# LOCAL MONITORING OF TRAFFIC-RELATED AIR POLLUTION AROUND SCHOOLS IN SOUTH EAST LONDON, UK

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ABSTRACT

Outdoor air quality (OAQ) presents a significant challenge for public health globally, especially in urban areas, with road traffic acting as the primary contributor to air pollution. Several studies have documented the antagonistic relation between traffic-related air pollution (TRAP) and the impact on health, especially to vulnerable members of the population, particularly young pupils. Generally, TRAP could restrict the ability of schoolchildren to learn and, more importantly, cause detrimental respiratory disease in their later life. But little is known about the specific exposure of children commuting to school and during the school day and the impact this may have on their overall exposure to pollution at a crucial time in their development. This project has set out to examine the air quality across primary schools in south east London (due to their massively increasing amount of redevelopment and population) and assesses the variability of data found based on their geographic location and surroundings. Nitrogen dioxide ($NO_2$) and PM contaminants ($PM_{2.5}$ and $PM_{10}$) were collected with diffusion tubes and portable monitoring equipment for eight schools across three local areas: Greenwich, Lewisham and Tower Hamlets. This study first examines the morphological features of the schools surrounding), then utilises two different methods to capture pollutant data. Moreover, comparing the obtained results with existing data from the London Air Quality Network (LAQN) to understand the differences in air quality pre- and post-pandemic. Most studies in this field have unfortunately neglected human exposure to pollutants and calculated referring to values from fixed monitoring stations. This paper introduces an alternative approach by calculating human exposure to air pollution from real-time data obtained when commuting around selected schools (driving routes and field walking).

*Keywords: geographical feature, human exposure, schools, traffic related air pollution.*

## 1 INTRODUCTION

The phenomenal increase in urbanisation in the past few decades, has consequently enlarged the population and the need for land transportation. However, ample evidence has pointed out that land transport is the main contributor to the elevated of air pollution in urban areas [1]. Pollution arising from the emissions of motor vehicles and road transportation (fossil fuel combustion) is typically referred to as traffic-related air pollution (TRAP) [2]. This type of air pollution can vastly increase mortality from stroke or heart disease and promote the development of cardiovascular diseases and respiratory illnesses, causing seven million people worldwide every year to die from this and 90% of the population to breathe air that exceeds the World Health Organization guideline limits containing high levels of pollutants [3].

Ten thousand pupils at more than 800 education institutions in London are exposed to extremely high levels of $NO_2$, well exceeding the EU legal limit of 40 $\mu g/m^3$ during school operating hours [4]. Among these institutions, over 400 primary schools with pupils under the age of 11 were designated, and 25% of schools were even found to be located in areas with dangerously high levels of air pollution [7]. Excessive inhalation of TRAP can cause a range of health issues. Short-term exposure can lead to the aggravation of existing respiratory problems. Long-term exposure could be linked to a greater susceptibility to infections of

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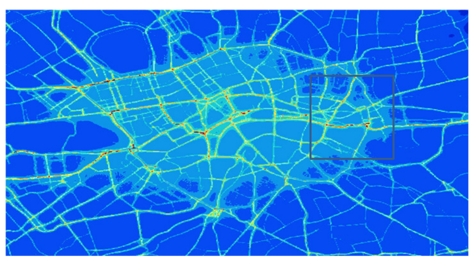
respiratory disease [5]. A growing number of studies have shown an association between TRAP with the exacerbation of respiratory (asthma) and allergic symptoms in children [6]. Young pupils are at an exceptionally high risk of exposure to air pollution. As their organs (lungs) are still developing, they are more at risk [7].

Ambient concentrations of many air pollutants are elevated near roadways. This has particularly caught scientists' attention to school children living in urban areas, as a number of them are living near a congested roadway, and required to commute and study in a school near such road. Concentrations of pollutant contaminants that occur in microenvironments, such as inside street canyons or buildings or in-vehicle, have been shown to be higher than those measured at fixed-site monitors. Background concentration from such street monitoring stations might not accurately represent the actual distribution in the street, due to the sensitivity of airflow to local street geometry [8], therefore, localised monitoring is required. Although multiple studies have monitored personal exposure to air pollutants in vehicles and during commutes by foot, most of them focused on carbon monoxide, particulate matter and volatile organic compounds [9]–[11]. While the personal exposure to nitrogen dioxide remains largely unexplored. Periods for children commuting from home to schools often coincide with traffic congestion peaks, studies have found these would result in the commuters receiving a large proportion of their daily TRAP exposures, despite the short commuting time [11]. An exposure model conducted for in-vehicle commutes on a Los Angeles school bus route from Behrentz et al. [12] and Sabin et al. [13], has determined that the school bus commute contributed 10% of the total daily $NO_2$ exposure of schoolchildren, and 15% of total daily $PM_{2.5}$ exposures.

Air pollution in London has improved in recent years as a result of policies reducing emissions, nevertheless, the most recently updated Annual Pollution Map from London Air Quality Network [14] (Fig. 1(a)) has shown significant exceedances of the annual mean of $NO_2$ contaminants, on main roads and all around them. With south east London benefitting from regeneration/ redevelopment over the last decade, the population and the ongoing pressure on road traffic in the area have highly been increased. As such, south east London has been found to consist of the two most traffic-congested routes, the Blackwall Tunnel and the A2 routes. Mainly, due to the lack of routes selection for travelling to central London. Especially, the Blackwall Tunnel, where drivers travelling across are facing daily queues with average delays of 20 minutes.

(a)



(b)


(c)

Figure 1: (a) Annual pollution map 2016; (b) Projected pollution map 2025; and (c) $NO_2$ index.

The SARS-CoV-2 (COVID-19) pandemic has ravaged the UK since late January 2020. The national lockdown alongside the public behaviours shifting towards work from home has significantly lowered vehicle traffic on roads in the UK. Motor vehicle usage nationally has reduced on average by 48%, meanwhile, the mean $NO_2$ concentrations have significantly reduced by 32% to 36% compared to the average of the previous seven years (2013–2019) [15]. This study aims to examine the localised exposure to TRAP around a selection of primary schools in south east London, in relation to the urban geometry, geographical features, and road configuration around these schools. The study was carried out in the context of a nationwide $NO_2$ reduction as a consequence of the COVID-19 pandemic, therefore this data is compared against the projected $NO_2$ annual map 2025 (2018; Fig. 1(b)), to highlight the benefits of a local reduction in emissions to reducing the actual exposures of schoolchildren.

## 2 METHODOLOGY

Nitrogen dioxide ($NO_2$) and PM contaminants ($PM_{2.5}$ and $PM_{10}$) were assessed in this study across eight schools in south east London. These schools are located in three main local areas across south east London: Greenwich, Lewisham and Tower Hamlets. The characteristics that schools are located in different areas allow them to be divided into batches when comparing results to understand how geographical factors can induce differences in pollution data. The overview of selected schools is shown in Fig. 2, with yellow placemarks representing their locations.

(a) (b)

Figure 2: Overview for selection of schools. (a) Whole of London; and (b) SE London.

The selection of schools is presented in Table 1. These schools are selected based on research completed in 2017 commissioned by the Mayor of London [7]. This research has ranked 3,261 educational institutions (schools, nurseries, colleges and universities) in London (1 being the school with the cleanest air surrounded and 3,261 being the school suffering from the worst air pollution). Data from this research has indicated that 802 out of 3,261 educational institutions, which included 360 primary schools, were within 150 m of nitrogen dioxide pollution spots that have pollutant levels that exceed the EU annual legal limit of 40 $\mu g/m^3$. Primary schools ranked the worst across the three main local areas and located closest to the major congested road routes (A2, A12 and Blackwall Tunnel) were selected. In addition, this paper also describes an assessment of the $NO_2$ exposures against the EU guidelines, where hourly and annually standards are, respectively, 200 and 40 $\mu g/m^3$ [16]. From Table 1 it can be observed that the majority of these schools are in areas with $NO_2$ exceeding the above stated annual legal limits.

Table 1: Selection of schools.

| School ID | Schools | Local Area | Mayor's Research (2017) | |
|---|---|---|---|---|
| | | | Ranking | $NO_2$ (μm/m$^3$) |
| 1 | Invicta Primary School | Greenwich | 3035 | 47.3 |
| 2 | Millennium Primary School | Greenwich | 2443 | 39.9 |
| 3 | St Mary Magdalene C of E School | Greenwich | 2490 | 40.3 |
| 4 | Kender Primary School | Lewisham | 2928 | 45.1 |
| 5 | St James Hatcham CE School | Lewisham | 3069 | 48.1 |
| 6 | Bow School | Tower Hamlet | 3152 | 52.1 |
| 7 | Marner Primary School | Tower Hamlet | 3095 | 48.9 |
| 8 | Woolmore Primary School | Tower Hamlet | 3240 | 61.8 |

## 2.1 Data collection

### 2.1.1 Passive monitoring

Nitrogen dioxide diffusion tubes that monitored the concentrations of $NO_2$ continuously were distributed across the eight schools, with a total number of 10 diffusion tubes installed. A location study was completed on the surrounding area of each school to select the optimal installation point prior to the setup of diffusion tubes. The $NO_2$ sampling method was molecular diffusion, allowing compounds to move from an area of high concentration (air) to an area of low concentration (diffusion tubes). The absorbent used was 50% triethanolamine/acetone and the desorption efficiency (d) is 0.98. To allow proper molecular diffusion, the tubes were installed at least 2–3 m above ground level. Under the technical restrictions that sufficient concentration of $NO_2$ compounds is required to be absorbed onto the tubes for detection during the laboratory analysis, long-term monitoring (duration of 2–4 weeks) is necessary. As such, the 10 sets of tubes were set up from 29 June to 19 July 2021. An insight into the location of diffusion tubes installed near a typical congested road around the school is shown in Fig. 3. The date and time of installation and removal of the equipment are recorded to calculate the overall exposure of $NO_2$ in the installed time period. Additional ODA data was obtained from the UK Automatic Urban and Rural Network (AURN) for the assessment of pre- and post-pandemic air quality. Specifically, the John Harrison Way,


(a) (b)

Figure 3: (a) GPS location for diffusion tube location; and (b) Bow School diffusion tube number 1.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Woolwich Flyover, New Cross and Blackwall monitoring stations were selected across the three regional areas.

#### 2.1.2 Active monitoring

TRAP was monitored both inside (commuting in vehicle) and outside vehicles (walking around the schools) during each route. Real-time data were collected for $NO_2$, $PM_{10}$ (TSI environmental monitor EVM-7) and $PM_{2.5}$ (TSI aerosol monitors SidePak AM520). The logging intervals were 1 second and 5 seconds for AM520 and EVM-7 respectively, and were averaged over the duration of each route. The resolution for the toxic gas sensor ($NO_2$) is 0.1 PPM and the resolution of both devices' particulate sensors is 0.001 mg/m$^3$. Both these devices collect real-time aerosol concentration using a 90° optical light scattering photometer to determine the total mass concentration. Although the particulate matter was measured in mg/m$^3$ and $NO_2$ was measured in PPM, these values are presented in µg/m$^3$, as these units are commonly used in air quality guidelines. To avoid technical difficulties with the equipment, field monitoring was only undertaken during rain-free days and with background humidity under 95%. In-vehicle monitoring was conducted in a typical diesel saloon vehicle, with monitors positioned in the passenger seat. All windows were opened, meanwhile, both the recirculation and heating/cooling system were kept in the off position at all times.

### 2.2 Route selection

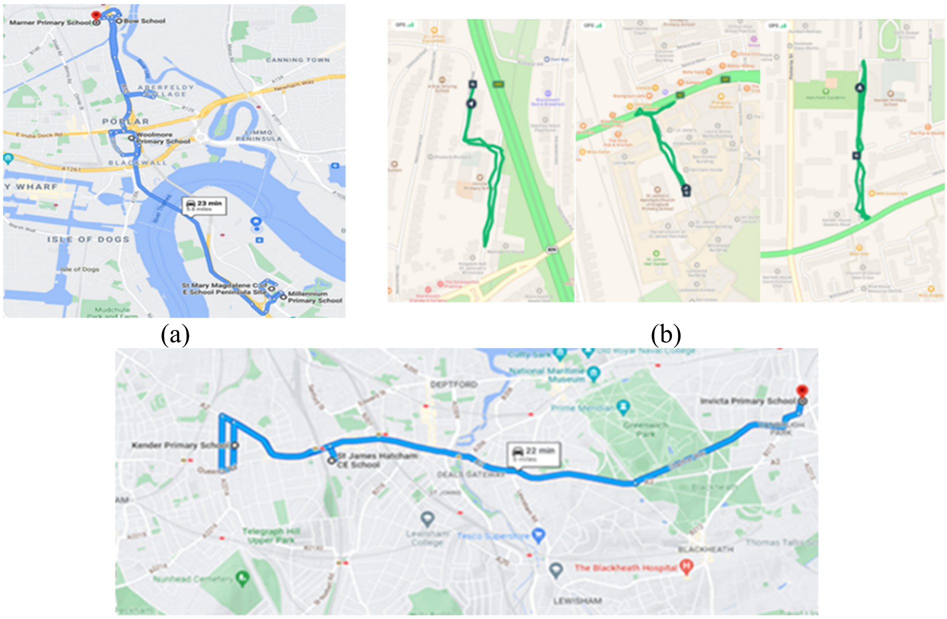
As minimal studies have focused their monitoring efforts specifically on characterised school operating hours, the field monitoring undertaken for this paper has taken place twice each day, during the morning (07:30–09:00) and afternoon school peak traffic hours (14:00–15:30). Three visits (experiment) were undertaken for PM monitoring and one was completed for $NO_2$ monitoring. Field monitoring was conducted on weekdays in August 2021 (summer). Dedicated routes were assigned for both driving and walking routes, driving routes 1 and 2 are shown in Fig. 4(a) and 4(c) respectively. Route 1 (A12) mainly focused on the Tower Hamlets area and the Blackwall Tunnel approach, whereas route 2 (A2) focused on the Lewisham area. In addition, route 1 was designed to investigate OAQ in highways (A102 and A12), and route 2 was designed to observe ordinary roadways. The sequential order of travelling for route 1 was school numbers 2, 3, 8, 6 and 7, whereas route 2 was school numbers 1, 5 and 4.

The driver stopped at each school along the designated route and commenced a 5–10 minute walk around the surroundings of the school. The monitors were turned on at the beginning of the drive and remained logging continuously until the end of the route. To minimise variability in results, walking paths were also assigned to follow for each school, an example of this for route 2 is shown in Fig. 4(b).

### 2.3 Morphological characteristics for the school surroundings

Analysis of the surrounding urban morphology was conducted with 3D images and tools from Google Earth. Major roads suffering from the most traffic congestion across each school were first identified. Then the distances between the school and these commuter roads were estimated along their vertical or horizontal direction. An example of such analysis for Bow School is shown in Fig. 5(a).

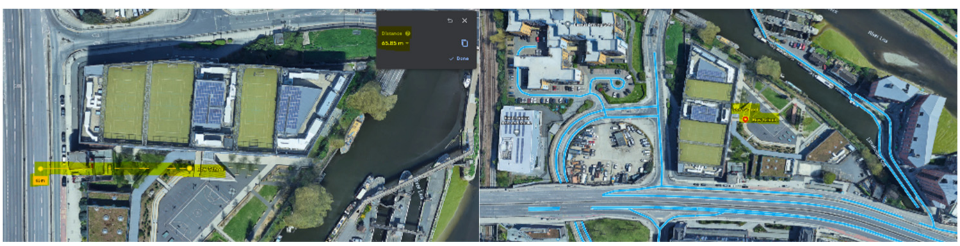
To understand the coverage of urban morphological features (e.g., road structure, green infrastructure, railway, and constructions sites) around each school, 3D images were




(a) (b)

(c)

Figure 4: (a) Route 1: Driving; (b) Route 2: Walking paths; and (c) Route 2: Driving.



(a) (b)

Figure 5: Local geometry of Bow School surrounding. (a) Distance to the main road; and (b) School surrounding shown in the 3D image (with urban road structure highlighted in blue).

procured from Google Earth at a scale of 1 to 40 m. The schools were placed in the middle of the image and the road structures surrounding the school were highlighted in light blue (Fig. 4(b)). The percentage of each feature compared to the total surface area of the images or school surroundings was conducted.

## 3 RESULT

Outdoor pollutants monitored in this paper were given colour indexes to be compared against the EU $NO_2$ and PM guidelines, where green, yellow and red indicate the pollutant concentration is safe, nearly exceeding and has exceeded the legal limit respectively.

### 3.1 Air quality: Fixed monitoring of nitrogen dioxide

Ten diffusion tubes were placed across the eight selected schools, where two diffusion tubes were installed around school numbers 4, 5 and 6. And one diffusion tube was installed around school numbers 2 and 3, as they are closely located next to each other. The majority of the schools have recorded a downwards trend for $NO_2$ concentrations when compared to the Mayor of London's research in 2017 (Table 1). This was expected, due to the public behaviours changes towards remote working. However, it can still be agreed that pollutants were still exceeding the EU legal guidelines. And even with the national lockdown restriction in place (during the period when diffusion tubes were installed), a significant increase of $NO_2$ reading can be observed in Bow School surroundings. Outdoor $NO_2$ readings from monitoring stations were obtained from the LAQN, chosen from the closest stations to the schools and are presented in Table 2. The John Harrison Way and Woolwich Flyover station are located in Greenwich near school numbers 1, 2 and 3. The New Cross station is located in Lewisham next to school numbers 4 and 5. The Blackwall station is located in Tower Hamlet close to school numbers 6, 7 and 8. Finally, $NO_2$ data in 2019 and 2021 are compared in terms of the pre- and post-COVID-19 pandemic air quality. The results show that all monitoring stations have recorded a reduction in $NO_2$ readings in 2021.

Table 2: Background and diffusion tubes $NO_2$ concentrations.

| Schools | Monitors No. | $NO_2$ ($\mu g/m^3$) | Outdoor Monitoring Stations Annual Mean: Station | 2019 $NO_2$ ($\mu g/m^3$) | 2021 $NO_2$ ($\mu g/m^3$) |
|---|---|---|---|---|---|
| 1 | 1 | 33 | Woolwich Flyover | 52 | 39 |
| 2 | 2 | 35 | John Harrison Way | 33 | 22 |
| 3 | | | | | |
| 4 | 3 (Minor Rd.) | 19 | New Cross | 38 | 30 |
| | 4 | 33 | | | |
| 5 | 5 (Minor Rd.) | 22 | | | |
| | 6 | 43 | | | |
| 6 | 7 | 62 | Blackwall | 47 | 38 |
| | 8 (Minor Rd.) | 28 | | | |
| 7 | 9 | 35 | | | |
| 8 | 10 | 39 | | | |

| UK Background Annual Mean (2020) (LAQN, 2022) | |
|---|---|
| Background | $NO_2$ ($\mu g/m^3$) |
| Urban background | 15 |
| Rural background | 5 |
| Urban Traffic | 23 |

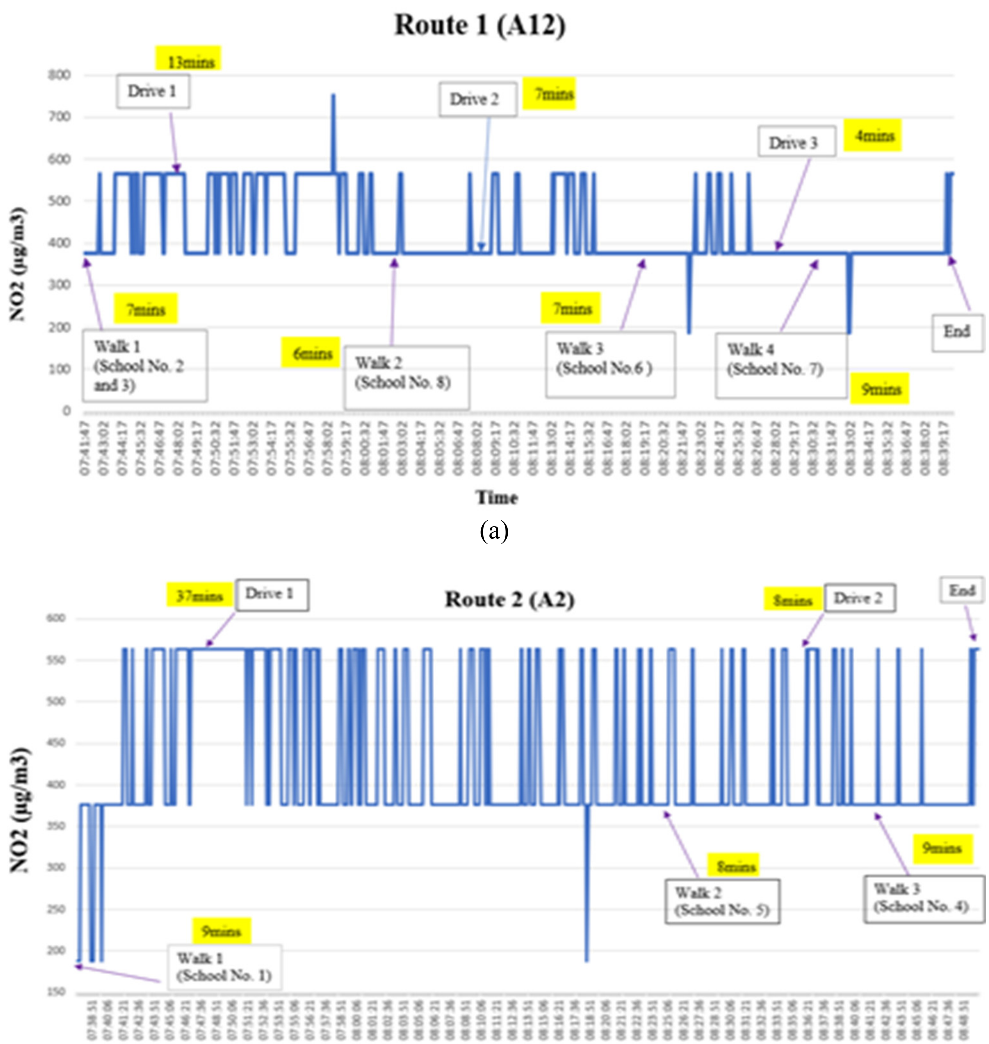
Note: (Minor Rd.) refers to diffusion tubes that were installed in a relatively less traffic-congested road (e.g., Bow School diffusion tube number 2 shown in Fig. 5(a))

### 3.2 Human exposure: Mobile monitoring

To calculate the total exposure during the entire commuting period, for each specific segment of travel, the average values of $NO_2$ pollutants were multiplied by the total time spent by an individual (eqn (1)). Where ε is integrated exposure over the specific period, $C_j$ equals the concentration experienced in environment $j$, $t_j$ is the time (minutes) in environment $j$, and $J$ represents the total number of environments occupied over a specific time. For example, the average recorded during "Walk 1" (A) is multiplied by the time (T) taken during this associated action. This step (A × T) is repeated for every following action. The exposures obtained are summed up to indicate the total exposures for the whole journey.

$$\varepsilon = C_j t_j. \tag{1}$$

Examples of the exposure throughout the journey with detailed timesteps are shown in Fig. 6. The actual time taken for commuting in-vehicle between schools (drive) and walking around each school (walk) were recorded and these are presented in Table 3. The hourly exposures were obtained by dividing the exposure of each associated action by the time (T) and multiplied by 60 minutes. This allows the exposures to be presented in hourly




(a)

(b)

Figure 6: Example of $NO_2$ exposure in detailed time steps. (a) Route 1; and (b) Route 2.

averages, to compare against the EU $NO_2$ hourly standard of 200 µm/m$^3$. The variability between morning and afternoon data is expected to be caused by the difference in traffic volume, leading to a longer commuting time.

### 3.3 Air quality: Particulate matter concentrations

The field experiment was undertaken three times to measure the PM concentrations during commuting to school and to evaluate against the EU Particulate Matter Guideline, where the annual guidelines for $PM_{2.5}$ and $PM_{10}$ are, 25 and 40 µg/m$^3$, respectively [16]. The $PM_{2.5}$ and

Table 3: Total $NO_2$ exposure for the entire route.

| Route 1 (A12) | | | | | | |
|---|---|---|---|---|---|---|
| | Morning | | | Afternoon | | |
| Action | Time (Mins) | Exposure (μg/m³) | Mean Exposure/ Hr | Time (Mins) | Exposure (μg/m³) | Mean Exposure/ Hr |
| Walk 1 | 7 | 3400 | 486 | 10 | 3100 | 310 |
| Drive 1 | 13 | 6500 | 500 | 16 | 6800 | 425 |
| Walk 2 | 6 | 2300 | 383 | 10 | 4000 | 400 |
| Drive 2 | 7 | 2900 | 417 | 10 | 4200 | 420 |
| Walk 3 | 7 | 2800 | 400 | 11 | 3700 | 333 |
| Drive 3 | 4 | 1600 | 400 | 5 | 2400 | 480 |
| Walk 4 | 9 | 3400 | 383 | 12 | 4300 | 358 |
| | Total Exposure | 23,000 | | Total Exposure | 28,000 | |
| Route 2 (A2) | | | | | | |
| Walk 1 | 9 | 3900 | 433 | 7 | 2000 | 283 |
| Drive 1 | 37 | 17000 | 467 | 18 | 6100 | 333 |
| Walk 2 | 8 | 3200 | 400 | 8 | 2400 | 300 |
| Drive 2 | 8 | 3400 | 433 | 9 | 3100 | 350 |
| Walk 3 | 9 | 3600 | 400 | 9 | 2800 | 317 |
| | Total Exposure | 31,000 | | Total Exposure | 17,000 | |

Table 4: Outdoor average $PM_{2.5}$ and $PM_{10}$ (μg/m³).

| | | 1st Visit | | 2nd Visit | | 3rd Visit | | Average PM Values | |
|---|---|---|---|---|---|---|---|---|---|
| | | A.M. | P.M. | A.M. | P.M. | A.M. | P.M. | A.M | P.M |
| Route 1 | PM 2.5 | 47 | 28 | 22 | 51 | 43 | 35 | 37 | 38 |
| | PM 10 | 10 | 80 | 40 | 10 | 50 | 30 | 33 | 40 |
| Route 2 | PM 2.5 | 57 | 38 | 29 | 36 | 44 | 45 | 43 | 40 |
| | PM 10 | 20 | 20 | 20 | 30 | 10 | 90 | 17 | 47 |

Note: A.M. refers to morning measurements; and P.M. refers to afternoon measurements.

$PM_{10}$ across each route are presented as averages in Table 4. Results show that values for $PM_{10}$ were generally under the annual guideline, whereas readings for $PM_{2.5}$ tend to significantly go above the EU standards.

### 3.4 Distance to closest major road and other urban morphological features

The urban morphology characteristics of each school are presented in Table 5. The two closest major roads were identified according to their average daily traffic volume. And the distance between each road and the schools were measured. All schools were found to be within 300 m of a major road, with school number 7 as close as 30 m. However, a number of these roads were highways that have larger traffic volumes (e.g., A12 has an approximate daily traffic flow of 80,000 vehicles) and contribute to higher emissions. The influence of railway services on the concentration of toxic pollutants to school pupils should not be

Table 5: Geographical characteristics of school surrounding.

| | Distance (meter) to the closest major road to school | | | | Percentage (%) coverage of geographical features | | | | Mean $NO_2$ (μg/m³) | | Mean PM (μg/m3) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| School | 1st Road | Distance | 2nd Road | Distance | Road | Green | Other | Notes | Monitors | Stations | PM10 | PM2.5 |
| 1 | B210 | 215 | A102 | 40 | 18 | 40 | - | - | 33 | 39 | 32 | 42 |
| 2 | Bugsby's Way | 110 | A102 | 245 | 19 | 20 | - | - | 35 | 22 | 37 | 38 |
| 3 | Millennium Way | 110 | A102 | 245 | 11 | 10 | 35 | Construction Site | 35 | 22 | 37 | 38 |
| 4 | A202 | 210 | A2 | 210 | 13 | 30 | 5 | Construction Site | 26 | 30 | 32 | 42 |
| 5 | Railway | 60 | A2 | 130 | 27 | 25 | 5 | Railway | 33 | 30 | 37 | 42 |
| 6 | A12 | 55 | - | - | 20 | 20 | 10 | Parking Slot | 45 | 38 | 37 | 38 |
| 7 | A12 | 130 | Devas Street | 30 | 16 | 15 | 15 | Parking Slot | 35 | 38 | 37 | 38 |
| 8 | A102 | 55 | - | - | 55 | 20 | 10 | Parking Slot | 39 | 38 | 37 | 38 |

Note: "Notes" provide additional detail to the features that "Others" are indicating; Grey highlight indicates that the associated road is considered a highway.

disregarded, as such, the distance of school number 5 to the nearby railway track was also measured.

Green infrastructure could improve air quality by providing barriers to sources of pollution. Therefore, to determine the variability of air quality in relation to geographical features, an estimation of the percentage of coverage to road structure, green infrastructure and other possible contributors to TRAP are conducted. Construction sites, parking slots and railways were identified to be other possible factors that could affect the quality of air around schools and therefore were defined as other (in Table 5). From the results, school number 8 has the highest percentage of road structure in its surroundings. Additionally, results presented have illustrated that $NO_2$ concentrations are much higher in schools surrounded by highways (school numbers 2, 3, 6, 7, 8), whereas $PM_{2.5}$ concentrations are often elevated in schools with ordinary roadways surrounded (school numbers 1, 4, 5).

## 4 DISCUSSION

The $NO_2$ concentrations monitored with diffusion tubes were used to assess the outdoor air quality at each school, by comparing data against values from fixed-site monitoring stations (Table 2). All of the schools have shown higher concentrations locally when compared to the closest available station, except for schools 1 and 7, this is likely due to the installed diffusion tubes for schools 1 and 7 being located at a side road (Table 2), which was far apart from where the enormous amount of traffic was congested and against the direction of dispersion of air pollutants. Furthermore, Table 2 indicated that the UK $NO_2$ average across the three different backgrounds was 14.3 μm/m$^3$, whereas the mean of data from local monitoring stations was 32.25 μm/m$^3$, which is a significant increase of 126%. Whilst the $NO_2$ average of localised monitors across the selection of schools was 34.9 μm/m$^3$ (an 8% increase when compared to the average of local monitoring stations). Hence, the significant increase in the averages from localised micro-environment measurements have consolidated the initial assumptions to the importance of localised monitoring.

The individual human exposures during commuting for routes 1 and 2 are shown with detailed timesteps in Fig. 6, and these demonstrate that $NO_2$ measurements are observed to be generally at their peak during commuting in a vehicle. The mean exposure per hour when travelling in routes 1 and 2 is found to be at least 55% and 41.5% above the EU $NO_2$ hourly legal limit of 200 μm/m$^3$, respectively.

The measured $PM_{2.5}$ concentrations for both routes (Table 4) were up to an order of magnitude higher than the suggested guidance value of 25 μm/m$^3$, whereas only some $PM_{10}$ concentrations were above the legal limit. This has suggested that TRAP is more likely to result in an elevated $PM_{2.5}$ concentration.

It is found from the local microenvironment measurements and the urban morphological analysis that schools located highly close to highways (route 1) might not necessarily experience the worst air pollutants. Instead, the worst traffic congestion nearby (route 2) might better explain poor air quality. For example, 37 minutes were taken to commute from school numbers 1–5 during morning commuting for route 2 (Fig. 6 and Table 3). The longer travelling time has resulted in a total exposure of 31,000 μm/m$^3$, which is almost twice the $NO_2$ exposure of afternoon commuting in route 2 and is 35% higher than that of route 1 morning commuting, suggesting the negative correlation of traffic volume and congestion to air quality.

Route 1 was designed to investigate OAQ in highways (Blackwall Tunnel (A102 and A12)), and route 2 was designed to observe ordinary roadways. The results indicated that, although route 1 is one of the busiest and most congested highways in London, no significant difference can be observed between the average $PM_{2.5}$ values recorded on route 1 when compared with route 2 (Table 4). This is likely due to the narrow street canyon geometry across streets near the A2, but further research is necessary to understand the causes.

As shown in Table 5, the $NO_2$ concentrations were higher in schools having major highways nearby (school numbers 2, 3, 6, 7 and 8). In contrast, PM values were relatively higher for the other schools. Moreover, the school with the surrounding covered by the highest percentage of road structure did not have elevated pollutant concentrations. Similarly, schools surrounded by a larger proportion of vegetation did not result in a lower pollutant concentration. These have suggested that the effect of coverage of localised road structure and green infrastructure to OAQ may be limited, but the sample size was too small to evaluate this with certainty.

## 5 CONCLUSION

In general, our findings suggested that school pupils commuting to schools may be repeatedly exposed to elevated levels of traffic-related air pollutants, especially to the exceedance of $PM_{2.5}$ and the hourly exposures of $NO_2$. Furthermore, suggesting that traffic characteristics, land usage and morphology are some of the important determinants to the elevated of TRAP exposures. To conclude, this paper has yielded significant benefits to understanding air quality across schools in south east London by determining the exposure for schoolchildren during their daily commuting. The importance of this work is to confirm the severity of TRAP relating to schoolchildren and promote the necessity of considering environmental sustainability for policymakers during decision making.

It is recommended that a statistically significant set of schools be assessed for their local urban morphology, wind direction and speed, and traffic volume, to determine whether there is a clear link to the effect of geographical features on OAQ.

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