Assessment of spatial variations of Nitrogen Dioxide, Black Carbon and Particle number, prior to traffic interventions in Glasgow.

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Abstract

Local authority air quality assessments do not give a complete indication of air pollution in the area because of a limited number of monitoring locations and equipment. The west end of Glasgow does not comply with air quality objectives for NO_2 levels and was declared an Air Quality Management Area. Efficient monitoring approaches can provide improved knowledge in such areas.

This study examines correlations between pollutants measured using spatial and mobile monitoring methods in an area of Glasgow with planned traffic control interventions to mitigate traffic related air pollution. Black Carbon (BC) aethalometers and Particle Number (PN) real-time monitors were used to make short term observations at 18 diffusion tubes sites on a weekly basis for five weeks during Oct/Nov.

High correlations were observed between NO_2 and BC (r=0.74), and between BC and PN (r=0.69). Lower correlation was observed between NO_2 and PN, (r=0.34). Higher concentrations of pollutants were observed close to busy roads; and lower concentrations were observed in visibly quieter residential streets; thus giving good indication of high traffic areas and a study into the area prior to traffic interventions.

Acknowledgments

The author would like to thank Dr Iain Beverland, Jonathan Gillespie and Nicola Masey (University of Strathclyde) for their contribution.

Introduction

Air pollution health around the world

The World Health Organisation indicates that across the world, 7,054,600 people died in 2012 from air pollution effects (WHO, 2014). It is well established that Traffic Related Air Pollution (TRAP) causes serious effects in human health and mortality (Walsh, 2013, Chen 2012, Australian Government, 2005). Black carbon (BC) and Nitrogen Dioxide (NO_2) are good indicators of TRAP (Brook et al. 2010, Donaldson et al. 2005). Overall, traffic related air pollutants are a major concern to the health of the population and more measures are needed to reduce these statistics.

Focus on Glasgow

Byres road and Dumbarton road, situated in the West end of Glasgow, are classed as an Air Quality Management Area (AQMA). Under EU law, controls should be planned to reduce pollutants and improve overall air quality. One of the busiest areas of Glasgow, thousands of vehicles currently passes through Byres Road each day.

Glasgow was one of three zones in the UK, and the only in Scotland, to fail and exceed the 200µg/m3 more than 18 times per annum (Brookes D et al. 2011). The opportunity to study new monitoring controls in a known polluted area could benefit from the monitoring control models.

Pollutant used to measure Traffic Related Air Pollution

NO_2 is a major component of current emissions, more is needed to reduce this pollution. In 2011, Scotland represented 10% of total NO_2 emissions in the UK. Road transport combustion sources accounted for 29% of total emissions in 2011 (Thistlethwaite, 2013).

Black carbon has become a major interest for policy makers as a good indicator of TRAP, global warming and adverse health effects; more evidence suggests BC as a pollutant to be monitored by the EU (Janssen et al. 2011). NO_2 is currently being monitored through EU legislation whereas Black Carbon is not monitored by local authorities.

In 2005, NO_2 European Union air quality objectives were set at 40µg/m3 as an annual mean and 200µg/m3 as an hourly mean, with 18 accidences allowed. The targets were not achieved on Byres road by 2005 or by 2010, resulting in the EU issuing the UK government heavy fines and penalties, as seen in the Council Directive on ambient air quality and cleaner air for Europe (2008/50/EC), and The Fourth Daughter Directive 2004/107/EC under the Air Quality Framework Directive (1996/62/EC).

Nitrogen Dioxide is easy to measure as it is a form of static monitoring, and considered in isolation when government offices are considering traffic polices, pollutant models and monitoring programmes (Tonne et al. 2008). Studies of the trends in NO_X and NO_2 emissions on UK roads suggest that standard engine tests that comply with EU emissions standards “did not reflect the performance of light vehicles or roadside measurement trends.” This study showed that UK NO_X and NO_2 emissions were substantially underestimated by ~25% and the UK would struggle to further meet EU NO_2 air quality objectives. Similar trends are predicted throughout the EU (Beevers D. et al. 2012). This indicates the need for co-monitoring of many pollutants to determine accurate monitoring statistics from static and mobile monitoring.

Local authorities at present, use Passive Diffusion Tubes (PDT) over a four week period before they are rotated. Studies in Edinburgh, found significantly lower concentrations in the 4-week results when compared to four sequential 1-week exposures over the same period (Heala et al. 1999). Effective use of the PDT is essential to gather an accurate picture of what an areas pollution levels are and to make an informed decision on action plans (Cape, 2009).

Black Carbon, second only to CO_2 as a climate change contributor, gives soot its black colour. CO_2 remains in the atmosphere for decades, whereas BC is only present for a period of 1-4 Weeks. If BC was reduced, immediate effects of reduced global warming would occur and reduce the atmospheric temperatures in the short term (Centre for climate and energy solutions, 2010). “Better information on spatial distribution, size, mixing state and monitoring” is needed (Highwood et al. 2006).

Traffic Related Air Pollutants (TRAP) metrics (NO2, BC, PN) need to be measured prior to traffic control interventions in Glasgow’s West. This study in collaboration with industrial partners, as part of NERC funded research, interfaced with the EU FP7 Carbotraf research project: (http://carbotraf.com/). Carbotraf is a traffic intervention project running from September 1st, 2011, to August 31st, 2014. Working in partnership, Strathclyde University has been involved in some measurements for this research project which looks at Glasgow and other European city pollutants. By analysing real-time data, models can be produced to measure TRAP in heavy traffic areas. The partnership has enabled the real-time data to be collected and correlated between pollutants. Correlations between these TRAP would benefit new designs in pollution controls, traffic technologies and monitoring relevant pollutants effectively.

Road characteristics and traffic controls affect the clarity and effectiveness of catalytic convertors and other filters in exhausts. A stop-and-go traffic system including traffic lights on roads increases TRAF (Traffic Related Air Pollutants) emissions due to acceleration temporarily reducing the efficiency of these filters (Fruin, S. 2008). Transport accounts for “almost a quarter of accumulated exposure” (Dons et al. 2013).

Identifying areas and characteristics of pollution could have an impact on future epidemiology and health of the population: identifying any correlations and patterns between static and mobile monitoring of air.

Difficulties in measuring Traffic Related Air Pollution

Particle Number is generally a good indicator of traffic areas, however, due to spatial and temporal variations difficulty can occur when taking measurements (Jimenez 2012). Glasgow is mainly composed of high tenement buildings making canyon like streets, this may cause difficulty in monitoring correlations between pollutants.

Despite the harmful effect on human health, a lack of scientific research into the relationships between NO_2, BC and PN, has indicated good scope for further study especially in Glasgow (Penttinen et al. 2000; PH Fischer et al. 2000). One such study into correlations between Nitrogen Dioxide and Black Carbon in Los Angeles showed a positive relationship between the two pollutants (Beckerman et al. 2008).

Options to control traffic pollution include: low emission zones, speed and traffic management (traffic lights), encourage cycling and public transport use, car manufacturers using new technologies in engines, electric motors, public awareness, reduction in car idling; to name a few. Monitoring sites are needed to help with planning effective traffic interventions to reduce air pollution.

Aim of project

To examine air quality in the west end of Glasgow, before traffic control interventions, and to examine the correlation between different metrics of Traffic Related Air Pollutants. To develop a novel monitoring technique to characterise spatial variations in Glasgow.

Methods

Site details and design

Air Quality Management Area (AQMA), the surrounding environment and high traffic volumes: were all reasons Byres Road was chosen for the study of correlations between pollutants and the before study of traffic control interventions. The sites were also chosen due to the contrast in traffic flow, wind direction and canyon effect in this residential area typically seen in the city of Glasgow.

The evaluation and surveying of traffic related air includes quantitative methods and metrics of TRAP to examine air quality prior to traffic control interventions. Around fifty-four diffusion tubes were deployed each week at eighteen sites in a 1 km area route from University Avenue, through Byres Road and down towards Dumbarton Road via Lawrence Street and Dowanhill Street. A five week period was chosen to focus on a small in-depth investigation during the months of October and November during rush period in Glasgow (8-10AM / weekday).

Figure 1: Photo of Byres Road

Two groups involved in data collection starting from the same point; one person to Kelvingrove Park to the chosen background site 18. The remaining people continued around the sites with monitors and tubes.

Three passive diffusion tubes (PDT) were deployed at each site. For each location, a five minute time period is spent to ensure accurate measure of pollutants, and to allow time for the PDTs to be placed securely at each site. One week later, each PDT would be recollected under the same requirements (five minute waiting period), this was completed for a period of five weeks.

The eighteen site street locations vary in traffic vehicle size and volume. Byres road and Dumbarton road (sites 6, 7, 16 and 17) have the highest volumes of continuous traffic passing by, including a wider variety of motorized vehicles (e.g. buses). On Lawrence Street and Dowanhill Street; this residential area has large volumes of parked cars and no bus access; overall less moving traffic in comparison with Byres Road. Sites 1-6 are surrounded by the University of Glasgow buildings and the Western Infirmary Hospital which has many vents directed onto the street sites (University Place).

Figure 2 and 3: Photo of Dowanhill Street and Laurence Street.

The local authority’s passive diffusion tubes are located on Lawrence Street and Dumbarton road. One deployed on each street, compared with the fifty four tubes being deployed in the same area, site 9 was the same post used by L.A. Photographs of figure 4 and 5 were taken at sites 6 and 18 (Byres road 6 and the background Kelvingrove park site 18).

Figure 4 and 5: deployment of tubes

Nitrogen dioxide

When passive diffusion tubes were being deployed, they are kept in dark sealed bags to prevent light degradation. The PDT is placed onto pre-chosen site posts, around two metres high and their bottom caps are removed to start the air exposure for a period of one week.

To prepare the passive diffusion tubes to absorb nitrogen dioxide, the absorbent triethanolamine (TEA) is used to coat two stainless steel meshes at the closed end of the PDT using an acetone-based solution (DEFRA, Feb 2008).

Prepared PDTs are kept in the fridge until needed; this reduces the risk of contamination or degradation of the mesh and chemical components of the tubes. Once the NO_2 has been extracted from the samples in the labs, the solution is passed through a spectrophotometer analyser where the concentration of NO_2 in each sample can be determined from the light absorbed by a coloured reaction product.

Black carbon and Particle number concentrations

Black Carbon (BC) is monitored by a palm sized aethalometer; microAeth® Model AE51 (figure 6), carried by one individual once a week to the park and around all sites (Aethalometer 2014). The aethalometer records data at a rate of one minute time resolution.

A handheld TSI condensation particle counter (CPC) 3007, is used in the measurements of particles size ranging from 0.01 to >1.0 µm. This is carried at waist height by one individual. The condensation enlarges the particles using a condensing fluid of alcohol. This inserted into the instrument during the warm up period and taken out once the study is finished. The condensation particle droplets are then passed through a laser beam to produce light. Each light is counted as one particle. “Number concentration on all CPCs ranges from zero to at least 10,000 particles/cm^3” (TSI, 2012). The CPC monitor measures particles in all sizes (PM 10/2.5) in order to gain a perspective on how many particles are in the air. This particular handheld monitor is best for this type of study. Both mobile real-time monitors (BC and PN) were on for the full time of the project each week (~2.5hrs) to keep a steady data collection.

Regression models and Data analysis

The least squares data modelling technique, Reduced Major Axis Regression model was chosen to correlate all data, a statistical choice of modelling air quality data (Ayres 2001). This method of statistical analysis by minimising the product of the X and Y deviations and the area of the triangle created between the two points. This method is best for air pollution monitoring as it accounts the random variances in the X and Y values and not just in the Y values. The analysis takes into consideration all the errors when finding the best fit line with least squares, using the mean and standard deviations of all weeks to calculate the slope and intercept, correlation and regression. The formulas used were: R-squared values and graphs to monitor data and correlations: Slope = a1 (RMA) = Sy/Sx
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Results and Discussion

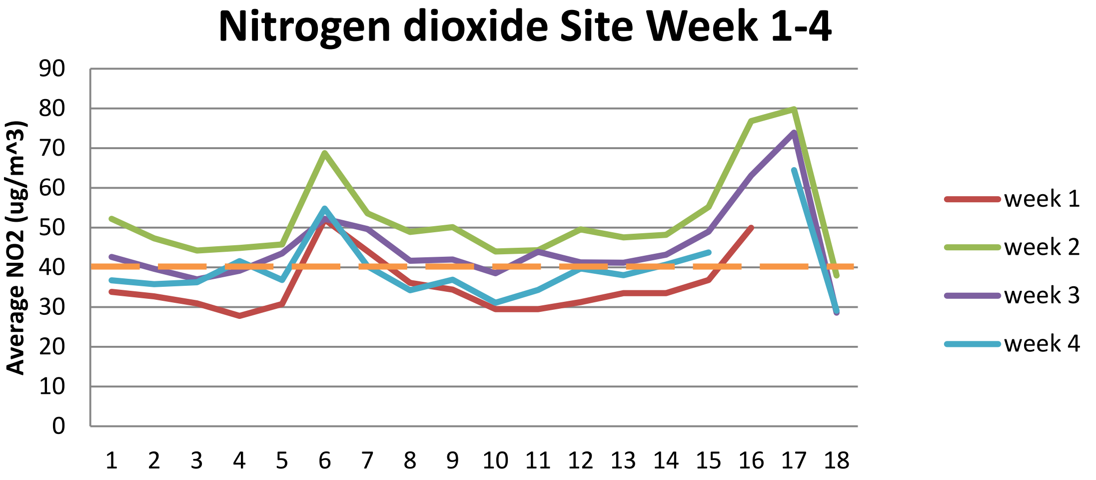

Figure 7: NO_2concentration Weeks 1-4 (ug/m3) at 18 sites. Dashed orange horizontal line illustrates EU annual air quality objective.

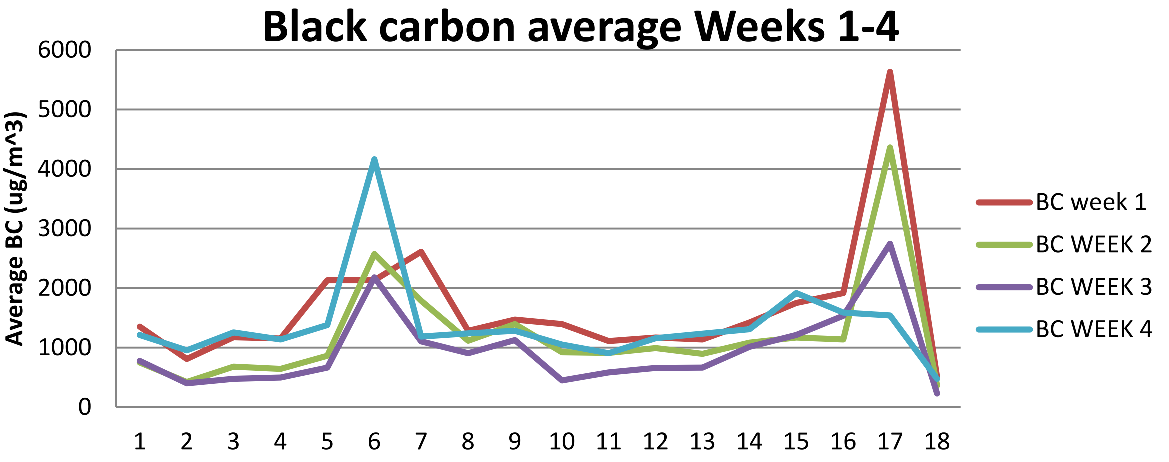

Figure 8: Black Carbon results. Weeks 1-4

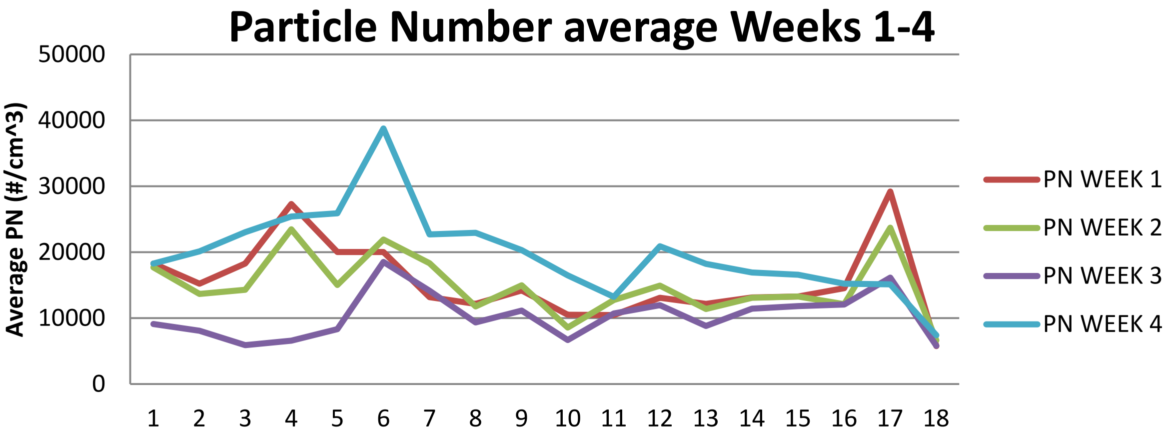

Figure 9: Particle number concentrations Weeks 1-4

Concentrations ranged from a minimum value of 27.8 ug/m³ (excluding site 18) to the maximum value of 79.8 ug/m³ (Figure 7). Many of the observations are above the limit EU annual objective (40 ug/m³), represented by the orange dashed line, particularly Byres road and Dumbarton road sites 6 and 17. Of the 216 tubes deployed, 210 were recovered, 97.2% recovery. Data is missing for site 17 in week 1 and site 16 in weeks 4 because of lost PDT (Figure 7).

A substantial contrast has shown between the higher values of sites 6 and 17, compared with the sites 8-15. On streets with lower traffic volumes (Laurence Street) a consistent pattern of lower results from site 1-5 and 8-15 can be established. The sites chosen show consistent patterns in NO_2 from week to week: high values correlated well with the road type and high traffic volumes.

The differences in 18 sites within a small area of Glasgow show decay in NO_2 and black carbon levels the further the site distance is from heavy traffic roads; Byres road and Dumbarton road. Sites 7-10 were calculated to be ~160m in length along Laurence Street from site 7 byres road site. Along this stretch of road, getting further away from the high traffic volume Byres Road, a sharp fall in results is observed. Sites 7-10 of Nitrogen Dioxide values decreased on average by 24% over the 160 metre stretch.

Byres road and Dumbarton road had the highest results in all weeks consistently for NO_2, Black carbon and Particle number. Sites 6, 7 and 16, 17 were on the same roads, only ~20 metre opposite each other, observed a difference in results between sites of 9.77ug/m³ (Average in the difference of Byres Road and Dumbarton Road results). This difference on same street sites could be as a result from a number of factors; wind direction, canyon effect of buildings, first contact with one specific side of the road, bus stops (site 17) among others. Higher results at site 6 than 7 would suggest a downwind from South Westerly to North east direction, causing site 6 nitrogen dioxide and real-time monitoring to be higher in value than site 7. This difference on some weeks would be the difference between a borderline fail and a dramatic fail of EU limits.

Site 9, a small junction where the local authority places their PDT monthly testing of NO_2, was a medium value compared with the Byres road and other high traffic road results. Average Site 9 results over 4 weeks are 40.88ug/m³, just outside the air quality objectives of 40µg/m3. Values were ranging from 34.42 to 50.16ug/m^3. Are local authorities getting a true representation of air pollution in the area?

Black carbon concentration results can be shown in figure 8. Peaks of Black carbon activity at sites 6 and 17, (high traffic volume streets) are observed, with some degree of pattern forming between weeks. Lower 1-4 and 8-16 results are on a similar low level trend line (urban, low traffic volume streets) to the NO_2 results.

For the particle numbers it is more difficult to distinguish a relationship between sites from week to week; there is no regularity of results shown and little difference between high traffic volume streets and lower traffic streets. The particle number CPC monitor was more sensitive to type of traffic passing (e.g. buses); difficult to determine which sites had more air pollution from the results. Overall, PN is not useful for a correlation site study in an area for traffic intervention controls.

Black carbon results are coherent and complementary throughout the weeks with very low data background changes, indicating black carbon was sourced from local traffic primarily. Coherent with black carbons main source of pollution being incomplete combustion from diesel engines (Janssen et al. 2011). Black carbon is a complete indicator of traffic volumes and results show an average reduction of black carbon, the further away a site is from the heavy polluted roads. Sites 7-10 (~160m apart) were observed to have an average black carbon reduction of 42% over the four weeks.

NO_2, BC and PN correlations

The Figures 10 shows the correlation values (r_2) between NO_2, BC and PN. Two average sets were calculated between the NO_2 and real-time monitoring results.

Correlations between PN and NO_2 have weaker correlations when local sources affect monitoring and are recorded in a canyon environment (Jimenez 2012). Poor temperamental monitoring results from particle number caused insignificant correlation between NO_2 and PN.

Average weekly data correlation	*WEEK 1*	*WEEK2*	*WEEK 3*	*WEEK 4*	***Total average correlation***
NO2/BC	0.68	0.77	0.90	0.59	**0.74**
NO2/PN	-0.02	0.43	0.72	0.24	**0.34**
PN/BC	0.59	0.59	0.86	0.71	**0.69**

Figure 10: Correlation values between the pollutants

Correlation between sites and the monitoring equipment have identified certain weeks of higher R-squared values than others. Week 3 showed the best results for weekly comparison between all pollutants. Overall, better results are shown when weekly tests are done, rather than one single monthly test as is done by local authority. Reliable results for the study before traffic interventions to actively indicate areas of poor air, the pollutants and the correlations shown between pollutants, that there are correlations between static and real-time monitoring.

Limitations and positive outcomes

Limitations from this study include the time spent at each site, the wind directions, time of day the study is done and where the sites are situated; whether situated next to bus stops, traffic lights or vents. Introducing larger time brackets for measurements being taken.

Overall, many positive outcomes have come from this study. High weekly correlations between NO_2 and Black carbon (r_2=0.74) can be used to show areas of high air pollution well. This correlation between mobile and static monitoring will allow more accurate controls and plans can be implemented for an area specific to results.

Conclusion

This study showed a unique opportunity to evaluate correlations between pollutants in the City of Glasgow. High correlations (r_2=0.74) were observed between static and mobile monitoring of nitrogen dioxide and black carbon respectively when analysed week by week. NO_2 and BC both showed similar spatial patterns in relation to nearby road traffic. High correlation between black carbon and particle number (r_2=0.69) was also observed as expected.

In conclusion, this study has shown relatively high correlations between weekly static data and 5-minute mobile data, and is reliable in indicating heavy traffic volumes and pollution problem areas. The approach taken can be used in other road side pollution and traffic control. The study supports the use of NO_2 and Black carbon as traffic pollution indicators to assess traffic control interventions.

This monitoring strategy can be used as a pre study before traffic interventions are implemented. Indicating high risk areas and better understanding of pollutant relations to plan reductions and current studies of traffic interventions in place. A comparison of a before and after traffic interventions of the site can now be done.

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