Transport for London

ROADS TASK FORCE
Thematic Analysis

Roads Task Force - Technical Note 21

What is air quality on the road network and how does this vary by road type, location and time of day?

Introduction

This paper forms one of a series of thematic analyses, produced to contribute to the Roads Task Force Evidence Base. This paper provides an overview of emissions and air quality on the road network. It looks at typical spatial and temporal patterns, and sets out the contribution of motorised road traffic to emissions in London.

Summary

- Motorised road traffic contributes 60 per cent of particulate matter (PM_{10}), 47 per cent of nitrogen oxides (NO_x) and 17 per cent of carbon dioxide (CO_2) emissions in London.
- The spatial pattern of total emissions (all sources) reflects both urban density and the road network. The density of emissions is highest towards inner and central London, reflecting general activity levels, and increases further with proximity to busy roads.
- Air quality (concentration) patterns broadly reflect those of emissions.
- Temporally, emissions and concentrations show a diurnal pattern corresponding to the peaks and troughs of traffic and other activity, although actual weather is a significant influence on how directly emissions are translated into concentrations.
- EU 'limit values' for PM_{10} have now been achieved at roadside locations across London, although there is no 'safe' level for this pollutant. Further reductions are desirable.
- NO_2 concentrations (arising from NO_x emissions) however still widely exceed EU limit values, putting London at risk of infraction proceedings and substantial fines for non-compliance, although the negative health impacts of NO_2 are thought to be less severe than PM_{10}.
- CO_2 is not of local health significance but is a key contributor to climate change, and is subject to ambitious Mayoral reduction targets.
- Most 'bad air days' in London result from variations in the weather acting on a generally consistent level of emissions. Reducing these emissions will result in fewer 'bad air days'.

Air quality basics

- The term 'emission' refers to the release of harmful gases into the air locally within London.
- 'Air Quality' refers to the concentration of these pollutants in the air near ground level.
- Concentrations in London reflect both locally-produced emissions and the 'importation' of pollution from elsewhere.
- Air behaves as a fluid. Pollutant concentrations are therefore continuously variable in three-dimensional space, as well as by time of day.
- The two pollutants of concern from a health viewpoint are particulate matter (PM_{10}) and Nitrogen Dioxide (NO_2). Note that NO_x (generic 'oxides of nitrogen) is the emission of concern for NO_2 concentrations,
- This note also briefly considers CO_2 - a 'global-scale' greenhouse gas hat is not of health significance locally, although is subject to ambitious Mayoral reduction targets.
- Road traffic contributes 60 per cent of particulate matter (PM_{10}), 47 per cent of nitrogen oxides (NO_x) and 17 per cent of carbon dioxide (CO_2) emissions in London.
- On average, a diesel vehicle will emit 22 times as much particulate matter and at least four times as much NOx as a petrol equivalent.

Basic spatial patterns

- Spatially, highest 'background' concentrations (poorest air quality) are found in central and inner London, where the density of roads and other activity is greatest.
- At the more local level, concentrations tend to be highest (above background concentrations) in the road carriageway itself, decreasing rapidly with distance. Pavements adjoining roads are therefore more polluted than conditions even a few metres back from the roadside.
- More locally still, locations with high volumes of motorised traffic, congestion and road junctions are all particularly associated with poor air quality, as they are characterised by high densities of slow-moving traffic.
- Large industrial sites and major infrastructure, such as Heathrow airport, are also associated with poor air quality – it is not 'just a roads problem'.

Basic temporal patterns

- Temporally, pollutant concentrations near roads reflect the daily ebb and flow of motorised traffic, being highest in the middle of the day/later afternoon, as it takes some time for emissions to disperse, and during this time there is the potential for the formation of 'secondary' pollutant through chemical reactions in the atmosphere.

- Air quality also shows a 'seasonal' pattern, reflecting change in prevailing weather over the course of the year.
- 'Bad air days' or 'episodes', where concentrations increase markedly over those usually experienced, can occur at any time as they are associated with stable air masses ('high pressure') that reduce natural dispersion (slow winds), carry pollution from continental Europe, and are characterised by strong sunlight that promotes photochemical reactions (formation of secondary pollutant) in the atmosphere.
- Given such conditions, air quality tends to deteriorate markedly over the course of several days as the 'cocktail' of pollution is trapped by poor dispersion.
- Importantly, during episodes, the amount of emissions released by motorised traffic remains broadly stable from day to day. It is the dispersion characteristics of the atmosphere that vary.
- Meeting air quality Limit values therefore implies reducing 'typical' emissions to a level where concentrations will not exceed limits under 'reasonably likely' extreme weather conditions – a complex and difficult challenge the full nature of which is often not properly understood.

Graphical illustration of spatial patterns

These characteristic spatial/temporal patterns are illustrated by the figures below.

Figure 1 shows prevailing concentrations of PM_{10} at the Greater London scale. Most of London now meets EU limit values with, on the road network, only the residual possibility (given a 'poor weather' year) of exceedence of limit values at a small number of locations (all in central London). Although now meeting limit values the margin of achievement is slender (although this will improve in future years). Prevailing concentrations are still such as to be associated with c. 4,000 'deaths brought forward' per year – there is no 'safe' level for PM_{10} and continued reductions are desirable for health reasons.

Figure 2 shows prevailing concentrations of NO_2 at the Greater London scale. Unlike PM_{10}, much of London currently fails to meet the applicable EU limit value (yellow-orange-red areas on the map). This pattern is replicated in most large cities in the EU and is not peculiar to London. The primary causes of this general failure to achieve limit values are the increased use of diesel fuelled vehicles (compared to that expected when the standards were set) coupled with an 'industry failure' relating to the performance of pollution abatement devices intended to reduce PM_{10}. Although these have 'delivered' for PM_{10} they have the undesirable side-effect of increasing NO_2 emissions (the actual chemistry here is complex). However, abatement devices are now becoming available specifically for NO_2 and these are likely to be a major focus for air quality policy going forward. At present however, the UK (London plus about a dozen provincial UK cities) is vulnerable to EU infraction proceedings and large.

Figure 1 Concentrations of particulate matter (PM_{10}) in London - 2011.

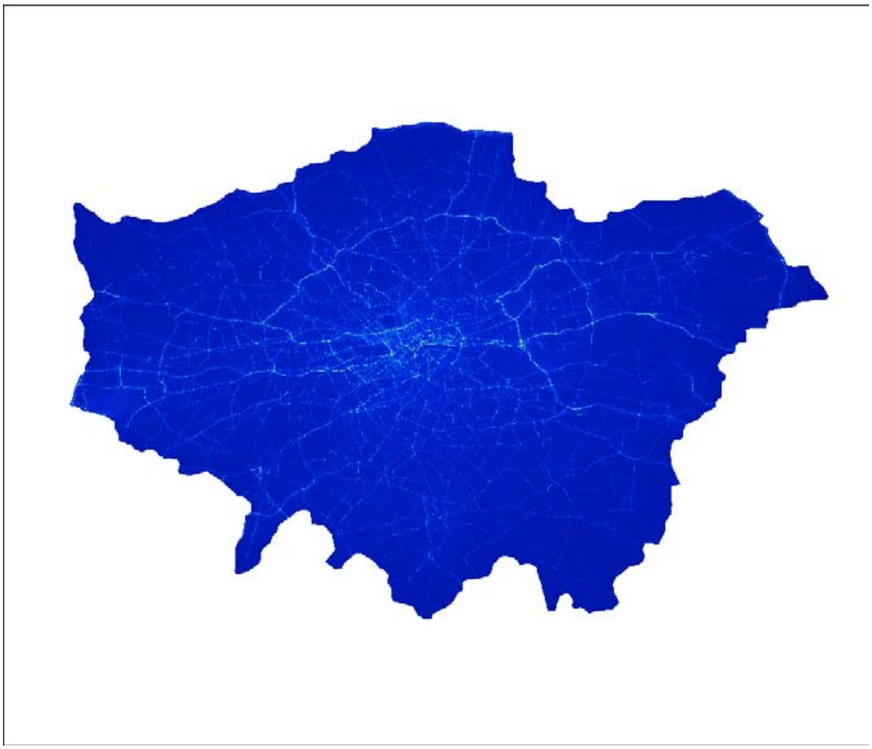
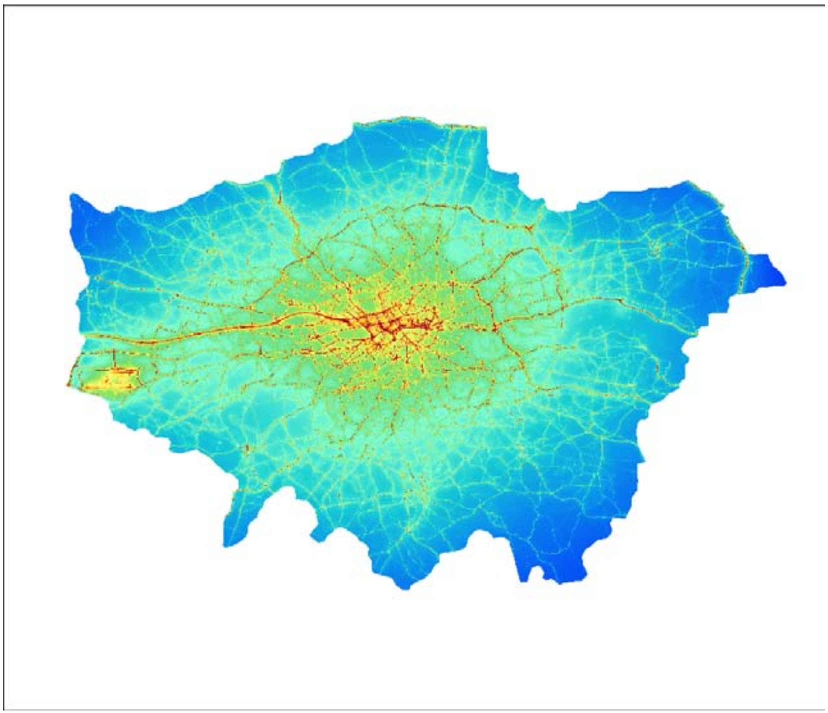


Figure 2 Concentrations of nitrogen dioxide (NO_2) in London - 2011.

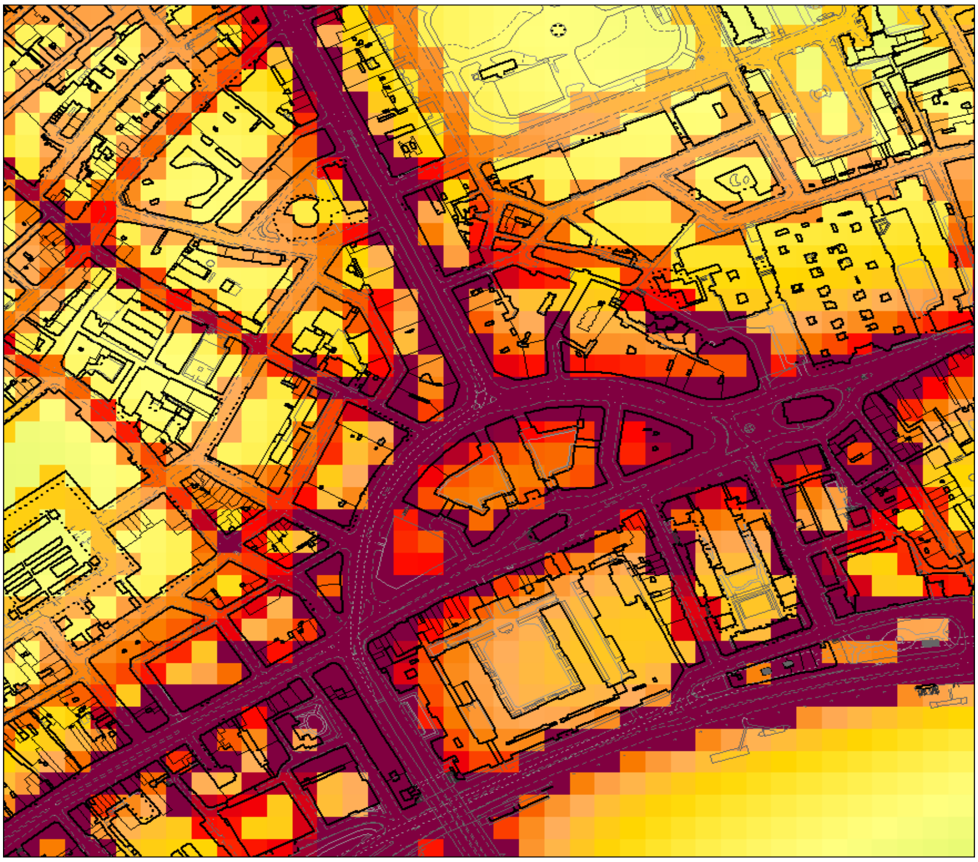


Concentrations at the more local scale

Figure 3 'zooms in' to show, using the example of the Aldwych Gyratory in central London, typical pollution concentration gradients in the vicinity of busy roads (in this case for NO_2).

The pattern is an intuitive one – pollution tends to be highest in the immediate vicinity of the road – decreasing to prevailing 'background' levels within a relatively short distance. Note that in this particular example, 'typical background' levels are well above the EU limit value. The scale of the 'increment' above background generally reflects traffic volumes (firstly) and traffic speed (secondly – see further below).

Figure 3 Example of local-scale variability in air quality – NO_2 concentrations around Aldwych gyratory, central London (2011).



'Street canyons'

A further consideration is 'street canyon' topology. This exacerbates concentrations in built-up roads by affecting the circulation of air within the canyon. Canyons aligned with the prevailing wind benefit from increased dispersion, as wind blows along the canyon dispersing pollution. Those opposed to the prevailing wind suffer from the entrapment of pollution within the canyon, as the wind blowing across the top of the canyon sets up circulatory currents within the canyon, trapping the pollution. In general, street canyon topology exacerbates pollution concentrations compared with more open environments.

Illustration of temporal patterns

Diurnal

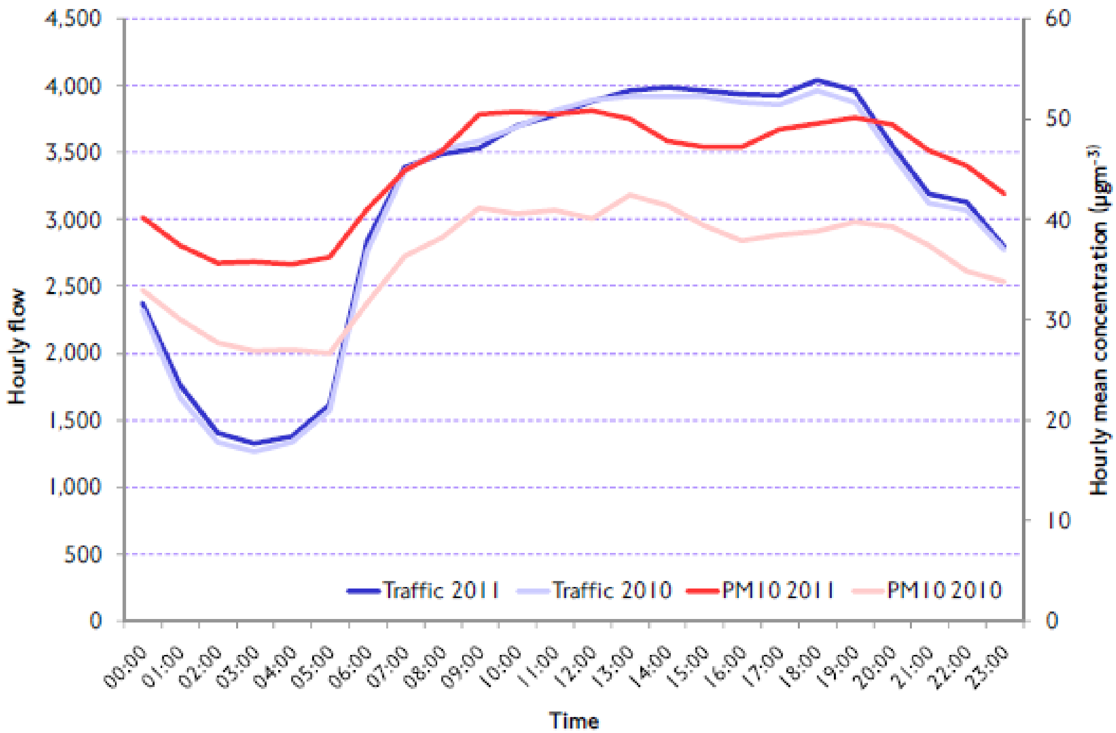
The basic spatial patterns described above are generally maintained throughout the hours of the day, although the intensity of the difference between 'background' and 'roadside' concentrations intensifies during working hours and into the evening, reflecting the daily ebb and flow of traffic (with a typical 'dispersion lag' affecting evening concentrations).

Seasonal

Emissions in London tend to vary little from month to month, although traffic levels and combustion of fuel for space-heating tend to be higher in the winter months. Concentrations however can be much more variable, reflecting different weather.

Figure 4 illustrates both of these patterns. It shows PM_{10} concentrations by hour of day at the central London Marylebone Road air quality monitoring site (right hands axis). These are plotted against average daily traffic flows along this road (left hand axis).

Figure 4 Example of temporal variability in air pollution and its relationship to changing traffic levels. Marylebone Road.



Looking first at the diurnal pattern (red lines), PM_{10} concentrations are lowest during the overnight hours, increasing during the working day and slowly tailing-off into the evening. Being a major central London road, overnight traffic flows at this location are substantial (blue lines).

Looking at the difference, however, between average concentrations in 2010 and 2011, it is clear that these are quite different between the years for a generally very similar level of traffic. 2011 was a 'bad' year for air quality, with frequent anticyclonic 'episodes', whereas weather conditions in 2010 were more benign (more favourable to the rapid dispersion of pollution). Importantly, therefore, out-turn pollution concentrations, against which EU limit values are assessed, can vary considerably from day-to-day, month-to-month and year-to-year, even though the level of emissions produced in London varies very little.

Emissions, concentrations and the relative contribution of road traffic

Particulate matter - PM_{10}

- Road traffic accounts for about 60 per cent of London's total PM_{10} emission.
- Importantly, 'road traffic PM_{10}' comprises several components – exhaust (out of tailpipe), tyre/brake wear and re-suspension (re-entrainment of carriageway dust).
- The recent update to the London emissions inventories re-quantifies the relative contribution from each of these (Table 1).
- 'Exhaust PM_{10}' is now very much the minor component – reflecting the success of the progressive adoption of higher 'Euro' emissions standards and initiatives such as the London Low Emission Zone.
- Tyre/brake and re-suspended emissions are much more intractable and there is as yet no clear technology or policy framework to tackle these, although road dust has been tackled through the 'local measures' initiative and the EU Limit values for PM_{10} are now largely achieved.

Table 1 Relative contribution to total road traffic emission for PM_{10} (2010).

Source	Tonnes	Percent
Total London PM_{10}	3,858	100
Total road transport	2,304	60
Exhaust	597	15
Tyre/brake	1,706	45
Re-suspension	1,004	n/a

Nitrogen oxides - NO_x/NO_2

- Road traffic contributes 47 per cent of London's total NO_x emission.
- Here, it is important to understand the basics of NO_x/NO_2 conversion. Emissions are measured in terms of NO_x (total nitrogen oxides). This includes NO_2 (nitrogen dioxide, the pollutant of direct concern for concentrations) but also other oxides (principally nitrogen oxide (NO)).

- NO is progressively converted to NO_2 by oxidation in the atmosphere, but the amount of NO_x that is released as NO_2 in the first place ('primary NO_2') and the rate at which the atmospheric conversion of NO to NO_2 happens are both variables.
- Relatively high proportions of primary NO_2 are associated with diesel fuelled vehicles and vehicles fitted with PM_{10} abatement devices. These have increased in number markedly in recent years.
- Relatively high conversion rates (of NO_x to NO_2) are associated with high Ozone (O_3) levels, which characterise summer high-pressure (anticyclonic) episodes.

The proportions of emissions from road traffic will vary locally – in locations with poor air quality the relative contribution from road traffic tends to be higher.

Some 'industrial' locations are also associated with poor air quality – the primary cause of remaining PM_{10} exceedences in London (these are not in scope for EU limit value compliance).

Carbon dioxide - CO_2

Carbon dioxide is a global greenhouse gas and concentrations are not of health or legislative significance locally. Nevertheless, London is required to reduce total CO_2 emissions by 60 per cent by 2025, and road transport is responsible for approximately 17 per cent of this total emission.

Carbon dioxide emissions are more directly related to fuel used than for PM_{10} and NO_2. Emissions therefore fairly directly reflect the volume of traffic (vehicle kilometres), and the speed at which it travels. Generally, more traffic (kilometres) equals more CO_2, and slower, less smooth traffic also equals higher CO_2 emissions.