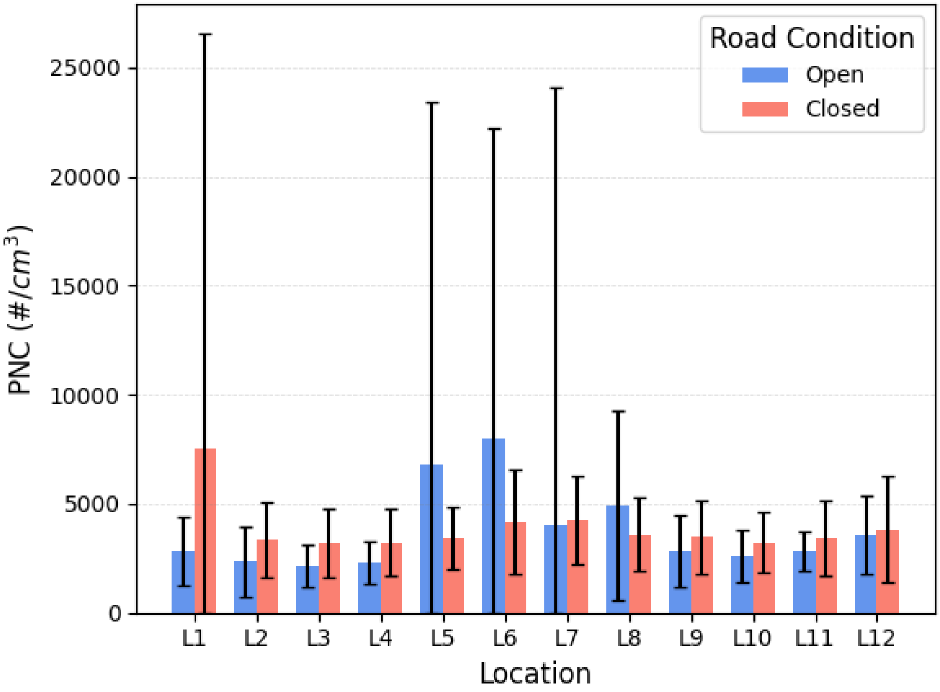

Figure 10: UFP number concentration (#/cm^3) means and standard deviations for open and closed road conditions across all fixed monitoring locations for all measured days.

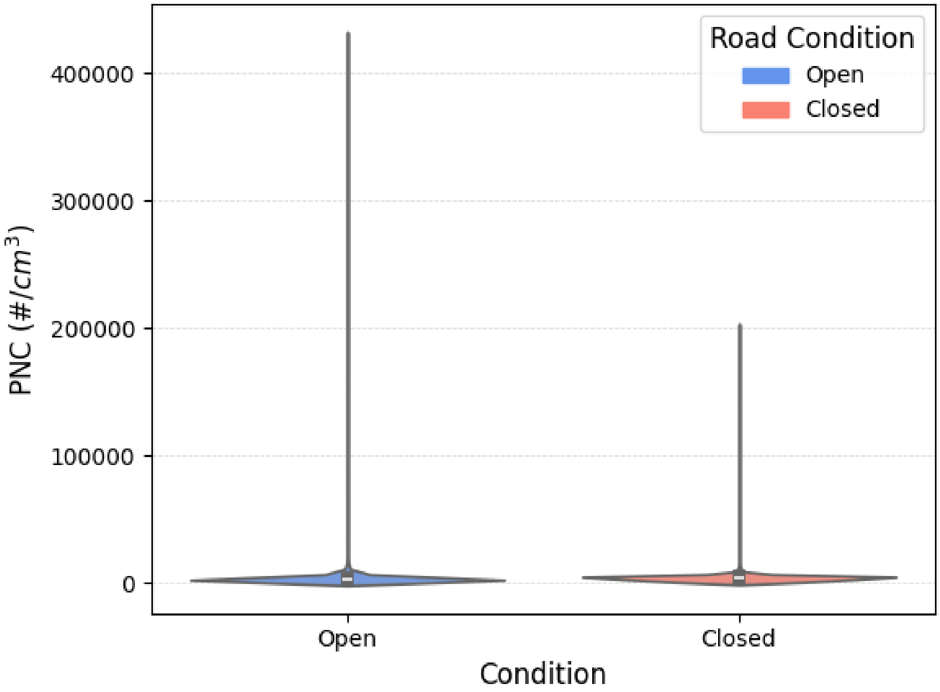

Figure 11: Comparison of UFP number concentration (#/cm^3) distributions for open and closed road conditions.

Due to the highly skewed nature of UFP concentrations observed, non-parametric tests were used to test for PNC differences between open and closed conditions. A statistical analysis of these results show that pedestrians experience an estimated median decrease of 743.0 #/cm^3 when QED is open to traffic (

Table 11), with sufficient evidence to conclude that the open road condition has elevated UFP concentrations by Mann-Whitney U test ($p < 0.01$).

Table 11: Statistical analysis of PNC (#/cm^3) differences for open and closed road conditions.

	Population Statistics				One-sided Mann-Whitney U test (Open vs. Closed)			
	Mean (#/cm^3)	Standard Deviation (#/cm^3)	Maximum (#/cm^3)	Minimum (#/cm^3)	U	p-value	Hodges-Lehmann Pseudo-median Difference (Open - Closed)	95% bootstrap confidence interval (Open - Closed) (#/cm^3)
Open	3769.21	8918.05	430274	323	126513652.0	< 0.01	-743.0	[-1284.5, -1149.5]
Closed	3897.31	5878.85	201827	93				

A summary of meteorological conditions experienced during individual test periods is provided in the Appendix (Table A3). Since weather conditions heavily fluctuated over these periods, an analysis was conducted across data with similar meteorology. For this investigation, measurements from the mornings of 06-17-2025 and 06-29-2025 to represent open and closed road condition populations, respectively. On both days, wind speeds were very similar at 3.7 m/s and 3.8 m/s respectively, with low variations in temperature and relative humidity. Consistent with LA_{eq} and $PM_{2.5}$ findings, significant differences between open and closed levels at all fixed monitoring locations were observed (Figure 12). While UFPs are particularly sensitive to weather, emission sources are notably more dominant than meteorological influences for $PM_{2.5}$ (Zhao et al., 2025).

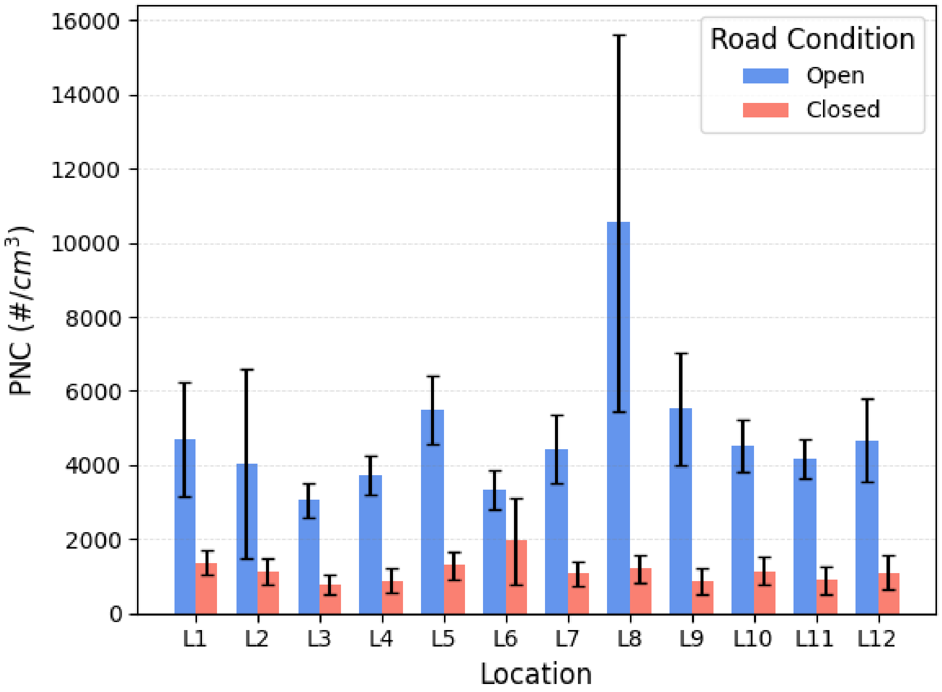

Figure 12: **UFP number concentration (#/cm^3) means and standard deviations for open and closed road conditions across all fixed monitoring locations and similar meteorological conditions.**

Table 12 shows a comparison across similar meteorology, showing sufficient evidence to conclude open concentrations are significantly greater than closed concentrations by Mann-Whitney U test ($p < 0.01$), with a Hodges-Lehmann estimated median difference of 3103.0 #/cm^3. Note that 95% bootstrap confidence intervals for PNC differences between open and closed conditions were computed using 20000 bootstrap resamples of the data. A notable reduction in standard deviation was also observed when weather conditions were controlled for, suggesting that UFP measurements across inconsistent weather conditions increases variability.

Table 12: **Statistical analysis of PNC (#/cm^3) differences for open and closed road conditions across similar meteorological conditions.**

	Population Statistics				One-sided Mann-Whitney U test (Open vs. Closed)			
	Mean (#/cm^3)	Standard Deviatio	Maximum (#/cm^3)	Minimum (#/cm^3)	U	p-value	Hodges-Lehmann Pseudo-median	95% bootstrap confidence interval

		n (#/cm^3)					Difference (Open - Closed)	(Open - Closed) (#/cm^3)
Open	4848.06	2629.76	29784	1680	12886064.5	< 0.01	3103.0	[3038.0, 3142.5]
Closed	1144.11	564.03	6989	93				

3.5 Combined Air and Noise Pollution Analysis

For this study, the Air-Noise Pollutant Reduction Index (King et al., 2016, King et al., 2009) was used to assess the combined pollution reduction affiliated with NCC's car-free day policy. Percent reductions for noise and air pollution were computed by aggregating the constituent percent reductions of noise pollution metrics (LA$_{eq}$) and air pollution metrics (PM$_{2.5}$, PNC) respectively. PM$_{2.5}$ background-adjusted concentrations and PNC levels during similar meteorology were employed to isolate traffic-based pollution. Results for pollutants and overall percent reductions are shown in Table 13. A decrease of 59.6% was observed when QED was closed to vehicles, suggesting that the presence of traffic significantly raises noise and air pollution levels.

Table 13: Pollutant and overall percentage reductions of noise and air pollutants. Note: Noise levels have been converted to Pascals to compute percent reduction.

		Open	Closed	% Decrease	% Decrease
Noise	LA$_{eq}$ (Pa)	0.01979	0.00966	51.2%	51.2%
Air	PM$_{2.5}$ (µg/m^3)	0.89	0.36	59.6%	68.0%
	PNC (#/cm^3)	4848.06	1144.11	76.4%	
ANP$_r$					59.6%

4 Discussion

4.1 Pollutant Exposure and Health Implications

4.1.1 LA$_{eq}$ Levels

Significant noise and air pollutant level increases were observed while QED was open to traffic when compared to closed, posing potential adverse health effects. Based on the results of this study, pedestrians experience a mean LA$_{eq}$ exposure level of 59.91 dBA - a 6.23 dBA increase from levels observed during weekend road closures. A 10 dBA increase represents a perceived increase twice as loud, indicating that a 6.23 dBA increase is significant. Though these levels do not pose significant risk of cardiovascular impacts or hearing loss (World Health Organization, 1999, Canada, 2024), they may cause annoyance and discomfort (World Health Organization, 1999), especially to vulnerable groups who are more sensitive to noise, such as children, the elderly, or those with auditory disabilities (Herrmann et al., 2018). Traffic noise may also affect pedestrians' ability to converse or exercise. This issue extends to residential areas near QED, where residents are exposed to such levels for longer periods of time. Moreover, LA_{eq} levels showed weak correlations with traffic volume, suggesting that even low traffic or passing vehicles can dramatically increase short-term noise exposure.

4.1.2 $PM_{2.5}$ Levels

Comparatively, $PM_{2.5}$ levels showed strong correlations with traffic volume, indicating that the pollutant reliably measures traffic-associated air pollution. Though an overall background-relative $PM_{2.5}$ concentration increase during vehicle presence was observed, levels during the road's closure were consistently greater between monitoring locations L9-L12. Traffic volume also accounted for a larger proportion of the absolute concentration increase observed between sites L1-L8 (25.5%) as compared to L1-L12 (14.4%). These findings suggest that pollution is not evenly distributed throughout the QED corridor. Lower observed concentrations between locations L9-L12 likely reflects the reduced traffic volumes observed and may indicate traffic displacement resulting from closures. Weekday absolute exposure means were also greater than WHO's recommended $PM_{2.5}$ annual average exposure of less than 5 $\mu g/m^3$ (World Health Organization, 2021). As such, frequent use of the MUP on days when QED is open to traffic could result in long-term health risks. For context, based on speeds of 5 km/h and 20 km/h for walking and cycling, exposure time just along this full stretch of road would be approximately 26 mins and 7 minutes, respectively. Additionally, the benefits of active transportation likely outweigh the consequences of exposure during the typical levels measured in this study.

4.1.3 UFP Levels

In contrast, UFP concentrations were greater during closures when considering all collected data. Measurement days during closures had consistently higher temperatures, lower relative humidities, and reduced wind speeds, all of which are known to significantly promote PNC production (Lin et al., 2025). A comparison of open and closed levels on measurements over similar weather conditions showed that QED traffic significantly increases pollutant concentration. These findings suggest that meteorology significantly influences measured UFP concentration, which is further indicated through the low linear correlations with traffic flow found. As such, though traffic volume increases PNC levels, closures do not guarantee a reduction in levels. It should also be noted that this comparison was conducted using data taken over similar meteorological conditions, and therefore comprised a smaller sample size. Furthermore, concentration hotspots observed at L5, L6, L7, and L8, located close to QED, suggest that distance from the source significantly dictates exposure levels. Such findings are also reaffirmed in literature (Abdillah et al., 2024, Xu et al., 2020, Sioutas et al., 2005, Kwon et al., 2020).

Guidelines and exposure limits are currently nonexistent for UFPs. However, a paper published by the European Federation of Clean Air and Environmental Protection Associations (EFCA) shows that the observed UFP concentrations are much greater than typical clean environment levels of < 1000 #/cm^3 (Cassee et al., 2019). Based on the comparison between similar meteorology, WHO's current Good Practice Statements report approximately low 24-hour mean exposure recommendation levels of 1000 #/cm^3 during closed days. In comparison, moderate levels were observed during open days for 24-hour PNC concentrations, considerably lower than the high PNC thresholds of 10000 #/cm^3 (24-hour) and 20000 #/cm^3 (1-hour) (World Health Organization, 2021).

4.1.4 Combined Pollutant Analysis Comparisons

The ANP$_r$ combined index value is also greater than results found in previous uses of the metric. (King et al., 2016) reports 36.5% when comparing New York City road levels to the High Line levels, while (King et al., 2009) reports an ANP$_r$ percent reduction of 53% when comparing levels between the road and nearby boardwalk in Dublin, Ireland. Findings from this paper show a greater decrease (60%) in overall pollution levels than both studies but are relatively consistent with past applications of the metric. Differences in pollution reductions between studies is expected due to the difference in geographical contexts and methods.

4.2 Policy Evaluation and Considerations

This paper's findings show Ottawa's car-free days effectively reduces noise and air pollution levels along the MUP, creating a safer space for pedestrians and cyclists. This paper's findings show Ottawa's car-free days effectively reduces noise and air pollution levels along the MUP, creating a safer space for pedestrians and cyclists (Feng et al., 2016, Kiesewetter et al., 2015).

Planners can also implement strategies to further reduce exposure to the MUP's users. Roadside barriers are a common practice in pedestrian-friendly road design and can be used to reduce both noise and air pollution levels (Hagler et al., 2011, Agency, 2017). More recent studies have examined the impact of vegetative barriers. Vegetation absorbs air pollutants and substantially lowers particulate matter and UFP concentrations. Findings show that smaller particles are reduced more effectively (Moronta-Sabad et al., 2025, Tong et al., 2016). Therefore, such barriers may prove useful in reducing UFP and PM$_{2.5}$ concentrations near pollutant hotspots or MUP areas adjacent to the road (ex. L5, L7). We note that this study did not explicitly control or deeply investigate the impact of trees and other vegetation.

Although car-free days lowers pollution on the road, studies have found that policies for adjacent roads are often ignored. The impacts of car-free day policies are highly variable and contingent on the frequency, duration, and geographic scope at which the policy is implemented. While most literature assessing pollution impacts and car-free day policies show reductions in noise and air pollution, reinforcing findings presented in this paper, some studies reported no change in levels (Glazener et al., 2022). Moreover, traffic congestion is typically displaced, unintentionally raising pollution levels in nearby areas (Glazener et al., 2022). $PM_{2.5}$ concentration findings presented in this paper point to weekend traffic displacement in the Golden Triangle area, between sites L9 and L12. To fully evaluate the efficacy of the NCC's policy at a larger urban context, further research should be conducted to determine the scale of traffic displacement and pollution increases in nearby areas. However, displacing cars away from major active transportation arteries likely still has a net benefit.

4.3 Limitations and Recommendations

4.3.1 External Factors and Uncertainties

This study sought to evaluate and compare noise and air pollution levels on QED across present and absent traffic volumes. Results may have been impacted by service work occurring near monitoring locations. A total of four instances of these events were observed during data collection, consisting of construction and lawn mowing. In contrast, no activity was observed during days when QED was closed. During these instances, the researchers moved slightly further away from monitoring sites. Air pollutant concentrations were still likely impacted due to the construction activity (Agency, 1993).

4.3.2 Mobile Measurements

The measurement approach on the MUP, which has varying distances to the road, has the benefit of revealing exposure of pollution to users. However, the consequence is that that variable distance from the road and vegetation level add variability across the 12 sampling locations. Set times were adhered to throughout the data collection period, limiting potential temporal fluctuations which would be otherwise observed. Future work should more precisely measure vegetation levels to explore and quantify its effect on pollution exposure.

Many studies have advocated for and implemented mobile measurements in addition to spot checks, helping identify detailed spatial trends overlooked with fixed monitoring (King et al., 2016, Chen et al., 2022, Van Den Bossche et al., 2015). Although the method was considered for this study, a mixed-method evaluation would have significantly increased temporal scope. For these reasons, a larger temporal scope and a mixed-method assessment involving mobile measurements is recommended for future studies quantifying pollution exposure in one area.

4.3.3 Improving Meteorological Control

Local wind gusts, typically experienced in urban environments, may reduce air pollutant concentrations and conversely increase noise levels. Future studies should consider the use of mobile wind measurements to filter out any resulting outlier levels observed. In addition, UFP results show a high degree of variability due to meteorology, increasing questionability of the observed measurements. Moreover, concentrations were taken over a short time frame and sampling intervals, which can be attributed to the inconsistent results observed in this paper. Given the sensitivity of UFPs, concentrations should be measured over a longer period and more days to reduce variability from weather and external variables. While meteorology can affect $PM_{2.5}$ and noise levels, the effects were not assessed to be significant and were not controlled or measured in this experiment.

4.3.4 UFP Measurement in Urban Contexts

Additional UFP sources were also not considered in this study. Areas on the QED segment are near many neighboring streets with typically high traffic volumes (i.e. commercial streets, a 6-lane highway, etc.). Although UFP measurements can be used to distinguish vehicle-emitted pollution from other sources, concentrations from adjacent roads and their corresponding traffic volumes were not measured or accounted for. Though likely only affecting locations L5 and L6, near the QED/Elgin/Hawthorne intersection, mean differences observed between open and closed road conditions may be slightly inaccurate. Recent studies have explored source apportionment modelling using Positive Matrix Factorization (Friend et al., 2012, Rivas et al., 2020). For future research seeking to quantify pollution effects in an area from a singular source, adjustment for other nearby UFP sources is strongly recommended to ensure accuracy in results.

5 Conclusion

This paper compared noise and air pollution levels along Queen Elizabeth Driveway's multi-use pathway when the road was open and closed to traffic. Measurements of LA_{eq}, $PM_{2.5}$ mass concentration, and UFP number concentration were taken across 12 fixed sampling locations three times of day (each taking the average of 300 measurements over five minutes), over a total of five days for each road condition.

Road closures were found to significantly improve noise and air quality for users of the multi-use pathway. Noise levels observed during traffic may cause annoyance and discomfort to pedestrians, especially for vulnerable or sensitive groups. During closures, a 14.4% decrease in traffic-associated $PM_{2.5}$ concentration was observed along the pathway, considering all sampling locations, with a total decrease of 59.6% from all pollution sources. $PM_{2.5}$ exposure concentrations were greater than WHO recommended guidelines, posing significant risk for frequent users. Highly variable UFP concentrations were found with high sensitivity to meteorology, with road closures decreasing PNC levels by 76.4%. Levels with vehicle traffic were significantly greater than typical clean environment thresholds, suggesting adverse health implications. An air-noise pollution index used in previous literature estimates that pedestrians and cyclists experience an approximate 60% reduction in pollution levels during road closures.

The literature frequently states that no air pollution threshold is considered safe. Therefore, this paper's findings strongly support car-free day policies and advocate for closures in Ottawa, for the purpose of increasing active transportation and providing a healthier and more desirable environment for users.

For future studies examining impacts from such initiatives, it is vital to investigate adverse effects occurring in nearby areas due to potentially induced traffic displacement. Studies should aim to capture data over larger temporal scopes, particularly for ultrafine particle analysis. A mixed-method analysis incorporating mobile measurements is also recommended for similar urban pollution studies to improve data richness and validity.

CRediT Authorship Contribution Statement

Kabir Patel: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review and editing. **William O'Brien:** Conceptualization, Project administration, Supervision, Writing – review and editing. **Farès Chéraitia:** Data curation, Investigation, Writing – review and editing. **Hugo Ratelier-Parchet:** Data curation, Investigation, Writing – review and editing. **Ryan Kulka:** Conceptualization, Investigation, Writing – review and editing.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of Generative AI Use

The authors declare that generative AI tools were not used throughout the research process.

Data Availability

Raw data is available from the corresponding author upon reasonable request.

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6 Appendix

Table A1: Sampling location GPS coordinates estimated using Google Maps.

Location No.	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**
Coordinates	45.40395°, -75.68193°	45.4055°, -75.68158°	45.40731°, -75.68183°	45.4095°, -75.6823°	45.41077°, -75.68383°	45.4118°, -75.68376°
Location No.	**L7**	**L8**	**L9**	**L10**	**L11**	**L12**
Coordinates	45.41371°, -75.68362°	45.41533°, -75.68264°	45.41679°, -75.68174°	45.41851°, -75.68091°	45.41955°, -75.68286°	45.42029°, -75.68486°

Table A2: Instruments used for Data Collection

Instrument	**Pollutant classification**	**Metric**	**Measurement ranges**	**Precision**	**Accuracy**
Danoplus Digital Sound Decibel Meter	Noise	A-weighted decibels (dBA)	30-130 dBA		± 1.5 dBA
Sensirion SPS30	Air	PM$_{2.5}$ mass concentration (μg/m^3)	0-1000 μg/m^3	± (5 μg/m^3 + 5% m.v.) for 0-100 μg/m^3	

				± 10% m.v. for 100-1000 μg/m^3	
Naneos Partector 2	Air	UFP number concentration (#/cm^3)	0-10^6 #/cm^3		± 30% (± 1000 #/cm^3)

Note: “Measured value” is represented by m.v.

Table A3: Meteorological conditions recorded at Ottawa CDA RCS weather station during data collection periods.

Date	Road condition	Measurement times of day	Temperature (°C)	Relative humidity (%)	Precipitation (mm)	Wind speed (m/s)	Wind direction (°CCW from N)
06/11/2025	Open	Morning	18.0	66.8	0.0	4.4	275.0
		Afternoon	23.6	51.5	0.0	6.0	227.5
06/12/2025	Open	Midday	17.7	55.8	0.0	7.3	310.1
06/17/2025	**Open**	**Morning**	**20.4**	**80.5**	**0.0**	**3.7**	**197.4**
		Afternoon	23.6	56.8	0.0	5.6	227.5
06/21/2025	Closed	Midday	24.2	43.0	0.0	3.3	190.0
06/29/2025	**Closed**	**Midday**	**18.8**	**73.3**	**0.0**	**3.8**	**287.5**
		Afternoon	25.1	54.0	0.0	3.3	267.5
07/05/2025	Closed	Morning	21.2	62.3	0.0	3.2	222.5
		Afternoon	27.7	47.0	0.0	6.2	212.5