Analysis of Air Pollution and Social Deprivation

A report produced for Department of the Environment, Transport and the Regions, The Scottish Executive, The National Assembly for Wales and Department of Environment for Northern Ireland

Katie King
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AEA Technology
E5 Culham
Abingdon
Oxfordshire
OX14 3ED

Telephone 01235 463715
Facsimile 01235 463574

	Name	**Signature**	**Date**
Author	Katie King John Stedman		
Reviewed by	John Stedman		
Approved by	John Stedman		

Executive Summary

Modelling work undertaken as part of the review of the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (AQS) has shown that there are likely to be some locations where the objectives for NO_2 and PM_{10} are exceeded. For NO_2, the annual average objective is expected to be achieved at all background locations, except inner London, and at most roadside locations by 2005. However, the national modelling identified a number of major urban road links where concentrations at the roadside may exceed the objective. For PM_{10}, the $40ugm^{-3}$ objective is not expected to be exceeded anywhere except possibly at the roadside on very busy roads in central London. The 24-hour limit value may be exceeded in the centre of London and at roadsides of busy roads in other city centres.

Given the geographical variation in predicted exceedances, there is a potential for some sectors of society to be differentially impacted by air pollution. For this reason this study analyses the spatial relationship between air quality and social deprivation and the extent to which policies which seek to improve air quality will bring disproportionate benefits to the more vulnerable members of society.

Five locations have been considered in the pilot study: Greater London, Birmingham, Glasgow, Belfast and Port Talbot. The air quality and social deprivation data sets are compared by using a Geographic Information System to overlay the two maps and to obtain an air concentration data point for each point or zone for which social deprivation data are available. The resulting sets of data pairs are then analysed using scatter plots and 'banded averaging' to examine for any correlation.

The following general conclusions are drawn from the pilot area analysis.

- There is tentative evidence for a general positive correlation between background air pollution (NO_2 and PM_{10}) and deprivation index in London, Belfast and Birmingham but in Glasgow there is an inverse relationship.
- Port Talbot also shows a weak negative correlation for PM_{10}, using PM_{10} concentration data that include a contribution from local point sources.
- A similar positive relationship is found between social deprivation and NO_2 concentrations at the roadside and background locations in London, but in Glasgow the roadside NO_2 analysis did not show a relationship with social deprivation.
- Variation in spatial scale is shown to have little influence on the results (Wards compared with Enumeration Districts).
- Analysis of the possible confounding factor of population density shows that there is a possible over estimate of PM_{10} emissions in some cites but that this is unlikely to have influenced the final results.
- Air quality maps are also compared with social class data. This analysis does not show a pattern. Although this could imply little relationship between air pollution and social deprivation, it is more probably because the social class indicator (based on generic occupation classes) is a poor proxy of real socio-economic conditions.

As a result of these conclusions for London, Belfast and Birmingham, it is likely that carefully targeted policies to reduce air pollution concentrations in areas where they are highest could impact marginally more beneficially in the more deprived communities, and therefore move some way to reducing this apparent inequity. In the case of Glasgow, further analysis is required to more fully explain the pattern found.

Contents

1 Introduction

1.1 BACKGROUND

The UK Government and devolved administrations are taking active measures to improve air quality through the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (AQS) (DETR et al 2000). This Strategy defines Air Quality Standards and Objectives for eight pollutants and identifies their major sources. The AQS gives the following objectives for nitrogen dioxide (NO_2) to be achieved by the end of 2005 and for PM10 by the end of 2004:

- NO_2 Annual mean: The annual mean must not exceed 40 μgm^{-3}
- NO_2 hourly mean: 200 μgm^{-3} not to be exceeded more than 18 times a year
- PM_{10} Annual mean: The annual mean must not exceed 40 μgm^{-3}
- PM_{10} 24 hour mean: 50 μgm^{-3} not to be exceeded more than 35 times a year.

The more stringent objective is expected to be the annual mean for NO_2 whereas for PM_{10} it is the 24 hour mean.

The PM_{10} objectives relate to PM_{10} in gravimetric measurement units, which are assumed to be 1.3 times those in TEOM (Tapered Element Oscillating Microbalance) units (APEG 1999). As PM_{10} has been mapped based on measurements made using TEOM instruments the conversion to gravimetric units has been done prior to the analysis described in this report.

The national modelling of roadside NO_2 concentrations (Stedman et al, 1998), carried out in support of the AQS, indicated that policies currently in place or to take effect before 2005 will lead to the annual average objective being achieved at all background locations, except inner London, and at most roadside locations by 2005. However, the national modelling identified a number of major urban road links where concentrations at the roadside may exceed the objective.

For PM_{10}, the 40ugm^{-3} objective is not expected to be exceeded anywhere except possibly at the roadside on very busy roads in central London. The 24-hour limit value may be exceeded in the centre of London and at roadsides of busy roads in other city centres.

Given the geographical variation in predicted exceedances, there is a potential for some sectors of society to be differentially impacted by air pollution. For this reason this study seeks to analyse the spatial relationship between air quality and social deprivation.

In order to fully assess whether there is any inequity causing more deprived communities to be exposed to higher levels of air pollution than less deprived communities, the analysis would ideally be undertaken at a detailed community level close to the zones of high air pollution, e.g. along road links. However, the deprivation data are not available at a sufficient level of detail to allow this. Therefore the analysis has been undertaken at the finest spatial resolution for which deprivation data are available.

1.2 STUDY OBJECTIVE

The broad objective of this study is to examine the distributional effects of air pollution in the UK to inform the following issues:

- the links between the environment and inequality and, in particular, on whether environmental problems impact most heavily on the most vulnerable;
- the extent to which policies which seek to improve air quality will bring disproportionate benefits to the more vulnerable members of society.

This report describes a pilot study of the relationship between social deprivation and air quality in both 1997 and the predicted reference case in 2004/5 (including policies up to April 2000) and therefore the latter objective can be analysed to some extent. Further work could be undertaken to consider the impact of future policies once more data become available.

2 Data Sources

2.1 INDICES OF SOCIAL DEPRIVATION

Different indices of social deprivation are used in the different regions of the UK. A summary is provided in Table 1.

An important difference between these indices is the geographical nature of the data, especially its spatial resolution. The smallest geographical unit on which the census data are collected is the Enumeration District (ED). This is the area that one census enumerator can cover on the day of the census, to collect completed surveys from each household. It is typically about 150 households and is therefore much smaller in urban areas than in rural areas. The Ward is the next geographical unit in the hierarchy, covering roughly 50 EDs. All census data are aggregated first to ED level to prevent any breach of confidentiality. The map in Figure 1 shows the sizes of EDs and Wards.

Postcode sectors are used in Scotland. These are areas that include all addresses with the same postcode except for the last two digits, e.g. all addresses with OX14 3__.

Figure 1 Comparison of ED and Ward Census units

As a result of the different methods used to compile these Indices, they are not directly comparable across regional boundaries. This study does not draw conclusions comparing the relationships between air pollution and deprivation between these regions other than on a generic basis.

Table 1 Summary of data available on Social Deprivation indices

Region	Index Date	Description	Sources *	Smallest Spatial resolution	Number of indicators at this level
England	1998	Only 1991 Census data were used to derive the ED level index. Other data were combined at a Ward level.	1991 Census	ED	5
	2000	The new Index of Multiple Deprivation is based on a variety of domains: income, employment, health and disability, housing, education and geographical access.	Various including: ONS, DSS, DfEE and others	Ward	6 domains each with a variety of indicators
Scotland	1998	A combination of census data and non-census (SMRs, unemployment, low birth weights, insurance weightings, education participation and income support recipients). It was developed to prioritise urban regeneration.	1991 Census, Scottish Office, NOMIS, DSS, Survey of High Street insurers	Postcode sector	6
Wales	1994	1991 Census data plus Standard Mortality Rates.	1991 Census	Ward	8
	2000	Index of Multiple Deprivation similar to that for England.	Various including: ONS, DSS, UCAS, Welsh Assembly and others	Electoral division	6 domains each with a variety of indicators
Northern Ireland	1994	ED level data all from 1991 Census. Other data added at Ward and District levels from DHSS, DoENI and so on.	1991 Census, DHSS, DoE(NI), DENI, DED	ED	9

* Data sources: ONS Office of National Statistics; DSS Department of Social Security; DfEE Department for Education and Employment; UCAS University and Colleges Admissions Service; DED Department of Economic Development (Northern Ireland); DENI Department of Education (Northern Ireland); NOMIS National Online Manpower Information System.

The methodology for compiling each index is similar: with the indicators normalised then summed together. In some cases a weighting is applied to each indicator to reflect its importance in relation to deprivation. In all cases a zero score reflects average social conditions and increasing scores reflect increasing deprivation. In all but the Northern Ireland index, scores below zero are disregarded because these represent below average deprivation. As a result of the variations in data sources and methods of compilation, the Index scores are not directly comparable.

2.1.1 England

In England the 1991 Index of Local Conditions was revised in 1998 and renamed the Index of Deprivation (DETR 1998). There are three spatial scales at which this Index is available – local authority district, ward and enumeration district (ED). The Ward and ED indices use the following indicators:

- Unemployment,
- Children in low earning households,
- Households with no car,
- Households lacking basic amenities,
- Overcrowded households,
- 17 year olds no longer in full time education (only at Ward level).

Data for the individual indicators have also been used in this study.

The new Index of Multiple Deprivation (IMD) 2000 was published in August 2000 (DETR 2000). The data from the new index were not available at the time that this analysis was carried out. The study therefore used the 1998 Index at the ward level, allowing easy update of the analysis using the 2000 Index in future.

2.1.2 Wales

In Wales, the National Assembly for Wales use an Index of Socio-Economic Conditions. The Index is calculated for every electoral ward in Wales. It is based upon the following indicators:

- Unemployment,
- The economically active population,
- Low socio-economic groups in the population,
- Population loss in the 20 to 59 years age group,
- The permanently sick in the population,
- Overcrowding in housing,
- Basic housing amenities,
- Standard Mortality Rate.

A new Index roughly equivalent to the IMD 2000 in England has recently been published for Wales, but not in time for inclusion in this study. The new data will also be incorporated into any further work on this issue (National Assembly for Wales, 2000)

2.1.3 Scotland

In Scotland a revised Area Deprivation Index has been produced on a postcode sector basis using a variety of data sources including the 1991 Census (Gibb et al 1998). The six indicators used are as follows:

- Overcrowding,
- Education participation,
- Unemployment,
- Income support claims,
- Standardised mortality rate,
- Home contents insurance.

The 1998 Index is an update of a previous index, which was based wholly on the 1991 census using Enumeration Districts as the basic geographic unit. The change to postcode sectors

reflects the difference in availability of alternative sources of data. This change has however caused a mismatch of geographies for analytical purposes because the postcode sectors do not necessarily coincide with local authority boundaries.

The Scottish index is relevant only for urban areas, as deprivation issues in rural areas are different, such as arising from remoteness, transport costs, accessibility and low income.

2.1.4 Northern Ireland

In Northern Ireland a similar system to that in England is used (Robson et al 1994).

There are 9 indicators at ED scale:

- Pensioners lacking central heating,
- Residents lacking bath, shower or WC,
- Households lacking a link to public sewers,
- Households living at 1.0+ persons per room,
- Households with no car,
- Children in households with no economically-active adult or with a single adult in part-time employment,
- Children in flats or non-permanent accommodation,
- Persons aged 18-24 with no qualifications,
- Unemployed economically active persons.

A new index similar to those for England and Wales is expected in early 2001.

2.2 OTHER INDICATORS OF DEPRIVATION

Alternative sources of socio-economic data have also been investigated. Marketing databases, such as the Lifestyle Census by Claritas, can provide information on household income by postcode sector. These databases have been derived from consumer surveys on a self-selecting basis. Therefore they are not guaranteed to represent an accurate cross section of the population and the data are not easily verified. The data are also very costly. For these reasons the household income data have not been included in this analysis.

Social class is an indicator of income based on generic occupation categories. Census data on numbers of people in the various social classes in each Ward are available from the 1991 Census. These data have also been analysed in this study to provide a comparison with the Indices described above. The proportion of the population in Social Classes IV (Partly skilled occupations) and V (Unskilled occupations) was used as the metric for this analysis. The data have been analysed for the pilot areas in England in the same way as the other indicators.

3 Geographical Analysis

3.1 PILOT AREAS

Five locations have been chosen for analysis in the pilot study:

- Greater London (all London boroughs)
- Birmingham City district
- Glasgow City district
- Belfast and surrounding districts (North Down, Carrickfergus, Newtownabbey, Lisburn and Castlereagh)
- Neath Port Talbot district

These areas were chosen because they include locations most likely to include exceedances of the air quality objective for NO_2 and PM_{10} and to include locations in each of the parts of the UK.

The maps of social deprivation have been combined with maps of air quality, both for 1997, using the then most up to date Emissions Inventory data (1997), and for the predicted reference situation in 2005, which includes current policies up to April 2000 (Stedman and Bush, in prep). Both NO_2 and PM_{10} have been analysed.

The Port Talbot pilot study has considered PM_{10} concentrations from point sources as well as background emissions, in order to provide a more realistic picture of actual population exposure given the importance of the steel works' impact on the local air quality (Rudd et al, 2000)

3.2 COMBINATION OF DATA SOURCES

As a result of the Deprivation Indices being available in different formats for the different regions of the UK, different methods are required for analysis. In general, the air quality and social deprivation data sets are compared by using a Geographic Information System to overlay the two maps and to obtain an air concentration data point for each point or zone for which social deprivation data are available. The resulting sets of data pairs are then analysed using scatter plots and 'banded averaging' (see below) to examine for any correlation.

3.2.1 Analysis at Enumeration District (ED) level

In Northern Ireland the data are available at ED level so this can be analysed using the mapped air concentration levels at the centre points of these EDs. In urban areas where the EDs are small this provides a good indication of the air concentration predicted for the area that the ED covers, but in rural areas it does not provide an average concentration across the ED as there may be more than one 1km grid square (for which air concentrations are estimated) within the ED. However, it is the urban areas that are of interest in this study so this issue is not considered important for this analysis. The map in Figure 2 shows the ED levels data for the Belfast area and the NO_2 concentration data. This illustrates the variation in ED density between urban and rural areas.

Figure 2 Map showing overlay of NO_2 concentrations by 1km grid square and ED level Deprivation Index

3.2.2 Analysis at Ward and Postcode sector level

Data for England and Wales have been analysed at Ward level. Data for Scotland have been analysed at Postcode Sector level. The postcode sector boundaries available are low resolution, i.e. highly generalised, but it is considered that owing to the uncertainties in the air quality mapping this generalisation does not cause problems for this study.

For both wards and postcode sectors the spatial units are defined by polygons. An average air concentration was calculated for each polygon to provide data pairs for analysis. Figure 3 shows the correspondence between the size of Wards in London and the 1km grid of NO_2 concentrations.

ED data are also available for England for the 1998 Index. Therefore, for the Birmingham pilot area some analysis has been done using these data for comparison with the ward level analysis. However, the bulk of the analysis for London and Birmingham has been undertaken using Ward level data in order that it can be easily updated with the new index (Ward level).

Figure 3 Wards in London and NO_2 concentrations

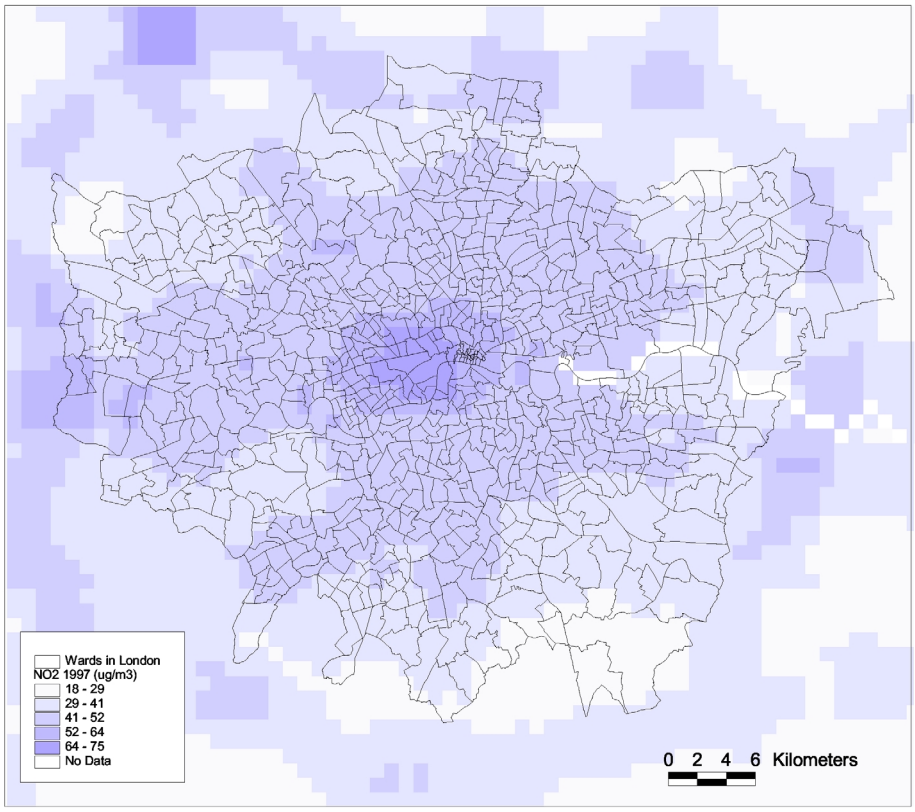
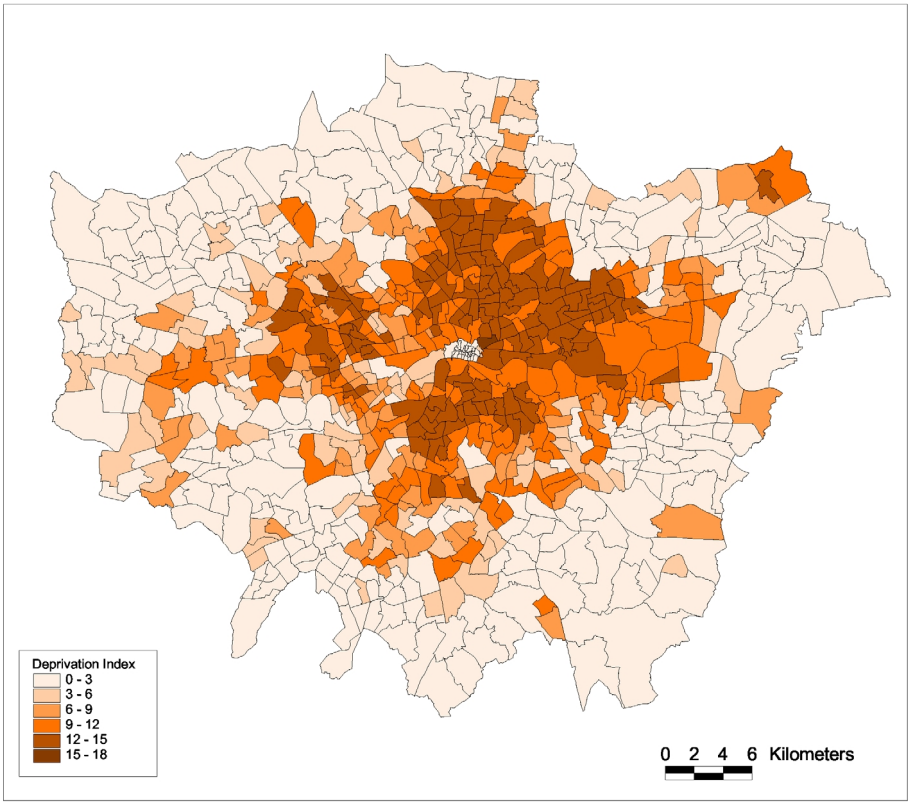


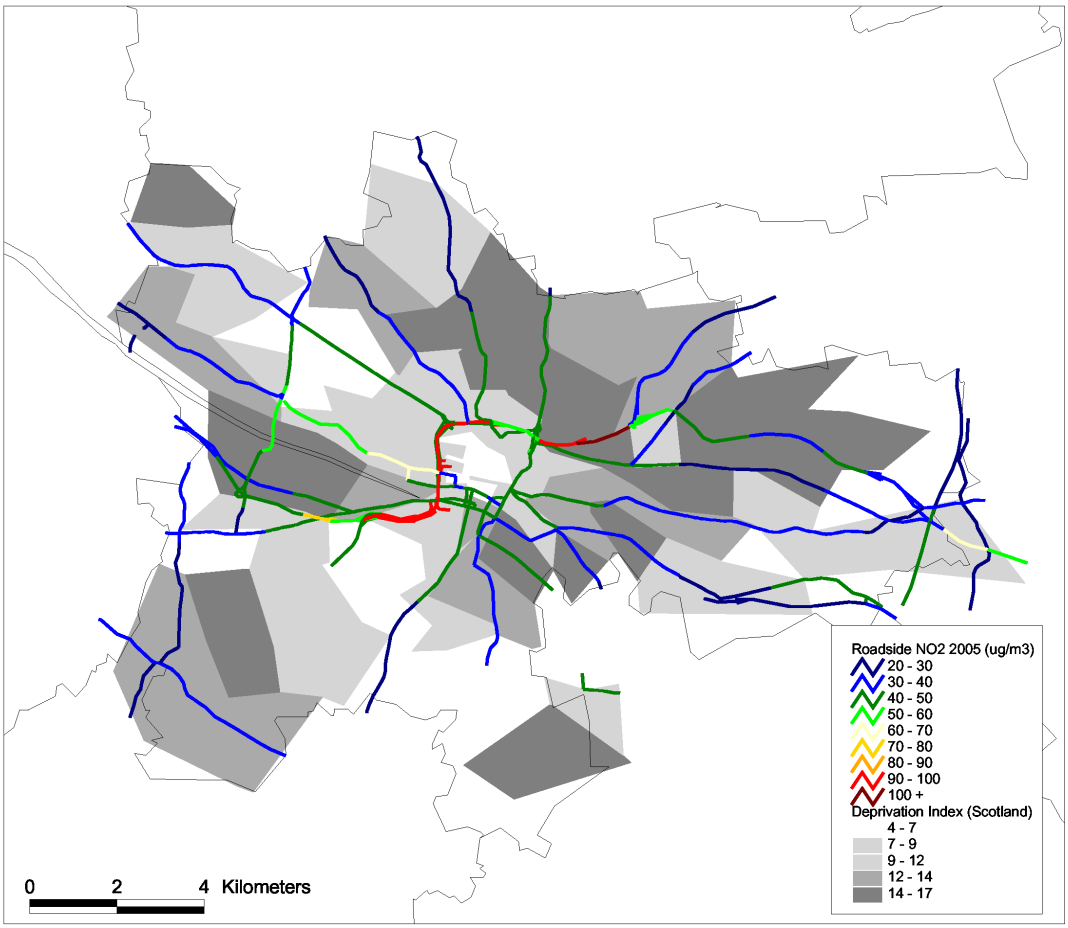
Figure 4 Deprivation Index in London by Ward



Roadside analysis

Roadside concentrations of NO_2 have also been compared with the Scottish Deprivation Index in Glasgow and the DETR Index in London, by correlating the concentration on each road link against the Deprivation Index for the ward and postcode area through which that link passes. This analysis is illustrated in Figure 5.

Figure 5 Glasgow: Roadside NO_2 in 2005 and Social Deprivation by Postcode Sector



4 Statistical Analysis

The data output from the geographical analysis have been analysed in a number of different ways:

1. Correlation of full index scores with background PM_{10} and NO_2 concentrations for 1997 and 2004/5 using scatter plots and banded averages.
2. Correlation of individual components of the English Deprivation Index with air pollution concentrations as above.
3. Comparison between ED and Ward level scores in Birmingham to assess the impact of spatial resolution
4. Correlation between roadside concentrations and deprivation score (in Glasgow and London).
5. Correlation with the predicted change in air concentrations between 1997 and 2004/5
6. Statistical significance tests.

4.1 ANALYSIS OF DEPRIVATION VERSES BACKGROUND NO_2 AND PM_{10}

A selection of the results are presented here for London and Birmingham. To avoid including too many charts within the main part of the report, results for all study areas are presented in Annex 1 for detailed comparisons.

Figure 6 and Figure 7 show the raw data pairs for London for first 1997 PM_{10} and then 1997 NO_2 against the 1998 Index of Local Deprivation. These plots show a fairly wide scatter, but indicate a weak spatial correlation between air pollution and deprivation. Trendlines have been added to these plots to give an indication of the correlation.

Figure 8 shows the result of the 'banded averaging' process - the average air concentrations found across all wards with Deprivation Indices within certain bands, e.g. between 1 and 2. The count of wards within each band is also shown on the chart. It provides a useful summary of these scatter plots and shows that although there is a lot of variation in the data, there is a general increase in air concentration with increasing deprivation.

In general, the patterns for NO_2 and PM_{10} are similar because higher concentrations of these pollutants tend to be in the same places. The spread is wider for NO_2 because of the wider range of pollution concentrations that exists.

The following scatter plots also show the relevant air quality monitoring station and the value of the deprivation index for the area in which they are located. Monitoring sites that are within wards with Index scores of zero (i.e. less than average deprivation) are not plotted (Eltham and Sutton). The data are generally consistent with the mapped air concentrations, providing a useful check on these results.

Figure 6 London PM_{10} 1997 compared with the Deprivation Index

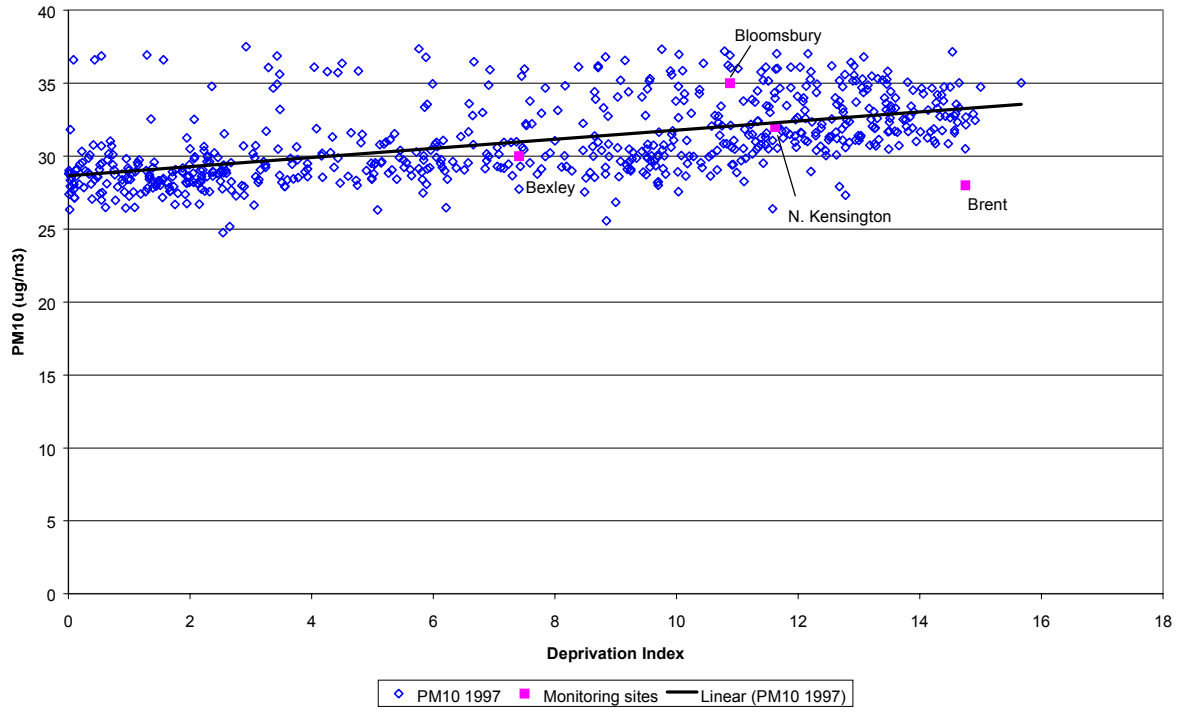


Figure 7 London NO_2 1997 compared with the Deprivation Index

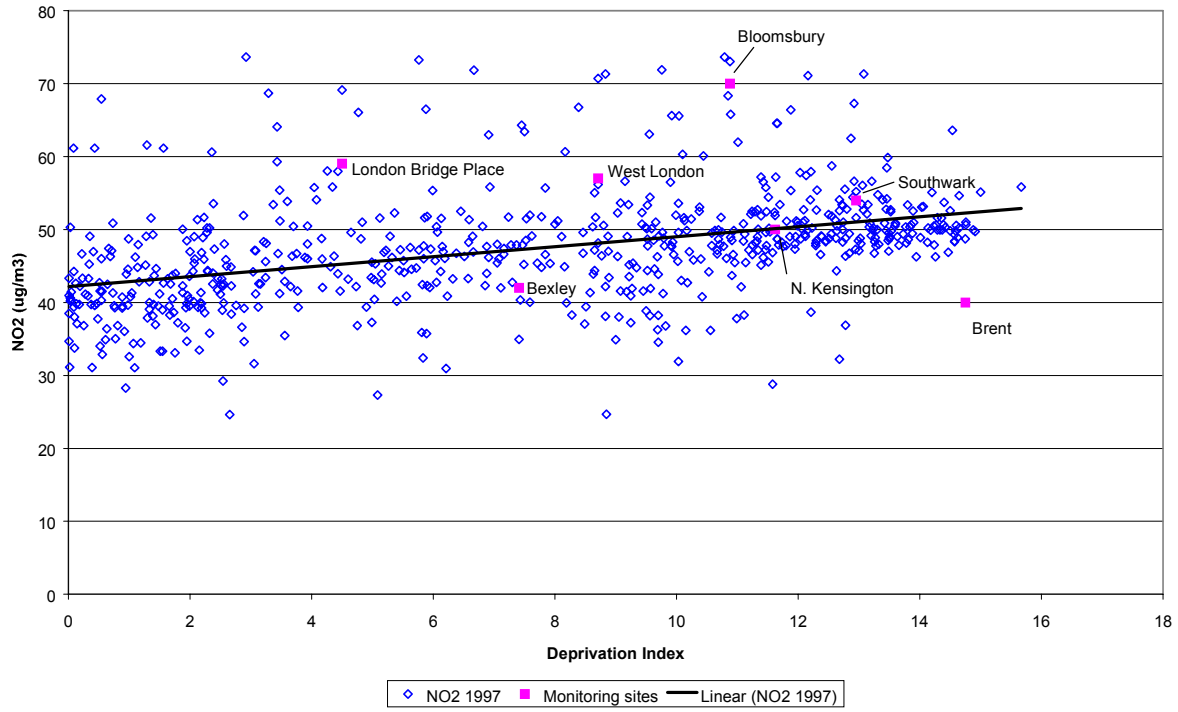
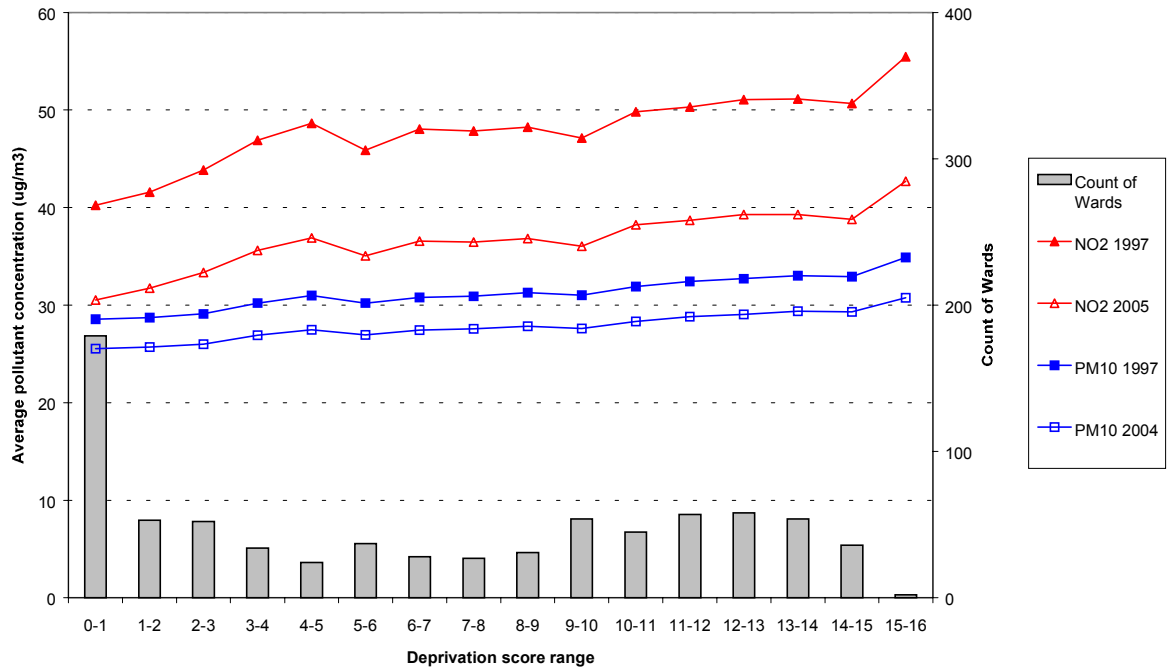


Figure 8 London: Average pollution concentrations in Deprivation Score ranges



The data for London can be compared with that for the other pilot areas. Figure 9 and Figure 10 show the banded averages for all areas for PM_{10} and NO_2 respectively. The deprivation scores are not directly comparable because of the different methods of compilation, i.e. it is not valid to conclude that Belfast is less deprived than the other areas, but the patterns of the curves shown are comparable.

The NO_2 curves are more variable than those for PM_{10}. The increase in deprivation with increasing air pollution is clearer for London and Belfast. For Glasgow the opposite pattern is evident, with a slight decrease in air concentration with increasing deprivation. This is likely to be owing to a different geography of deprivation in Glasgow compared with the other cities, possibly because of large peripheral housing estates built as part of city centre slum clearance schemes. Figure 5 shows the geographical distribution of deprivation in Glasgow, with generally higher levels in the outer part of the city and lower levels in the inner city.

Birmingham is more variable than those for London, Belfast and Glasgow overall possibly because the analysis includes fewer data points than for these areas.

Port Talbot shows little relationship between either NO_2 or PM_{10} and social deprivation, but there are few data points in this series. Generally the levels of air pollution are lower here than in the other study areas because unlike other study areas this is not a city location. PM_{10} concentrations are closer to those in the other study areas than NO_2, partly reflecting the contribution from industrial emissions in this area.

Figure 9 Average 1997 PM_{10} levels by deprivation score range

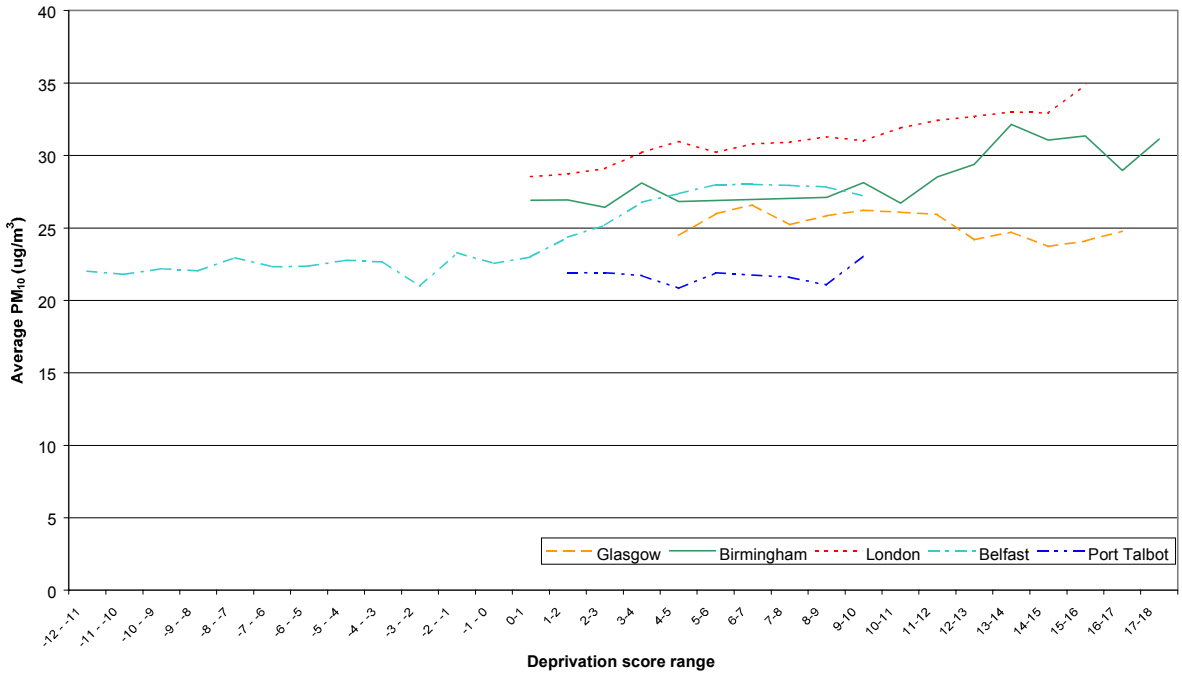
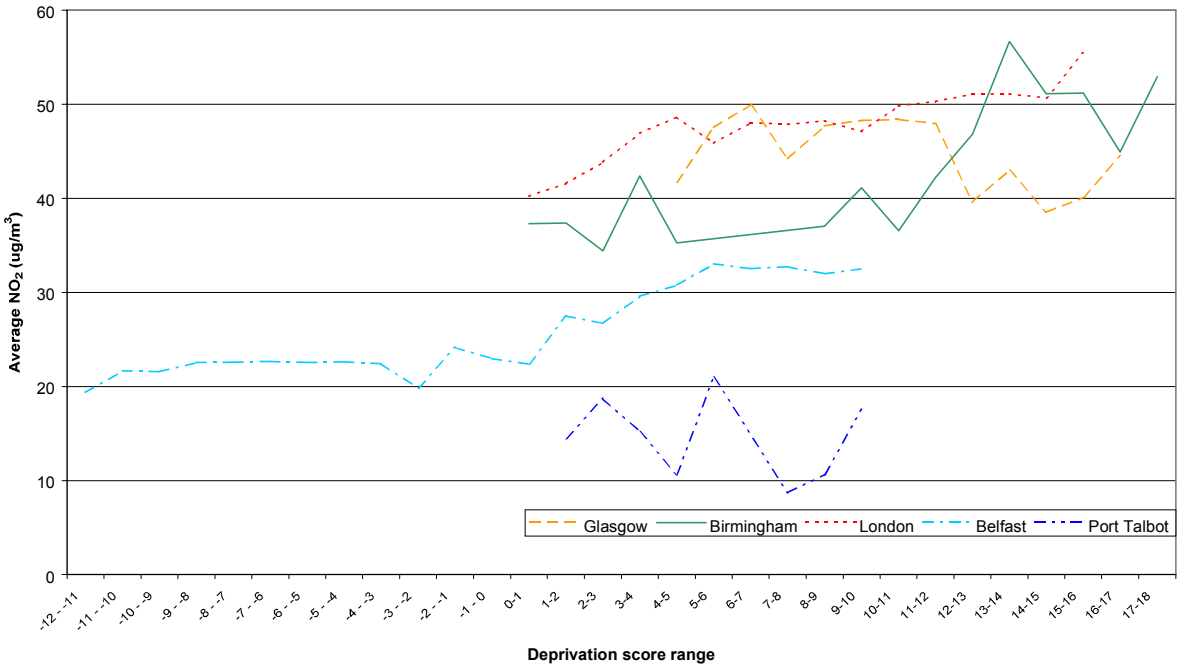


Figure 10 Average 1997 NO_2 levels by deprivation score range



4.2 COMPARISON WITH IMPROVEMENTS IN AIR QUALITY

A further comparison can be made relating to the second objective for this study: analysis of the extent to which policies which seek to improve air quality will bring disproportionate benefits to the more vulnerable members of society. Figure 11 and Figure 12 below show the reductions in air concentration of PM_{10} and NO_2 respectively in London at each of the points sampled in the analysis discussed so far.

The figures show positive correlations, i.e. those points where there are the largest decreases in air concentrations the deprivation tends to be highest also. This therefore provides positive evidence that future policies could help to reduce the apparent inequity in exposure to air pollution found in some locations by this study.

Figure 11 London PM_{10} reductions between 1997 and 2004

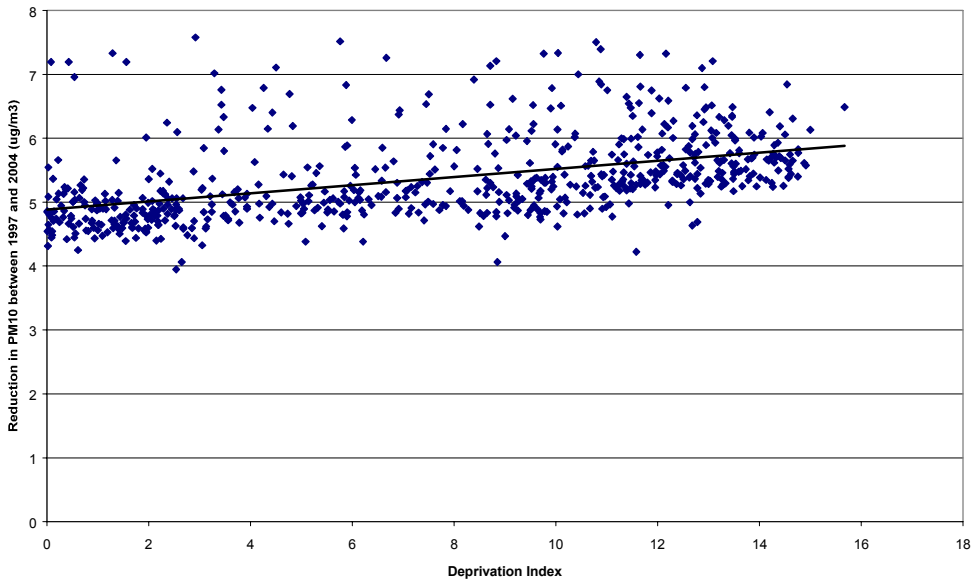
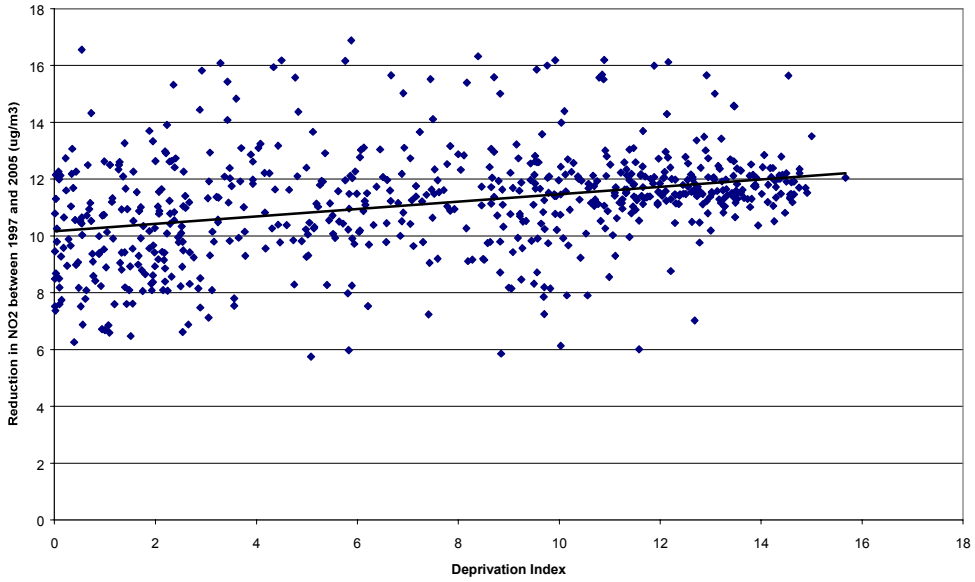


Figure 12 London NO_2 reductions between 1997 and 2005



4.3 ANALYSIS OF COMPONENT PARTS OF DEPRIVATION INDEX

Further analysis has been undertaken using the individual indicators within the DETR Index of Deprivation. The indicators included in the index are as follows:

- Unemployment,
- Children in low earning households,
- Households with no car,
- Households lacking basic amenities,
- Overcrowded households,
- 17 year olds no longer in full time education.

In compiling the 1998 Index for England, the overall score for a ward is the sum of the scores for each of the above indicators, not including any where the score is less than zero. A zero value represents an England-wide average score for the indicator. The exclusion of negative values prevents a lowering of the overall score for that ward. However, for the purpose of the current analysis it is useful to consider the whole pattern covering wards where deprivation is lower than average and above average. The graphs below therefore show the full range of the specific indicator in question.

The indicators that gave the strongest patterns were 'Households with No Car', a proxy measure for household income, and 'Unemployment'. There was no correlation with '17 year olds not in education'. The plots are shown in Figure 13, Figure 14 and Figure 15 below. The trend lines added to the scatter graphs are third order polynomials as these gave the best fit. Annex 2 contains charts showing each of the individual indicators compared with NO_2 concentrations in London. Similar patterns are found in the data for PM_{10} as for NO_2.

Figure 13 London 1997 NO_2 verses Households with No Car

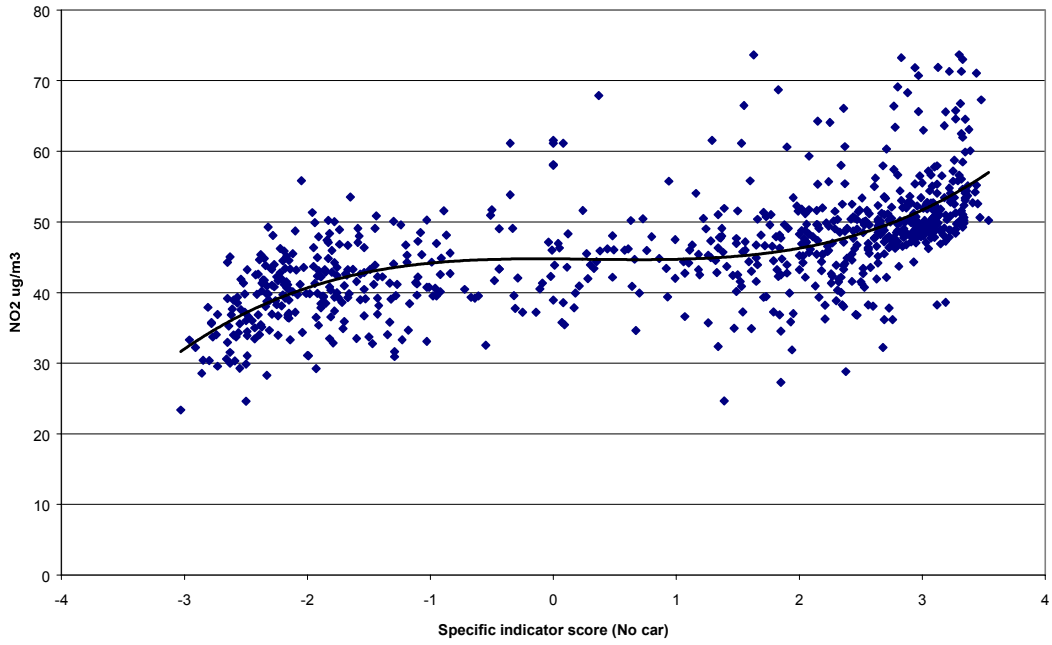


Figure 14 London 1997 Average NO_2 verses 'No Car' score ranges

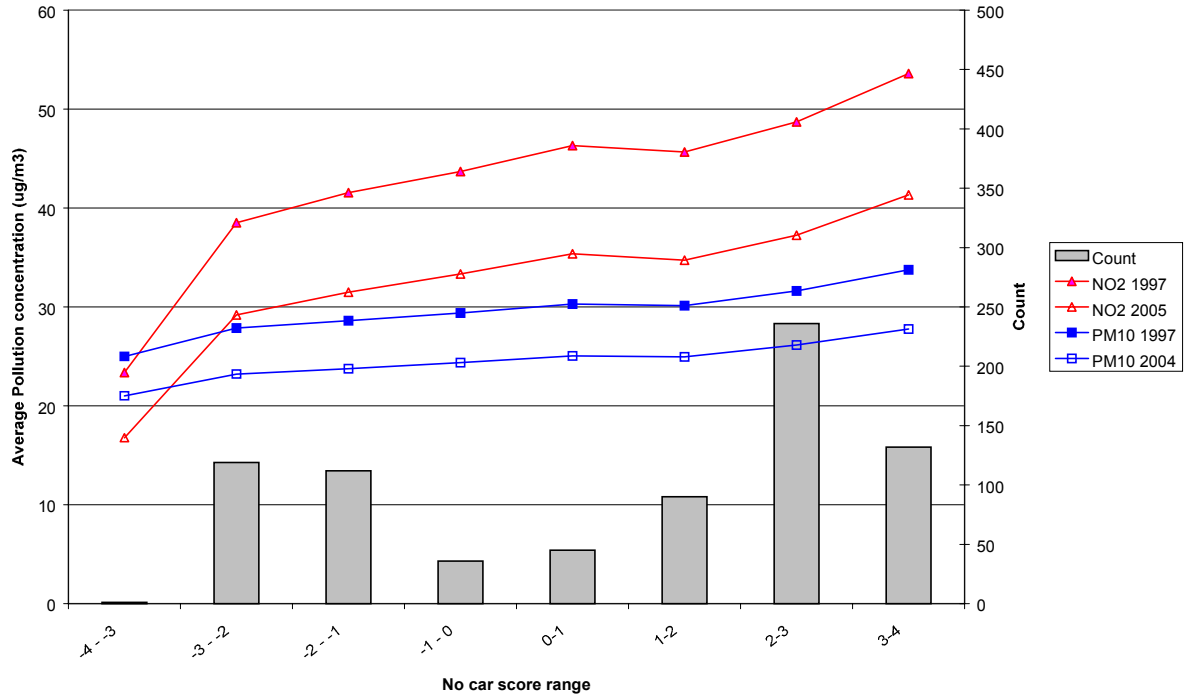
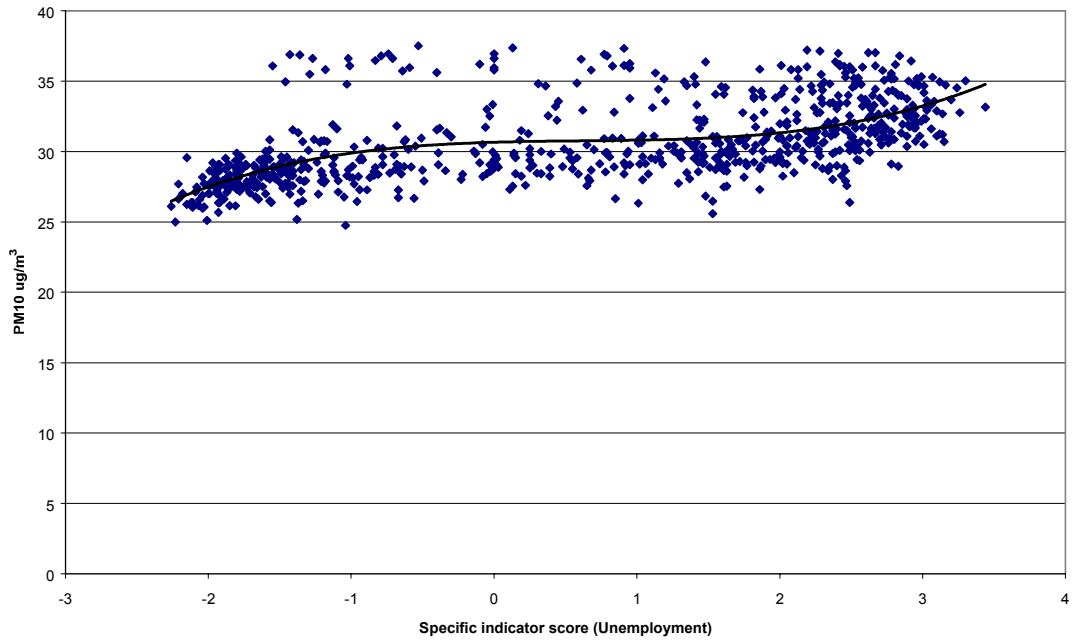


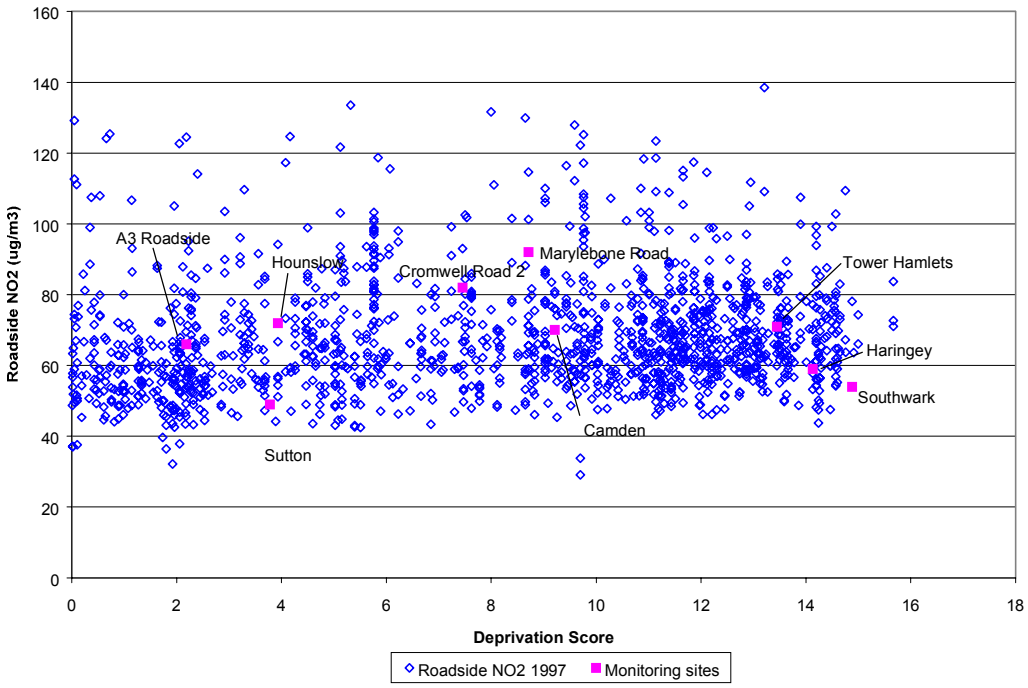
Figure 15 London 1997 PM_{10} verses unemployment



4.4 ANALYSIS OF DEPRIVATION VERSES ROADSIDE NO_2

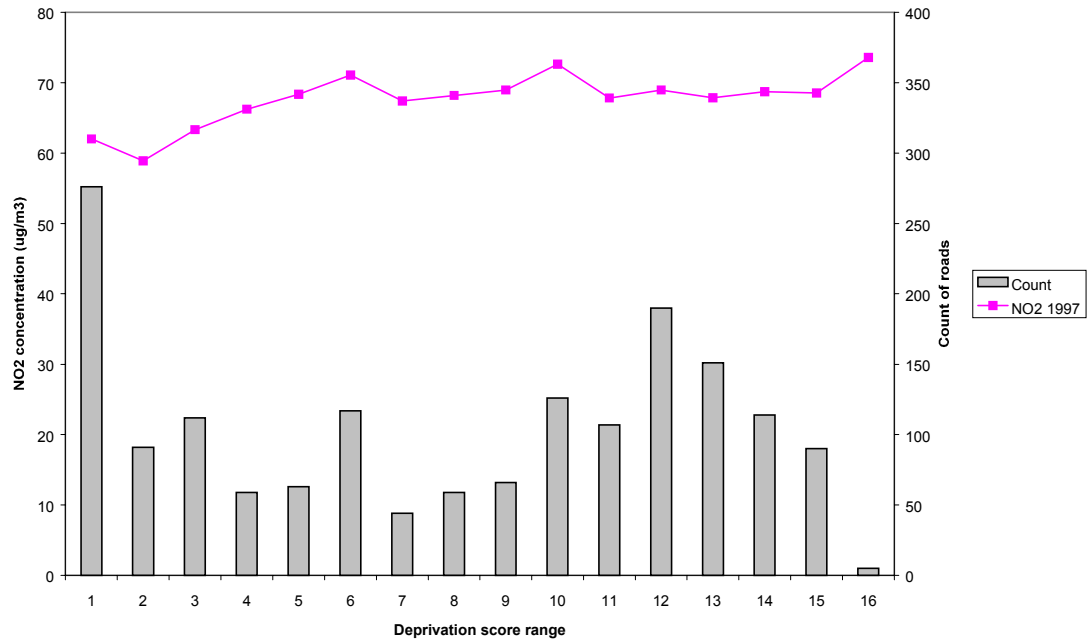
For each ward through which a major road passes, the roadside NO_2 concentration estimated for that link is plotted against the level of deprivation in the ward. Figure 16 and Figure 17 show the results of this analysis for London. They show a similar pattern to those concerning background concentrations (Figure 7 and Figure 8) with a general increase in NO_2 concentration with increasing deprivation. However, in Glasgow, as in the case of the background concentrations, this pattern is not seen (see charts in Annex 3).

Figure 16 Roadside NO_2 by deprivation score in London



The highest levels for roadside NO_2 shown on this graph are along very major roads, such as the A40 and, in the case of Glasgow, the M8 (see Annex 3). However, previous analysis of potential exposure to these high roadside concentrations has shown that many of the busiest roads in cities have few people living close to them (King et al 1999). It has not been possible as part of the current analysis to identify only those roadside locations where there are houses close by.

Figure 17 Average roadside NO_2 by Deprivation score range in London



4.5 COMPARISON BETWEEN ED AND WARD LEVEL INDICES

As a further check on the effect of spatial resolution, a comparison has been made between Ward and ED level analysis for Birmingham. However, the data at these two different geographical scales are not directly comparable because of the inclusion of an additional indicator at Ward level (17 year olds not in education), resulting in higher overall scores for the wards. The graphs below show that the relationship is similar at ED and Ward level.

Figure 18 Birmingham Ward level data - PM10 1997

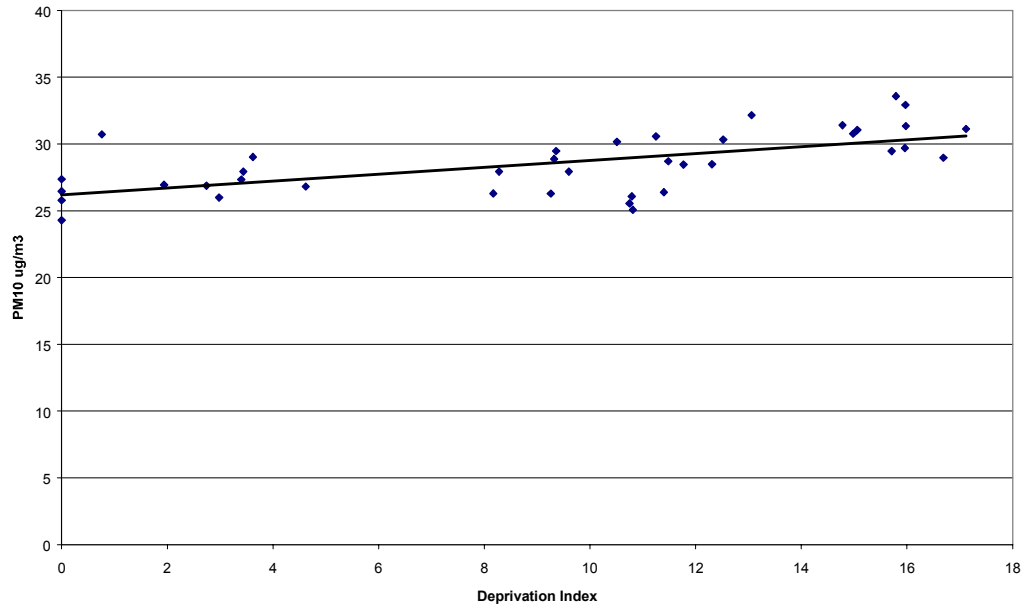
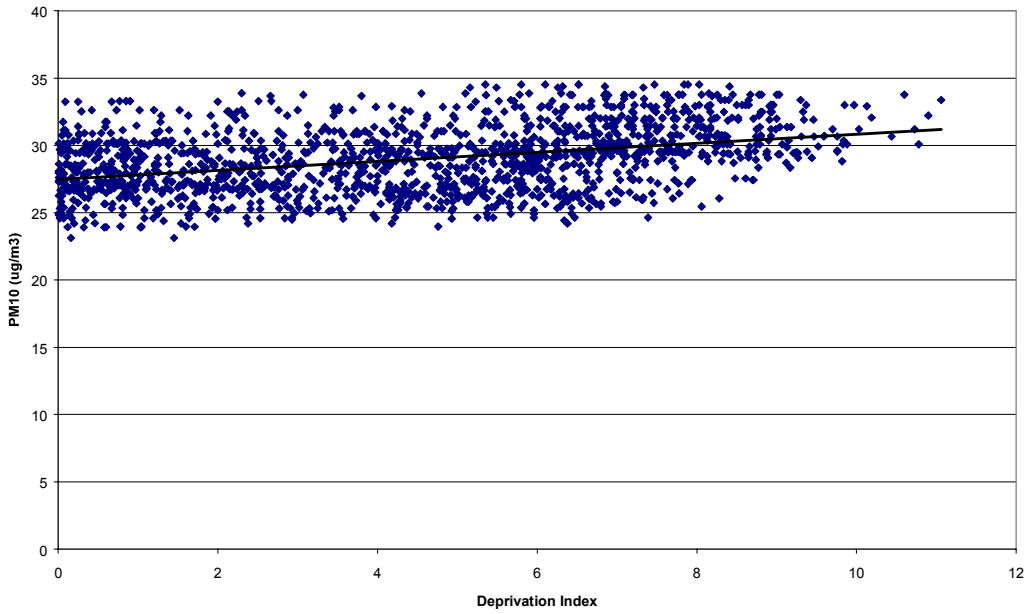


Figure 19 Birmingham ED level data - PM10 1997



4.6 ANALYSIS OF SOCIAL CLASS DATA

Figure 20 and Figure 21 show that there is no trend in the data for social class. The correlation coefficient for this data set is 0.11. This is probably explained by the fact that social class is a broad classification and is dependent solely on employment information. It therefore does not accurately reflect local social conditions. The Deprivation Indices will better reflect the true geographical variations in social conditions, by taking account of many more variables.

Figure 20 Comparison of social class score and background NO_2 in London

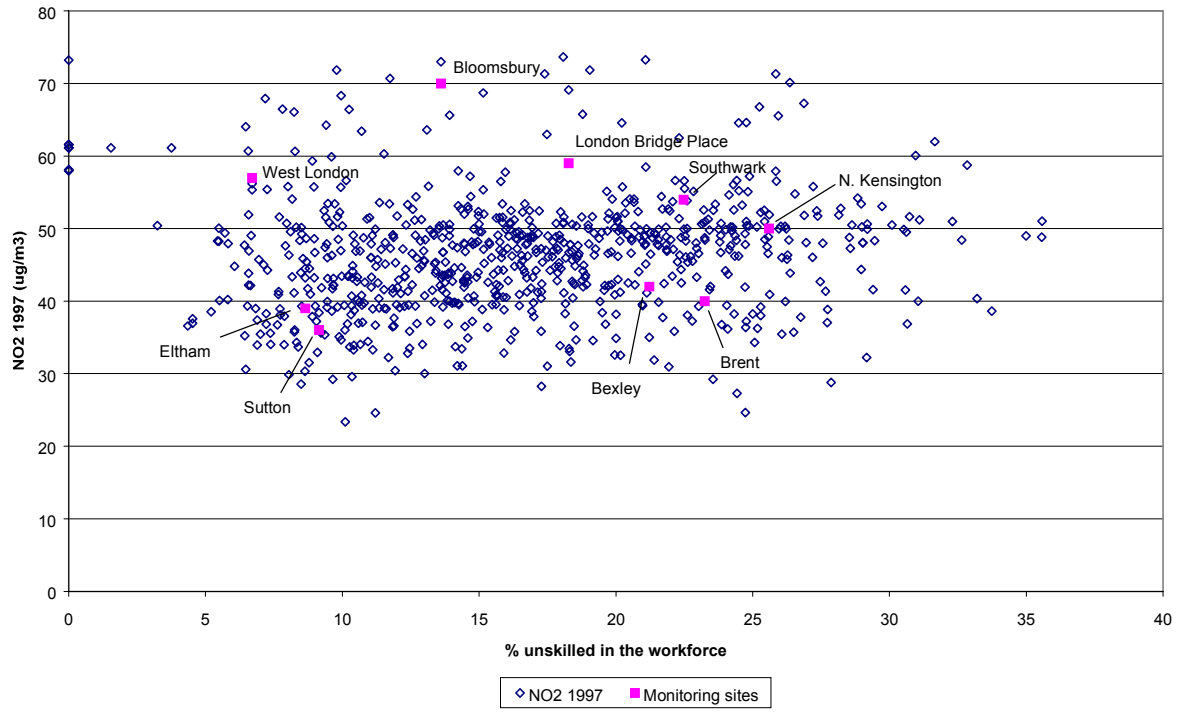
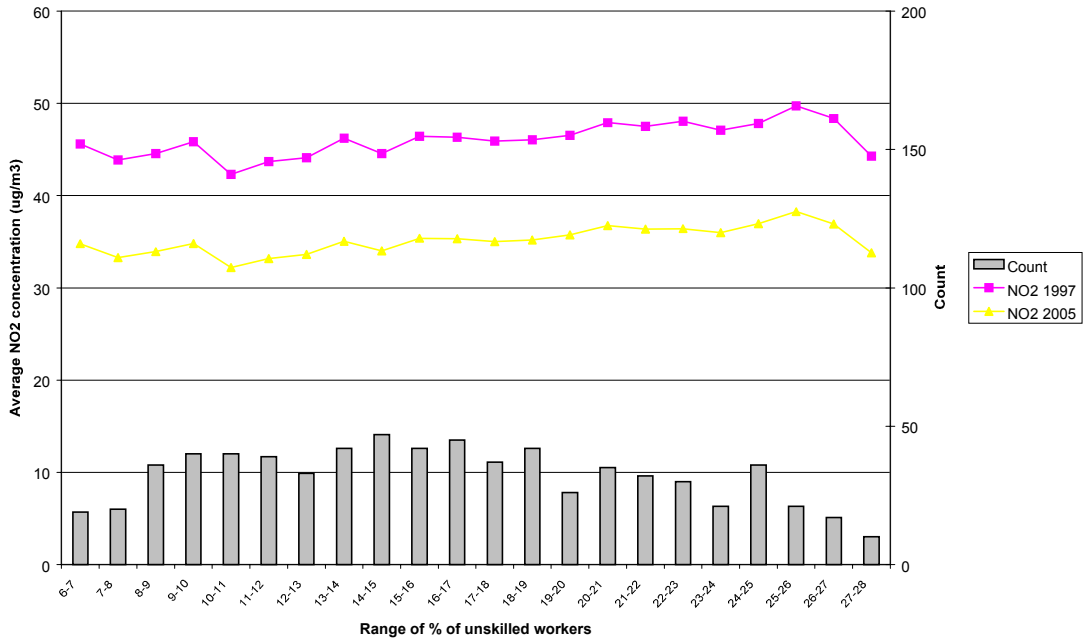


Figure 21 Average NO_2 concentrations by social class score range in London



4.7 ANALYSIS OF STATISTICAL SIGNIFICANCE

Table 2 shows the correlation coefficients for each of the pairs of data for the London pilot area. The correlation coefficient is a measure of the degree of linear association between two variables and can take values between –1 and +1. A correlation coefficient close to zero implies a lack of association while a coefficient close to one implies a close and positive correlation. Correlation coefficients, however, do not say anything about causality.

Table 2 Correlation coefficients for the London pilot area

r	PM_{10} 1997	PM_{10} 2004	NO_2 1997	NO_2 2005	NO_2 change (1997-2005)	PM_{10} change (1997-2004)
1998 Index Score	0.441	0.445	0.355	0.372	0.258	0.407
Unemployed	0.561	**0.581**	0.458	0.472	0.247	0.372
Over-crowded	0.531	0.547	0.516	0.525	0.333	0.352
Lacking amenities	0.511	0.532	0.474	0.476	0.339	0.334
Low earning	0.533	0.547	0.430	0.448	0.211	0.369
No car	**0.690**	**0.704**	**0.605**	**0.621**	0.420	0.563
17yrs not in education	0.002	-0.004	-0.069	-0.057	-0.245	-0.115

Those with the five highest values are highlighted. As shown earlier, the indicators of deprivation that are best correlated with air pollution are 'Unemployment' and 'No car'. The coefficients relating to change in pollution over time are lower in general than those related to the specific current and future concentrations.

Tables for the other pilot areas are provided in Annex 4, with a simple analysis of statistical significance. In Birmingham and Belfast similar patterns to that in London have been observed with almost all correlations being significant ($p = 0.01$). Correlation coefficient values are generally higher in Birmingham than in London and lower in Belfast. In Belfast the indicator

that did not show a significant correlation was 'Non permanent accommodation'. The 'No sewerage' indicator showed a negative correlation, but this has a very skewed distribution, with very few high values.

In Glasgow all correlation coefficients were negative, but only significant for PM_{10} 1997, PM_{10} 2004 and NO_2 2005 ($p = 0.05$). The results for Port Talbot are also all negative coefficients except for PM_{10} change from 1997-2004, but show little correlation. The coefficients are significant for only PM_{10} 1997 and PM_{10} 2004 ($p = 0.05$). The Port Talbot data set was small ($n = 31$).

4.8 POSSIBLE CONFOUNDING FACTOR OF POPULATION DENSITY

A potential confounding factor in this analysis is that of population density. This factor is used in emissions modelling to map emissions from domestic and some other sectors for which better data sets of geographical distribution are not available. This emission mapping is used as an input to the background air concentration mapping.

The social deprivation indices also use measures of population density, for example over crowded housing, and this may introduce a confounding factor. This issue is dealt with in more detail in Appendix 5.

The analysis shows that for PM_{10} the largest possible over-estimates of PM_{10} are in London, Birmingham and Glasgow and consequently a possible overestimate of modelled PM_{10} concentrations. This could have resulted in a more positive correlation between air concentration and social deprivation. However, the overall results show a negative correlation between these variables in Glasgow and therefore it is reasonable to conclude that this confounding factor does not have a dominant influence on the final results. Additionally, recent uncertainty analysis as shown that small variations in the emissions inventory do not have significant impacts on the modelled PM_{10} emissions in comparison with other, more uncertain, model inputs (King and Stedman 2000).

5 Conclusions

The following general conclusions can be drawn from the pilot area analysis:

- There is tentative evidence for a general positive correlation between background air pollution (NO_2 and PM_{10}) and deprivation index in London, Belfast and Birmingham but in Glasgow there is an inverse relationship.
- Port Talbot also shows a weak negative correlation for PM_{10}, using PM_{10} concentration data that include a contribution from local point sources.
- A similar positive relationship is found between social deprivation and NO_2 concentrations at the roadside and background locations in London, but in Glasgow the roadside NO_2 analysis did not show a relationship with social deprivation.
- Variation in spatial scale is shown to have little influence on the results (Wards compared with Enumeration Districts).
- Analysis of the possible confounding factor of population density shows that there is a possible over estimate of PM_{10} emissions in some cites but that this is unlikely to have influenced the final results.
- Air quality maps are also compared with social class data. This analysis does not show a pattern. Although this could imply little relationship between air pollution and social deprivation, it is more probably because the social class indicator (based on generic occupation classes) is a poor proxy of real socio-economic conditions.

As a result of these conclusions for London, Belfast and Birmingham, it is likely that carefully targeted policies to reduce air pollution concentrations in areas where they are highest could impact marginally more beneficially in the more deprived communities, and therefore move some way to reducing this apparent inequity. In the case of Glasgow, further analysis is required to more fully explain the pattern found.

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Annexes

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Annex 1 Results for each Pilot Area

LONDON

Figure 22 London PM_{10} 1997

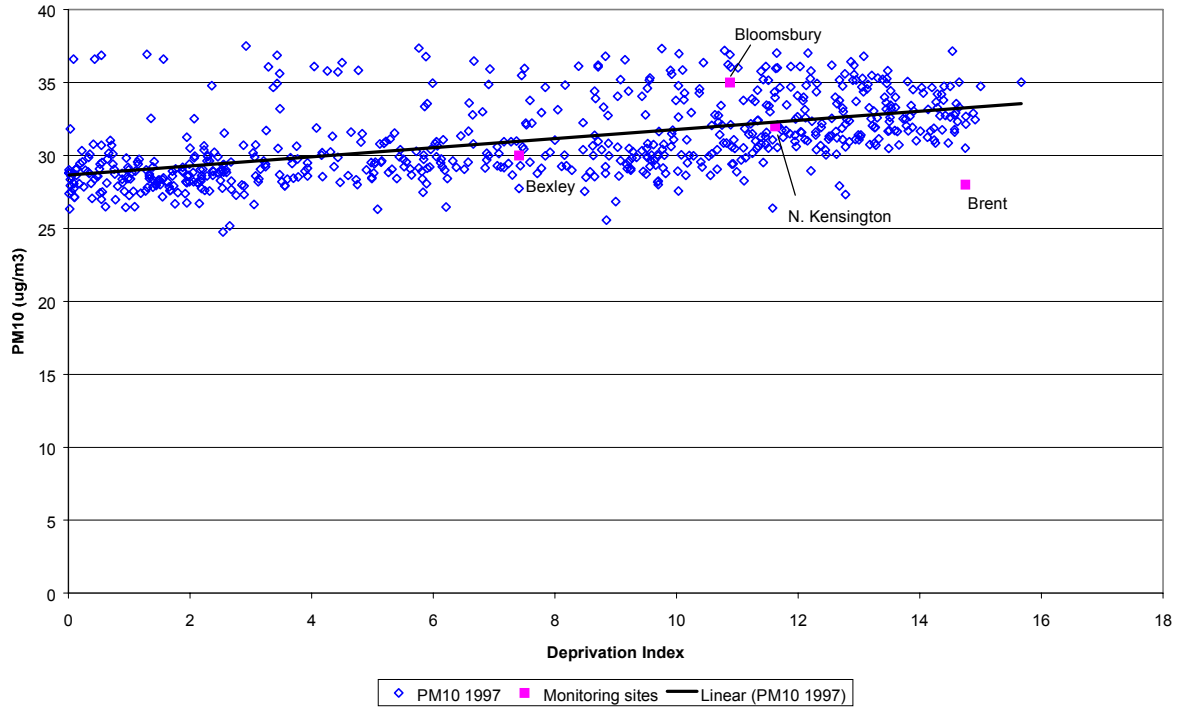


Figure 23 London NO_2 1997

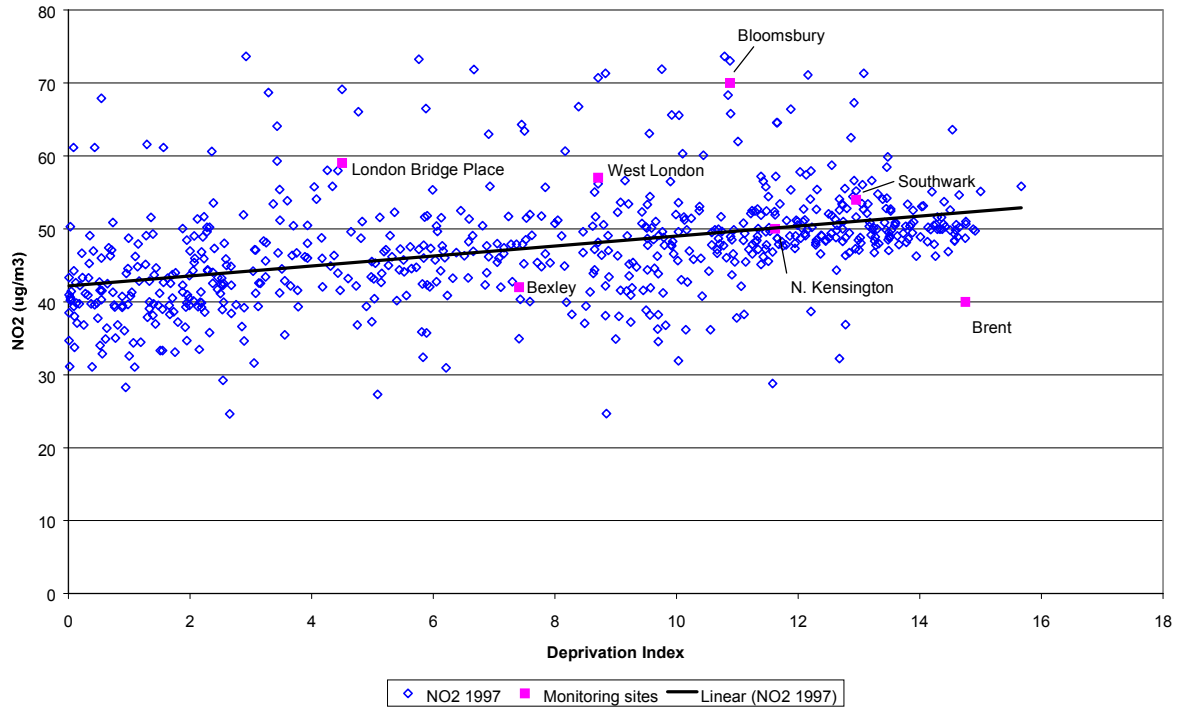
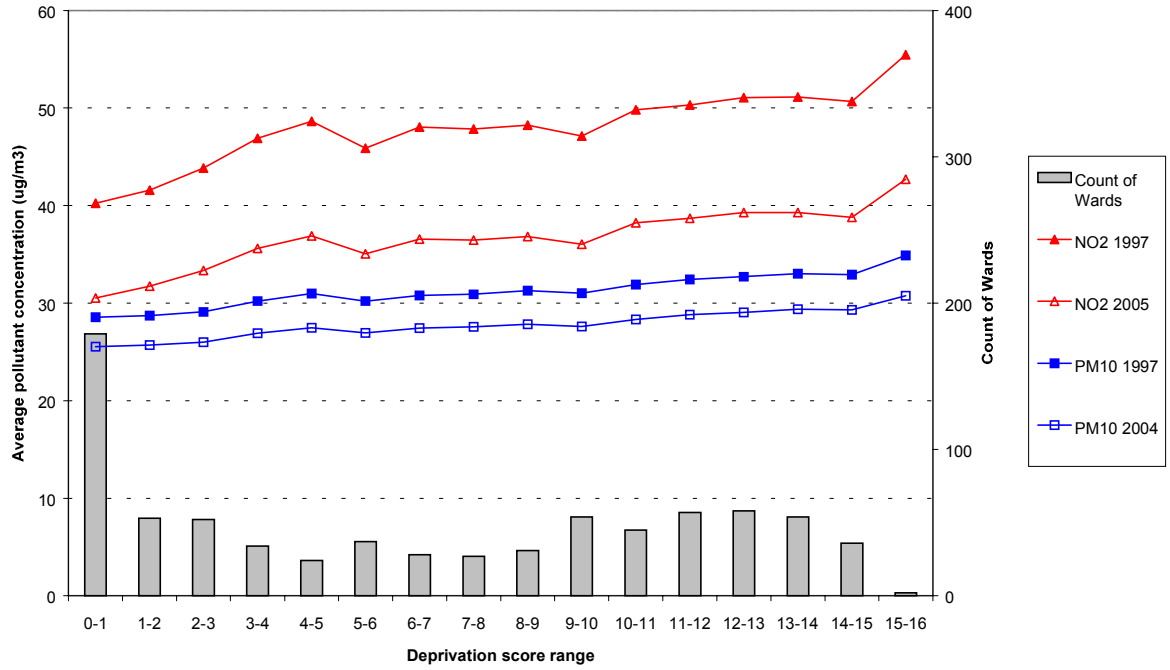


Figure 24 London Average pollution concentrations in Deprivation Score ranges



BIRMINGHAM

Figure 25 Birmingham PM_{10} 1997

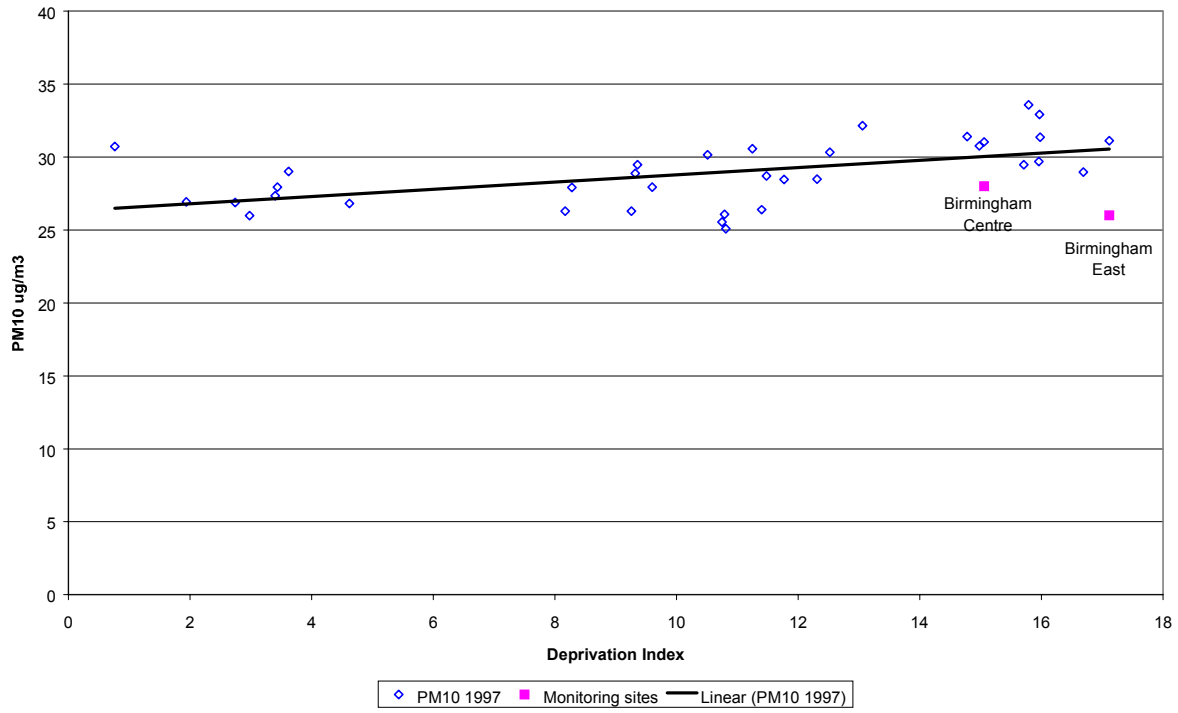


Figure 26 Birmingham NO_2 1997

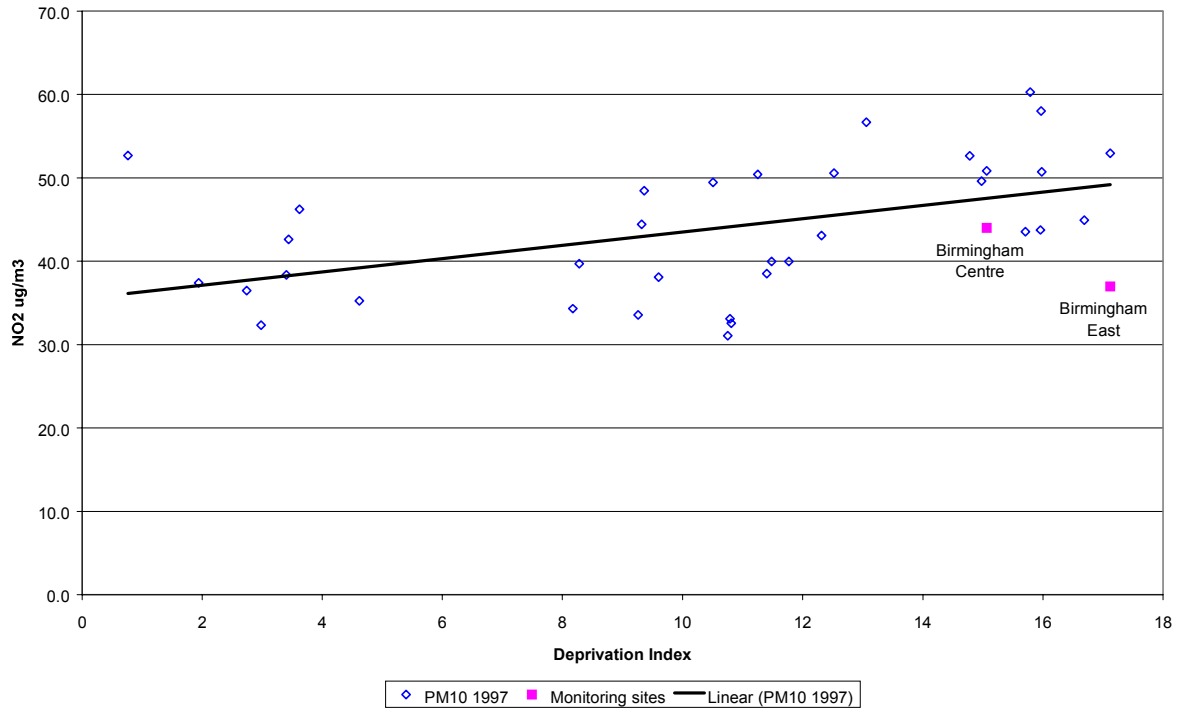
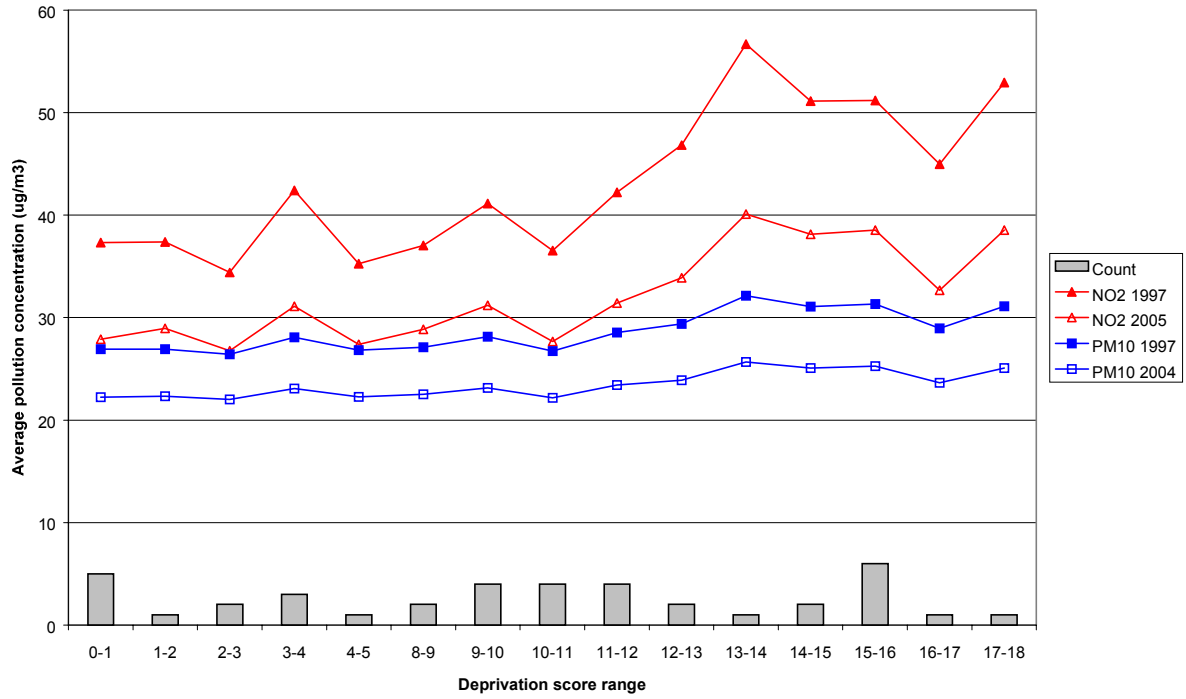


Figure 27 Birmingham Average pollution concentrations in Deprivation Score ranges



BELFAST

Figure 28 Belfast PM_{10} 1997

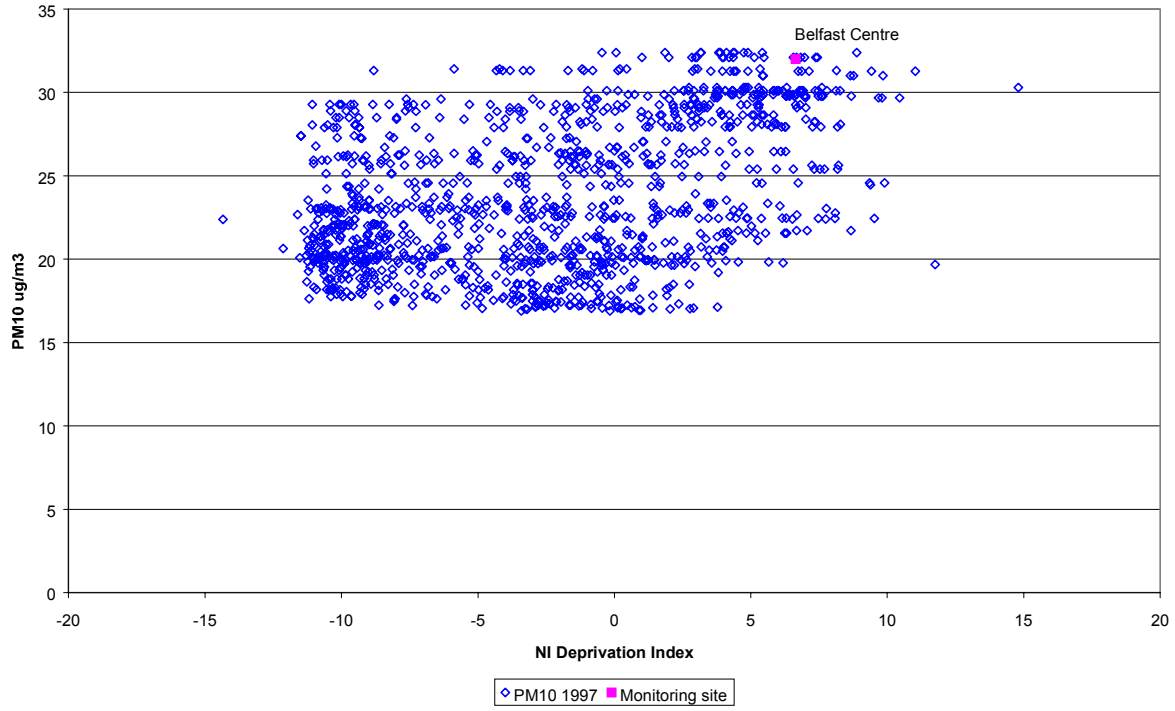


Figure 29 Belfast NO_2 1997

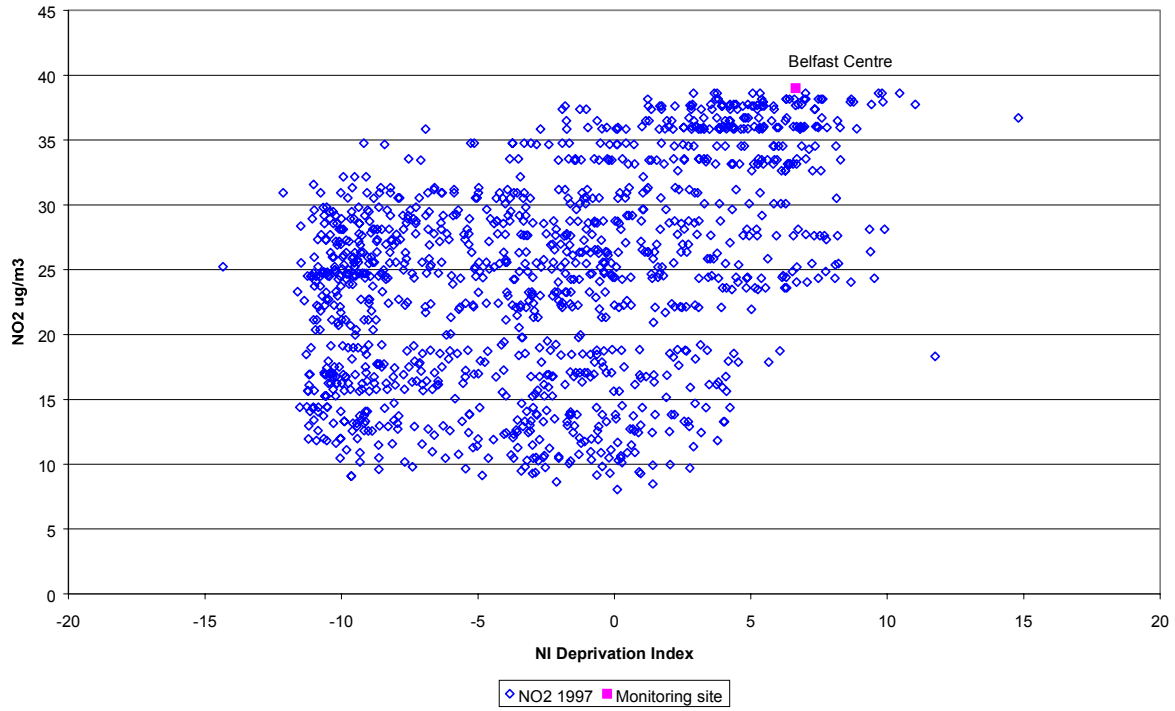
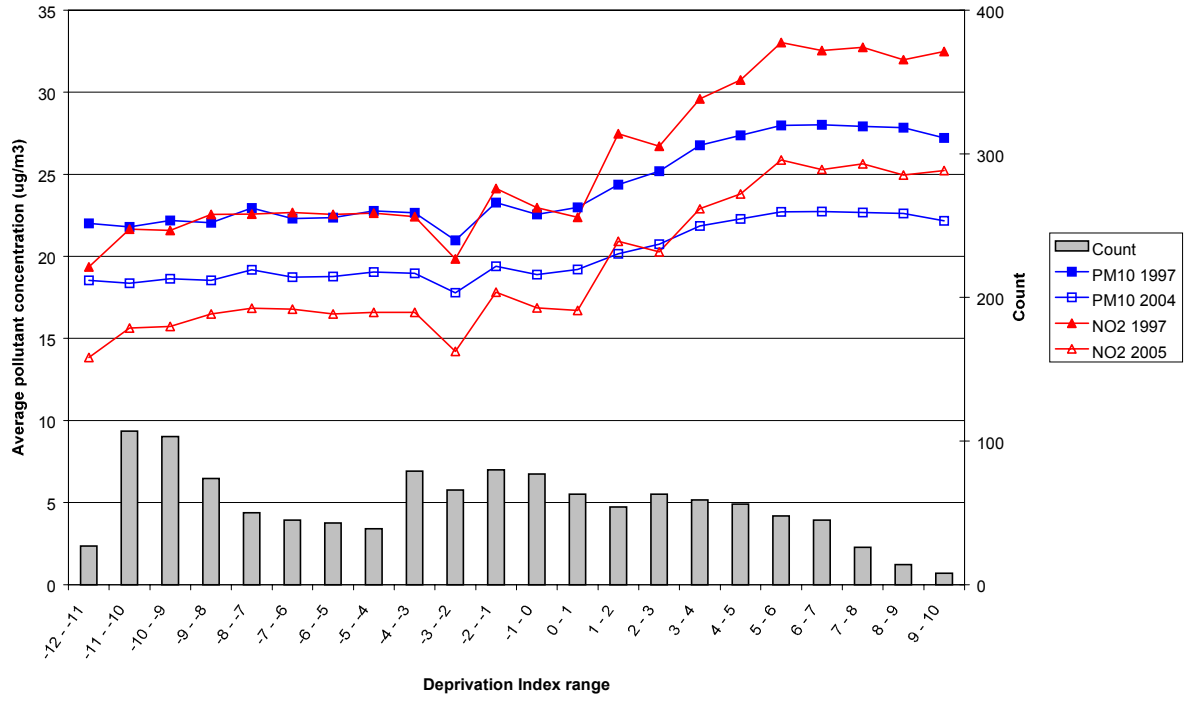


Figure 30 Belfast Average pollution concentrations in Deprivation Score ranges



GLASGOW

Figure 31 Glasgow PM_{10} 1997

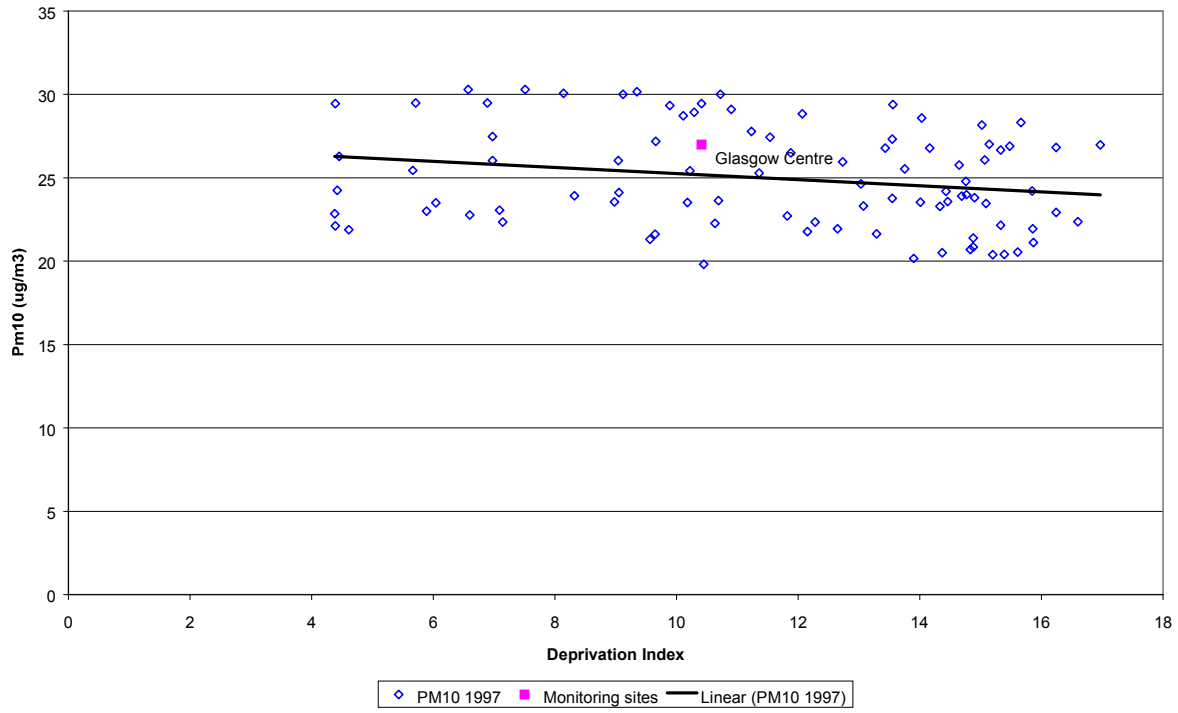


Figure 32 Glasgow NO_2 1997

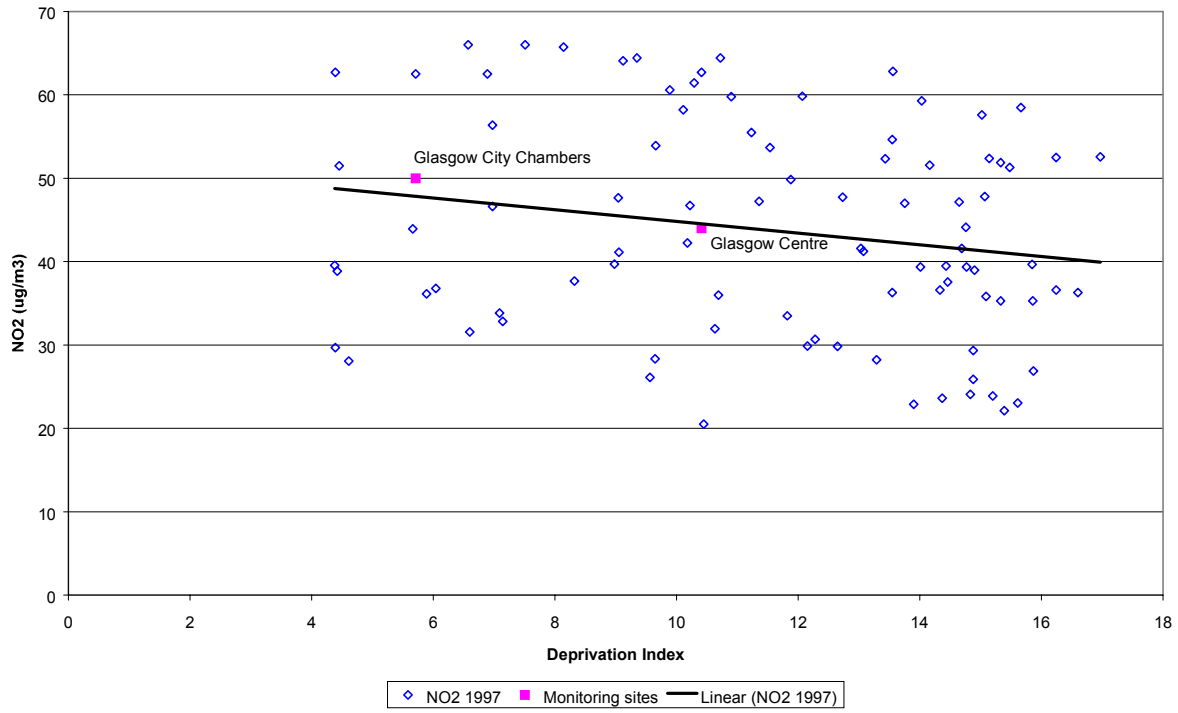
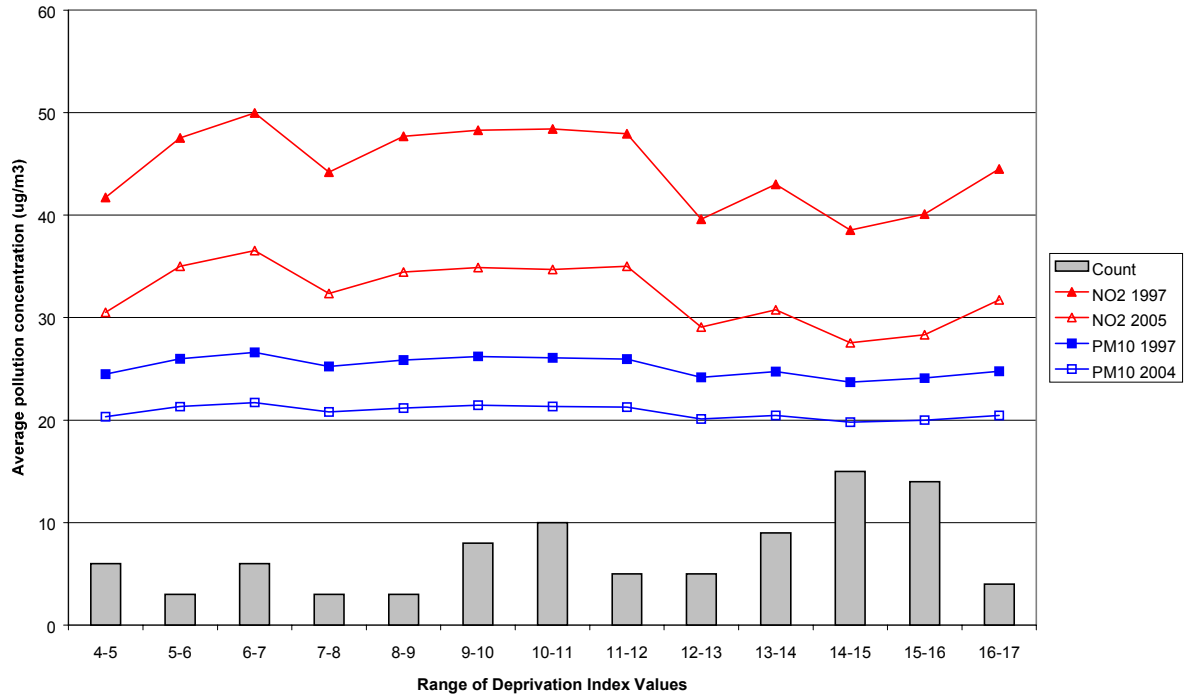


Figure 33 Glasgow Average pollution concentrations in Deprivation Score ranges



PORT TALBOT

Figure 34 Port Talbot PM_{10} 1997

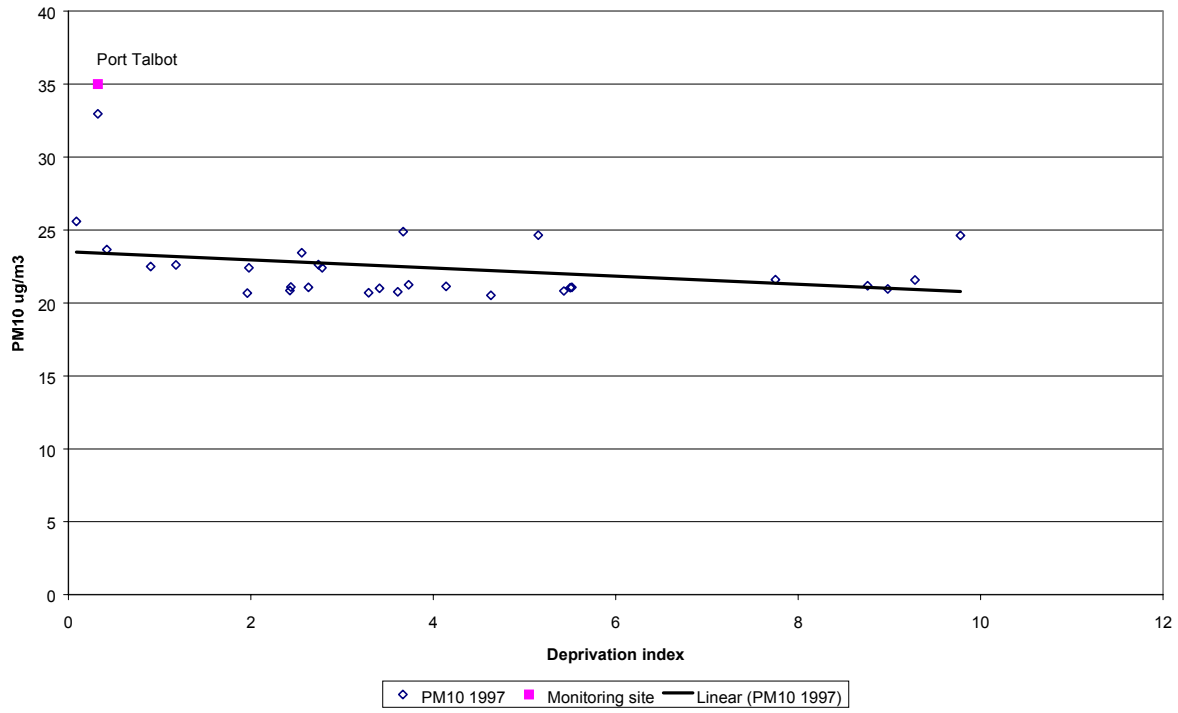


Figure 35 Port Talbot NO_2 1997

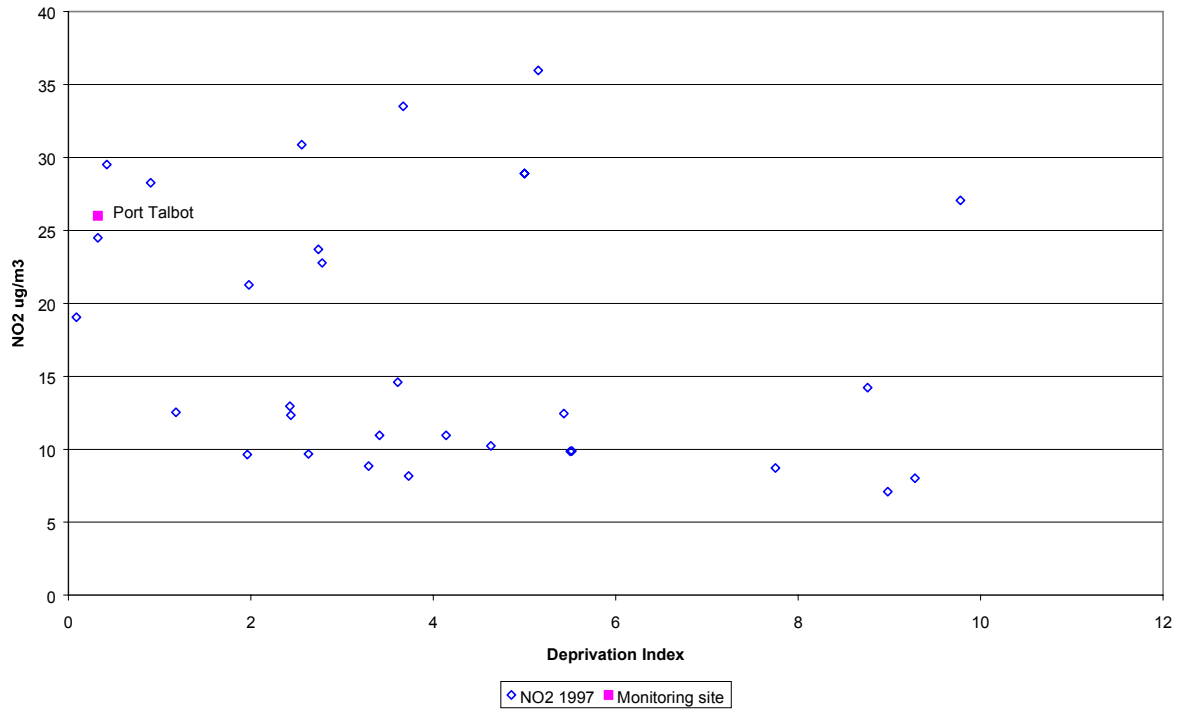
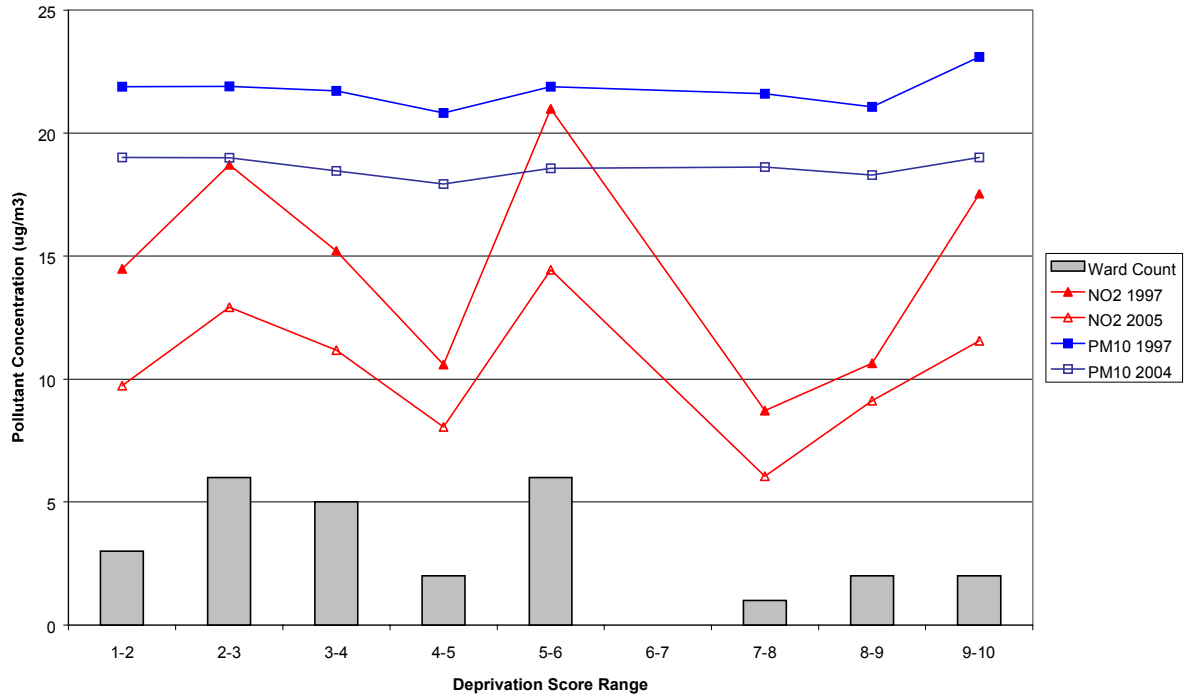


Figure 36 Port Talbot Average pollution concentrations in Deprivation Score ranges



Annex 2 Specific Deprivation Indicators

The following graphs are all for Wards in London.

Figure 37 NO_2 concentration by 'No Car' deprivation indicator

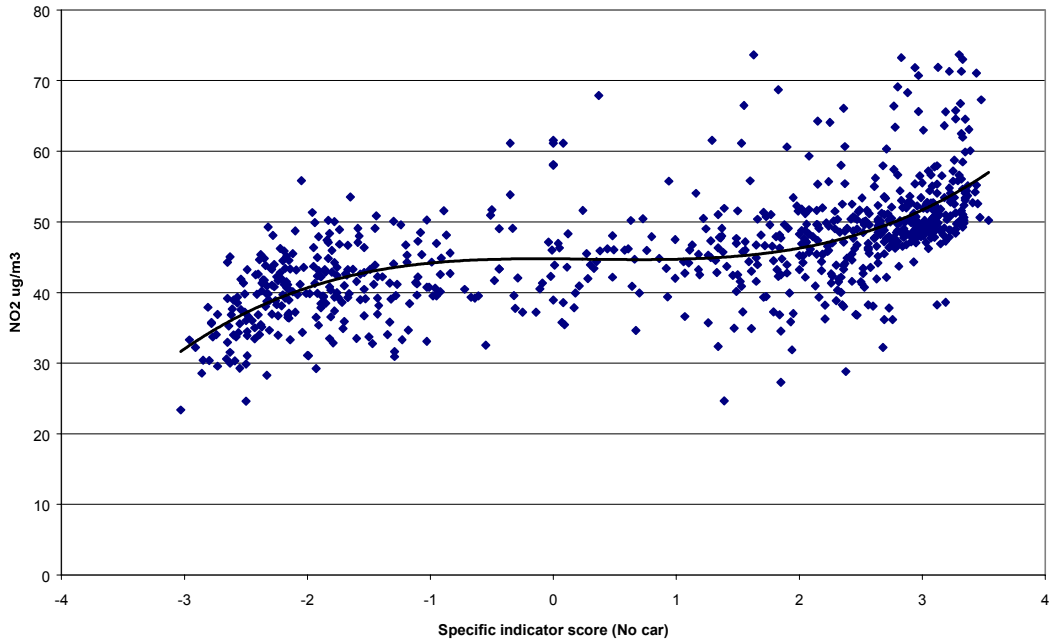


Figure 38 NO_2 concentration by 'Overcrowding' deprivation indicator

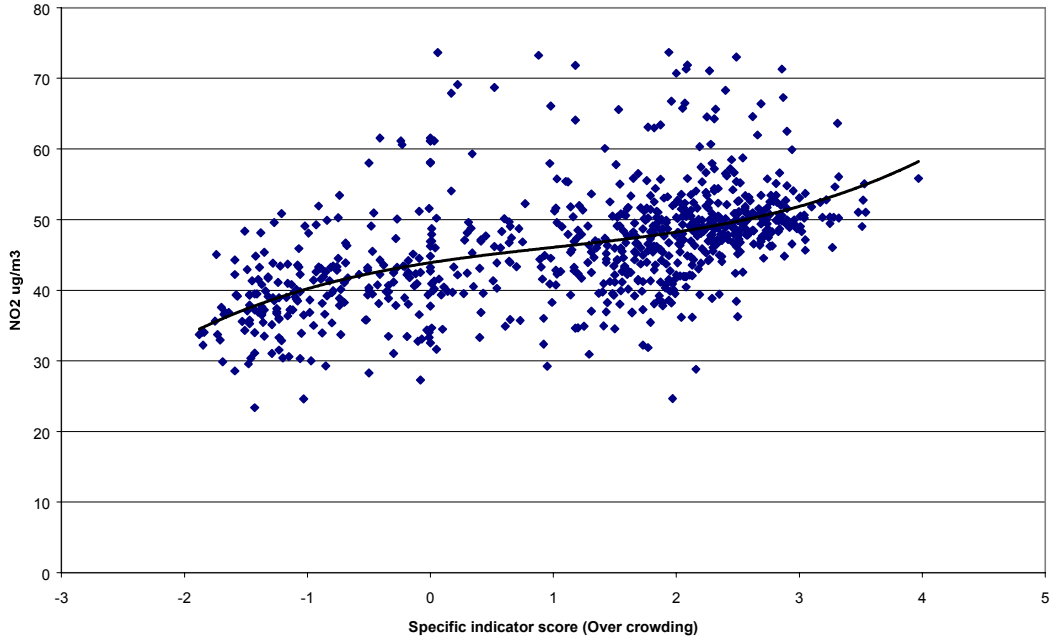


Figure 39 NO_2 concentration by '17yr olds not in education' deprivation indicator

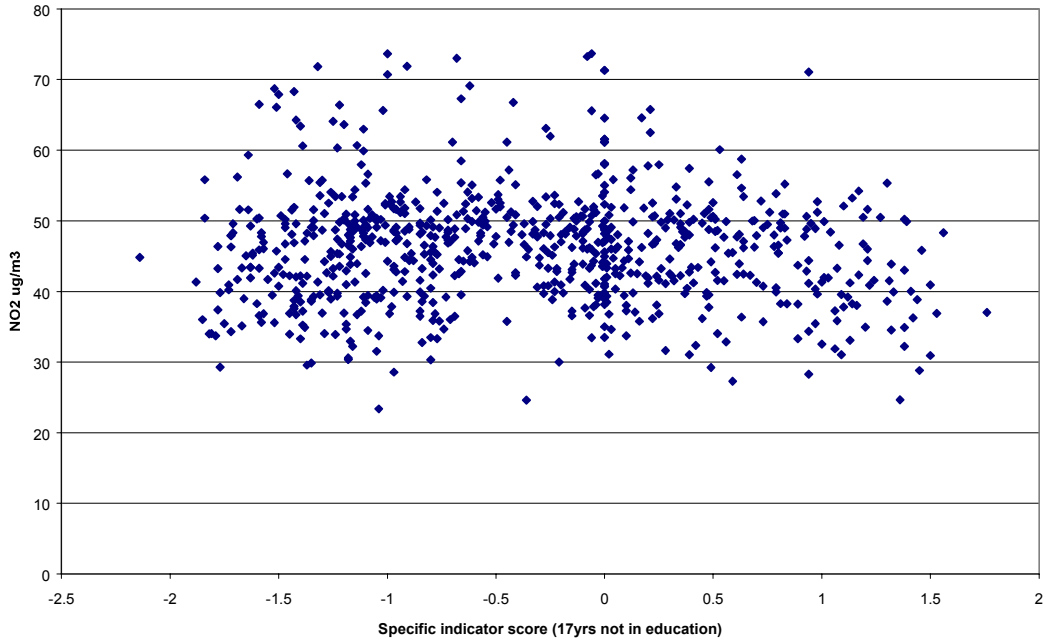


Figure 40 NO_2 concentration by 'Unemployment' deprivation indicator

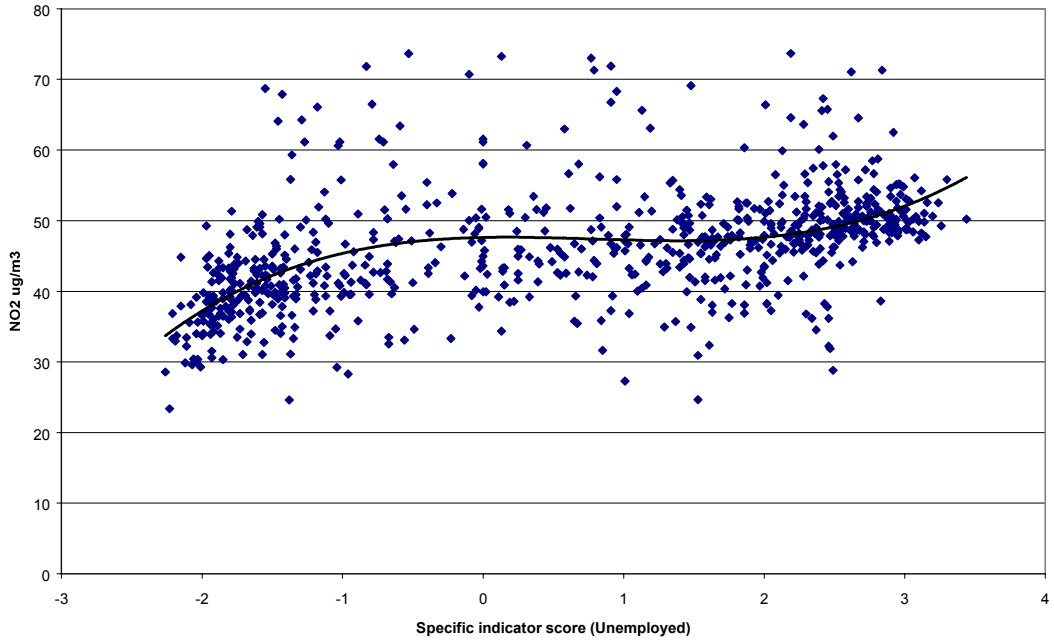


Figure 41 NO_2 concentration by 'Lacking amenities' deprivation indicator

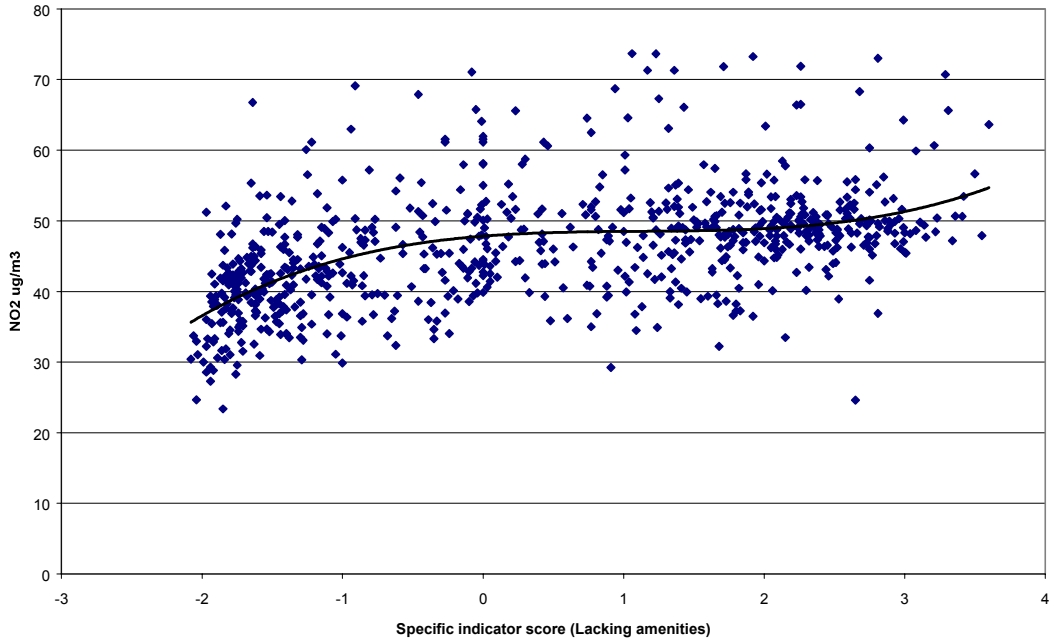
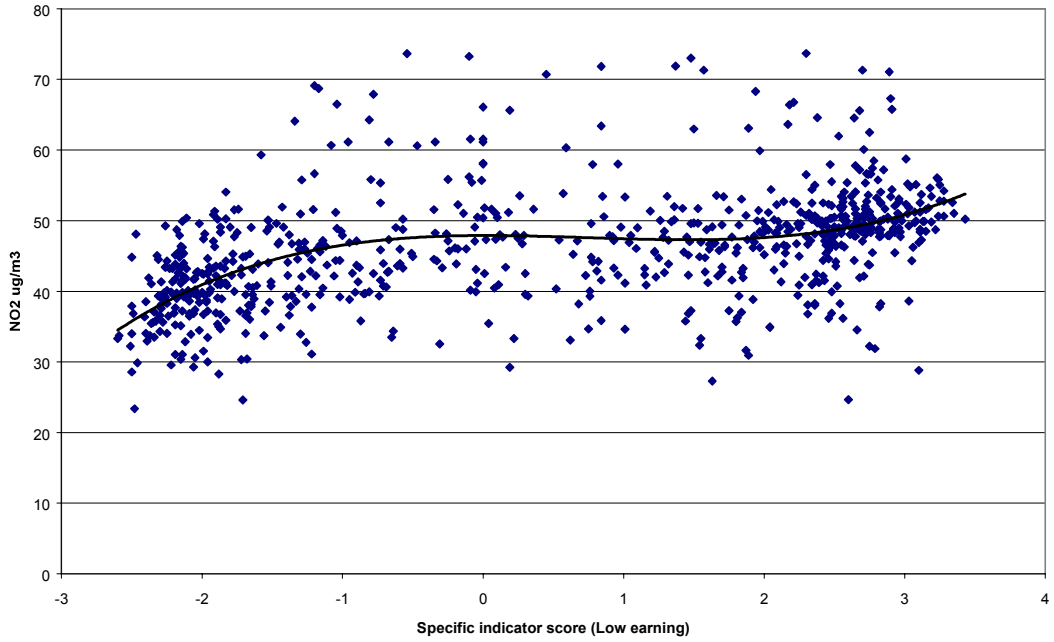


Figure 42 NO_2 concentration by 'Low earning' deprivation indicator



Annex 3 Roadside Results

LONDON

Figure 43 Roadside NO_2 by deprivation score in London

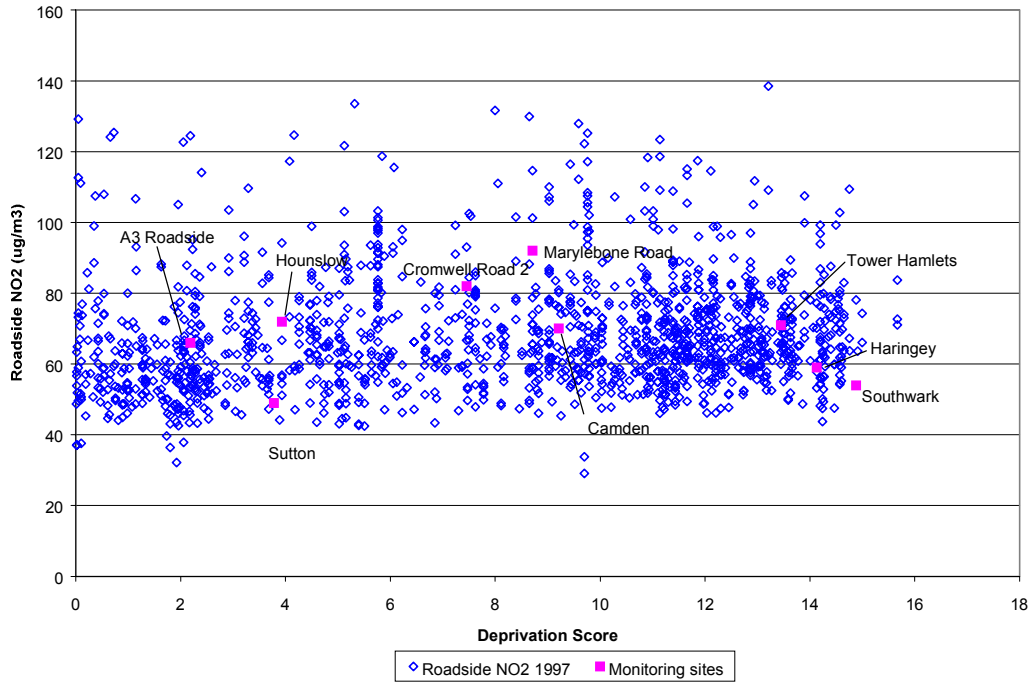
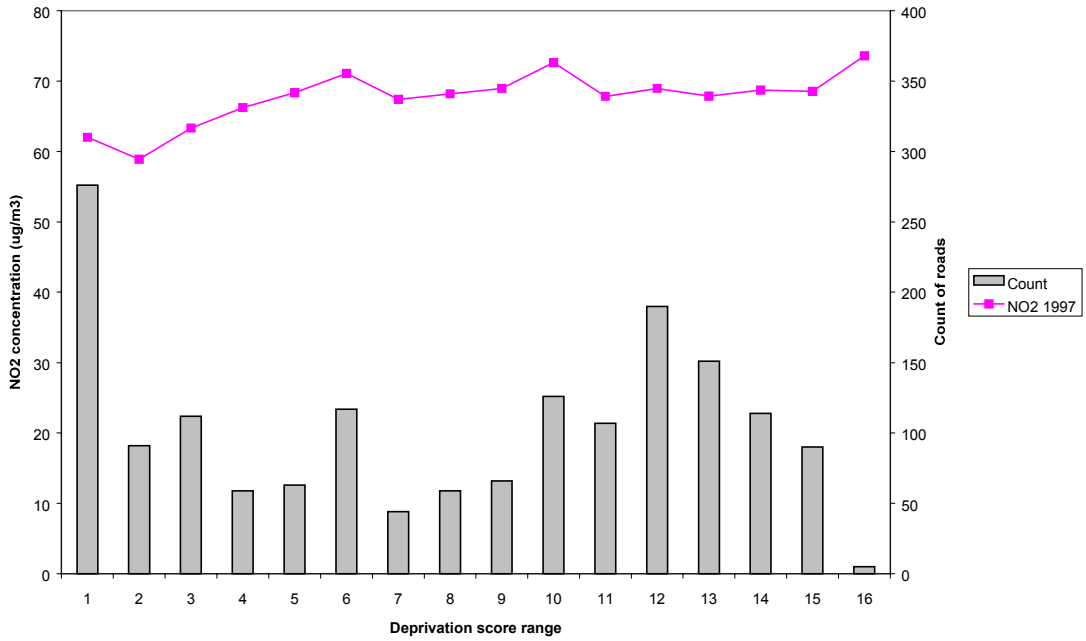


Figure 44 Average roadside NO_2 by Deprivation score range in London



GLASGOW

Figure 45 Roadside NO_2 by deprivation score in Glasgow

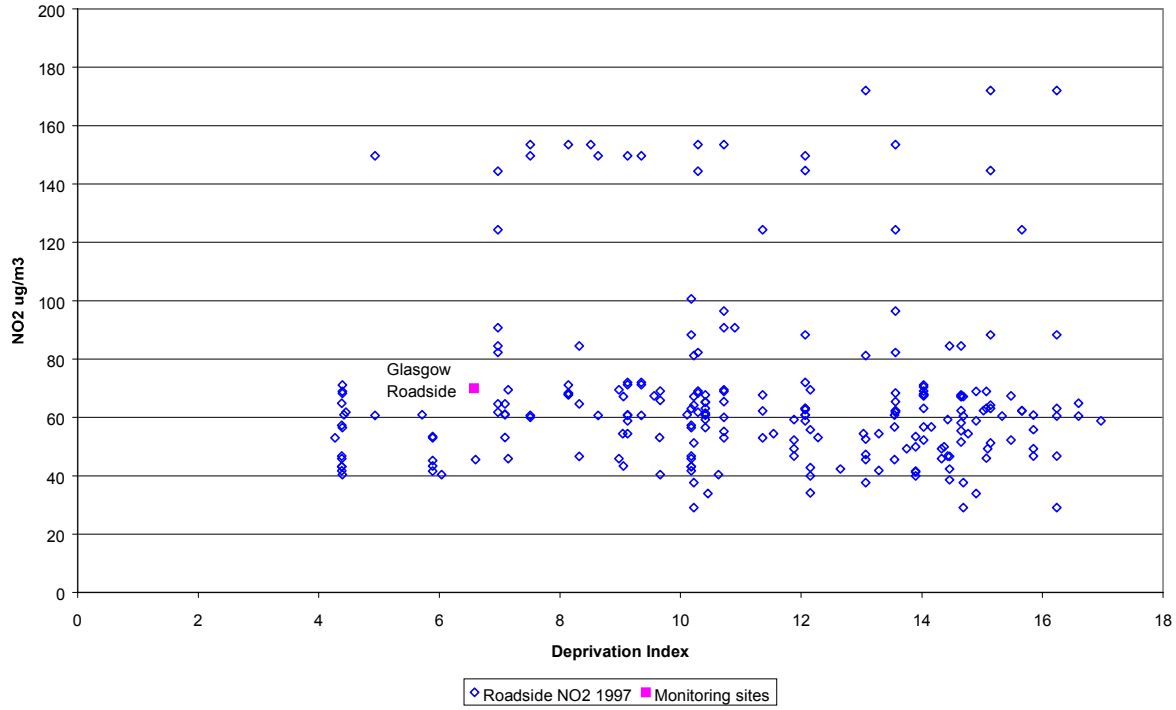
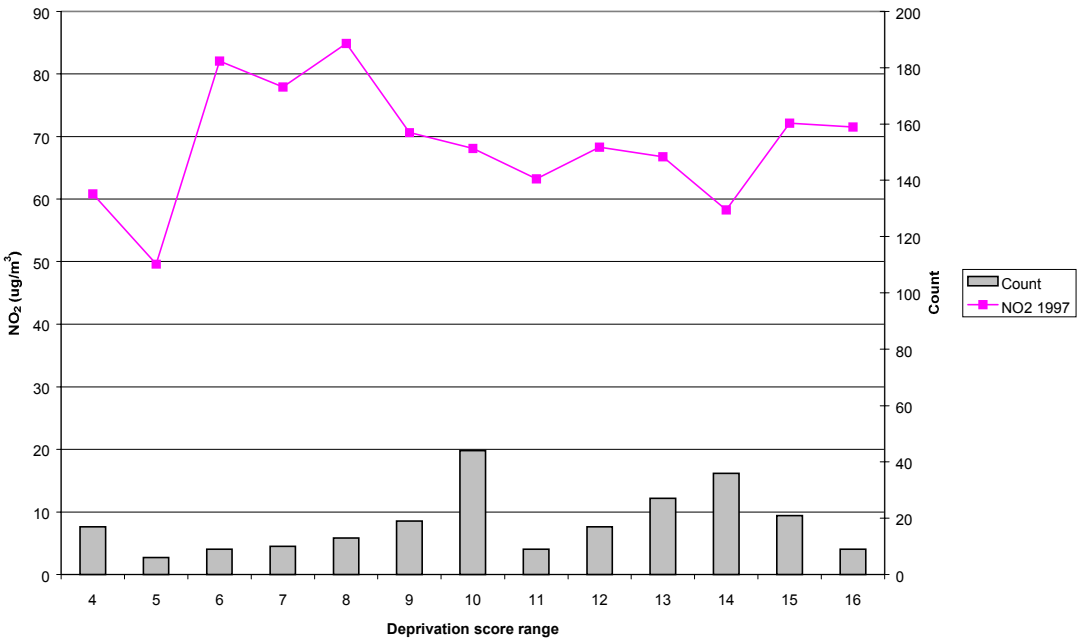


Figure 46 Average roadside NO_2 by Deprivation score range in Glasgow



Annex 4 Analysis of Statistical Significance

Testing for statistical significance can be illustrated using the London data set as an example. Using the statistical test for independence the critical value for r in a sample this size (n = 770) is 0.09 (p=0.01). Therefore the values for r must exceed this critical value in order that the coefficient can be considered significant with a probability of 0.99. Therefore nearly all of the correlation coefficients below are significant (shown in bold), the exceptions being those for the deprivation indicator '17 year olds not in education'.

London (n =770; critical r =0.09)

r	PM_{10} 1997	PM_{10} 2004	NO_2 1997	NO_2 2005	NO_2 change	PM_{10} change
1998 Index Score	**0.441**	**0.445**	**0.355**	**0.372**	**0.258**	**0.407**
Unemployed	**0.561**	**0.581**	**0.458**	**0.472**	**0.247**	**0.372**
Over-crowded	**0.531**	**0.547**	**0.516**	**0.525**	**0.333**	**0.352**
Lacking amenities	**0.511**	**0.532**	**0.474**	**0.476**	**0.339**	**0.334**
Low earning	**0.533**	**0.547**	**0.430**	**0.448**	**0.211**	**0.369**
No car	**0.690**	**0.704**	**0.605**	**0.621**	**0.420**	**0.563**
17yrs not in education	0.002	-0.004	-0.069	-0.057	**-0.245**	**-0.115**

Figures in **bold** are significant (p=0.01), those underlined show the five with the highest correlation coefficients

The results for the other study areas are shown below.

Birmingham (n=39; critical r = 0.405, p = 0.01)

r	PM_{10} 1997	PM_{10} 2004	NO_2 1997	NO_2 2005	NO_2 change	PM_{10} change
1998 Index Score	**0.625**	**0.638**	**0.578**	**0.619**	**0.591**	**0.470**
Unemployed	**0.567**	**0.583**	**0.523**	**0.570**	**0.529**	**0.406**
Over-crowded	**0.689**	**0.711**	**0.632**	**0.679**	**0.638**	**0.508**
Lacking amenities	**0.605**	**0.624**	**0.540**	**0.583**	**0.560**	**0.432**
Low earning	**0.459**	**0.476**	**0.419**	**0.465**	**0.422**	0.312
No car	**0.513**	**0.534**	**0.481**	**0.518**	**0.466**	0.386
17yrs not in education	0.191	0.198	0.196	0.168	0.175	0.235

Figures in **bold** are significant (p=0.01), those underlined show the five with the highest correlation coefficients

Belfast (n = 1221; critical r = 0.075, p = 0.01)

r	PM_{10} 1997	PM_{10} 2004	NO_2 1997	NO_2 2005	NO_2 change	PM_{10} change
INDEX	**0.431**	**0.430**	**0.419**	**0.433**	**0.260**	**0.434**
Lacking bath etc	**0.289**	**0.287**	**0.290**	**0.306**	**0.149**	**0.293**
No sewerage	**-0.419**	**-0.419**	**-0.421**	**-0.405**	**-0.405**	**-0.419**
High density	**0.243**	**0.244**	**0.274**	**0.290**	**0.133**	**0.243**
No car	**0.552**	**0.551**	**0.529**	**0.534**	**0.387**	**0.554**
Low income	**0.417**	**0.417**	**0.409**	**0.410**	**0.312**	**0.419**
Non perm accom	0.075	0.075	**0.081**	0.071	**0.110**	0.077
No qualifications	**0.340**	**0.340**	**0.314**	**0.320**	**0.216**	**0.341**
Unemployed	**0.488**	**0.487**	**0.477**	**0.491**	**0.303**	**0.489**
Pensioners with no CH	**0.142**	**0.141**	**0.131**	**0.145**	0.033	**0.145**

Figures in **bold** are significant (p=0.01), those underlined show the five with the highest correlation coefficients

Glasgow (n=91; critical r = 0.205, p = 0.05) n.b. lower level of significance

	PM_{10} 1997	PM_{10} 2004	NO2 1997	NO2 2005	NO_2 change	PM_{10} change
r	**-0.220**	**-0.229**	-0.197	**-0.229**	-0.103	-0.201

Figures in bold are significant (p=0.05)

Port Talbot (n=31, critical r =0.301, p = 0.05) n.b. lower level of significance

	PM_{10} 1997	PM_{10} 2004	NO2 1997	NO2 2005	NO_2 change	PM_{10} change
r	**-0.308**	**-0.394**	-0.238	-0.195	-0.290	0.301

Figures in bold are significant (p=0.05)

Annex 5 Confounding factor of population density

A potential confounding factor in this analysis is that of population density. This factor is used in emissions modelling to map emissions from domestic and some other sectors for which better data sets of geographical distribution are not available. This emission mapping is used as an input to the background air concentration mapping.

The social deprivation indices also use measures of population density, for example over crowded housing, and this may introduce a confounding factor. However, because it is clear that there is a causal link between population density, domestic heating emissions and air concentration, this confounding is only an issue if the emission mapping is inaccurate for other sources, for which the emissions should not be dependent on population density. That is, if excess emissions are mapped in areas of high population density, an overestimate in the air pollution mapping may cause unreliable results in this comparison between social deprivation and air quality.

Analysis of the emissions maps has shown that there is considerable variation between the emissions patterns in the areas considered in this study. Table 3 provides data on the proportion of area source emissions (i.e. not including point sources, which are not used in the background air pollution mapping) that are mapped using population density. These are divided into domestic sectors and non-domestic sectors. The latter are mapped using population because a better map is not available and therefore population density is used as a surrogate measure.

Table 3 Contribution of domestic and other sectors to emissions mapped by population density

	Area source total (t)	Domestic (t)	Non-domestic sector mapped by population (t)	Percent total non-domestic
PM10				
Belfast	2272	1520	64	3
Birmingham	732	119	91	12
Glasgow	426	70	54	13
London	4914	853	648	13
Port Talbot	236	69	13	6
NOx				
Belfast	8561	792	205	2
Birmingham	9899	1192	295	3
Glasgow	6764	706	174	3
London	68655	8447	2089	3
Port Talbot	3111	171	42	1

The main reason for the variations in PM_{10} emissions between the different areas is domestic fuel type. More coal is burnt in Belfast and Port Talbot, and hence the domestic emissions are a higher proportion of the total in these areas, with consequently less from other sectors. In the case of NO_x, there is little variation between locations in the percent of total non-domestic emissions mapped using population.

The table shows that up to 13% of area sources of PM_{10} and 3% of NO_x which are not directly related to emissions from the domestic sector are mapped using population density. Sectors mapped in this way include construction, some industrial processes for which location data are not available, military aircraft and landfill. This does not mean to say that the emissions in these areas are too high by 13 or 3 %, because, for many of the sectors concerned, emissions are concentrated in urban areas. But there may be some over estimation of emissions where population densities are high.

In conclusion, the analysis shows that for PM_{10} the largest possible over-estimates of PM_{10} are in London, Birmingham and Glasgow and consequently a possible overestimate of modelled PM_{10} concentrations. This could have resulted in a more positive correlation between air concentration and social deprivation. However, the overall results show a negative correlation between these variables in Glasgow and therefore it is reasonable to conclude that this confounding factor does not have a dominant influence on the final results. Additionally, recent uncertainty analysis as shown that small variations in the emissions inventory do not have significant impacts on the modelled PM_{10} emissions in comparison with other, more uncertain, model inputs (King and Stedman 2000).