Simulation of traffic-related air pollution in Southampton using computer-based modelling

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Abstract—**The city of Southampton is committed to monitoring and reducing outdoor air pollution, in particular, Nitrogen Dioxide (NO_2) and Particulate Matter (PM2.5/PM10), which have been linked with adverse health effects under short- or long-term exposure. This project investigates the air pollution contributed by road sources in Southampton, by using Atmospheric Dispersion Modelling Software (ADMS-Roads). The model was validated by comparing the modelled concentration with the observed data from the Southampton AURN monitoring station. This study has found out that although the simulation exhibits a tendency to underpredict pollution concentrations, the dynamics of the model managed to capture the trends over time of the concentration of air pollutants consistently. The simulation has also correctly predicted poorer air quality within the Air Quality Management Areas (AQMA) declared by Southampton City Council (SCC), which implies that road sources have a notable contribution to air pollution. The advantages of this model are that it can be quickly altered to predict response to future policy actions and that it has sufficient resolution to be used for epidemiological studies linking air pollution with the prevalence of health conditions in the city. The findings so far indicate that further pollution control measures are still warranted as most of the pollutant concentrations from road sources exceed the latest (2021) WHO air quality guidelines developed to protect public health from the effects of exposure to air pollutants.**

Keywords—**Air pollution, air quality modelling, sustainable cities.**

I. INTRODUCTION

AIR POLLUTION is a global threat to people's health and to the environment. In order to protect public health from diseases associated with air pollution, the World Health Organization (WHO) recently revised their Air Quality Guidelines (AQG) levels as shown in Table I [1]. However, even exposure to air pollution below these regulated concentrations has been shown to affect health, with the range and magnitude of these effects still poorly understood. Therefore, continuous efforts are required to monitor and tackle air pollution.

The City of Southampton has had an Air Quality Action Plan since 2005 to address the poor air quality in the city, which is predominantly attributed to road traffic [6]. Since then, the city has seen steady improvement in air quality; however, continued modelling is still important to help inform future mitigation strategies.

TABLE I

WHO AIR QUALITY GUIDELINE (AQG) LEVELS [1]

Pollutant	Concentration ($\mu g/m^3$)		Measured as	Percentile
	2005	2021		
NO_2	40	10	Annual Mean	N/A
	-	25	24-hour Mean	99th
PM10	20	15	Annual Mean	N/A
	50	45	24-hour Mean	99th
PM2.5	10	5	Annual Mean	N/A
	25	15	24-hour Mean	99th

A. Aims and objectives

This project aims to model the contribution of road traffic to the air pollutants such as Nitrogen Dioxide (NO_2) and Particulate Matter (PM10/2.5) in Southampton in 2019 using ADMS-Roads. The objectives of the project are specified as follows:

- Identify appropriate selection of inputs such as road traffic, meteorological and measuring site data for the model;
- Create a dispersion model to predict the resulting pollutant concentrations from road traffic sources based on the inputs mentioned above;
- Perform model validation on a single-day event, which is the ABP Southampton Marathon Day against the short-term simulation results by tuning the settings based on sensible judgement;
- Perform further model validation by comparing the annual hourly pollutant concentrations obtained from Southampton Centre Monitoring Station (SOUT) with the short-term simulation results;
- Analyse the contour plots of long-term simulation, compare with WHO Air Quality Guidelines (AQG) levels and correlate with Air Quality Management Areas (AQMAs).

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II. METHODOLOGY

A. *Modelling approach (ADMS-Roads)*

ADMS-Roads software predicts the dispersion of air pollution from specified sources based on the Gaussian Plume equation. Required inputs to the model include the properties of the air pollution sources and background sources as well as meteorological data; these are detailed below. The model then outputs the resulting concentration map on a short-term hourly basis or as long-term annual statistics (ie. annual mean and 99th percentile of 24-hour exceedances).

This study focuses on modelling road sources to understand the contribution of road traffic in terms of pollutant concentrations in central Southampton over the span of a year. The domain of interest defined in this study shown in Fig. 1 encompasses most of the major "A" roads and other minor roads in Southampton.

The year of interest for the model is 2019. The reason for this choice is that due to the lockdowns in 2020, traffic data was significantly affected and had an atypical effect on air pollution. Because the objective of this project is to develop an accurate simulation of the traffic-related air pollution in Southampton that could be adapted in the future to inform new mitigation strategies, we decided to validate with 2019 data, which represents the most recent typical full year.

B. *Input data*

1) *Road sources data*

This study focuses on road traffic pollution in Southampton and includes the dominant road sources within the city to the exclusion of industrial sources. A total number of seven major roads were modelled in this study, namely A33, A35, A27, A335, A3024, A3035 and A3057 as shown in Fig. 1. Furthermore, several minor roads were identified manually to further investigate the contribution of minor roads to road traffic pollution.

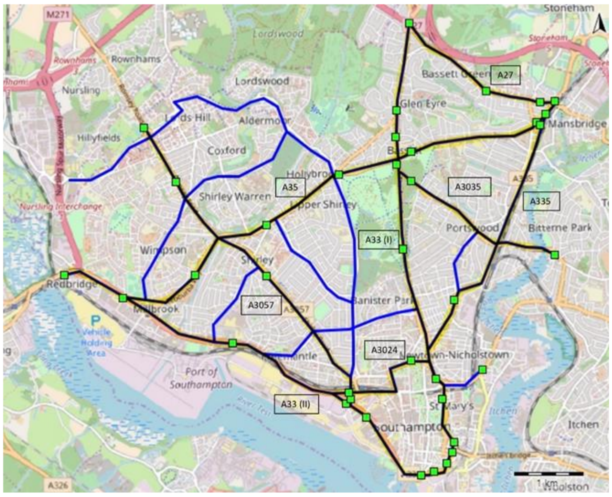


Fig. 1. *The geometries of major "A" (black) roads, minor (blue) roads and traffic count points of major roads (green boxes).*

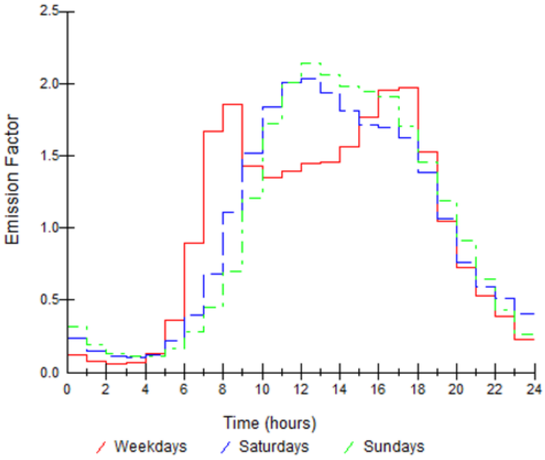


Fig 2. *Time series plot of the emission factor for Weekdays, Saturdays and Sundays.*

The vehicle count data on each major and minor road was acquired from the annual average traffic flow provided by the Department for Transport [2], which provides the sum of light and heavy-duty vehicles recorded by each traffic count point that lies within the roads. The emission rates of the pollutants by the road sources were automatically calculated based on this traffic flow information, using the Emission Factor Toolkit (EFT) v9.0 published by Department for Environment, Food & Rural Affairs (DEFRA) which is included in ADMS [5]. The year of emission was set to 2019 whereas the type of road emission was chosen as England (Urban) which best suits the simulation. The speed of the vehicle used in this simulation was taken from the Department for Transport road statistical data [3] which provided the average vehicle's speed on local "A" roads. In this model, the speed was assumed to be the same for both light and heavy-duty vehicles, which was approximately 42 km/h.

The road geometries of the model were identified and drawn manually within an accuracy of 1m in the Mapper of the ADMS-Roads software by joining the traffic count points of specific roads based on the map as shown in Fig. 1. Road elevation, gradient and canyon height were neglected since the topography throughout Southampton is considerably flat and buildings in Southampton are generally short.

2) *Time-varying emission factor*

As a starting point, the hourly traffic counts of each road were obtained through simple division of the newly computed daily traffic counts by 24-hour respectively. To reflect how traffic volume varies with the time of day, a time-varying emission factor was then applied based on Department for Transport data [4]. The time series plot of the emission factor is shown in Fig. 2. It can be observed that the emission factor of the night is the lowest across the week as the traffic activities are relatively less during that period. On weekdays, the emission factor reaches its peak twice at two separate periods, which are around 6 am to 8 am in the morning and 4 pm to 6 pm in the evening. This phenomenon is reasonable as these are the rush hours which correspond to the start and the end of the day. On the other hand, the emission factor for weekends shows a different trend compared to weekdays as the period where the emission factor peaked at around 12 pm to 2 pm in the afternoon.

3) *Meteorological data*

Meteorological data is an essential input to characterise the atmospheric conditions and calculate the effective diffusivity of the model. Unlike other models which use Pasquill-Gifford stability categories, ADMS-Roads determines the atmospheric stability from the boundary layer depth and Monin-Obukhov length from the meteorological inputs provided. There is a minimum requirement of at least 3 meteorological parameters to be inputted in order to run the model, which are stated below:

a. Wind speed;
b. Wind direction;
c. And one of the following:
  - The inverse length of Monin-Obukhov
  - Cloud cover, time of day and year
  - Surface sensible heat flux

The Monin-Obukhov inverse length and surface sensible heat flux are relatively difficult to acquire due to their complexity and low availability. Hence, the cloud cover, time of day and year data were selected to be one of the three required inputs in this model.

Hourly sequential meteorological data from January 1st, 2019, to December 31st, 2019, was obtained through direct purchase from Met Office, UK [7]. This includes data of cloud cover, wind speed and direction from the Middle Wallop Station. The wind conditions of the year 2019 are summarised in Fig. 3 using the wind rose plot generated by ADMS-Roads software. Additional information such as the hourly data of temperature, relative humidity and precipitation where estimated from the nearby Otterbourne Waterworks Station. These additional parameters aid the model in providing a better estimation of the boundary layer height if it is not specified as suggested in the ADMS-Roads User Guide [5].

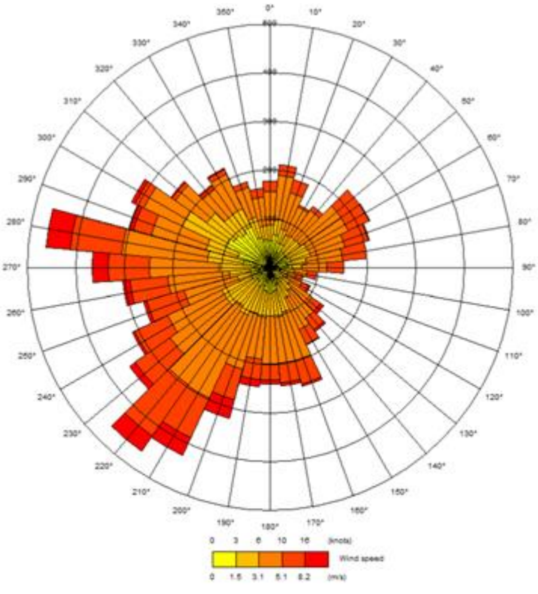


Fig. 3. *Wind rose plot of Southampton between 1st January 2019 to 31st December 2019.*

TABLE II
SUMMARY OF ADDITIONAL MODEL PARAMETERS

Surface roughness	1.5 m
Surface albedo	0.23
Priestley-Taylor parameter	1

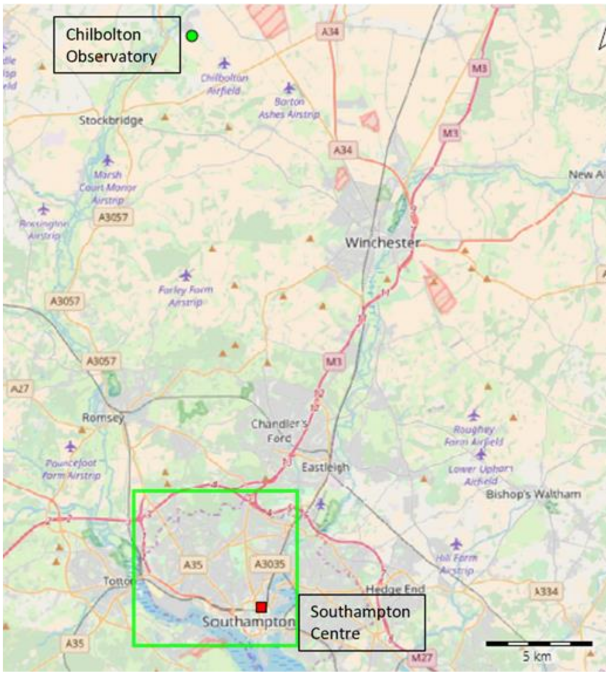


Fig. 4. *Location of AURN's Chilbolton Observatory (green circle) and Southampton Centre Monitoring Station (red box)*

Advanced parameters also included in the model to obtain more accurate results and are summarised in Table II. The surface roughness for both measurement sites were set to 1.5m which corresponds to an urban area which represents the terrain of Southampton. The value of surface albedo was 0.23 which correlates to the ground that is not covered by snow. This selection is justified by the rarity of snowfall in Southampton throughout the year. The Priestley-Taylor parameter which tells the moisture of the surface available for evaporation was adjusted to 1 as this value corresponds to moist grassland, which is the closest representation of the environment of Southampton among other selections. Lastly, the minimum Monin-Obukhov length was toggled such that it will be automatically calculated by the model based on the selection of the surface roughness.

4) *Background and sensor data*

A background station provides the level of pollutant contributions from other sources which are not modelled in the study. The Chilbolton Observatory (CHBO) is the only rural monitoring site nearest to the simulation domain. It is part of the Automatic Urban & Rural Network (AURN), which is the largest automatic monitoring network currently operated by DEFRA in the UK [8]. This rural site is located approximately 20 km away from the experimental site of this study as shown in Fig. 4. The background data of the concentration of the pollutants extracted from the CHBO are NO_2, PM10 and PM2.5 for the year 2019.

The main urban monitoring station located in Southampton is the Southampton Centre Monitoring Station (SOUT) which is also run through AURN [8]. It is not suitable to be used as background data due to its proximity to road sources. Nevertheless, the pollutant concentrations data from SOUT are still used for the purpose of model validation of this study.

5) *Output*

The default output grid resolution for the model is 31 x 31 grid points. The idea of increasing the number of grid points to achieve higher resolution was retracted due to several reasons. This is because finer resolution will yield drastic amount of simulation time, but the pollutant dispersion and concentration far away from the sources could be insubstantial to be considered in certain scenarios as the grid points will always be evenly distributed regardless of the number. Therefore, in order to obtain results with greater accuracy without increasing the number of grid points and compromising the simulation time, source-oriented grids feature was used in this model. By toggling this feature, ADMS-Roads software will automatically increase the number of receptor points around the sources which improves the resolution significantly. Hence, this feature provides finer resolution whilst retaining the number of grid points defined by the user with adequate simulation time.

As mentioned previously, the type of pollutants that will be studied in this model are NO_2, PM10 and PM2.5 as these are the pollutants that received the most attention based on legal guidelines in Southampton. It is worth mentioning that the non-exhaust sources of PM such as brake, road and tyre wear were included in the model output for this study.

ADMS-Roads software provides two types of simulations, short and long-term simulations, which serve different purposes in this study. The short-term simulation will provide a hourly pollutant concentration values of a specific point, which is particularly useful in validating the model [5]. Hence, model validation of this study was carried out by comparing the result of the short-term simulation of different scenarios with the pollutant concentration data extracted from SOUT. Conversely, the long-term simulation provides only a single set of pollutant concentration data by compiling statistics from over the year, and contour plots can be generated based on the dataset. Thus, long-term simulation was used in this study to analyse the annual pollutant dispersion and its concentration based on the contour plots. Not only that, additional features exclusive to long-term simulation such as percentiles and exceedance thresholds were also defined accordingly so that the results can be used to compare with the latest WHO air quality guidelines.

III. MODEL VALIDATION

Model validation is a crucial aspect of this study as it can be used to verify how predictive the model is, as well as provide the details of the model's nature. This can be done by comparing the pollutant concentrations from the monitoring sites with the modelled values obtained from short-term simulation and performing in-depth quantitative and qualitative analysis based on two different scenarios for all three pollutants mentioned above.

A. *Special scenario: Marathon Day (Single day validation)*

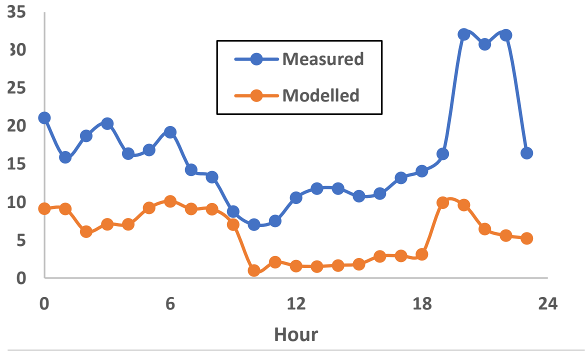
A short investigation was carried out by identifying one particular event which resulted in temporary road closures in order to evaluate the dynamics of the model in predicting the changes in pollutant concentrations depending on the scenario of a single day. The ABP Southampton Marathon Day held on 5th May 2019 with multiple road closures was selected as a special scenario.

Short-term simulation was performed by turning three major roads which are the A335, A3035 and A3024 off in the model to mimic the effect of the road closures, with an assumption that these roads will be closed for 24 hours on that day due to the limitation of the ADMS-Roads software. These roads were omitted because they were the roads with the longest period of closure whilst the other major roads were either unaffected by the event, or the time of closure was minimal.

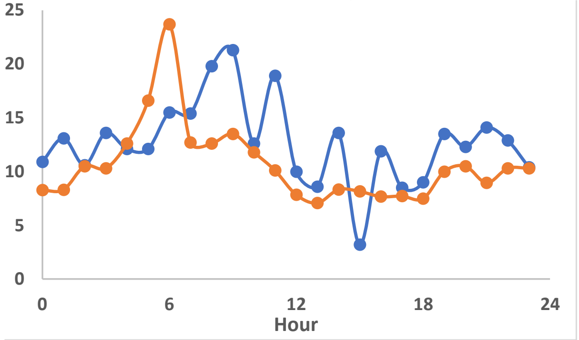
A time-series of the resulting pollutant concentrations over the day from the simulation are plotted alongside the actual measured pollutant concentrations obtained from the SOUT station in Fig. 5. A qualitative comparison of the measured and modelled data provides some insights to the validity of the model.

From the time-series plot shown in Fig. 5(a), it can be seen that the model clearly underpredicts the NO_2 concentration; however this bias is not unsurprising and simply suggests that there are sources of NO_2 other than road-traffic that make a significant contribution at this location. However, the model clearly reflects the same temporal trend of NO_2 over the day, showing that the model accurately captures the dynamics of NO_2 concentrations.

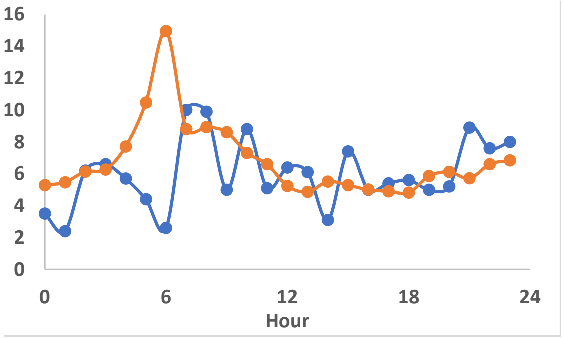
The plots in Figs. 5(a) and (b) show quite good agreement between the modelled and measured concentrations of PM10 and PM2.5. The lack of significant bias confirms that road traffic is the predominant source of these pollutants. The fact that the plots exhibit similar trends over the duration of the day confirms that the model properly captures the dynamics of the pollutant dispersion. The only notable difference is around 6 am in the morning at which time the modelled PM10 and PM2.5 concentrations were significantly higher than the respective measured concentrations. One scenario that could explain this would be if the weather station data indicated stable atmospheric conditions that morning,



(a) NO_2 ($\mu g/m^3$)



(b) PM10 ($\mu g/m^3$)



(c) PM2.5 ($\mu g/m^3$)

Fig. 5. *The hourly concentration of (a) NO_2, (b) PM10 and (c) PM2.5 over 24 hours on 5th May 2019 (ABP Southampton Marathon Day)*

which could trap pollution, which had already cleared at the SOUT monitoring station.

In general, the conclusion that can be drawn from this test case is that the model does a good job at capturing the magnitudes and dynamics of the three pollutants, however, underpredicts NO_2. This test also showcases the relatively flexibility of the model as it can be tuned accordingly to adapt to special scenarios while retaining a good prediction of pollutant concentration over time.

Nonetheless, validation with a single day is not entirely sufficient to fully evaluate the model's performance. In the next section, further validations of the hourly pollutant concentrations across the entire year are performed to obtain a more quantitative appraisal of the model's performance.

B. *Annual hourly pollutant concentrations validation*

Further validation was done by comparing the modelled pollutant concentrations with the measured pollutant concentrations extracted from SOUT for every hour of meteorological data available throughout the year 2019. The simulated hourly pollutant concentrations were obtained by defining the SOUT station as the receptor point when running a short-term calculation. This data was then used to construct scatter plots of the modelled versus measured hourly concentrations to analyse the correlation between the values as shown in Fig. 6.

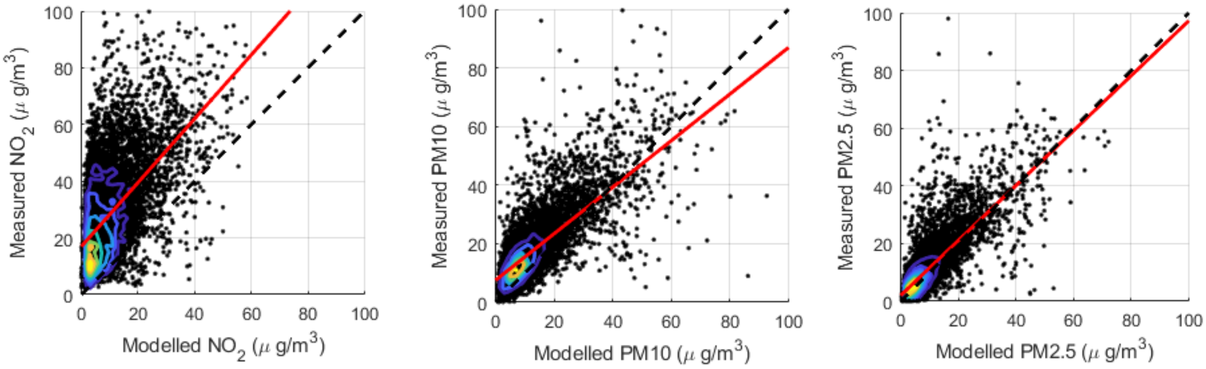
A combination of regression and statistical analysis is used to evaluate model. If the model was perfect, all values would fall on a 1:1 line; however, from the scatter plots we can evaluate the random and bias errors of the simulation.

The bias error can be calculated as the y-intercept of the trend lines through the scatter plots in Fig. 6. Bias offsets of 17.0 $\mu g/m^3$, 7.3 $\mu g/m^3$ and 1.8 $\mu g/m^3$ were observed for NO_2, PM10 and PM2.5 respectively. These values indicate that the model is under-predicting the pollutant concentrations compared to real life and are equivalent to 61%, 42% and 19% of the mean measured pollutant concentrations for NO_2, PM10 and PM2.5 respectively. As mentioned previously, this under-estimation is not surprising due to several reasons. For one, the location of the monitoring site where the background data was extracted is relatively far away from the Southampton city centre. As such, the background data might not capture the pollutant concentrations contributed by other major nearby sources and thus lead to under-reporting of background level concentration in the simulation. This could be improved if more background data were available. Secondly, sources of pollution other than road traffic might be having a significant effect. Given that Southampton is a major port city, pollutant emissions from ships and other industrial activity could be contributing to this bias. Assuming that these additional sources of pollution are fairly constant in time, if this model is used to test future scenarios, the percentage bias offset found in the regression model can be used as a reference to formulate correction factor to overcome the underpredicting issue of the model.

The dynamics of the pollution dispersion appear to be captured well by the model. This can be seen in Fig. 6 as the gradients of the best fit lines for all three pollutants are approaching 1:1, which shows a positive correlation between the measured and modelled pollutant concentrations. This provides confidence that the dynamics of the model are capturing and predicting the changes in PM concentration over time consistently. It can be concluded that the results of the model still are relatively promising despite the under-predicting issue.

IV. RESULTS

Long-term simulations were used to generate contour plots of key statistics of each concentration in order to visualise the distribution of air pollution across the city. Annual average concentrations and 24-hour mean exceedance percentiles of each pollutant were determined from the simulation in order to compare the simulated air



(a) NO_2

(b) PM10

(c) PM2.5

Fig. 6. *Scatter plots of all the hourly pollutant concentrations for the full year measured at the Southampton Centre Monitoring Station (SOUT) against the respective modelled hourly concentrations for (a) NO2, (b) PM10 and (c) PM2.5. Coloured contour lines help visualise the density of the cloud of data. A red line represents the trend line, which if there was perfect correlation would fall on the 1:1 line indicated by the dashed line.*

quality of Southampton with the WHO global AQG levels shown in Table I. The regions of the map with the highest air pollution concentrations are compared with the locations of the designated Air Quality Management Areas (AQMAs) in Southampton.

A. *Annual Mean Concentrations (contour plots)*

Contour plots of the annual average concentration of all the pollutants are shown in Fig. 7. A few conclusions can be drawn. It can be observed that NO_2 and particularly, PM2.5 tend to disperse to the northeast direction as the prevailing wind in Southampton is predominantly from the southwest direction as shown in the wind rose plot in Fig. 3. PM10 does not disperse as much as the other two pollutants as it is heavier and hence falls out relatively earlier. On the contrary, the gradient of the PM2.5 concentration across the area is significantly small as the difference between the lowest and highest concentration is approximately 1.4 $\mu g/m^3$, which suggests that PM2.5 has the greatest dispersion among other pollutants, and it can stay in the atmosphere for a longer period as expected. The dispersion of NO_2 is fairly uniform which concentrates among the road sources. It is also worth noting that the locations with the highest pollutant concentrations are the junctions where the major roads intersect one another. This will be further discussed in the AQMA section. It can also be seen clearly that minor roads have minimal contribution towards air pollution compared to the major roads.

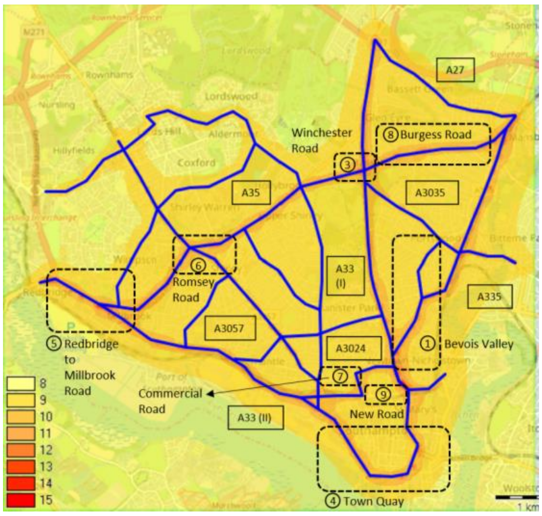
It should be highlighted that in certain areas of the city, the annual average concentration exceeds the WHO AQM levels for NO_2 and PM2.5. This doesn't consider the fact that the model was shown to under-predict all three concentrations. Moreover, the exceedance of NO_2 and PM2.5 concentrations are observed in most of the regions in the simulation, which indicates that even the background level concentration is reaching the borderline.

B. *24-hour mean (contour plots)*

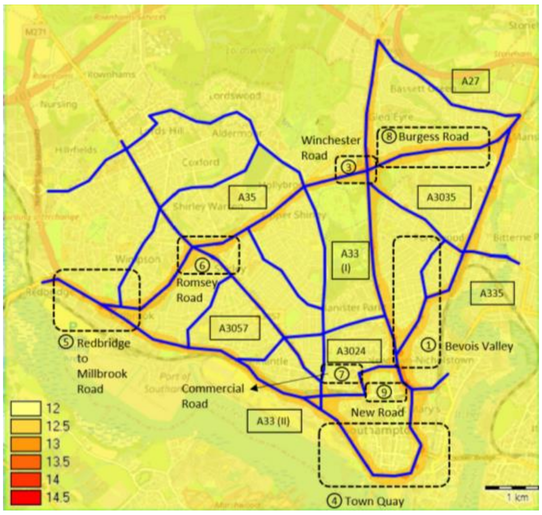
Contour plots of the 99th percentile of the 24-hour mean are presented in Fig. 8 for NO_2, PM10 and PM2.5. The 99th percentile is equivalent to the 4th highest value of the 24-hour mean measured over the entire year. These plots can be compared with the exceedance thresholds of the AQG level for each pollutant from Table I. From Fig. 8, it can be concluded that the 99th percentile of NO_2, PM10 and PM2.5 concentrations have failed to meet the latest AQG level, with PM2.5 as the worst exceedance of approximately 160%. NO_2 concentrations were exceeded by 80% while PM10, being the lowest exceedance among the pollutants, was exceeded by 6%. Based on these findings, this suggests that the air quality around Southampton could pose serious health issues for the public, especially those who reside near road sources could experience the worst air quality compared to other areas.

C. *Air Quality Management Areas (AQMAs)*

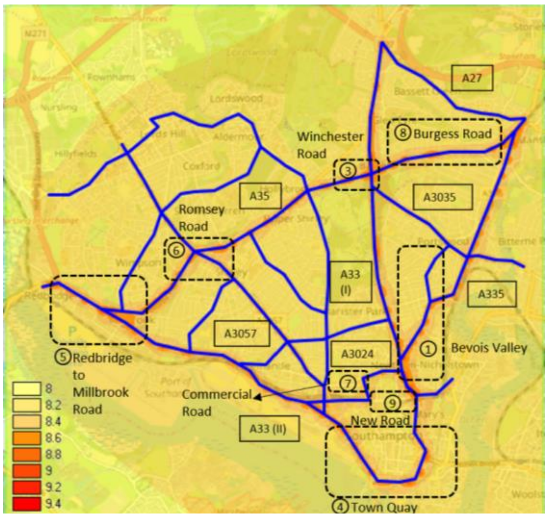
In 2005, the Southampton City Council (SCC) declared areas within the city with high level of pollutant concentration level as Air Quality Management Areas (AQMAs) such that further remedial actions can be undertaken to improve the air quality. The list of the AQMAs declared within Southampton are tabulated in Table III. Out of the ten AQMAs in Southampton, Bitterne Road West and Victoria Road were excluded from this study as they are located outside of the simulation domain. Furthermore, Commercial Road and New Road were not modelled in the study as they comprise minor roads with insufficient traffic data available. This could lead to rising concerns over potential undetected minor roads with notable pollutants contribution within Southampton and it should be one of the top priorities for future work. Nevertheless, the location of these two areas is close to the A33 resulting in high NO_2 concentrations anyways, as shown in Fig. 7(a).



(a) NO$_2$ ($\mu g/m^3$) – AQG limit is 10 $\mu g/m^3$

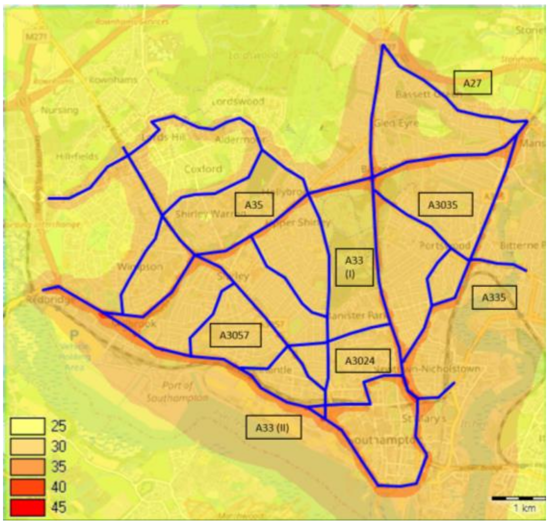


(b) PM 10 ($\mu g/m^3$) – AQG limit is 15 $\mu g/m^3$

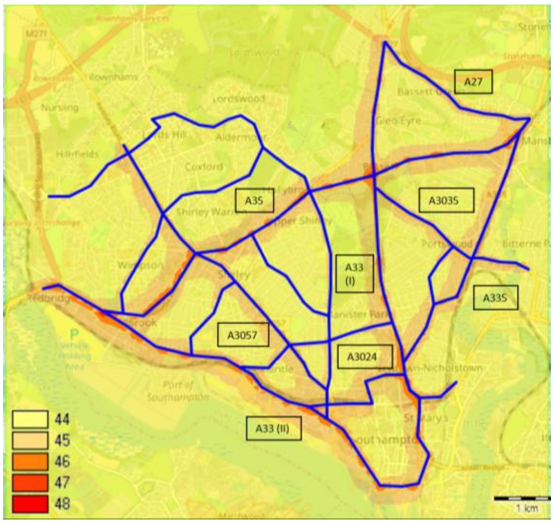


(c) PM2.5 ($\mu g/m^3$) – AQG limit is 5 $\mu g/m^3$

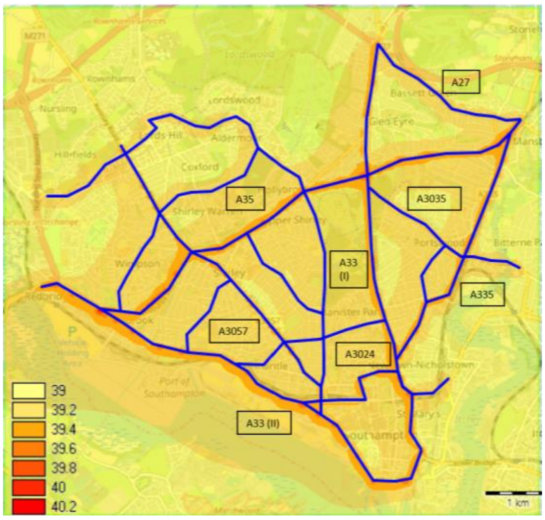
Fig. 7. *Comparison between AQMAs and the annual average concentration maps of (a) NO$_2$, (b) PM10 and (c) PM2.5*



(a) NO$_2$ ($\mu g/m^3$) – AQG limit is 25 $\mu g/m^3$



(b) PM 10 ($\mu g/m^3$) – AQG limit is 45 $\mu g/m^3$



(c) PM 2.5 ($\mu g/m^3$) – AQG limit is 15 $\mu g/m^3$

Fig. 8. *Maps of 99th percentile of the 24-hour mean concentrations of (a) NO$_2$, (b) PM10 and (c) PM2.5*

TABLE III
LIST OF AIR QUALITY MANAGEMENT AREAS (AQMAS) IN SOUTHAMPTON [6]

No.	AQMA	Remarks
1	Bevois Valley	Modelled
2	Bitterne Road West	Outside simulation domain
3	Winchester Road	Modelled
4	Town Quay	Modelled
5	Redbridge to Millbrook Road	Modelled
6	Romsey Road	Modelled
7	Commercial Road	Not included in model
8	Burgess Road	Modelled
9	New Road	Not included in model
10	Victoria Road	Outside simulation domain

By comparing the locations of the listed AQMAs with the contour plot of the annual average NO_2 concentration in Fig. 7(a), it can be observed that most of the areas with high levels of NO_2 concentrations lie within the AQMAs. The areas with the highest NO_2 concentration are typically the junctions of the major roads especially the Redbridge to Millbrook Road junction, Winchester Road junction, to name just a few, which are part of A33 and A35. This is due to the traffic build-up at the junction during peak hours which leads to higher emission of pollutants near the road sources. The build-up of the traffic will also subsequently affect the roads leading towards the junction and thus result in higher pollutant concentrations, as seen in Burgess Road. It is safe to conclude that the results of the long-term simulation agree well with real-life as the model accurately predicted most of the AQMAs within Southampton.

The AQMAs declared are mainly focusing on the level of NO_2, however, further finding discovered that PM10 and PM2.5 also exhibit a trend of high concentration in similar spots that were observed in the case of NO_2 from the contour plots in Fig. 7(b) and (c). This suggests that the AQMAs monitoring efforts should also include PM as one of the pollutants to be monitored periodically as it could potentially threaten public health by exposure to that level of concentration based on the AQG level.

V. Conclusions

It can be concluded that the results confirm that Southampton has failed to meet the latest WHO air quality guideline levels and that road sources are indeed one of the main contributors to NO_2, PM10 and PM2.5. The areas with the worst air quality are at the junctions of major roads and are captured well by the city's designcated Air Quality Management Areas (AQMAs). This suggests that individuals that reside near major roads could potentially face higher health risks associated with poor air quality. Therefore, these findings signify that prompt and remedial actions should be taken soonest possible to achieve the WHO air quality guideline levels set to reduce the risk of public health against exposure to air pollutants. We have demonstrated that this model can be a powerful tool for evaluating future policy interventions and traffic management strategies to meet safety guidelines for public health.

A. *Future Improvements and Recommendations*

The model could be improved by focusing on overcoming the limiting factors. Correction factors can be formulated to counteract the under-prediction; however, preferred improvements would include:

- Modelling additional major sources of pollutants emissions, such as maritime and air traffic, power stations and the "M" roads.
- Setting up additional background stations at desired locations.
- More detailed and accurate road traffic data especially for minor roads is needed.

Future work will use this model to predict the outcomes of traffic calming plans and other mitigation strategies on the air quality in the city. We hope to further leverage this data as a medical research tool for exploring associations between disease and air pollution and approximating personal exposure without heavy reliance on monitoring stations.

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