Urban Air quality Comparison on Bike and Driving routes: A Case Study for UK

Lakshmi Babu Saheer*, Negar Ahmadpoor, Jayasooryan Thundikandi Maroli

Anglia Ruskin University, Cambridge, UK

E-mail: `lakshmi.babu-saheer@aru.ac.uk`, `negar.ahmadpoor@aru.ac.uk`, `jayasooryan.tm@outlook.com`

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Abstract. Air quality in cities is very important in both tackling climate change and promoting healthy sustainable urban living. Understanding the air quality around cities has been a challenge faced by local authorities around the world. With the new net zero targets in place, government and charitable organisations across the UK have been trying hard to both monitor and control air pollutants to influence citizen behavior towards environmentally friendly living. This study looks at urban air quality in two UK cities with the idea of understanding air quality and its relation to the mode of transport, health and well-being. This case study compares the urban air quality as Particulate Matter (PM_{10} and $PM_{2.5}$) and gaseous pollutants (NO_2) on the bike and motor driving routes in Cambridge and Colchester. The study designed experiments and data collection campaigns to understand the factors leading to air quality fluctuations in urban traffic routes. The resulting measurements show that NO_2 concentrations are higher in motor driving routes and in certain locations on the bike routes that are part of (or very close to) the motor route. The PM concentrations are generally higher near parks and open greenspaces but can be argued to be within the recommended limits. Finally, this paper proposes steps to improve the urban infrastructure to tackle emissions and spread awareness among the citizens.

Keywords: Air quality Monitoring , Green Transport Infrastructure, Sustainable Urban planning, Climate Change, Citizen behaviour change

1. Introduction

The quality of air, especially in urban cities has a great influence on the general health and well-being of the citizens [27, 82, 61]. The main source of air pollution in cities is identified as the emissions from transport and road traffic (contributing to 26% of the UK's total emissions in 2021 - with 32% of Nitrogen Oxides emissions and 14% of particulate matter, PM2.5 coming from transport [26]). This in turn affects the environment due to the greenhouse gas contents (represented as CO_2 equivalent) in the emissions, further leading to climate change-related issues[33]. The net-zero targets aim to reduce the CO_2 equivalent pollutants in the atmosphere as part of climate action. It is very important to transform the world with sustainable transportation as well as nudge citizen behaviour to green transport for reducing transport-related pollutants.

Sustainable urban transportation has been evolving from cycling and walking to e-scooters/e-bikes and electric vehicles. Cycling and walking are not only better modes of transport for air quality, but these modes could also be beneficial to the general health and well-being of citizens as a source of physical activity or exercise [57, 59]. Hence it is important to promote citizen behaviour change towards cycling and walking as the best mode of transport whenever possible. Authorities have time and again tried both positive and negative reinforcement techniques to stir public behaviour towards sustainable transportation. The positive reinforcements could include policies like "bike to work", or better infrastructure and public transport service. While the negative reinforcements include penalties like congestion charges and variable vehicle tax based on emissions. It has been observed in psychological studies [36] that positive reinforcement might have better chances of success in behaviour modification than penalties. Thus, it can be safely assumed that citizen behaviour change can be instigated better through persuasive positive action plans like monitoring air quality around biking or walking routes and spreading awareness of these measurements and about the health benefits of these modes of transport.

Sustainable transportation modes have shown to be less harmful contributors to local air quality [58]. However, the infrastructure required for sustainable transportation is not yet fully developed in UK cities, and for this same reason, citizens have been reluctant to adopt green modes of transportation. The UK national cycle strategy introduced in 1996 aimed to double the number of cycle trips by 2002 and quadruple the number by 2012 [62]. Unfortunately, these targets are still not met mainly due to the missing commitment from authorities to facilitate sustainable transport through proper infrastructure. These targets can only be achieved with participation and motivation from the general public along with support from local, regional, and national authorities. There have been consultations and discussions at both national and regional levels on planning urban infrastructure including road safety and political or policy-related hurdles. There have been discussions around instilling citizen behaviour and attitude changes toward sustainable transport. The drive towards sustainable transport needs to be based on the foundations of strong green infrastructure provided by government authorities, urban planners, and policymakers. Alongside this change, the citizens should take up responsibility and encourage each other to use green modes of transportation. The behaviour change even with proper infrastructure and support could be a slow process mainly due to existing social and cultural practices or sheer comfort. There is usually a group of citizens who feel responsible and use bikes and other sustainable modes of transportation in every situation (including non-ideal ones) due to their moral sense or sometimes, even due to financial and other constraints. The use of bikes as a mode of transportation is usually limited to short and medium distances. While long-distance cycling is often considered a sport or leisure activity [47]. There are groups of citizens who would not consider cycling at any point in their lives, whilst there is the exact opposite group that would always love to use the bike given a choice.

Research [46] has shown that while some measures such as having the right sustainable infrastructure and technology may theoretically seem to be effective in using sustainable transport, the effectiveness may be minimal if people do not accept the implementation of those measures or do not use them (Cambridge Transport Plan [19]). For example, many people can be reluctant to give up the perceived comfort of owning a car or using it as the primary mode of transportation. Authorities sometimes have to take stricter actions like introducing congestion charges which reduced congestion by 30%, boosted bus travel by 33% in the past 20 years [74] and created a rise of 37% in cycle usage within 3 years in London city. Councils like Cambridge city also considered similar measures to penalise the usage of private motor transport by introducing congestion charges in the city from 2027 [13] or increasing the peak hours parking charges [12] and expect to have a considerable increase in the use of cycles. But such measures could fail to create a positive behaviour change since these policies are based on negative reinforcements and penalties rather than positive reinforcement by improving citizen awareness. Changing behaviour and attitude toward using sustainable transport and benefiting from better air quality have been discussed in most of the sustainable transportation and air quality strategies, policies, and projects. Raising awareness about the importance of using public transport and its positive impacts including air quality can prompt planners, decision-makers, and politicians to take their commitment to sustainable transportation more seriously and could positively influence the citizens. Raising public awareness can be performed through different methods and strategies. One of these methods is to present the research data to citizens, planners, decision-makers, and politicians to nudge behaviour change.

This research aims to study the air quality in relation to modes of transportation (motor vehicles and cycling or walking) in cities. The research looks at two different urban environments in Cambridge and Colchester and measures the air quality data in those settings to study the data in the context of bike and motor traffic as specific modes of transport. Two parallel car and bike routes in both cities are directly compared in this research. The output of this study as air quality measurements will be presented to the authorities and general public with an aim to instigate positive behaviour change with regards to cycling and walking as the mode of transportation to support climate action and general public health. This paper is organised as follows: Section 2 briefly looks at some of the air quality monitoring systems in urban cities and efforts on building sustainable cities to validate the methodology of this study. Section 3 looks at the monitoring devices and general considerations made in planning the data collection in this research. Section 3.4 presents the details of the data collection with an analysis of the data and results presented in section 4. Finally, conclusions and future work are discussed in section 5.

2. Background

This section looks at the background literature on understanding air quality in cities along with green space planning and the impacts of traffic on cyclists. This helps to validate the context and design of this study.

2.1. Sources of Air pollutants in Urban environment

Historically, the burning of fossil fuels for domestic and industrial purposes has been attributed as the major source of air pollution. These sources have been stabilized or even improved over time. Currently, the main source of urban air pollution for UK cities is road transport as per the reports from the Department for Environment Food and Rural Affairs (DEFRA) [24, 23]. The pollutants like oxides of nitrogen (NOx), carbon monoxide (CO), particulate matter (including PM_{10} and $PM_{2.5}$) and volatile organic compounds (VOCs) are directly emitted by the combustion of diesel and petrol. Photochemical reactions due to the sunlight acting on these emitted NOx and VOCs further generate secondary pollutants like ozone (O_3).

2.1.1. Urban Transportation Traffic emissions have been a major concern in cities and urban areas mainly because there has been a high mortality rate associated with traffic-related pollutants [38] along with other health risks like lung cancer risk [4], and worsening of respiratory health [6]. According to [28], air pollution has been mainly caused by road traffic in Western and Northern Europe. NOx has been the main cause of pollution in city centers due to the close proximity to heavy traffic and main roads contributing to two-thirds of all air quality standard violations from 2014 to 2020. In response to that, the UK and most European cities, have come up with air quality action plans with a focus on reducing pollutant emissions from traffic. Some of the strategies in this plan include policies and regulations to aid traffic flow improvement, usage of ring roads, speed limit reduction, the introduction of low-emission zones, and perks for using public transportation. Studies show that there have been mixed results regarding the effectiveness of these policies [6].

Moreover, active travel modes such as cycling, and walking have proven to be the most sustainable transport methods with zero negative impact on air quality and great positive contributors to people's health and well-being. As mentioned earlier, cycling and walking have been recognised as modes of transport for short and medium distances. In more recent years, e-bikes and scooters have offered the opportunity for longer-distance traveling as well. There have been policies and actions in place by governments to encourage people to walk and cycle (e.g., see Sustainable Modes of Travel Strategy 2020, and Gear Change: A bold vision for cycling and walking 2020 from Essex County Council). Some cities such as Amsterdam and Copenhagen have been more successful than other European cities in normalising cycling and walking. Infrastructural, institutional, and behavioural factors have been discussed as barriers to the complete success of walking and cycling plans in many cities. Air quality can also be seen both as an encourager and barrier factor for walking and cycling. Studies have shown that people prefer to walk and cycle in areas with better air quality. Studies (in Spain) have shown that citizens often find smell and bad air quality as barriers to exercising and walking in cities [29]. There were factors that influenced the citizen's attitude and habits like information on potential ranges of air pollutants and their health risks (as a traffic light system - red, amber, green) which could potentially encourage citizens to walk [9]. As per this study, citizens are attracted to walking in green spaces even if they have to walk long distances. The likelihood of choosing greener and healthier routes was seven times higher if people were aware of the air quality around the area. The results of the above studies demonstrate that there is a two-way relationship between air quality and walking and cycling. Better air quality in urban places will encourage people to walk and cycle within those places, and when more cycling and walking take place in cities, there will be better air quality in cities.

2.2. Urban green space planning

Plants and trees are natural carbon sequestration agents. Greenery in different forms, including large parks, pocket parks (i.e., a small park accessible to the public), street and park trees, hedges, green walls, and roofs, etc., have been seen as a mediator for air quality [30, 55, 52]. Small quantities of pollutants get deposited on leaves and plants, perhaps depending greatly on the aerodynamics and may not have any significant removal effect [40, 75]. Both removal and disposition effects may depend on the type of tree, pollutant, planting pattern, and the design of the surrounding environment [39]. Greenery in the form of trees and hedges can work as barriers between emission sources (i.e., road traffic) and people on sidewalks. In this way, pollutants cannot flow toward people walking on the sidewalk due to the aerodynamic effects of greeneries. Also, pollutants passing through vegetation are filtered by deposition [5, 73, 72].

However, there are research studies on the street canyon that evidence the pollutants concentrating in the canyon due to the wake flow. [16, 64, 69]. Also, research has shown that tree canyons could restrict airflow resulting in pollutants accumulating within canyons, often with an exaggerated effect due to larger leaf area coverage or density or due to larger aspect ratios in bigger canyons [76]. The pollutant concentration can be reduced by planting hedges, but the extent of that would depend on the height and porosity of hedges [35, 45, 77]. Nonetheless, it has been proved that wind direction and canyon aspect ratio (canyon height to canyon width) are more effective than greenery density[8]. Parks, being the main areas of vegetation in a city, usually have a positive impact on air quality by depositing pollutants at the city scale and enhancing aerodynamic effects. Parks are often reported to have a lower concentration of pollutants including Ozone and better air quality compared to nearby street canyons [42, 43, 81, 15, 20, 34]. Moradpour and Hosseini [48] indicates that the impact of urban parks on air quality depends on wind direction and vegetation type, based on which others like Qin et al. [60] have identified design factors for parks as design guidelines for vegetation to reduce the PM concentrations to attain the World Health Organization (WHO) recommendations.

Several studies provide evidence that city form, land use distribution, street network, and green spaces, determine the pattern of urban traffic and the location of emission sources, which have an impact on air quality. However, few studies have discussed the implications of their findings for urban planning and design. Researchers [3, 50, 67] recommend vegetation as well as having urban parks with the claim that urban design should incorporate more ground-level plantings or green roofs and walls into cities to reduce air pollution [2]. There have been recommendations on using different plant species based on their impact on air quality [14]. Regarding planting trees on urban streets, other considerations could dominate beyond the air quality guidelines. Hence, there may not be clear guidelines on how to design urban canyons or plant trees on open roads for landscape planning and design. Studies have suggested using hedges and trees within streets depending on street ratio, density, and wind direction. However, none of these studies have measured air pollutants near the urban parks as proposed in this study to understand the real impact.

2.3. Air quality monitoring in cities

Air quality is an important problem to tackle from the perspective of climate action and citizen health for cities worldwide. The WHO global air quality guidelines [79] states that clean air is fundamental to human health and looks into the classical pollutants including particulate matter ($PM_{2.5}$ and PM_{10}), NO_2, Ozone, CO and sulfur dioxide after discovering that the biggest environmental threat to human health is the pollutants in the air. The report further identifies air pollutants as the major risk factor for noncommunicable diseases like asthma, cancer, chronic obstructive pulmonary disease (COPD), stroke, and other heart diseases and even comparable to other global health risks like smoking and unhealthy diet. There were 4.1 million premature deaths worldwide due to pollution, 91% of which occurred in low- and middle-income countries in 2016 [78]. WHO provides quantitative air quality guidelines (AQG) for the aforementioned pollutants as illustrated in Table 1 for governments and authorities to devise urgent regulatory measures to support the 99% world population living in areas that exceed these pollutant limits. It would be more realistic to try and achieve interim targets as set by the guidelines.

Initiated by the mayor of London, Ken Livingstone, mayors from 100 world-leading cities formed a

Pollutant	Averaging time	AQG level
$PM_{2.5}$, µg/m3	Annual	5
PM_{10}, µg/m3	Annual	15
O_3, µg/m3	Peak season	60
NO_2, µg/m3	Annual	10
SO_2, µg/m3	24 hours	40
CO, mg/m3	24 hours	4

Table 1: WHO Recommended AQG levels

consortium named "C40" to urgently tackle the climate crisis [10]. Since its origin over 15 years ago, the vision of this consortium still remains to "halve the emissions within a decade". As part of achieving the WHO guidelines, the consortium initiated community-led projects like "Breathe London" [7] which makes use of low-cost IoT-based air quality sensing networks to monitor and determine the impacts of air pollution on health and provide the foundation stone for research and policy development. Earlier air quality monitoring programs like London Air, Air Quality England and Defra used industrial-grade instruments and are undertaken by central or local governments [22]. The regulatory-grade air quality monitors are accurate but very expensive and out of reach for citizens and community groups. A recent trend has been towards the use of an affordable hybrid network of industrial-grade monitors alongside community-led air quality monitoring. This paradigm shift has been endorsed by new sensor technologies and innovation and flexibility in air quality data collection [10, 31]. The aim of such projects is to use the sensor network to identify pollution risk levels, spatial patterns especially with high exposure areas, sources of pollution, generate citizen awareness to instigate behavior changes, and test the efficacy of policies and enforcing regulations.

2.3.1. Similar case studies Based on the new hybrid monitoring paradigm, several cities around the world have been exploring IoT-based air quality monitoring systems for effective air quality monitoring and management. The earlier mentioned C40 consortium report [10] presents findings from 11 international cities with diverse cultures and challenges. This includes cities like Addis Ababa, Dar es Salaam, Denver, Lima, Lisbon, London, Los Angeles, Mumbai, Paris, Portland, and Quezon City that deployed low-cost sensor networks as a first and fundamental step towards clean air. These systems just monitor the pollution and try to understand the areas of congestion and high pollution. There is limited evidence in the literature on policy changes made based on this monitoring. European cities have been pioneering car-free zones and encouraging public transport and biking/walking within certain areas of the city. The circulation plan in the city of Ghent in Belgium deserves special mention as the city has dedicated bike streets with a combination of car-free or even completely traffic-free (including bikes) areas improving the sustainable bike share mode of transportation by 35% in 2019 (with 30% of inhabitants not owning a car) and making the city green and alive [18]. The city is divided into a central historic zone and 6 other zones around it with no through traffic allowed across the zones. Vehicles need to use a ring road to travel around the zones and enter each zone only with special permits. None of these aforementioned studies directly monitor or compare the air quality in car vs bike routes as presented in this study to understand the characteristics of these routes and their impacts on air quality. The novelty presented in this research includes the new methodology of studying these parallel car and bike routes and comparing them in terms of directly measured air quality, traffic patterns and urban settings including surrounding green spaces or road layout.

2.3.2. Air quality impacts on Cyclists Many studies look at the impact of pollutants on cyclists mainly with the aim of improving the cycling infrastructure [80, 37, 51, 65]. A study in Barcelona, Spain compared multiple modes of travel (including car, bike, bus, and walking) which showed that car routes were very high in concentration for all pollutants including, Black carbon (BC), ultrafine particles (UFP), CO, fine particle mass (PM2.5) and CO_2[51]. A study in Bogota, Columbia monitored two bike lanes to discover an exposure to PM2.5 ranging between 10.5 and 36.0 μg/m3 and BC between 4.5 and 7.9 μg/m3, respectively [37]. The highest pollutant concentrations are observed on the bike lanes when they are adjacent to major vehicular routes. Studies could not establish a clear negative impact of exposure to pollutants when compared with the positive health impacts of cycling due to insufficient biking time to establish any causality [65]. There has been limited or no research that directly measures air quality comparing parallel car vs bike routes with an intention to change citizen behaviour pattern like the one presented in this study. The novelty of the research aside from the intention of public awareness is to design a novel affordable methodology of data collection considering traffic patterns and urban characteristics with the aim of improving cycling infrastructure for greener urban infrastructure planning.

3. Methodology

The air quality is analysed in this study for two types of pollutants: particulate matter ($PM_{2.5}$ and PM_{10}) and gaseous pollutant (NO_2). PM particles are the particulate matter of varying diameters - $PM_{2.5}$ and PM_{10} which are mainly debris or particles from smoke, burning, leaves/tree parts, dust, tyre, or traffic waste. The gaseous pollutants include the gases emitted from different sources and may include NO_2, CO_2, SO_2, O_3, etc of which NO_2 has been particularly monitored by the councils as this is the main pollutant generated by the burning of fossil fuels, especially from transport and NO_2 levels in the UK have been recorded as higher than the recommended annual average [25]. Higher concentrations are very harmful to human health causing inflammation of the lungs, especially in people with asthma and other respiratory conditions [21]. Our proposed research also looks at NO_2 as one of the major traffic pollutants as it is considered harmful to human health.

This section presents the methodology behind scheduling the air quality monitoring comparing bike and car routes and identifies the factors that need to be considered when planning such a data collection; like the factors that affect the pollutant concentration such as traffic, weather and location of placement of the pollutant monitors. The logistics or other factors including cost, power and battery life of the devices, and Wi-Fi connectivity may also need to be considered and are not discussed here.

3.1. Air quality monitoring devices

The local authorities often use industrial-grade air quality monitors that are fixed at pre-identified locations. Since the data had to be collected at different locations, different air quality monitoring devices were explored in this research mainly for monitoring the particulate matter, $PM_{2.5}$ and PM_{10} and gaseous pollutant, NO_2. The deployment of sensors comes with challenges like regular calibration and servicing of the sensors or local conditions like dust and humidity affecting the accuracy of local sensors. It is important to understand if the equipment used is reliable. A range of options are available for air quality monitors. The industrial grade monitors like Aeroqual [1] can be an ideal compromise between mobility and reliability of readings.

The handheld air quality monitoring equipment considered for this study includes:

- Aeroqual – an industrial-grade commercial sensor.
- Plume – a commercial low-cost sensor that includes a lot of pollutants including VOCs.
- In-house Custom Sensor – a custom sensor designed by the research group using standard chipsets and Raspberry Pi controller.

3.2. Planning the Collection Locations

In transit-oriented studies by Tissayakorn et.al.[70], [71], the term ”catchment area” refers to the geographic area affected by transport strategies and the area from which passengers are drawn to use the station. This concept helps define the context of their studies. In this paper, the definition is adapted to refer specifically to the geographic area from which passengers are drawn to use the study routes. The catchment areas for the study routes in Cambridge and Colchester include the immediate neighborhoods around the routes as well as the city centers, as the selected routes are the primary transition routes to the city centers. The route chosen is one of the main school and office commute routes in both cities. The catchment route length in Cambridge is around 1.5km while in Colchester is approximately a 3km road stretch.

four different routes in Colchester and Cambridge were selected to understand the relationship between air quality and the use of cars and bikes. In Colchester, two parallel routes are chosen, one of which is a car route (i.e., Mersea Road) and the parallel route is a bike route introduced by Colchester City Council. A large part of the bike route is separated from the main Road (i.e., Berechurch Road) but has some intersections with other roads as well (See Figure 1). During rush hours, it is expected that cars, in order to avoid the traffic on Mersea Road, use Berechurch Road which is next to the bike route. Therefore, there is a possibility of higher pollution levels appearing on the bike route which can affect people's health. The two parallel routes for cars and bikes are shown on the map in Figure 1(a). Four distinct locations were identified on each route with corresponding locations on the parallel route. These location points are to be monitored for air quality to compare the two routes. These tactically placed locations are identified as epicenters of congestion like the junctions and roundabouts. Locations 1, 2, 3, and 4 represent the motor vehicle route, and locations 5, 6, 7, and 8 represent the corresponding parallel locations on the bike route.

A similar set of parallel routes were also identified in another UK city, Cambridge (Figure 1(b)), where bikes are popularly used and the local authority has recently considered bringing in congestion charges for motor vehicle usage within the city. One of the chosen routes is a car route and the parallel route is a car route with adjacent bike lanes which is referred to as a car-bike route in this paper. In Cambridge, most bike lanes

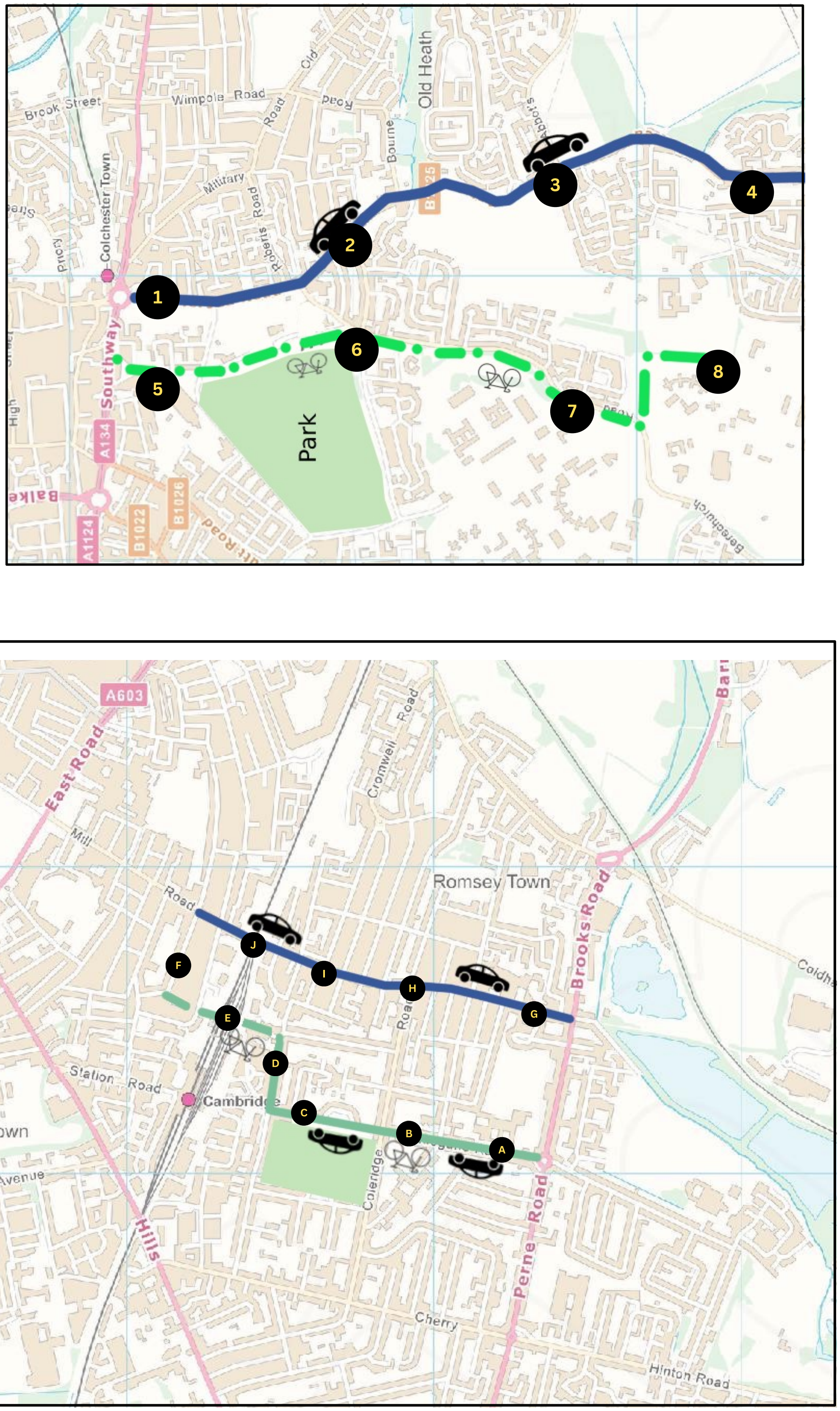


Figure 1: Bike and Car Routes in a) Colchester and b) Cambridge

are adjacent to the car traffic road. The five points of data collection are selected on each path: points A, B, C, D and E are on the car-bike route, while F, G, H, I and J are on the car route. This set of analyses can help to understand the pros and cons of having bike routes (i.e., used only by bikes with minimum intersections with car routes), car-bike (i.e., car routes with adjacent bike lanes), and road routes (i.e. cars only) with regard to air quality.

3.3. Traffic Data Prediction

Pollution concentrations in the air is mainly dependent on the traffic. Hence, the data collection schedule needs to be optimised to capture the right timings to represent the traffic flow and related concentration of pollutants in the air. This research analyses the traffic flow including patterns and peak traffic to schedule data collection with the limited resources at hand. Ideally, traffic data should represent the number of vehicles on the road. Cambridge City Council monitors real-time traffic at different locations within the city available as the number of vehicles passing through the road. Unfortunately, not all roads are monitored and similar information is unavailable in Colchester. Hence alternate options of online data sources are explored. Google Maps provides a traffic API layer representing the traffic congestion on the various roads around the city. Even though it is reliable, this is not an exact measure of traffic. Google traffic represents congestion through a color-coded map representing the average traffic speed. A machine learning model is trained to predict the exact traffic on the road by mapping these color codes to real traffic information based on the traffic data available in Cambridge.

The dataset for training the machine learning model was acquired from Google Maps traffic view layer and Cambridge City Council. The color-coded map is converted into a tabular dataset by assigning a range of numbers between 0 and 6. 0 being the lowest traffic and 6 being the highest traffic congestion. Since each road has two lanes, the sum of each lane is used to represent the total traffic count on the road. Traffic data as actual number of vehicles is available at an hourly interval which is coupled with the Google traffic code to find the correlation between the two and train regression models. Experiments are performed using different machine learning algorithms including Linear Regression, ElasticNet Regression, Support Vector Regression, RandomForest Regression, GradientBoosting Regression, AdaBoost Regression, and XGBoost Regression (XGBRegressor). Experiment results of trained algorithms are shown in table 2. The XGBRegressor gave the lowest root mean squared error of 1.62, and R-squared of 0.999. Different metrics for the XGBoost regressor are presented in table 3.

Algorithm	RMSE
Linear Regression	92.14
Ridge Regression	92.11
Lasso Regression	91.76
ElasticNet Regression	89.56
SVR	95.78
Random Forest	2.4
Gradient Boosting	16.85
AdaBoost	25.36
XGBoost	2.19
CatBoost	4.21

Table 2: Traffic count prediction models

Algorithm	RMSE	MAE	R^2
XGBoost	1.62	1.2	0.999

Table 3: Optimised Traffic count prediction model

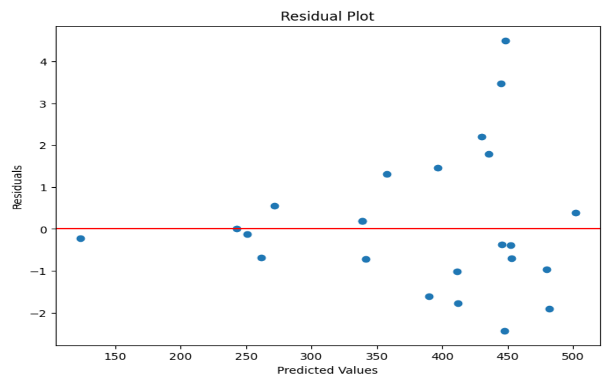


Figure 2: Residual Plot for XGBRegressor

The residual plot of this model as shown in Figure 2 shows how well the model maps the relationship between Google Maps traffic layer data and actual traffic count from the council dataset. This plot shows that points are distributed around 0 on the x-axis which means the actual values and predicted values are very similar. This model is used to predict the traffic count at different times of the day to plan the data collection during peak hours.

3.3.1. Traffic analysis It is important to understand the traffic patterns in the routes before planning the schedule for pollutant measurements. It is ideal to monitor the pollutants at peak traffic timings to understand the worst conditions. When there is low or no traffic, there may be a low concentration of pollutants as they get dispersed out and may not represent the real-world scenario in the peak timings with congestion. Figure 3 and figure 4 represent the traffic congestion details on a weekday, Wednesday between morning 06:00 to evening 10:00

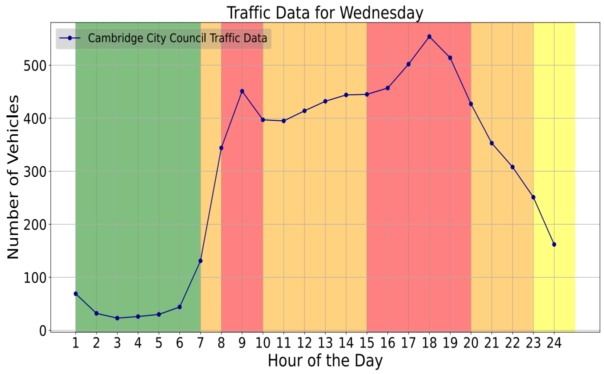


Figure 3: Weekday Traffic Congestion for Cambridge

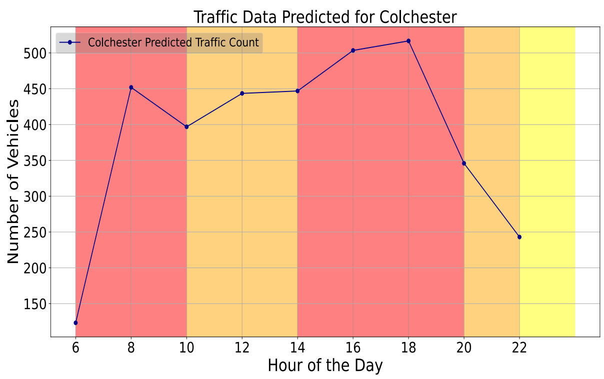
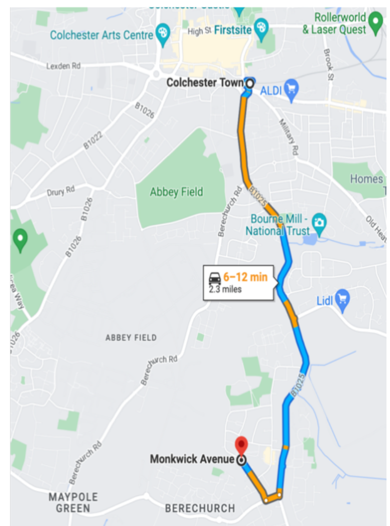


Figure 4: Traffic Prediction for Car Route in Colchester

PM in Cambridge and Colchester respectively. The number of vehicles are mapped to color codes of four colors: green (0-149), yellow (150-299), orange (300-449) and red (450+) for ease of readability. It can be observed that there is very high traffic congestion between morning 06:00 AM to 08:00 AM and afternoon 02:00 PM to 04:00 PM. There is also high traffic from 08:00 AM to 10:00 AM in the morning. These timings represent the peak traffic for school drop-off and pick-ups and work travel hours. It can be noticed that the traffic becomes really calm after 08:00 PM at night.

Further analyzing the route from Colchester town railway station to Monkwick Avenue, it was observed that the bike route takes around 11-12 min and the car route takes around 6 - 12 minutes depending on the traffic timings as shown in Figure 5. The car route shows the peak congestion zones as observed in Figure 5. A further traffic analysis on the car route based on the peak timings for 8:00 AM in the morning and 4:00 PM in the evening is shown in Figure 6. All the junctions experience high traffic congestion in general. The most congested location is near the Colchester Town roundabout. This fact seems to be true for both morning and evening traffic. A data collection

(a) Bike Route Traffic

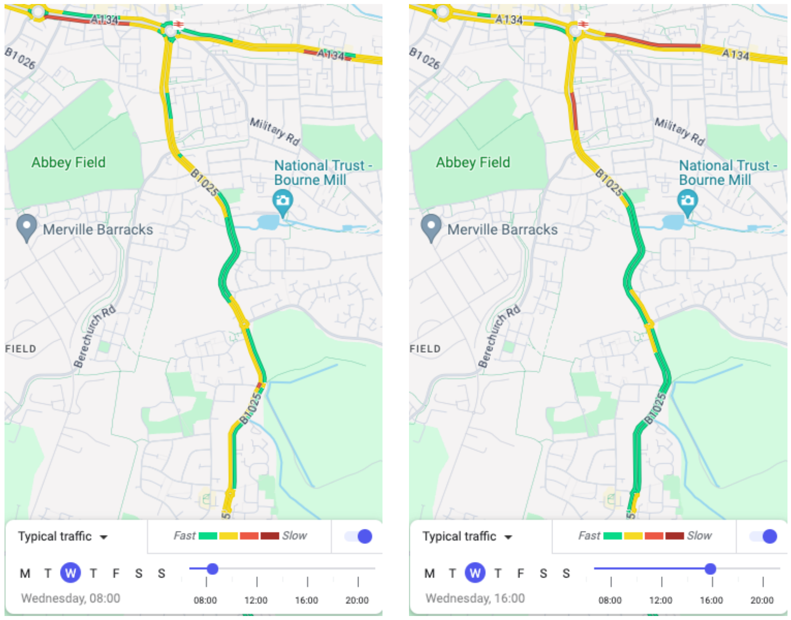


(b) Car Route Traffic

Figure 5: Traffic in Colchester

plan could be devised taking into account this traffic information.

The traffic patterns in Cambridge are a bit different as the road in consideration is a commercial street with shops and houses. There is always heavy traffic with delivery vans and trucks and is en route to the city center. Each of the points on the traffic route is analysed for traffic as plotted in Figure 7. The major junctions always have heavy traffic and the peak traffic seems to be between morning 8:00 AM to evening 8:00 PM.



(a) Traffic at 08:00 AM (b) Traffic at 04:00 PM

Figure 6: Traffic Congestion in Colchester Car Route

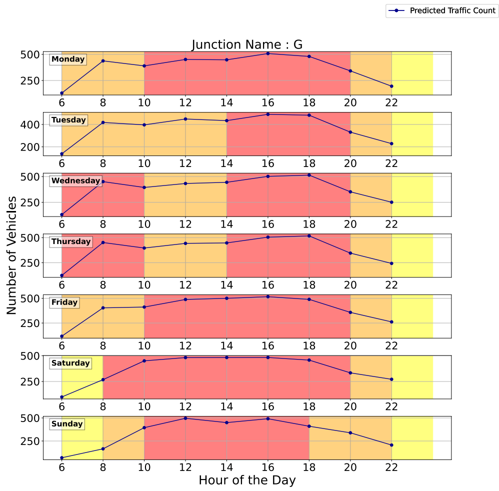
3.4. Experiment Design

The aim of this study is to compare air quality on the car, bike, and car-bike routes in Cambridge and Colchester. These analyses can inform local authorities' decisions for developing bike routes as well as the decisions of the citizens to make conscious choices for their mode of travel and the route they choose for their journey according to air quality. Traffic patterns were studied on these routes to monitor air quality during active traffic periods (both days and times) to avoid any bias of traffic calm timings. Similarly, weather and other factors like festive events or other changes in the usual traffic are considered while planning the data collection to avoid any external bias in the monitoring.

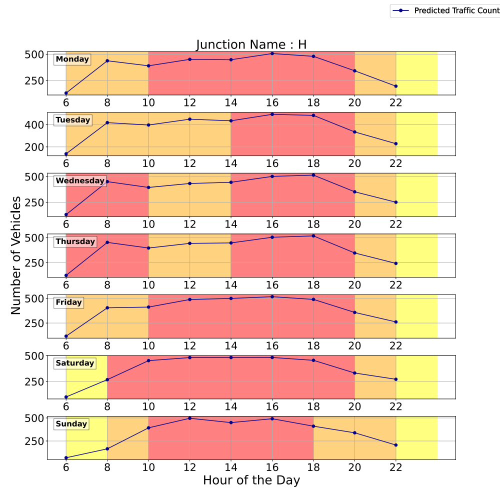
3.4.1. Data Collection Schedule Once the locations and peak traffic timings were identified for both cities, a data collection schedule was prepared. Simultaneous data collection at all locations was not possible due to a lack of resources. Days and times with similar traffic patterns and weather conditions were identified for both locations to collect data from identified locations. Weather conditions need to be considered when planning the data collection. It would be physically challenging to be out in the rain, especially because particulate matter may settle down or may not have normal readings in rainy or windy conditions.

It was identified that the best schedule to perform data collection was on a weekday during the school term time in Colchester as the traffic pattern was very much correlated to school dropoffs and pickups. Considering the weather conditions and summer closures of the schools, Colchester data collection was planned for Thursday, July 21^{st}, 2022 for the motor route and Friday, July 22^{nd}, 2022 for the bike route. The data collection was performed on weekdays at similar timings across parallel points on both car and bike routes in Cambridge as well. The Cambridge data was collected between 17^{th} May to 8^{th} June 2022. Approximately 2-2.5 hours of data were collected from each point for both locations.

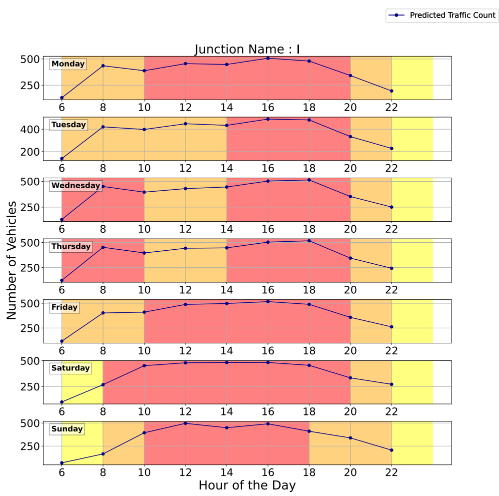
3.4.2. Execution of the Collection and Challenges The following observations are made on the routes in Cambridge. The experiments in Cambridge are based on the comparison between a car route (i.e., Mill Road) versus a car-bike route (Davy Road). For the car-bike route, the bike path is adjacent to the main road or on the road itself as seen in Figure 8. Hence, the car-bike route cannot be considered strictly a healthy bike path. There could be cars and other motor vehicles passing by on the side. Citizens often use these internal roads to avoid traffic and congestion on the main streets. Some locations even involved road works causing further congestion and pollution. Only the dedicated cycle bridge on the car-bike route is where there is no other motor vehicle. However, the bridge is for crossing the railway lines running underneath. The cycle bridge is an enclosed structure and not an ideal design to disperse any pollutants coming from



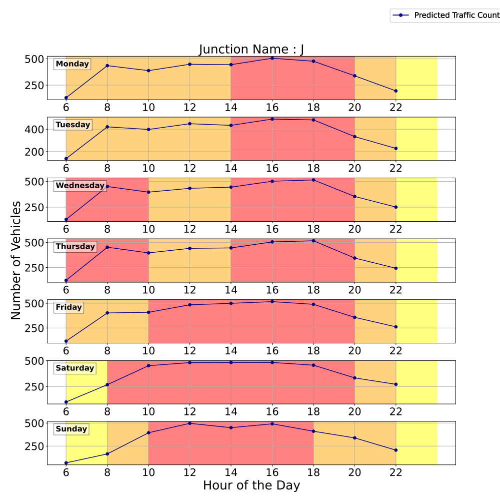
(a) Traffic at Point G



(b) Traffic at Point H



(c) Traffic at Point I



(d) Traffic at Point J

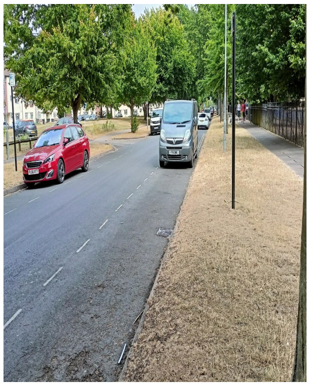
Figure 7: Traffic Congestion in Cambridge Car Route

the railways. All paths are through residential areas and some parts of the path are enclosed by buildings causing a tunnel effect.

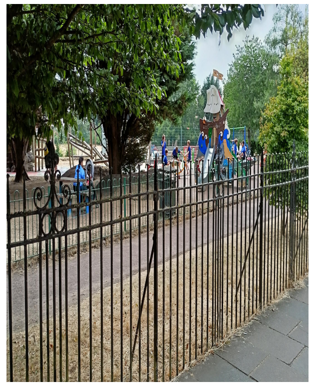
The car route (i.e., Mersea Road) in Colchester versus the bike route near the edge of the parks and green spaces is an interesting area to compare air quality. Some parts of the bike route are not strictly for bikes like in Location 5 compared to Location 6 (Figure 9), especially the ones adjacent to the park. There are also hedges along the green spaces which may also cause urban canyons or tunnel effects. Locations 3 and 4 are more polluted as they are major junctions on the car route (refer Figure 9). The data collection timings were a bit more restricted in Colchester due to resource constraints.

The main pollutants being monitored are particulate matter, $PM_{2.5}$, and PM_{10}, and gaseous pollutant, NO_2. As mentioned earlier, multiple air quality equipment were used for this study including Aeroqual industrial grade sensor, low-cost Plume sensor, and the custom sensor developed in-house. The Plume device demands a 7-day burnout period, particularly in a new location. Hence the readings from this device did not seem reliable or were not showing reasonable values. There were two Plume devices and both devices were showing entirely different readings. These device readings did not render useful for this study.

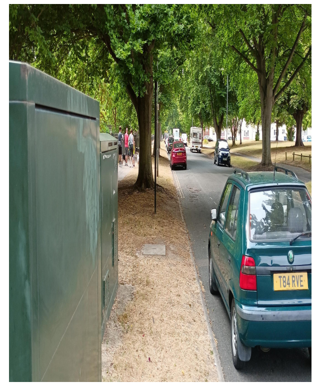
The custom sensors were designed by the group using sensor chips connected to Raspberry Pi3 and Pi Pico for PM particles and NO_2 respectively. These custom sensors on the other hand are a bit naive and not calibrated or evaluated extensively. Hence



(a) Location C



(b) Location C



(c) Location C

(d) Location B

(e) Location B

Figure 8: Bike Path locations for Cambridge

(a) Location 3 Car route

(b) Location 4 Car route

(c) Location 5 Bike route

(d) Location 6 - Bike route

Figure 9: Car and Bike Path locations for Colchester

Aeroqual was accepted as the agreed choice of monitor. The results here are focused on the Aeroqual sensor that looks at the 3 pollutants mentioned above.

4. Results and Discussions

The air quality monitored at different locations in Cambridge and Colchester are averaged and plotted as heatmaps on the map. The heatmaps are available at the link

https://thriving-travesseiro-3c3ad6.netlify.app/.

4.1. Measurements and Data Analysis

The heatmaps showing the average value of the pollutants at each location in Colchester are demonstrated in Figure 10 and the corresponding location-wise distribution of the readings is shown in Figure 11. The diameter of the colored circles represents the average values at each location. As mentioned earlier, locations 1-4 are on car routes, and locations 5-8 are on bike or car-bike routes.

Aeroqual PM_{10} distribution - It can be observed that the open green parks have slightly more PM_{10} particles. These particles could be mainly debris from trees, grass, pollen and dust from the open green space around them [11, 66]. The open parks may have higher quantities of dust particles based on wind speeds, temperature and humidity [63]. Depending on the type or constitution of the particles, this pollutant may cause global warming and may affect climate change. These particles could also adversely affect human health if higher in number or with long-term human exposure. Overall, the distribution shows very low values for this pollutant, well below the WHO-recommended values.

Aeroqual $PM_{2.5}$ distribution - The $PM_{2.5}$ particles are particularly low in numbers here. It can be observed that the open green parks have slightly more $PM_{2.5}$ particles. These could be mainly constituted of smaller particles from trees, grass, pollen and dust from the open green space around the area. On-road transportation may also have a marginal ($\tilde{1}$%) impact on this pollutant [44]. They may also adversely affect human health if present in high numbers [68, 32] or with long-term human exposure [56, 17]. Overall, they are very low in count and may not be a concern at this location.

Particulate matter could also be emitted by the friction of tyres and wear and tear of the vehicles on the road. All the bike paths are adjacent to the car routes. Both PM_{10} and $PM_{2.5}$ could cause short-term health effects for citizens like allergic reactions (such as coughing, sneezing, eye, throat, nose and lung irritation, runny nose and shortness of breath), asthma and chronic respiratory diseases. But both these particles seem to be less than the WHO recommended maximum values of 0.015 and 0.005 mg/m^3 respectively.

Aeroqual NO_2 distribution - The NO_2 particles are the major pollutants from road traffic that are dangerous and emitted from the motor exhaust. It can be observed that there is a high concentration of pollutants in the major traffic junctions and is of major concern here. Location 3 seems to be the highest in pollutant concentration. Locations 5 and 8 even though on the bike route are very close to the main road traffic and hence have higher values. Overall the NO_2 values are more than the recommended maximum of 0.01 mg/m^3 for NO_2 emissions. NO_2 is harmful to humans and vegetation and is a precursor to tropospheric Ozone that contributes to climate change. This pollutant can also interact with other chemicals to form acid rain that can damage ecosystems and built environments. Hence this is a major pollutant that needs to be controlled. As mentioned earlier, NO_2 is generated by the burning of fossil fuels like petrol and diesel from motor transport.

The heatmaps for locations in Cambridge are shown in Figure 12 and the corresponding location-wise distribution of the readings are shown in Figure 13. As mentioned earlier, locations A-E are on car-bike routes and locations F-J are on car routes.

Aeroqual PM_{10} distribution - Similar to the Colchester, the bike path in Cambridge being adjacent to parks has a higher PM_{10} distribution. Again leaves and dust particles could be the main contributors to this pollutant.

Aeroqual $PM_{2.5}$ distribution - The distribution of $PM_{2.5}$ particles is very low. It can be assumed that some of the smaller dust particles including from the traffic on the route are negligible.

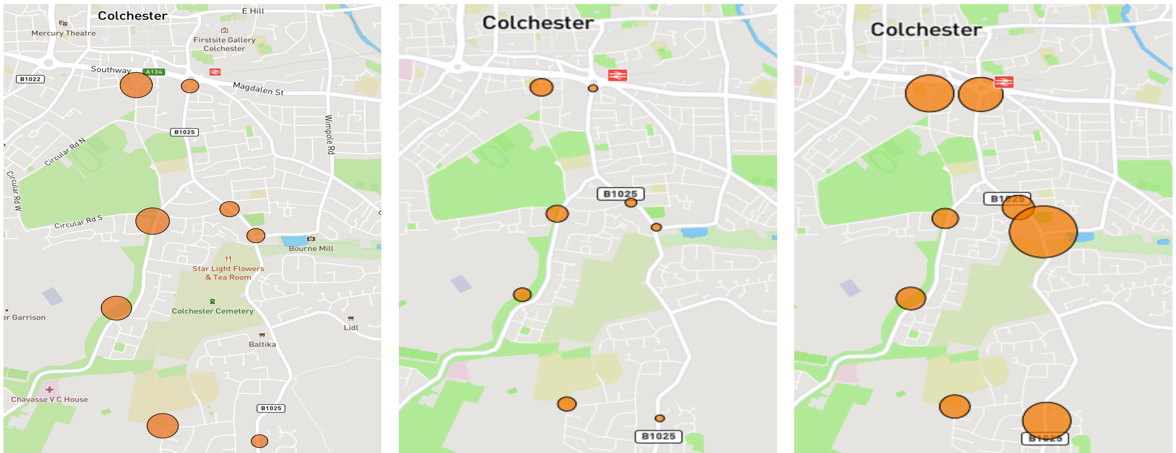
The overall distribution of particulate matter per location has an average close to 0 and overall below the recommended maximum values. Hence, they may not be a concern at this location.

Aeroqual NO_2 distribution - It is observed that the NO_2 distribution is higher in the busy junctions and roundabouts. Even on the bike path such heavy traffic junctions exist and it can be seen that the pollutant distribution is higher at these locations. The traffic junctions F and G have very high concentrations of this pollutant even more than the recommended maximum limits and hence may require urgent action.

Finally, the following interpretations could be made based on the results from this data.

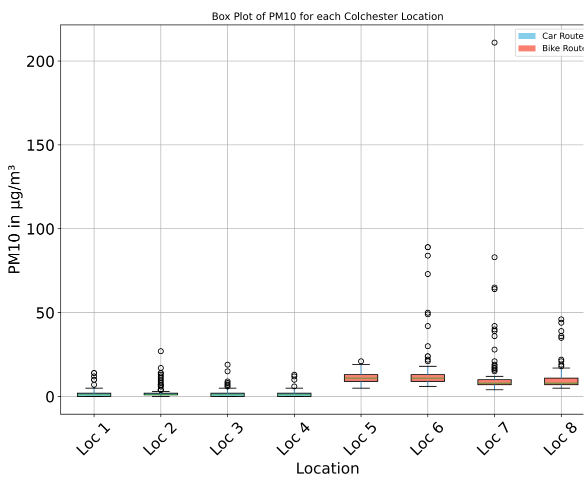
1. PM particles especially PM_{10} and $PM_{2.5}$ are more prevalent in open parks. But these are within the recommended maximum limits.

2. NO_2 as associated with traffic emissions are more prevalent in traffic zones and way over the allowed

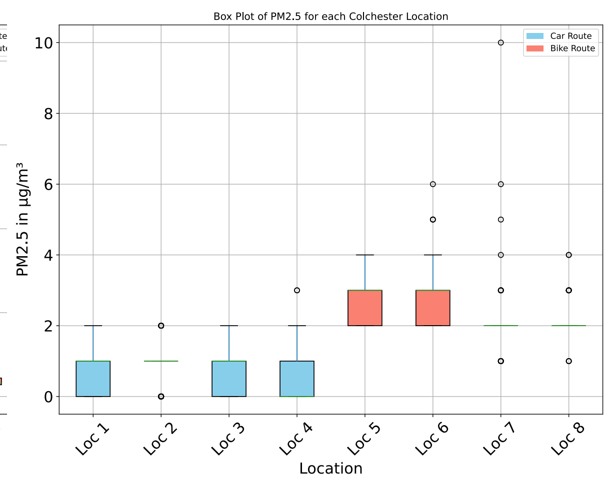


(a) PM_{10} in $\mu g/m^3$ (Min:0, Max:211) (b) $PM2.5$ in $\mu g/m^3$ (Min:0, Max:10) (c) NO_2 in $\mu g/m^3$(Min:0, Max:42)

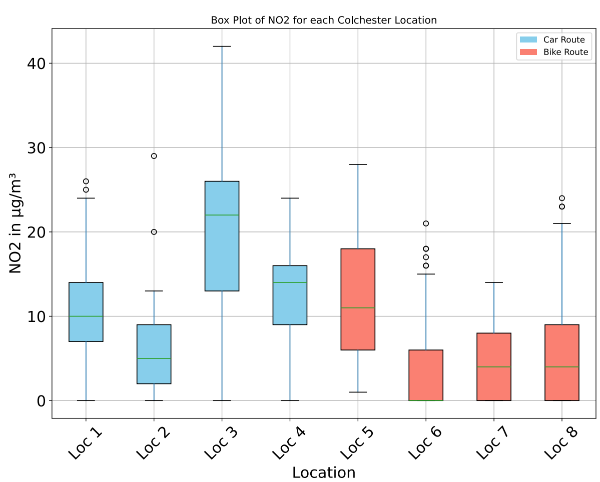
Figure 10: Air Quality Heatmaps for Colchester



(a) PM_{10} particles

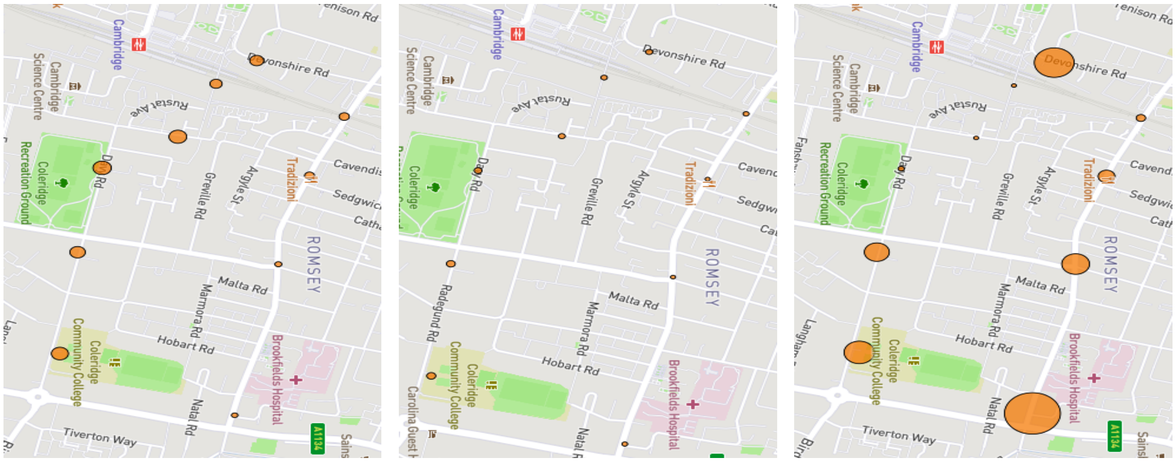


(b) $PM_{2.5}$ particles



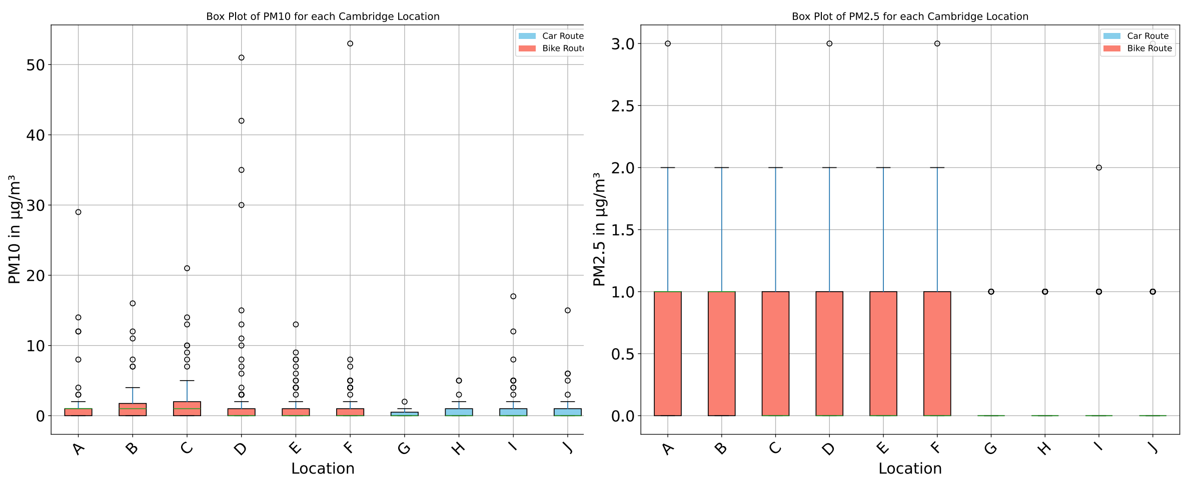
(c) NO_2

Figure 11: Air Quality Location-wise distribution for Colchester

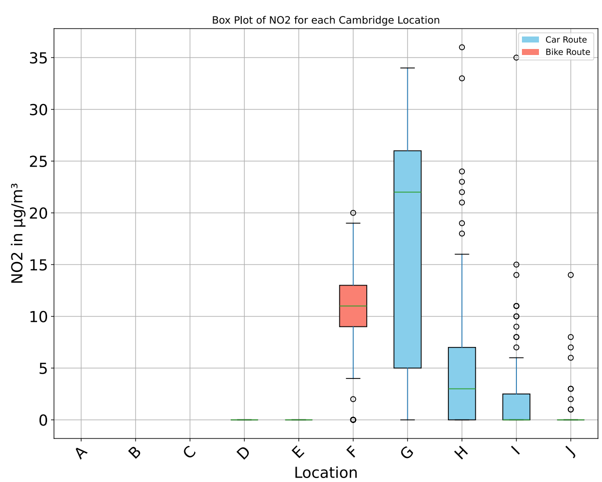


(a) PM_{10} in $\mu g/m^3$ (Min:0, Max:51) (b) $PM_{2.5}$ in $\mu g/m^3$ (Min:0, Max:3) (c) NO_2 in $\mu g/m^3$(Min:0, Max:36)

Figure 12: Air Quality Heatmaps for Cambridge



(a) PM_{10} particles (b) $PM_{2.5}$ particles



(c) NO_2

Figure 13: Air Quality Location-wise distribution for Cambridge

maximum limits.

3. There are outliers for both observations in both locations. E.g.
   - The dedicated/isolated bike paths in both cities rather than obvious car-bike routes could also address some of the safety concerns of the citizens on bikes.
   - The covered cycle bridge in Cambridge seems to be causing the urban canyon or tunnel effect as expected.
   - Residential roads with road constructions next to bike paths in Cambridge possibly due to diverted traffic or new urban planning are exceptional locations of concern.
   - The main junction or roundabout close to Mersea road in Colchester which is high in all pollutants due to heavy traffic and congestion.

The urban design perspectives for improving overall air quality are discussed in the following section.

4.2. Implication for Urban Planning and Local Authorities

City centres can be busier than the other areas due to the presence of activities and shops like our case studies. There are mitigation actions to be taken to reduce car use and pollution in city centres. The most fundamental action is to plan cities for people rather than cars. Nieuwenhuijsen [53] highlights the importance of inversing the transport planning pyramid. Cycling, walking, and use of public transport need to be prioritised over motor vehicles and cars. There are other mitigation actions that have been found effective in reducing car use and consequent reduction in pollution that local authorities could try with appropriate infrastructure and public transportation in place. For example, Congestion charges reported 12-33% reduction in city-centre cars, parking and traffic control seemed to have 11-19% drop in city-centre cars, and a limited traffic zone (excluding cars from part of the city, except for residents) had 10-20% reduction in city-centre cars [41]. But these drastic measures need to be accompanied by proper infrastructure and alternative transport options including frequent and affordable public transportation as available in the main European cities. Another way is to educate people through innovative methods on the consequences of their travel decisions which can encourage people to cycle and walk more.

Encouraging people to cycle and walk without providing the right infrastructure would not be an effective strategy as it cannot support the health and mental well-being of the citizens. According to the findings of this study, using car-bike routes, which are car routes with adjacent bike lanes, does not seem to be healthy for bikers given the current levels of pollution. On these routes, bikers are at risk of the direct impact of air pollution which was monitored in this study. Therefore, it's vital to provide bikers with dedicated bike routes that do not have high levels of air pollution at different times of the day. Where providing dedicated bike routes is not possible, the least strategy to protect the bikers from direct air pollution impacts is to separate bike lanes from car routes by vegetation in the form of hedges and trees. Having said that, in using vegetation, their types, and heights should be studied for any specific location to avoid any potential canyon effect. Another option to consider for the car-bike routes is to restrict motor transport on these routes during peak hours to prioritise bikers on these roads. The infrastructure should also include good connectivity with alternative and frequent public transport to cater to citizens who cannot use bikes or walk as a mode of transport or when the weather does not permit the use of these modes. For example, the congestion charges in London have been deemed a success only due to the extensive metro, bus and other modes of public transportation available to the citizens, which may not be the case in Cambridge while introducing similar measures in this city.

Planners and local authorities should be aware that any policy, action, or legislation, for new and existing urban developments, needs to consider health improvements as well, which is often not the case [49]. Furthermore, they should use health impact assessments [54] for the current and new mobility infrastructure and policies in cities to come up with the healthiest planning scenarios. To implement these scenarios, they should also make data-driven decisions based on the local data in relevant areas such as air quality data similar to the one presented in this paper.

One of the limitations of this study is that only two parallel roads have been considered in the two cities and measurements are made only on selected days. This study could be expanded to other routes, locations and cities in the UK or worldwide to generate wider impactful case studies. Also, multiple weather conditions are not considered due to resource limitations (including funds for extensive data collection). The next step in this research that the team is currently pursuing is using technologies like cityscape digital twins to model air quality and other factors using artificial intelligence for better policy visualisation to scale the locations of consideration for green travel infrastructure.

5. Conclusions and Future Work

This study looked at the parallel car and bike routes in two major cities in the UK - Colchester and Cambridge. Both gaseous pollutants and particulate matter as air quality metrics were directly monitored and recorded for further analysis. The data analysis on these recordings shows that there is a considerable amount of NO_2 emissions from road transport which could be controlled by green modes of travel including electric cars. The particulate matter though high in bike routes is mainly under the allowed limits and caused due to urban canyons and car routes being adjacent to it as well. The proposed policy recommendations include considering the bike path infrastructure in the light of public health like avoiding car-bike routes or limiting traffic near or on the bike routes or even designing green belt to separate these paths from roads that could encourage citizens to pursue this green mode of transport based on the clean air health benefits.

The results of this study will be presented to the respective local authorities to consider appropriate plans to improve infrastructure and sustainable urban planning for the future. The next steps would be to trigger citizen behaviour changes by encouraging the public to use the green mode of travel which could help climate action and facilitate healthy living. Similar data analysis studies need to be considered by the local authorities to understand the epicenters of emissions to plan appropriate action plans. Furthermore, policymakers should be able to use technologies like digital twins to be able to visualise infrastructure planning and their strategic actions to ensure the pathways to net zero. The research will focus on digital twins for air quality monitoring as the next immediate step in working toward climate action.

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