AEAT/ENV/R/0865

# Further Analysis of $NO_2$ and $PM_{10}$ Air Pollution and Social Deprivation

A report produced for the Department for Environment, Food and Rural Affairs, The National Assembly for Wales and Department of the Environment in Northern Ireland

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# Executive Summary

'Given the geographical variation in predicted exceedances, there is 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 more vulnerable members of society.' This was the main premise for the analysis of the relationship between air pollution and social deprivation as stated in the report 'Analysis of Air Pollution and Social Deprivation' (King and Stedman 2000), and remains relevant for this further analysis.

In this study, four locations have been included for analysis: Greater London and Birmingham City District in England, Cardiff City Council in Wales, and Greater Belfast in Northern Ireland. In this analysis, the air quality and social deprivation data sets are compared using Geographic Information System techniques to assess what relationship, if any, exists between the two data sets. The GIS methodology uses the two spatial data sets to obtain an average pollutant concentration within a ward boundary for which social deprivation data is available. The resulting data pairs are then analysed using scatter plots and banded average analysis to examine for correlation.

The following conclusions can be drawn from the analysis undertaken in this study.

- Greater London, Birmingham City District and Greater Belfast appear to show a positive correlation between air pollution and social deprivation, with higher pollutant concentrations of $NO_2$ and $PM_{10}$ found in areas exhibiting higher levels of deprivation.
- Cardiff City Council does not appear to show any significant relationship between air pollution and social deprivation.
- Individual domains within the multiple deprivation index may show very different trends when they are analysed on an individual basis against air pollutant concentrations. However, in general, most domains follow the trend of a positive correlation between pollutant concentration and deprivation index. Important conclusions from this section of analysis include:

    - Income, employment, health and housing domains all have significant positive correlations with pollutant concentrations for Greater London. The 'housing' domain has the strongest positive correlation while the 'access to services' domain has a very strong negative correlation. The education domain does not exhibit a significant correlation with pollutant concentrations.
    - Birmingham City District follows the same pattern to Greater London although the 'education' domain has a more significant relationship.
    - All domains have significant relationships for Greater Belfast, with the 'health' domain possessing the strongest positive correlation coefficient and the 'housing' domain possessing the weakest coefficient. The 'access to services' domain shows a strong negative correlation.
    - The 'housing' and 'access to services' domains show significant correlations for Cardiff District Council. The access to services domain follows the trend seen in other cities, with a negative correlation, while the 'housing' domain shows a strong positive correlation. These trends are not reflected in the overall multiple deprivation index.

The above points illustrate the importance of looking at individual domains of deprivation, to gain an understanding of the relationship between indicators of deprivation and pollutant concentrations.

- Based on analyses undertaken, there appears to be a weak positive relationship between roadside $NO_2$ and $PM_{10}$ pollution and levels of deprivation.
- Variation in the spatial scale of analysis (ward and enumeration district levels) seems to have limited effect on the results.
- Based on the results from this analysis, policies to reduce air pollution in English cities could have greater benefits for more deprived communities, and for central urban locations that have the highest $NO_2$ and $PM_{10}$ pollutant concentrations. This appears true for Greater Belfast although under the 2010 scenario where additional measures are included, such measures do not appear to have increased benefits for more deprived areas.[1] This does not appear to be the case for Cardiff City Council, where policies to reduce air pollution could have greater marginal benefits for less deprived communities.
- For the areas of Greater London, Birmingham City District and Greater Belfast, it may be likely that targeted policies to reduce air pollution concentrations in areas where they are high could impact marginally more beneficially in more deprived communities, and therefore move towards reducing the apparent inequity.

[1] See section 1.2 for full description of 2010 scenarios.

# Contents


1 INTRODUCTION 1

1.1 BACKGROUND TO STUDY 1
1.2 STUDY OBJECTIVE 2

2 DATA SOURCES 3

2.1 INDICES OF SOCIAL DEPRIVATION 3
2.1.1 Index Methodology 3
2.1.2 England 5
2.1.3 Wales 5
2.1.4 Northern Ireland 5
2.2 POLLUTANT CONCENTRATION MAPS 6

3 GEOGRAPHICAL ANALYSIS 7

3.1 STUDY AREAS 7
3.2 SPATIAL ANALYSIS METHODOLOGY 7
3.2.1 Analysis at Ward and ED level 7
3.2.2 Roadside analysis 13

4 STATISTICAL ANALYSIS 15

4.1 ANALYSIS OF MULTIPLE DEPRIVATION VERSUS BACKGROUND $NO_2$ AND $PM_{10}$ 15
4.1.1 Analysis using Scatter Plots 15
4.1.2 Analysis using Banded Average Plots 21
4.2 COMPARISON OF DEPRIVATION – POLLUTANT CONCENTRATION CORRELATIONS BETWEEN REGIONS 24
4.3 ANALYSIS OF COMPONENT PARTS OF DEPRIVATION INDEX 26
4.4 ANALYSIS OF ROADSIDE POLLUTANT CONCENTRATIONS VERSUS DEPRIVATION 30
4.5 COMPARISON WITH IMPROVEMENTS IN AIR QUALITY 32
4.6 COMPARISON BETWEEN ED AND WARD LEVEL INDICES 36
4.7 ANALYSIS OF STATISTICAL SIGNIFICANCE 37
4.8 POSSIBLE CONFOUNDING FACTOR OF POPULATION DENSITY 38
4.9 COMPARISON BETWEEN INITIAL STUDY AND PRESENT ANALYSIS 39

5 CONCLUSIONS 41

6 REFERENCES 43

ANNEXES 45

ANNEX 1 MULTIPLE DEPRIVATION VERSUS POLLUTANT CONCENTRATION: BIRMINGHAM ANALYSIS 46
ANNEX 2 SPECIFIC DOMAINS VERSUS POLLUTANT CONCENTRATIONS 48
ANNEX 3 COMPARATIVE ROADSIDE ANALYSIS 53
ANNEX 4 COMPARISON WITH IMPROVEMENTS IN AIR QUALITY 54
ANNEX 5 ANALYSIS OF STATISTICAL SIGNIFICANCE 62

# 1 Introduction

## 1.1 BACKGROUND TO STUDY

This study updates an analysis carried out by King and Stedman (2000) which examined the relationship between air pollution and social deprivation. New deprivation indices and pollutant concentration maps are now available; further analysis has therefore been undertaken to update the initial pilot study.

The background to this study is similar to that explained in the previous study. 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 $PM_{10}$ by the end of 2004:

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

A recently published consultation document (DEFRA et al, 2001) presents proposals to strengthen substantially the Air Quality Strategy objectives for particles by supplementing the present objectives with new provisional objectives of:

- for all parts of the UK, except London and Scotland, a 24-hour mean of 50 $\mu gm^{-3}$ not to be exceeded more than 7 times per year and an annual mean of 20 $\mu gm^{-3}$, both to be achieved by the end of 2010;
- for London, a 24-hour mean of 50 $\mu gm^{-3}$ not to be exceeded more than 10-14 times per year and an annual mean of 23-25 $\mu gm^{-3}$, both to be achieved by the end of 2010;
- for Scotland, a 24-hour mean of 50 $\mu gm^{-3}$ not to be exceeded more than 7 times per year and an annual mean of 18 $\mu gm^{-3}$, both to be achieved by the end of 2010.

It is proposed that the Mayor and London authorities should work towards a target of 20 $\mu gm^{-3}$ after 2010, with the aim of achieving it by 2015 where cost effective and proportionate local action can be identified.

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.

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

In order to assess fully 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, which in the case of this analysis is the spatial level of ward.

## 1.2 STUDY OBJECTIVE

The broad objectives of this study remain the same as those stated in the initial pilot study (King and Stedman 2000) which were to examine the distributional effects of $NO_2$ and $PM_{10}$, the two pollutants for which the air quality objectives are expected to be the most challenging, in order to examine some aspects of 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 further analysis based on that undertaken in the initial pilot study. This study assesses the relationship between social deprivation and air quality in both 1998 and the predicted reference case in 2010 (2010b) plus a 2010 'with measures' case (2010wm).[2] Details of both the current policies baseline reference case and the 'with measures' scenarios for 2010 are provided in DEFRA et al (2001) and supporting technical documents (Stedman et al 2001a, 2001b). The 'with measures' case is the illustrative additional measures scenario from DEFRA et al (2001). This illustrative scenario includes a range of possible additional measures to reduce $PM_{10}$ emissions from both traffic and stationary sources. Measure specifically aimed at reducing $NO_2$ concentrations have not been examined but the impact of the possible traffic measures to reduce $PM_{10}$ on $NO_2$ have been calculated. The impact of the possible measures for stationary sources on $NO_2$ concentrations in city centres is expected to be small and has not been included here.

[2] Two scenario cases have been outlined for 2010. In the graphs, the 2010 baseline will be refered to as '2010b' and the 2010 'with measures' scenario will be refered to as '2010wm'.

# 2 Data Sources

## 2.1 INDICES OF SOCIAL DEPRIVATION

An Index of Deprivation has been developed for each devolved region of the UK - for England, Wales and Northern Ireland, indices have recently been published, all of which have been developed by the Social Disadvantage Research Centre at Oxford University. The availability of a reasonably consistent set of deprivation indices allows for greater inter-regional comparison within this analysis. The indices are consistent both in terms of spatial scale, having been compiled at the ward level, and in terms of the methodology used for constructing the indices.

In the previous report (King and Stedman 2000), social deprivation indices were used for each devolved region of the UK which had been developed using different methodologies. Due to differences in methodology, and analysis undertaken at different spatial scales, inter-regional comparison was difficult.

All indices used in this analysis use the ward level boundary (or a directly comparable geographic scale) as the resolution at which to compile deprivation index data. The ward level is the next geographical unit in the electoral boundary hierarchy above enumeration districts. The enumeration district (ED) is the smallest geographical unit on which census data are collected. An ED is typically the area that a census enumerator can cover on the day of the census to collect completed forms. It is typically about 150 households and is therefore much smaller in urban areas than in rural areas. The ward area covers approximately 50 enumeration districts. For all three indices used, ward level data are the primary spatial level for data. The Northern Ireland index also provides data at the ED level but in a different, less comprehensive format. The Welsh index uses electoral divisions which are similar to the ward level boundaries as observed in England and Northern Ireland.

### 2.1.1 Index Methodology

The methodology used for the construction of the three deprivation indices is similar. A comparison of the summary information for each index can be seen in Table 1. Due to the similarity in indices for each devolved region, some comparison can be made across regional boundaries. This was done on a generic basis in the previous report although no conclusions were drawn from such a comparison. In this analysis, a comparison has also been made; conclusions drawn have been treated with caution due to other factors that make such a comparison difficult.

**Table 1** Summary information on Social Deprivation Indices

| Region | Index Date | Description | Source* | Spatial resolution |
|---|---|---|---|---|
| England | 2000 | Known as the 'Indices of Deprivation 2000'. An index of multiple deprivation has been produced based on six domains: income; employment; health deprivation and disability; education, skills and training; housing; and geographical access to services. | Commissioned by the DETR in 1998 to update the 1998 Index of Local Deprivation | Ward level |
| Wales | 2000 | Known as the 'Welsh Index of Multiple Deprivation'. An overall index of multiple deprivation has been produced based on the domains outlined in the English index. | Commissioned by the Welsh Office in 1999. | Electoral division level |
| Northern Ireland | 2001 | Known as 'Measures of Deprivation in Northern Ireland'. An overall index of multiple deprivation has been produced based on the domains outlined in the English index plus an extra domain called Social environment. | Commissioned by the Northern Ireland Statistics and Research Agency (NISRA) to update the 1994 'Robson Measures of relative deprivation. | Ward level; ED level (with less detail). |

* All indices have been produced by the Social Disadvantage Research Centre at Oxford University.

Individual domains are produced within each index, using a set of indicators and aggregated together to produce an index of multiple deprivation. The domains are combined in two stages. Firstly, each domain is transformed to a standard distribution, using an exponential transformation method – as a result, every domain is converted to an identical distribution with the same maximum and minimum values. The domains are then weighted according to their relative importance (see section 2.1.2) and combined.

Each domain looks to represent a different aspect of deprivation. However, there are differences in terms of which indicators are used to compile the domains within each index. The domain 'Geographical Access to Services', for example, seeks to address the access of different communities to a range of different services. Table 2 provides a comparison of the indicators used to construct this domain. A further important point is that even if two similar indicators are used to construct a domain, they may have used different measuring methodologies or statistical data sets. These factors need to be considered when attempting to make any inter-regional comparisons.

**Table 2** Geographical Access to Services domain: A comparison of indicators

| England | Wales | Northern Ireland |
|---|---|---|
| Access to a post office | Access to a post office | Access to a post office |
| Access to food shops | Access to large food shops | Access to a GP |
| Access to a GP | Access to a GP | Access to A&E facilities |
| Access to a primary school | Access to A&E facilities | Access to a dentist |
| | | Access to an optician |
| | | Access to a pharmacist |
| | | Access to a library |
| | | Access to a museum |
| | | Access to a social security office or a training and employment agency |

The following sections outline some specific information concerning each index.

### 2.1.2 England

The English index uses the following domains (Each domain is weighted within the overall deprivation index according to the bracketed percentage as shown for each domain):

- Income (including a subset of 'Child Poverty') (25%)
- Employment (25%)
- Health Deprivation and Disability (15%)
- Education, Skills and Training (15%)
- Geographical Access to Services (10%)
- Housing (10%)

Within this new index, there are no spatial data at ED level. More information on the English index can be found at the following website:
http://www.regeneration.dtlr.gov.uk/research/id2000/index.htm

### 2.1.3 Wales

The Welsh index uses the same domains as seen listed for the English Index, with the same weightings accorded to the domains. All of the domains, although representing the same category of deprivation, incorporate different indicators. For example, the Welsh 'Housing' domain looks more at physical housing condition while the English index domain uses indicators which reflect housing occupiers. Data are provided at the spatial resolution of electoral division which is directly comparable to the ward resolution.

More information on the Welsh Index can be found at the following website:
http://www.wales.gov.uk/keypubstatisticsforwales/content/publication/social/2000/deprivation/intro_e.htm

### 2.1.4 Northern Ireland

The Northern Ireland index uses the same domains as the other indices in this analysis but also includes an extra domain, Social Environment, weighted at 5% of the overall index. This domain uses indicators which reflect crime statistics. Geographical Access to Services (5%)

domain is reduced from 10% as seen in the other indices to 5% due to the extra Social Environment domain.

The primary change from the previous index (from 1994) is that data are provided at the ward level and at the enumeration district (ED) level. In the new index, ED data are provided for two of the 7 domains, making it a secondary source within this analysis.

More information on the NI Index can be found at the following website:
http://www.nisra.gov.uk/whatsnew/dep/index.html

## 2.2 POLLUTANT CONCENTRATION MAPS

$NO_2$ and $PM_{10}$ concentration maps have been used in this analysis, and combined with the social deprivation coverages. The methods used to calculate maps of background and roadside $PM_{10}$ and $NO_2$ concentrations used here have been described by Stedman et al (2001a, 2001b) and in associated documents (DEFRA et al, 2001). Concentration maps have been calculated from the 1998 emission inventory for the UK using a combination of monitoring data for 1998 and empirically derived dispersion coefficients. These coefficients have also been applied to maps of projected emissions in 2010 for the reference and 'with measures' cases.

# 3 Geographical Analysis

## 3.1 STUDY AREAS

Four areas have been used in this analysis and include:

- Greater London (which includes the wards of all London Boroughs)
- Birmingham City District
- Cardiff City Council
- Greater Belfast (which includes the districts of Belfast, North Down, Carrickfergus, Newtownabbey, Lisburn and Castlereagh)

The previous analysis used the Welsh geographical location of Port Talbot District. Port Talbot was not included this time due to the inconclusive nature of results produced. Cardiff City Council is used as a replacement area, being an appropriate district as a major urban area in Wales with certain air quality issues, and encompassing a range of communities with different levels of deprivation. Glasgow City District is omitted from this analysis due to there being no new deprivation index for Scotland. Inconclusive results were produced under the previous analysis and would probably be repeated in an analysis where the index of deprivation remained the same. The same geographical areas are used for England and Northern Ireland.

## 3.2 SPATIAL ANALYSIS METHODOLOGY

### 3.2.1 Analysis at Ward and ED level

Due to the similar spatial nature of all indices of social deprivation, most of the analysis was undertaken at the ward boundary level. Some analysis was done at ED spatial resolution for Greater Belfast to provide some comparison between the results derived when using two different spatial data sets.

Changes to electoral boundaries meant that new ward boundary sets were used in this analysis. A new 1998 OS ward boundary set was used for England while for Wales, a 1998 electoral division boundary set was used. An up to date ward boundary set was used for Northern Ireland.

The ward and electoral division boundary sets that have been used are defined in the mapping system as polygons. Each separate polygon has the appropriate deprivation score assigned to it, as illustrated in Figure 1 for Greater London. This figure shows the higher levels of deprivation as darker colours, showing an area to the east and north east of the City of London as the most deprived.

**Figure 1** Deprivation Index in Greater London by Ward

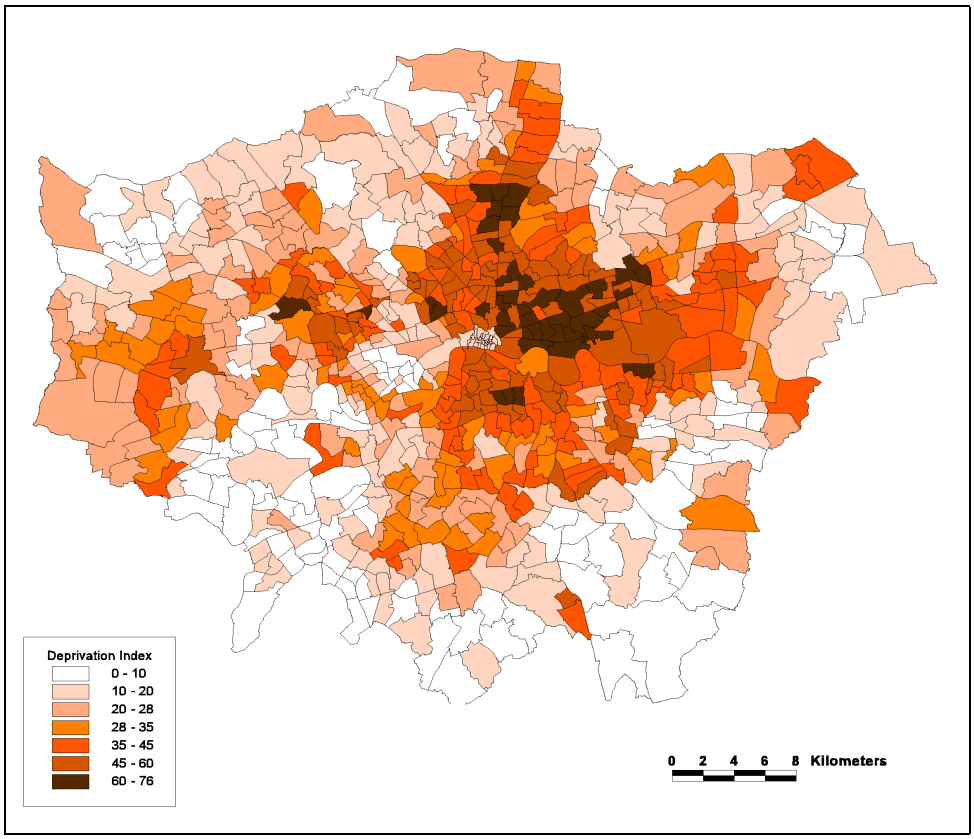
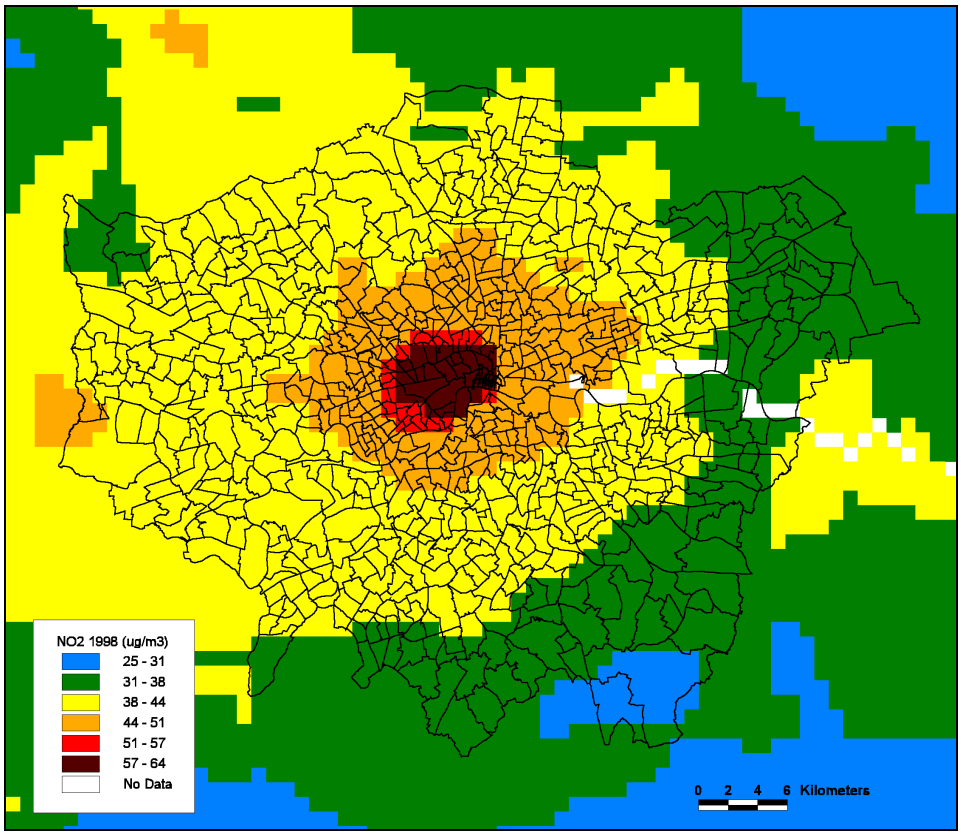



Figure 2 illustrates how the ward boundaries, again for Greater London, can be overlaid on to the pollutant concentration map to generate data which can be used to assess any potential relationship between the two parameters. The pollutant concentration maps are 1x1 km grids, providing an average pollutant concentration figure within that spatial resolution. An average pollutant concentration is derived from the grid for each of the polygon areas. These pollutant concentrations can then be compared to the deprivation data which corresponds to specific ward areas.

**Figure 2** Annual mean $NO_2$ concentrations (1998) and Greater London Wards




Data at the Enumeration district (ED) level have been used within this analysis to look at differences in relationships due to analysis at different resolutions. Northern Ireland has the only index where data are provided at the spatial level of ED so Greater Belfast has been used for the analysis. In the GIS methodology, each ED is represented as a point, as shown in Figure 3. At each point, a pollutant concentration can be derived from the pollutant concentration grids, and subsequently compared to the corresponding deprivation data for that ED. Figure 3 shows ED deprivation scores while Figure 4 shows deprivation scores at the level of ward.

**Figure 3** Deprivation Index data at the ED level for Greater Belfast

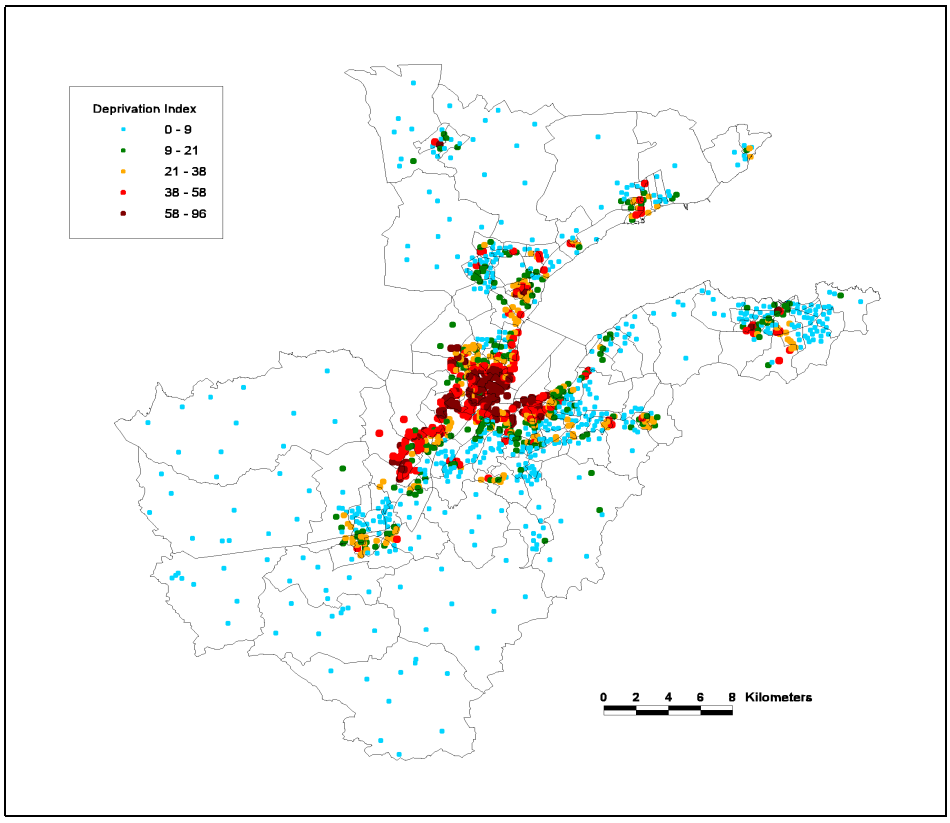
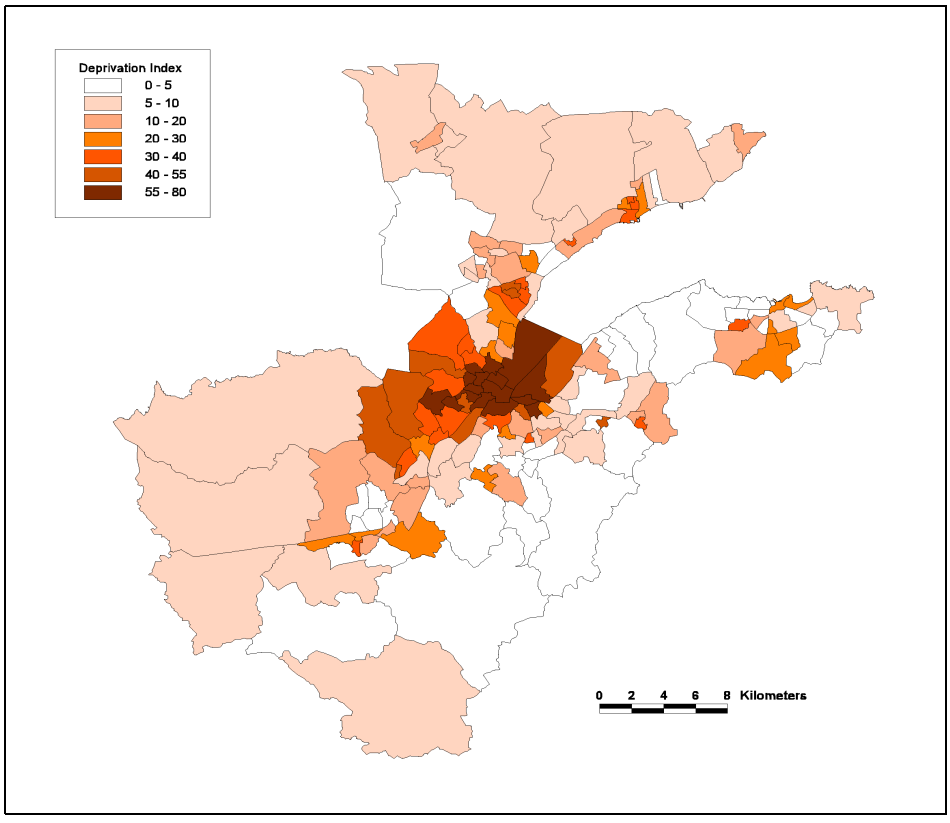



**Figure 4** Deprivation index data at Ward level for Greater Belfast



In Figures 5, 6 and 7, Cardiff City Council is represented. Figure 5 and Figure 6 show average pollutant concentrations in each electoral boundary, derived from the pollutant concentration 1x1 km grids. Figure 7 shows the deprivation score for each boundary area. Before any statistical analysis has been carried out, these figures can provide a visual representation on any potential relationship between the two parameters.

**Figure 5** Average annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric) concentrations by Ward for Cardiff City Council

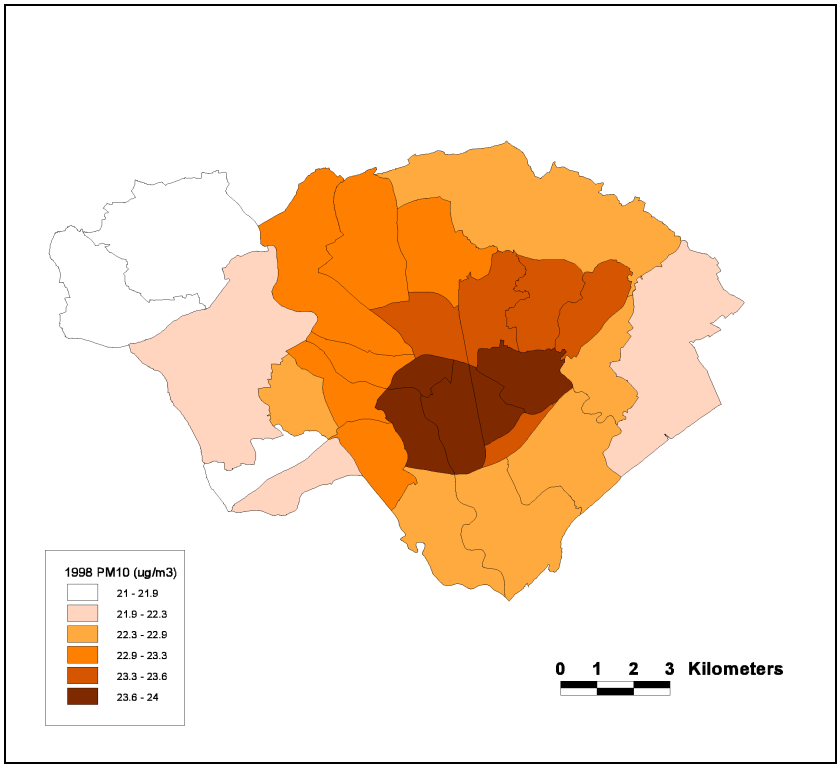


**Figure 6** Average annual mean $NO_2$ concentrations by Ward for Cardiff City Council

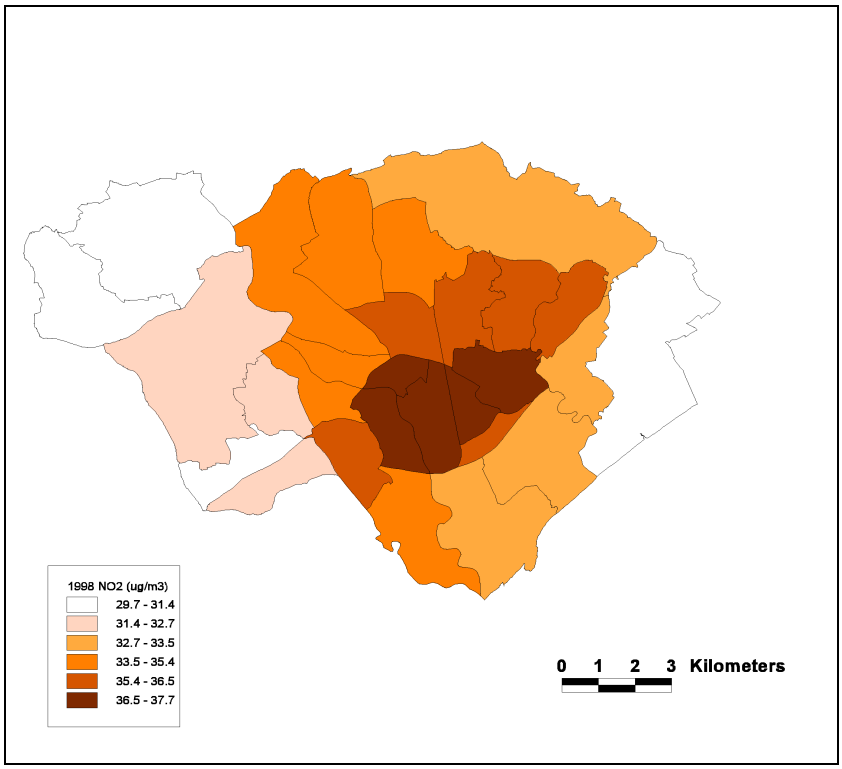
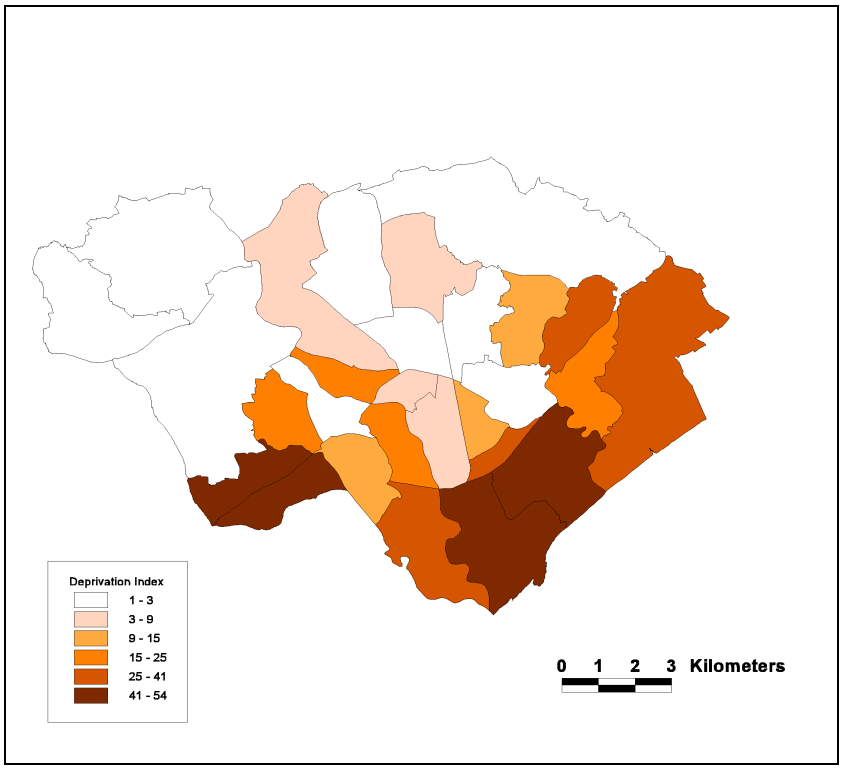


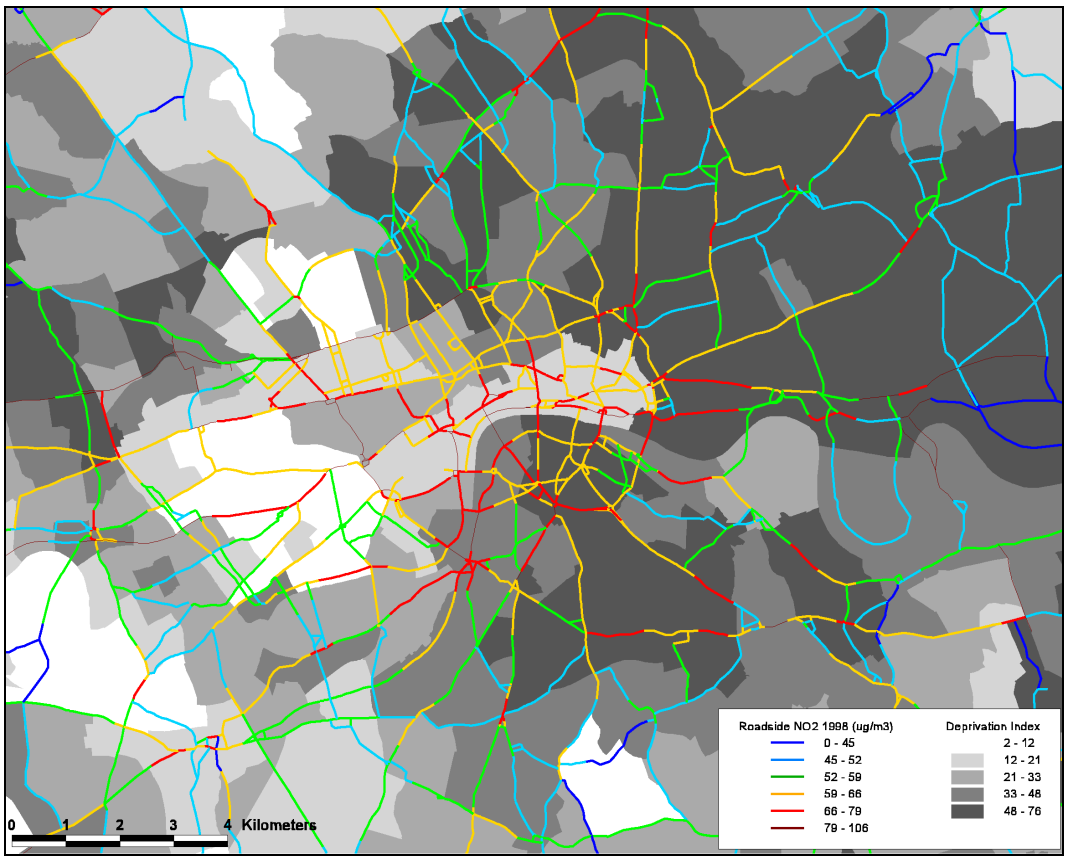

**Figure 7** Deprivation index scores by Ward for Cardiff City Council



### 3.2.2 Roadside analysis

London roadside concentrations of $NO_2$ and $PM_{10}$ have been compared with the overall multiple deprivation index for England by correlating the concentration on each road link (built-up A roads and motorways) against the deprivation index for the ward through which that link passes. The type of analysis undertaken is illustrated in Figure 8.

**Figure 8** Annual mean roadside $NO_2$ in 1998 and Ward deprivation index scores in Central London



# 4 Statistical Analysis

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

1. Correlation of multiple index scores with background $NO_2$ and $PM_{10}$ concentrations for 1998 and 2010 baseline / 'with measures' scenario, using scatter plots and banded averages.
2. Comparison of the above correlation across the three different regions.
3. Correlation of individual components of the deprivation indices with $NO_2$ and $PM_{10}$ concentrations.
4. Correlation between roadside concentrations and deprivation score in Greater London
5. Correlation with the predicted change in pollution concentrations between 1998 and 2010 baseline, and between 2010 baseline and 2010 'with measures'.
6. Comparison between ED and ward level scores in Greater Belfast to assess the impact of spatial resolution.
7. Statistical significance tests.

Section 4.9 of this chapter looks at comparisons between the previous report (King and Stedman 2000) and the current analysis to examine whether any conclusions can be drawn concerning changes in deprivation index methodology or changes in concentration maps.

This study has not undertaken any analysis using other indicators of deprivation. In the previous study, social class data was compared with pollutant concentrations. The correlation between the two variables was not very strong, possibly explained by the fact that social class is a broad classification and is dependent solely on employment information, and therefore, does not represent local social conditions.

This analysis has not been undertaken in this study for two reasons. Firstly, the use of 1998 pollutant concentration maps would produce similar results to the previous analysis. Secondly, the social class data is 10 years old, derived from the 1991census, and therefore would not reflect changes that have since occurred in the demographics of employment.

## 4.1 ANALYSIS OF MULTIPLE DEPRIVATION VERSUS BACKGROUND $NO_2$ AND $PM_{10}$

This section presents selected results showing the correlation between values of annual average $PM_{10}$ and $NO_2$ concentrations and Multiple Deprivation Index scores for all areas. Graphs for Greater London, Cardiff City Council and Greater Belfast are presented in this section while Birmingham City District analysis graphs can be found in Annex 1.

### 4.1.1 Analysis using Scatter Plots

The following scatter plots also show the annual mean concentrations determined at monitoring stations of the national automatic air monitoring network and the value of the deprivation index for the ward in which they are located. These data are generally consistent with the mapped air concentrations, thus providing a useful check of the mapping results.

Figures 9 and 10 show the $NO_2$ and $PM_{10}$ correlations with the Multiple Deprivation Index scores for Greater London.

Although both plots exhibit a degree of scatter, for both pollutants the fitted regression indicates that a general positive spatial correlation occurs between air pollution and deprivation, with increased air concentrations occurring in wards that have higher levels of social deprivation. It is perhaps not surprising that similar trends are observed for the two pollutants, as higher concentrations of these species will tend to occur in the same geographical locations. The $PM_{10}$ concentrations in Figure 10 are observed to be less scattered than those in the corresponding $NO_2$ plot (Figure 9), reflecting the lower background concentration range that normally occurs for this pollutant.

Concentration data from the automatic monitoring sites that are plotted on the two figures generally show an acceptable agreement with the modelled ward concentrations. Where differences are observed (e.g. at the Brent monitoring site where $NO_2$ and $PM_{10}$ concentrations were lower than the predicted ward concentration) it is should be noted that a certain amount of systematic difference between the monitoring data and ward concentrations is expected. For example, ward values have been obtained by averaging the 1x1 km grid modelled concentrations that fall within the ward boundaries, meaning local variations within a ward will contribute to differences observed from the mean value. Additionally, models cannot take into account the precise local conditions leading to a measured pollutant concentration at any one point, and hence a degree of modelling uncertainty will occur.

Comparison of these results with those from the previous study (King and Stedman 2000) shows that in general the corresponding plots for $NO_2$ and $PM_{10}$ are reasonably similar, although the predicted concentration ranges of the two pollutants over all wards has reduced in these latest results. For both pollutants, this reduction is largely due to the implementation of refinements in the modelling procedure used.

Although the mapped concentrations of $NO_2$ across all wards are broadly similar between this work and the previous study, the mapped values of the 1998 $PM_{10}$ concentrations are somewhat lower in this study than in the 1997 work, with the $PM_{10}$ concentrations in the majority of wards now falling within a 25-30 $\mu gm^{-3}$ range in contrast to the 27-37 $\mu gm^{-3}$ range identified previously. Reductions in emissions of primary $PM_{10}$ and of emissions leading to the formation of secondary particles along with differences in meteorology combined to significantly reduce the measured $PM_{10}$ concentrations in 1998 relative to those in 1997.

**Figure 9** Greater London 1998 annual mean $NO_2$ versus Deprivation Index

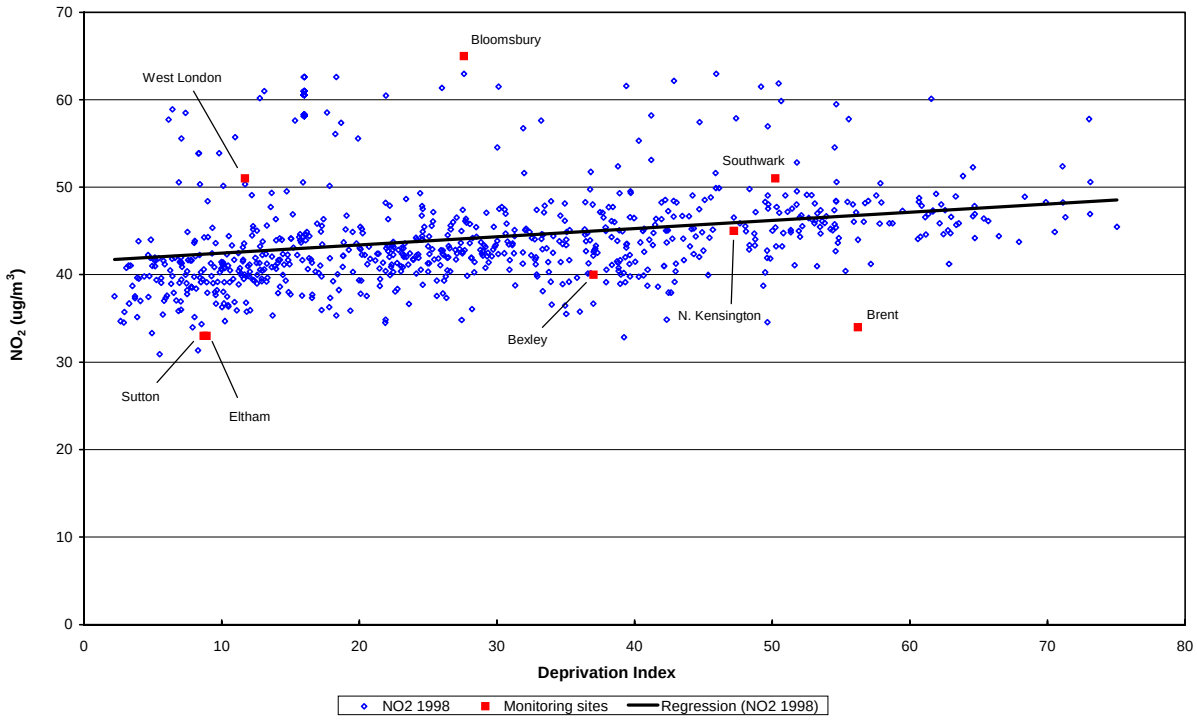
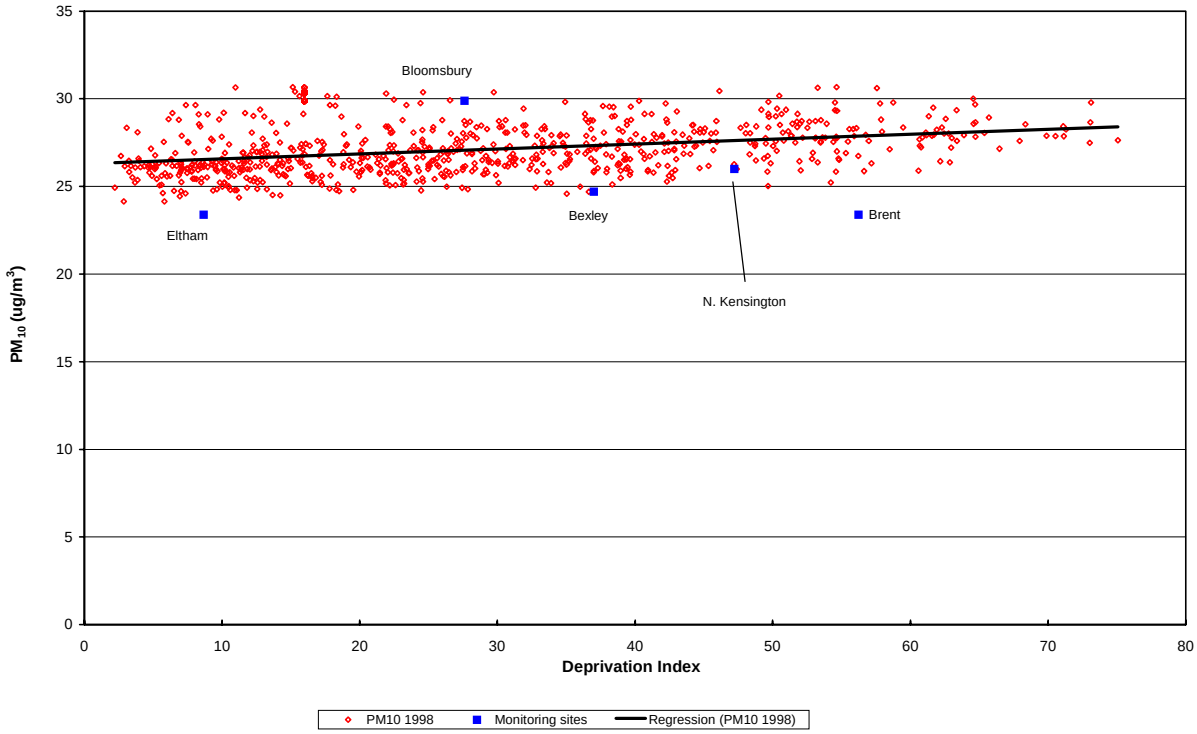



**Figure 10** Greater London 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) versus Deprivation Index



The analysis graphs for Birmingham can be found in Annex 1. The general trend appears to be similar to that observed in the analysis for Greater London; air pollutant concentrations seem to be higher with increasing levels of deprivation, with the $NO_2$ graph producing a slightly stronger positive correlation than $PM_{10}$. The monitoring site of Birmingham East does not follow the observed trend while the Birmingham Central site does. Lack of correlation at monitoring sites reflects the uncertainties associated with strategic mapping methods used to estimate the measured concentration at precise monitoring site locations.

Figure 11 and Figure 12 represent analysis of multiple deprivation versus 1998 $PM_{10}$ and $NO_2$ concentrations for Greater Belfast. A wide range of $NO_2$ and $PM_{10}$ concentrations observed in wards of lower deprivation seems to suggest that there is no clear relationship between deprivation and pollutant concentration. However, in wards which have higher levels of deprivation, higher concentrations of $NO_2$ and $PM_{10}$ are observed which result in a positive regression line slope between concentrations and deprivation index values. It appears that a positive correlation exists although such a conclusion is complicated by the amount of data point scatter in less deprived wards.

These relationships for Greater Belfast are somewhat clearer than those obtained for the 1997 data, where pollutant concentration data was plotted at the ED level. This resulted in very scattered plots for which no trend across social deprivation levels was apparent, which is in contrast to the present work where the relationships are clearer. Monitoring site data has been plotted for Belfast Centre. Again, this data fits reasonably with the mapped concentrations.

**Figure 11** Greater Belfast 1998 annual mean $NO_2$ versus Deprivation Index

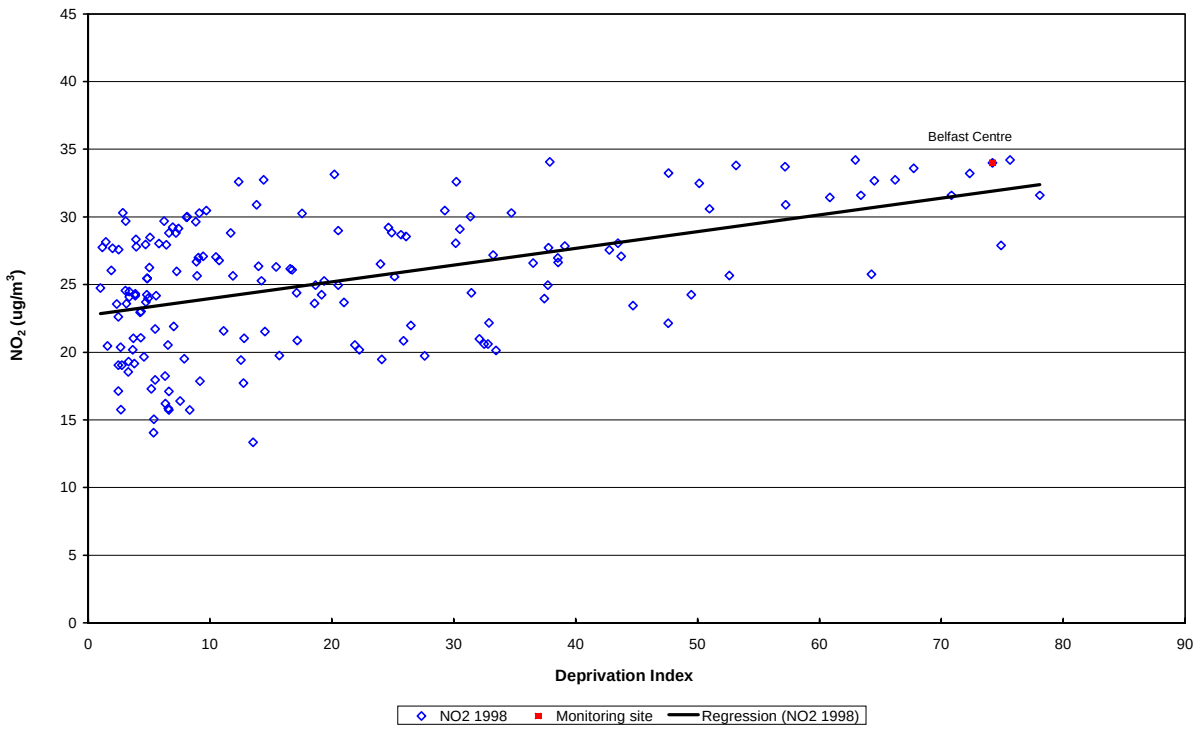


**Figure 12** Greater Belfast 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) versus Deprivation Index

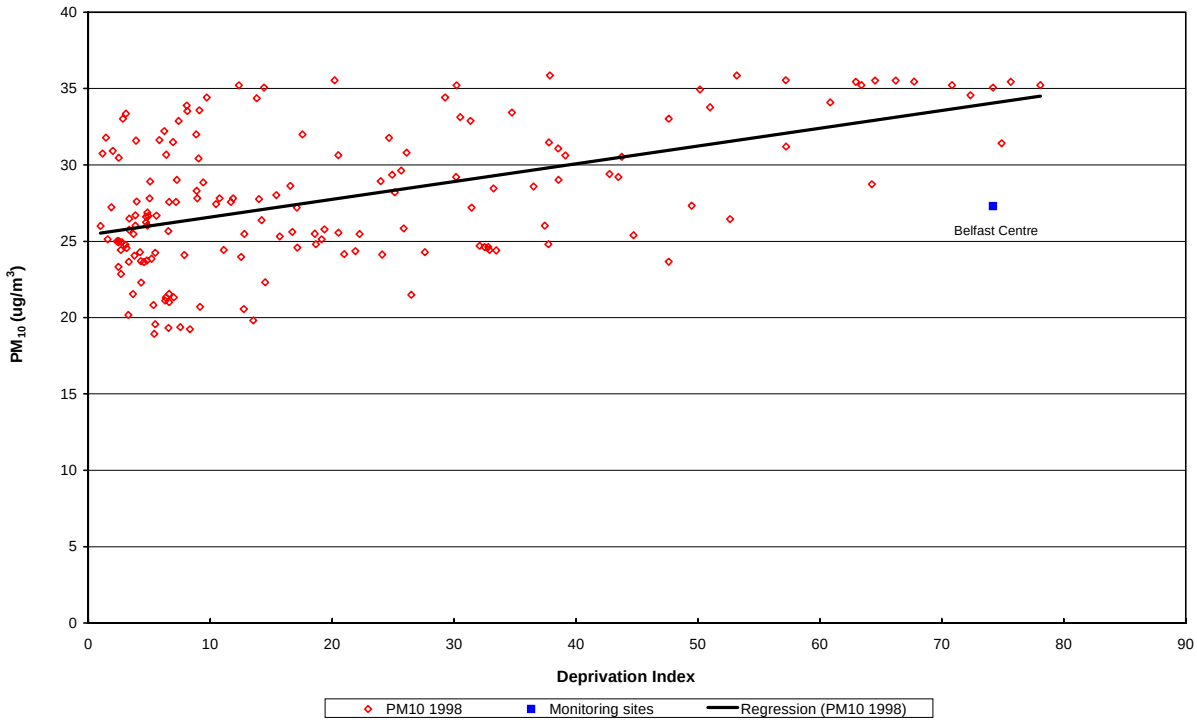



Figure 13 and Figure 14 shows the analyses for Cardiff City Council of multiple deprivation versus 1998 $PM_{10}$ and $NO_2$ concentrations. These analyses show no clear relationship between deprivation scores and pollutant concentrations. For both pollutants, the horizontal trend lines indicate that ward areas of different deprivation score have similar concentrations of air pollutants. Figures 5, 6 and 7 (in section 3.2.1) show that the most deprived wards of Cardiff appear to be in the area between Cardiff Bay and the city centre while the wards with the highest pollutant concentrations are in the city centre.

**Figure 13** Cardiff 1998 annual mean $NO_2$ versus Deprivation Index

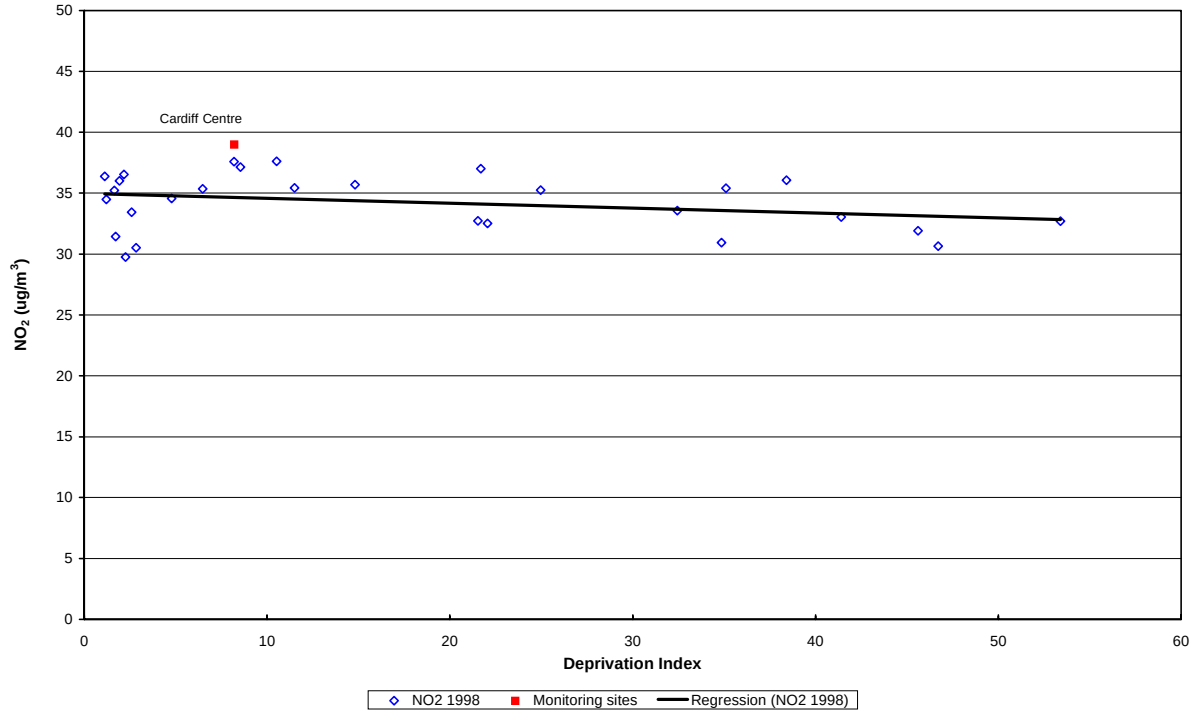
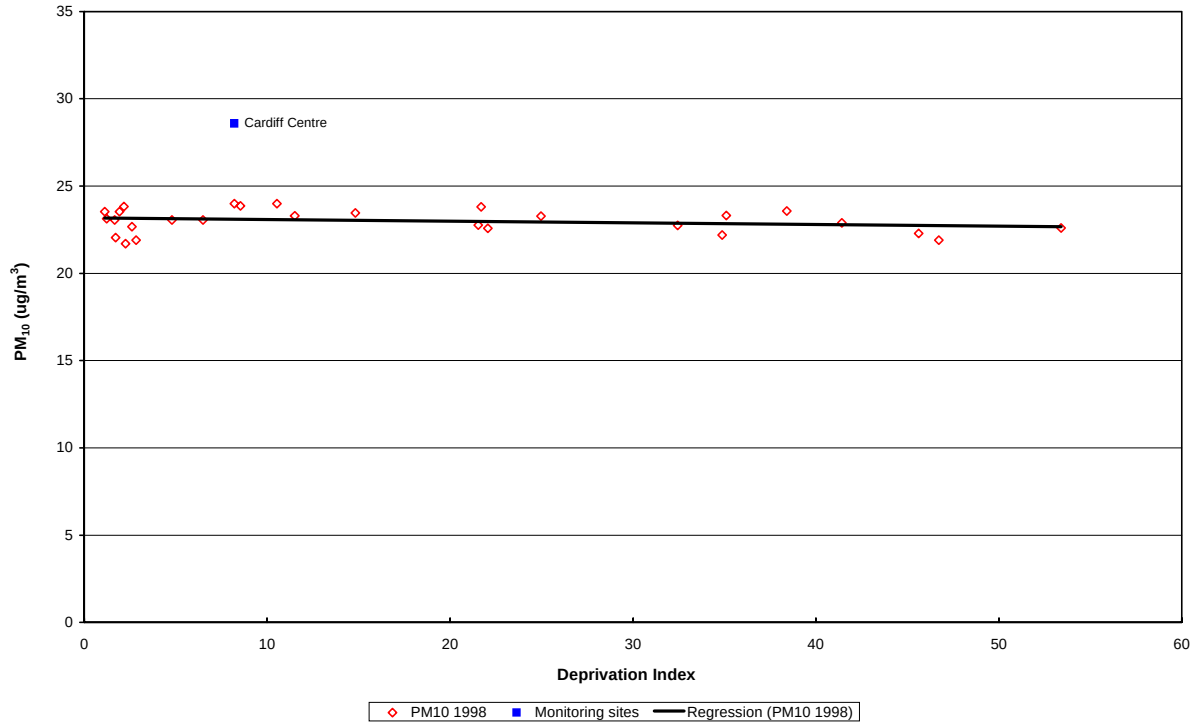



**Figure 14** Cardiff City Council 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) versus Deprivation Index



### 4.1.2 Analysis using Banded Average Plots

Figures 15, 16 and 17 below show the results of the 'banded averaging' process for both geographical areas. The banding averaging process provides an average air concentration value for a group of wards that fall into certain deprivation index ranges. In this case, five point intervals (0-5, 5-10) have been used for each range. The graphs show the average pollutant concentration for each score range for the six different data series (including the 2010 scenarios[3]) plus a count of the number of wards that can be categorised into each range. The graphs provide useful summary information regarding the scatter plots. Trends not easily identified using the scatter plot analysis can be seen more clearly using this process as average values are plotted.

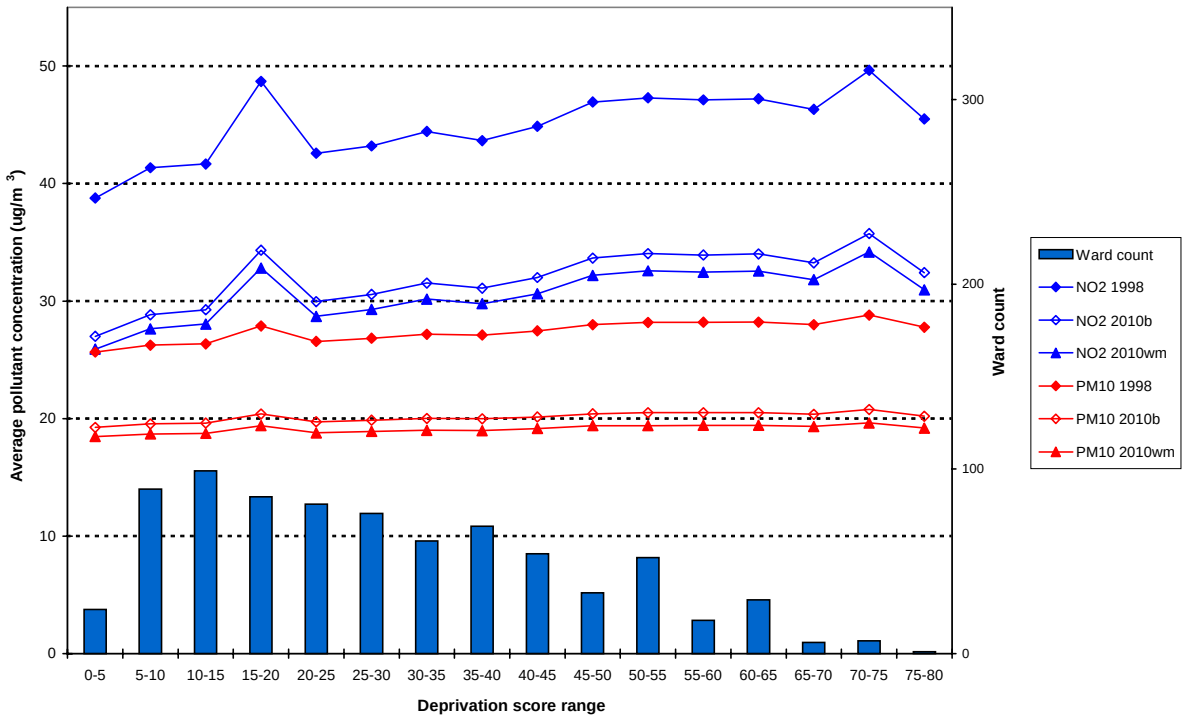
Figure 15 shows the data for Greater London. In general terms, there is an increase in pollutant concentrations with increasing deprivation. For $NO_2$, this increase looks more marked with the $PM_{10}$ trends being more flat. In 2010, both $PM_{10}$ scenarios show flat trends, with similar pollutant concentrations across all deprivation ranges.

The $NO_2$ data series has an interesting peak on the 15-20 deprivation score range, with a high average concentration value. This data has been skewed by the 25 City of London wards which all have the same deprivation score of 15.99 and high $NO_2$ concentrations. Other central London wards also have relatively high pollutant concentrations but low levels of deprivation (for instance, in the range of 15-20).[4] This same pattern is reflected in the $PM_{10}$ data but not to the same extent. 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.

[3] Two scenario cases have been outlined for 2010. In the graphs, the 2010 baseline will be refered to as '2010b' and the 2010 'with measures' scenario will be refered to as '2010wm'.

[4] See Figures 46 and 47 in Annex 3 for a good graphical representation of this peak.

**Figure 15** Greater London: Average annual mean pollution concentrations by Deprivation Score range




The banded average graph for Birmingham can be found in Annex 1. Similar trends to those seen for Greater London can be observed. The banded average graph shows a strong positive correlation for $NO_2$ and a much flatter trend for the three $PM_{10}$ cases.

Figure 16 shows Greater Belfast's average pollutant concentrations by deprivation score range. $NO_2$ and $PM_{10}$ follow a similar general trend, with pollutant concentrations increasing with deprivation scores. The linear trend is quite gradual either side of a significant increase at the deprivation score of 50. This apparent trend is much clearer using this analysis as opposed to analysis using scatter plots.

Another interesting feature of this graph is the level of annual mean $PM_{10}$ concentrations observed in the most deprived wards for both the 2010 baseline and 2010 'with measures' scenario. Both cases show that concentrations exceed the 20 $\mu gm^{-3}$ level, a limit proposed in a recent consultation document (DEFRA et al, 2001) setting out strengthened air quality objectives. This indicates that the illustrated policies to reduce $PM_{10}$ levels may be insufficient to adequately reduce concentrations to the proposed objective in the most deprived wards.

**Figure 16** Greater Belfast: Average annual mean pollution concentrations by Deprivation Score range

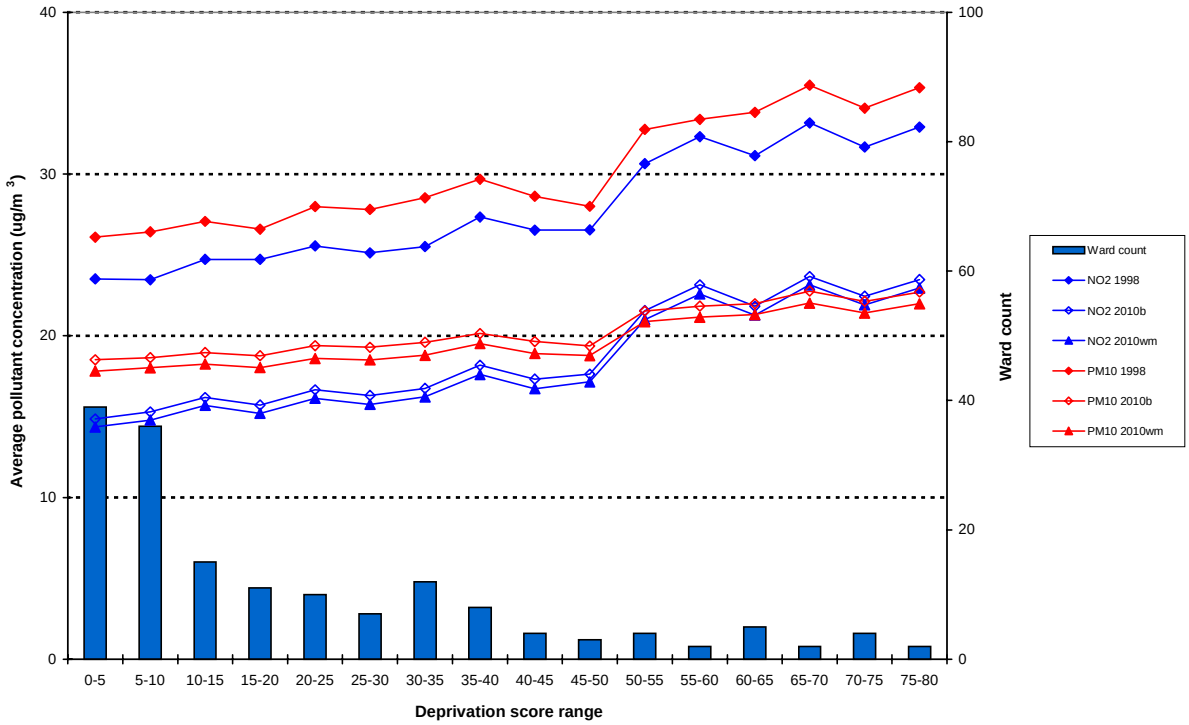
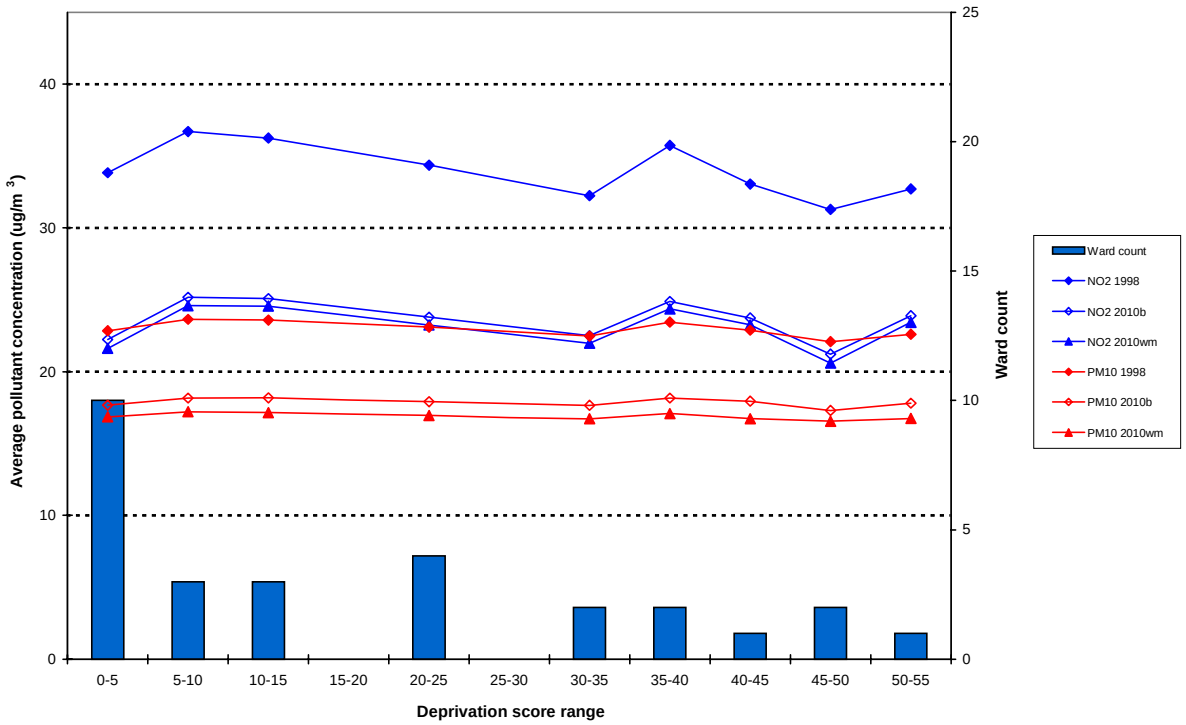



Figure 17 shows the banded average graphs for Cardiff City Council. It can be clearly seen that no significant correlation exists between the two parameters. There is no observed relationship between the level of social deprivation and the levels of $NO_2$ and $PM_{10}$ air pollution observed in the city. It should be noted that relatively few data points were used in this Cardiff analysis and it therefore might be worthwhile expanding the geographical range in any future study.

**Figure 17** Cardiff City Council: Average annual mean pollution concentrations by Deprivation Score range




## 4.2 COMPARISON OF DEPRIVATION – POLLUTANT CONCENTRATION CORRELATIONS BETWEEN REGIONS

Figures 18 and 19 show a comparison in the trends between pollutant concentration and deprivation scores for each of the four geographical areas. In this analysis, the three deprivation indices are much more comparable across regions than they were in the previous analysis, having been formulated using the same methodologies, and using the same spatial level of ward area. The only significant difference between the three indices is that the Northern Ireland index incorporates one extra domain called 'Social environment'. However, this extra domain is only given a small weighting of 5% in the overall multiple deprivation index for Northern Ireland.

The main benefit of this comparative analysis is that the trends in the different locations can be visually compared, as can the levels of pollutant concentrations. In terms of pollutant concentrations, Belfast has much higher $PM_{10}$ than in other regions, particularly in the most deprived wards, but lower $NO_2$, reflecting the high use of solid fuel in domestic burning and lower levels of traffic relative to the other analysis areas. From Figures 18 and 19, the observed trend for the English city areas and Greater Belfast is a weak positive correlation, demonstrating increasing pollutant concentrations in areas of greater deprivation. For Cardiff City Council, there appears to be no obvious trend.

Similar deprivation score ranges in the English Cities and Greater Belfast are observed in Figures 18 and 19. This reflects the similarities in index construction methodology for each region. However, caution is needed when making such a comparison due to differences that do still exist between indices.

One of the interesting features of the graphs is that Cardiff City Council does not appear to have the very high levels of deprivation seen in other urban areas. Higher levels of deprivation may exist in the Cardiff area but at a smaller resolution than ward level, and therefore may not be represented in this analysis due to the averaging process over the ward area. However, it is not possible to say whether this is the case due to the lack of more disaggregated deprivation scores.

**Figure 18** Regional average annual mean 1998 $NO_2$ Levels by Deprivation score range

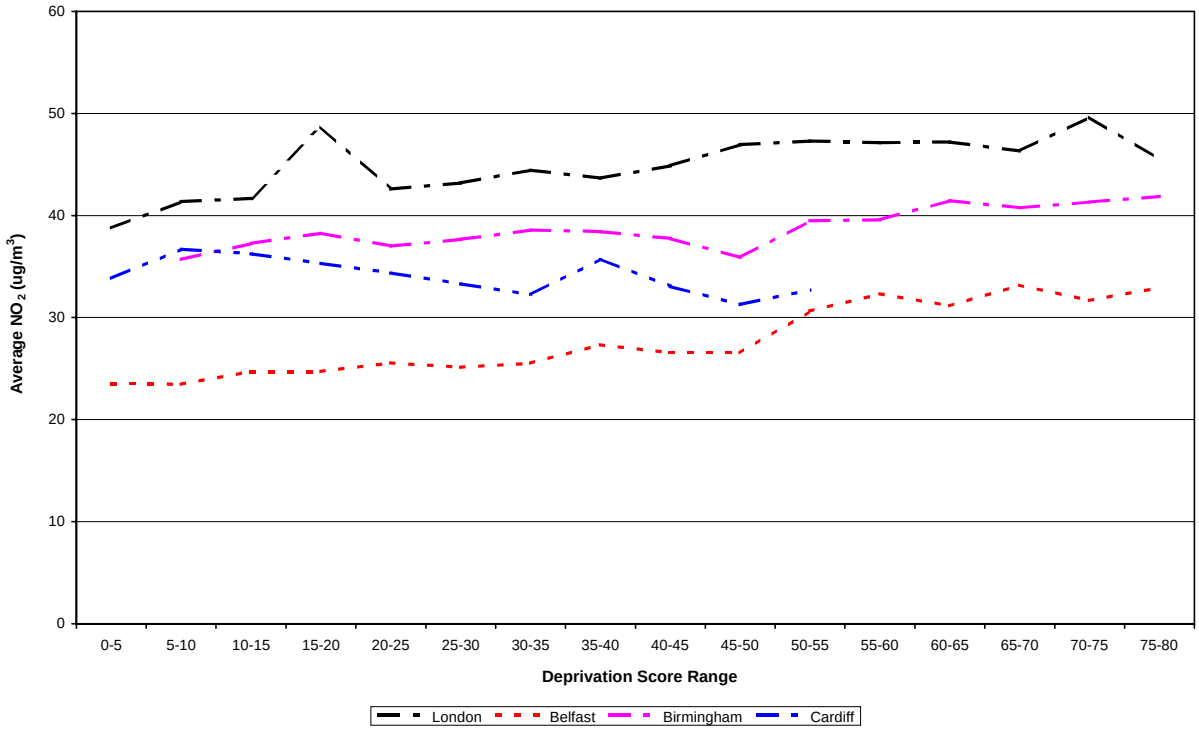
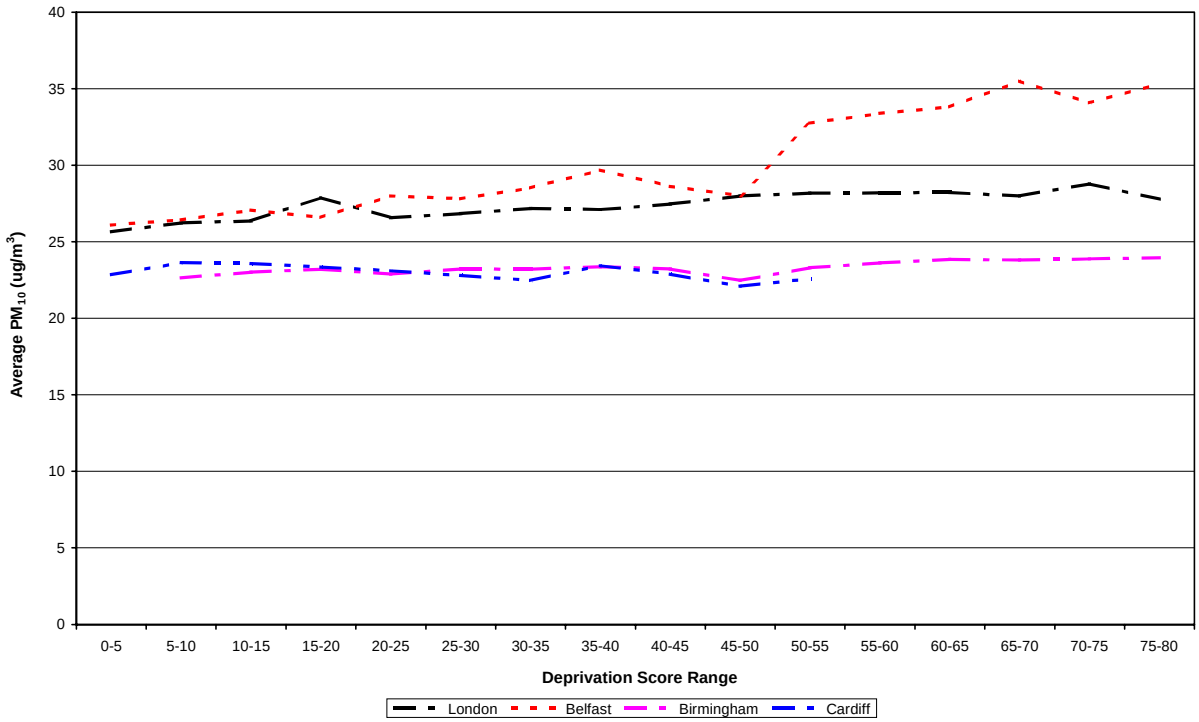


**Figure 19** Regional average annual mean 1998 $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) levels by Deprivation score range




## 4.3 ANALYSIS OF COMPONENT PARTS OF DEPRIVATION INDEX

The multiple deprivation index is made up of a number of different domains, each of which have a specific deprivation score. In this section, the relationship between the individual indicator and pollutant concentration has been analysed for the Greater London area. Further statistical analysis has also been carried out, assessing the relationships between individual indicators and pollutant concentrations for all geographical areas. This section is important as it provides more detailed analysis of the different aspects of deprivation and their relationship with $NO_2$ and $PM_{10}$.

The Deprivation index for England includes six different domains, which are in turn constructed from a set of indicators. These domains include:

- Income (including a subset called 'Child Poverty')
- Employment
- Health Deprivation and Disability
- Education, Skills and Training
- Housing
- Geographical Access to Services

The full set of graphs showing relationships between individual domain and specific pollutants can be found in Annex 2 of this report, while some examples are shown here (Figures 20-22). The domains of income (plus its subset of child poverty), employment, health, and housing reflect the trend observed in the previous analysis sections for Greater London. Pollutant concentrations tend to increase with the individual domain score. There is no significant correlation for the education domain, illustrated by a flat trend line.

Interestingly, the geographical access to services domain shows a reasonably strong negative correlation, indicating that higher pollutant concentrations are found in wards that have better access to services. Within urban districts, this may not be a particularly useful indicator of deprivation. In cities, many of the most deprived inner city areas have the highest population densities. In areas with greater densities, more services are likely to be required and retained for these populations. Access will not only be improved by more service provision but also due to better public transport infrastructure in urban areas. This may also be a factor in less deprived city centre wards that have higher pollutant concentrations. In less deprived areas in the urban suburbs, lower population densities will probably mean lower levels of service provision. Therefore, a negative trend between the index indicator and pollutant correlations is observed.

$NO_2$ and $PM_{10}$ show very similar trends in each of the graphs (see Annex 2 for complete set). However, $PM_{10}$ shows a much tighter correlation with deprivation score while $NO_2$ data show greater variation from the trend line.

**Figure 20** Greater London 1998 annual mean $NO_2$ versus Housing Deprivation domain

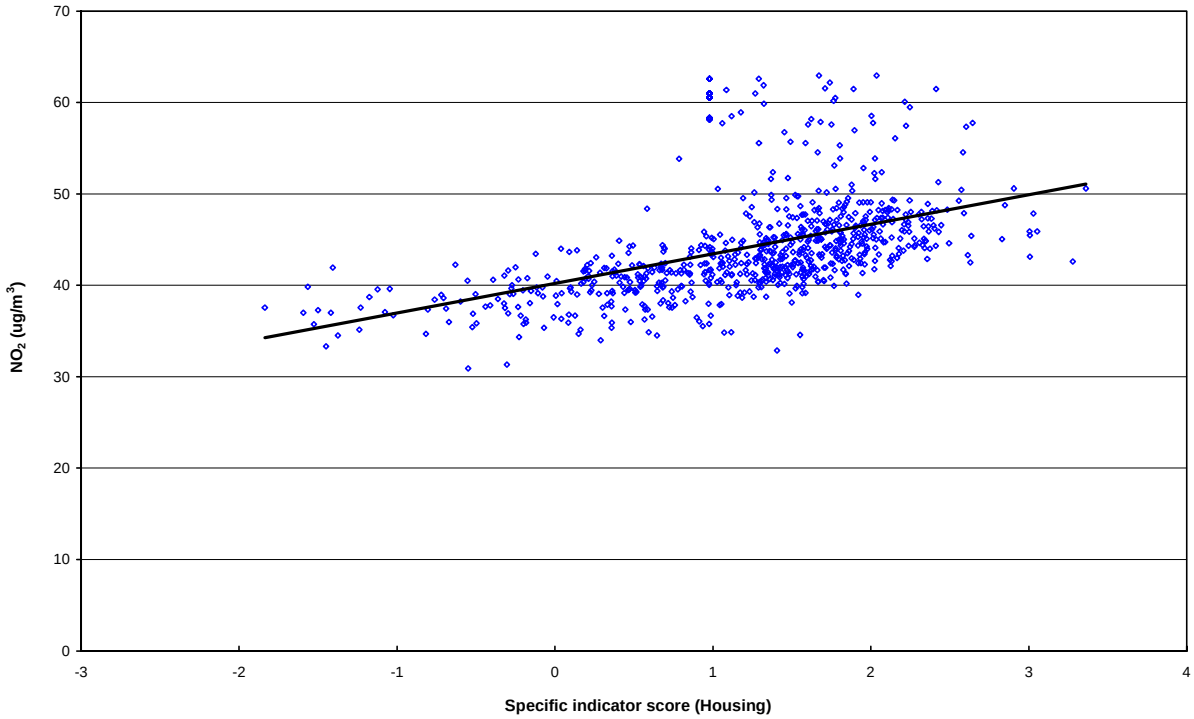


**Figure 21** Greater London 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) versus Education deprivation domain

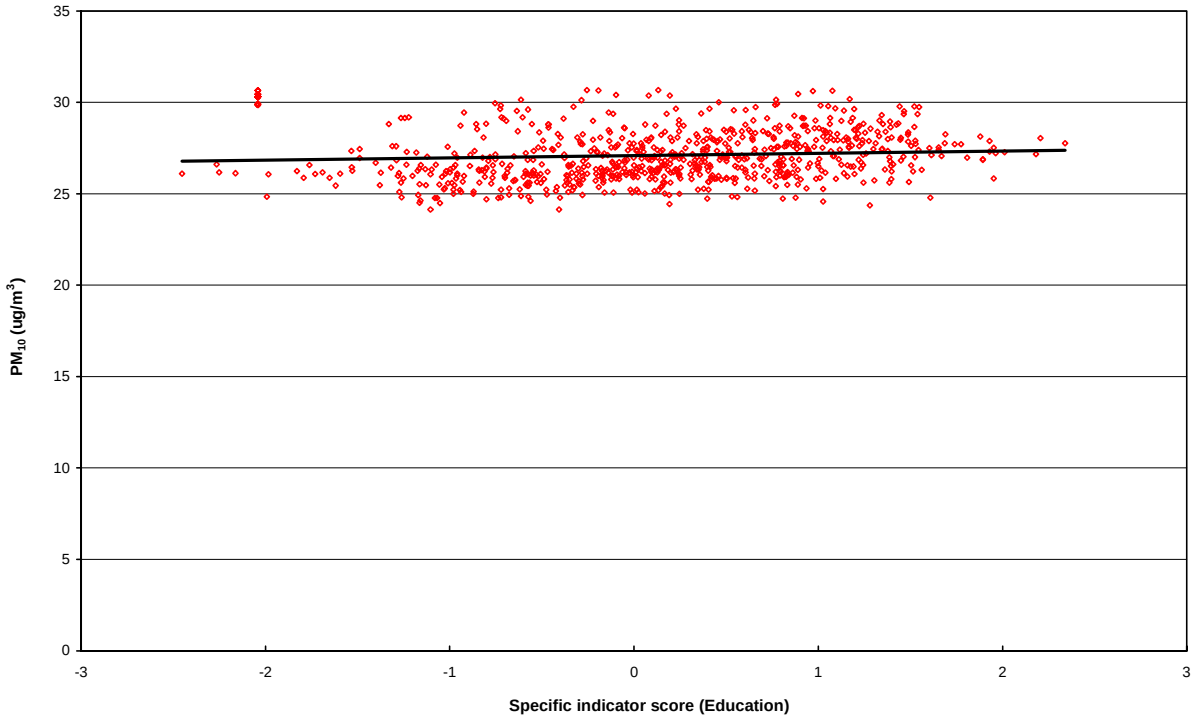



**Figure 22** Greater London 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) versus Access deprivation domain

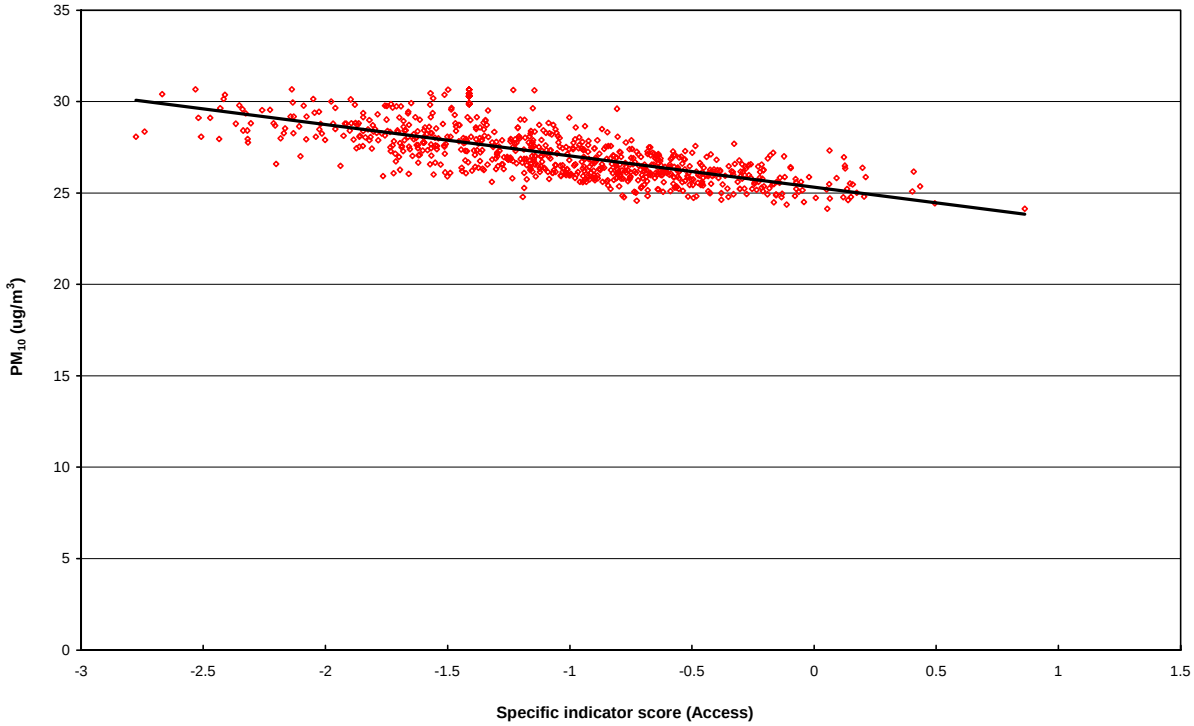


Table 3 below provides statistical analysis for all of the geographic regions, illustrating the strength of relationship between the individual domain and pollutant concentration.

**Table 3** Correlation coefficients for 1998 pollutant concentrations vs deprivation index domains

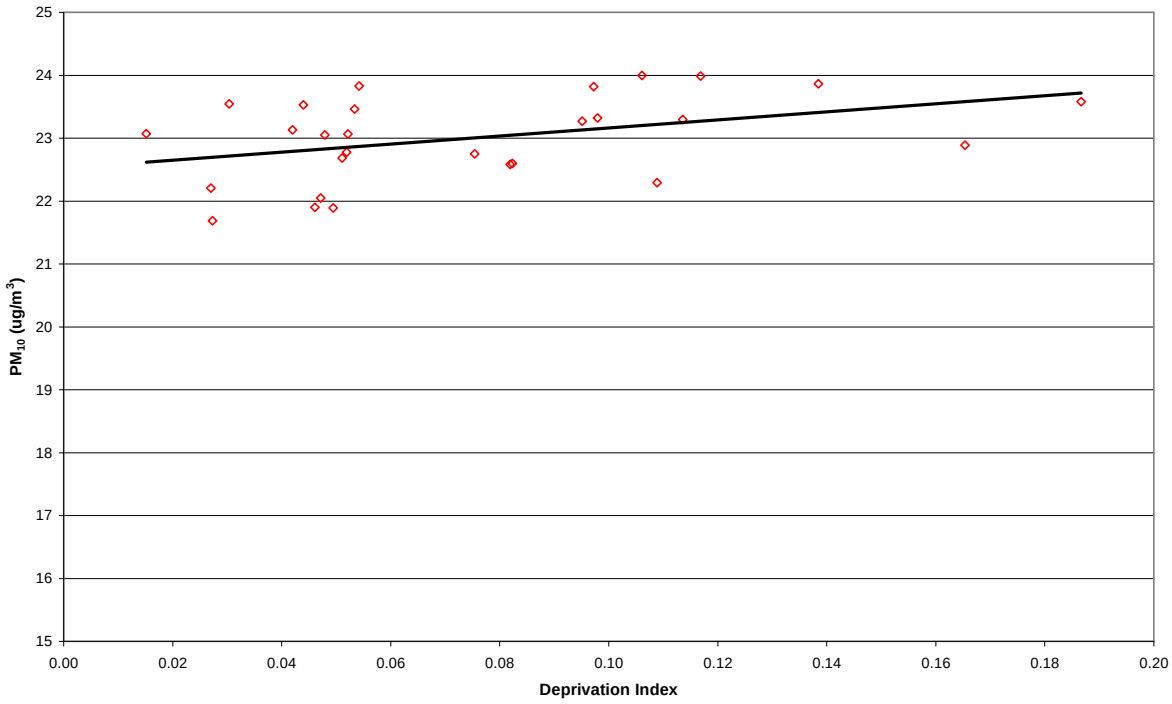
| | **Greater London** | | **Birmingham City District** | | **Cardiff City Council** | | **Greater Belfast** | |
|---|---|---|---|---|---|---|---|---|
| | $NO_2$ | $PM_{10}$ | $NO_2$ | $PM_{10}$ | $NO_2$ | $PM_{10}$ | $NO_2$ | $PM_{10}$ |
| Overall Index | **0.277** | **0.412** | **0.600** | **0.608** | -0.291 | -0.236 | **0.499** | **0.517** |
| Income | **0.233** | **0.370** | **0.606** | **0.611** | -0.271 | -0.210 | **0.484** | **0.487** |
| Employment | **0.352** | **0.488** | **0.597** | **0.598** | -0.260 | -0.210 | **0.489** | **0.515** |
| Health | **0.211** | **0.318** | **0.522** | **0.565** | -0.262 | -0.213 | **0.587** | **0.583** |
| Education | -0.070 | 0.084 | **0.412** | **0.453** | 0.048 | 0.115 | **0.368** | **0.347** |
| Housing | **0.464** | **0.518** | **0.642** | **0.627** | 0.356 | **0.406** | 0.204 | **0.298** |
| Access to geographical services | **-0.641** | **-0.718** | **-0.564** | **-0.582** | **-0.568** | **-0.601** | **-0.753** | **-0.801** |
| Child Poverty | **0.256** | **0.381** | **0.565** | **0.568** | -0.139 | -0.072 | **0.491** | **0.487** |
| Social Environment | | | | | | | **0.469** | **0.468** |

Figures in bold indicate statistical significance as illustrated in Annex 5, while figures in red denote the highest positive coefficients.

Greater London correlation coefficients follow the trends seen in Figures 20, 21 and 22, and Annex 3. The coefficients produced in the Birmingham analysis are all statistically significant, showing similar trends to those for Greater London. The 'access to services' domain shows a strong negative relationship, while the 'housing' domain again shows the strongest correlation.

A strong positive correlation for the 'housing' domain is also found for Cardiff City Council, while a significant negative correlation is shown again for the 'access' domain. The overall index for Cardiff City Council did not show any relationship; therefore evaluating the index in a disaggregated way is important to assess individual aspects of deprivation and their relationship to pollutant concentrations. The 'housing' domain plot for Cardiff City Council can be seen below in Figure 23. Greater Belfast shows the same trends as observed for Greater London and Birmingham with all domains showing significant relationships. The main differences are that the 'housing' domain has the lowest coefficients while the 'health' domain has the highest coefficients.

**Figure 23** Cardiff City Council 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) versus Housing Deprivation domain




## 4.4 ANALYSIS OF ROADSIDE POLLUTANT CONCENTRATIONS VERSUS DEPRIVATION

Each major road link (A roads and motorways) within the Greater London area has an associated roadside $NO_2$ and $PM_{10}$ concentration, derived from individual census points for which traffic count data has been collected. Each ward within this geographical area of Greater London has a major road going through it in most instances.[5] In this section, the associated $NO_2$ and $PM_{10}$ concentrations on a specific road link are compared to the multiple deprivation score within a specific ward. Figure 24 and 25 show results of this analysis for Greater London.

The $NO_2$ analysis shows a similar trend to that seen in the previous analysis (King and Stedman 2000). There is a potentially weak pattern present where $NO_2$ concentrations increase with higher deprivation scores. However, such a trend could well be disputed due to the range of scatter observed. The $PM_{10}$ graph shows a similar pattern with less data point scatter. Figure 26, the banded average analysis, provides a clearer illustration of the positive correlation observed in the scatter plots.

The monitoring site data appears to correspond with the modelled concentrations. An interesting feature of this analysis is the change in relative deprivation score of Marylebone Road between this analysis and the previous study (King and Stedman 2000). Within this analysis, this monitoring site falls into Baker Street ward. The deprivation index score has

[5] In this analysis, 730 out of 785 Greater London wards had an associated major road link from which a roadside concentration was derived.

changed significantly, with the 2000 index showing far lower levels of deprivation relative to other London wards.

**Figure 24** 1998 Individual road annual mean roadside $NO_2$ by Deprivation Index for Greater London

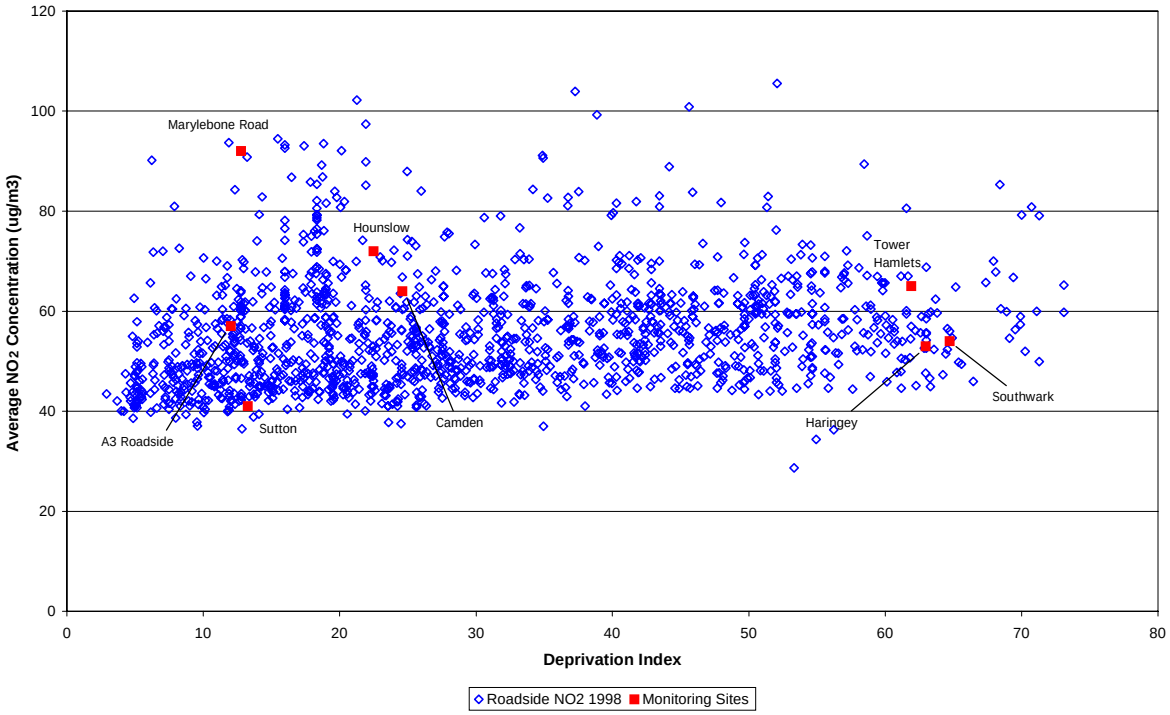



**Figure 25** 1998 Individual road annual mean roadside $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) by Deprivation Index for Greater London

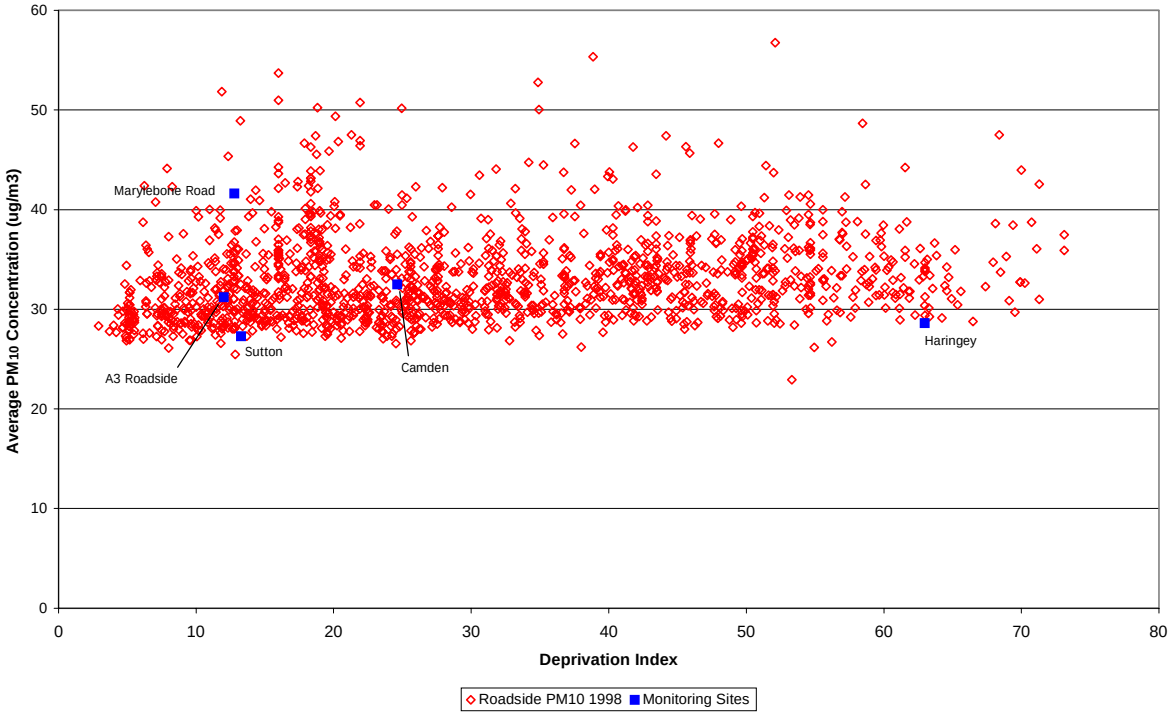
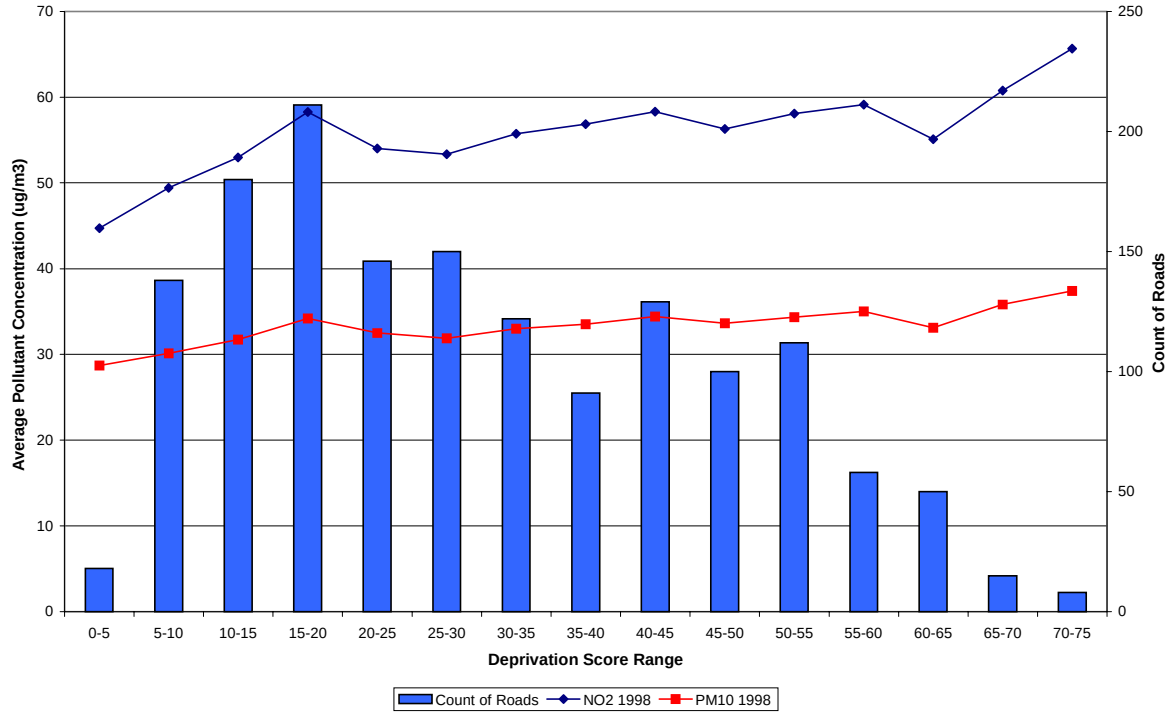


**Figure 26** Average annual mean roadside $NO_2$ and $PM_{10}$ by Deprivation score range in Greater London




An alternative roadside analysis was carried out to observe the effect of using a different methodology on the above results. The resulting graphs can be seen in Annex 3 of this report. This alternative analysis has taken the average roadside pollutant concentration of each ward rather than the concentrations by road link. The result of taking a ward average can be seen in the graphs, where fewer outliers are seen. These graphs, along with Figure 26 which plots averages across deprivation score ranges, provide clearer trends for both pollutants, reflecting the trends observed for Greater London in the preceding analysis sections of this report.

## 4.5 COMPARISON WITH IMPROVEMENTS IN AIR QUALITY

An objective of the previous study, which this further analysis is updating, relates to the extent to which policies which seek to improve air quality will bring disproportionate benefits to the more vulnerable members of society. The graphs below (Figures 27-30) show the reductions in air concentration of $PM_{10}$ and $NO_2$ in Greater London (Figures 27 and 28) and Cardiff (Figures 29 and 30) at each of the points sampled, between 1998 and 2010 baselines. The graphs in Annex 4 show the reductions in air concentrations between the 2010 baseline and the 2010 'with measures' case, plus analysis for Greater Belfast.

The general conclusion that can be drawn from the graphs of Greater London is that greater improvements in air quality occur in areas with higher deprivation scores. For $PM_{10}$, there is not a huge amount of variation in these graphs, with points grouped closely either side of the trend line. There are two significant outliers in the graph showing $PM_{10}$ reductions between 2010b and 2010 with associated measures. These points represent the wards of Victoria (Ealing) and Eastbury (Barking and Dagenham). The reason for these more significant reductions in

$PM_{10}$ is that there are probably industrial sites within these wards which have significant reductions in industrial emissions under the 2010 'with measures' scenario.

The pattern emerging for $NO_2$ from these graphs is that the main trend is similar to that of $PM_{10}$. However, there is a group of points that lie significantly above the trend line, representing wards that would gain extra benefit from policies to reduce pollutant concentrations. Table 5 in Annex 4 lists the wards represented by these outlying points. These wards encompass the whole range of deprivation scores. The majority of the listed wards are Central London wards, particularly from the boroughs of City of London and Westminster, and are wards where the highest pollutant concentrations are found.

The positive correlations demonstrated in these graphs provide some evidence that future targeted policies could help to reduce the apparent inequity in exposure to air pollution found in Greater London.

**Figure 27** Greater London annual mean $NO_2$ reductions between 1998 and 2010

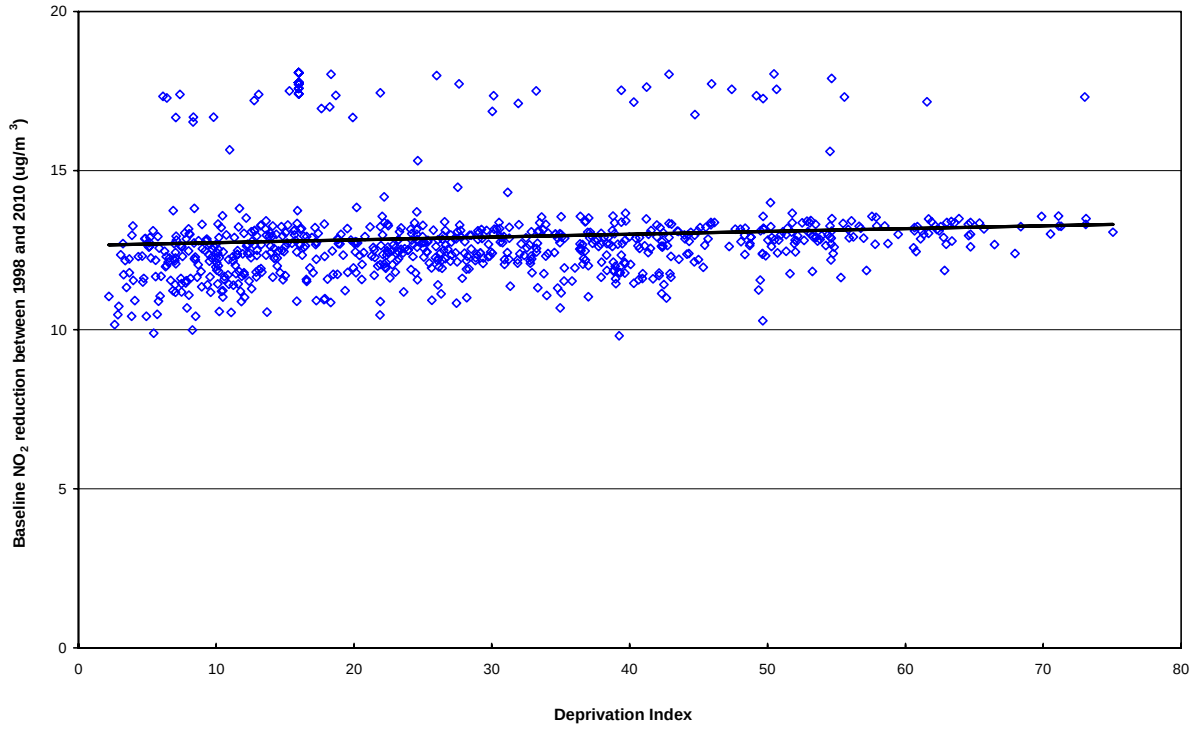
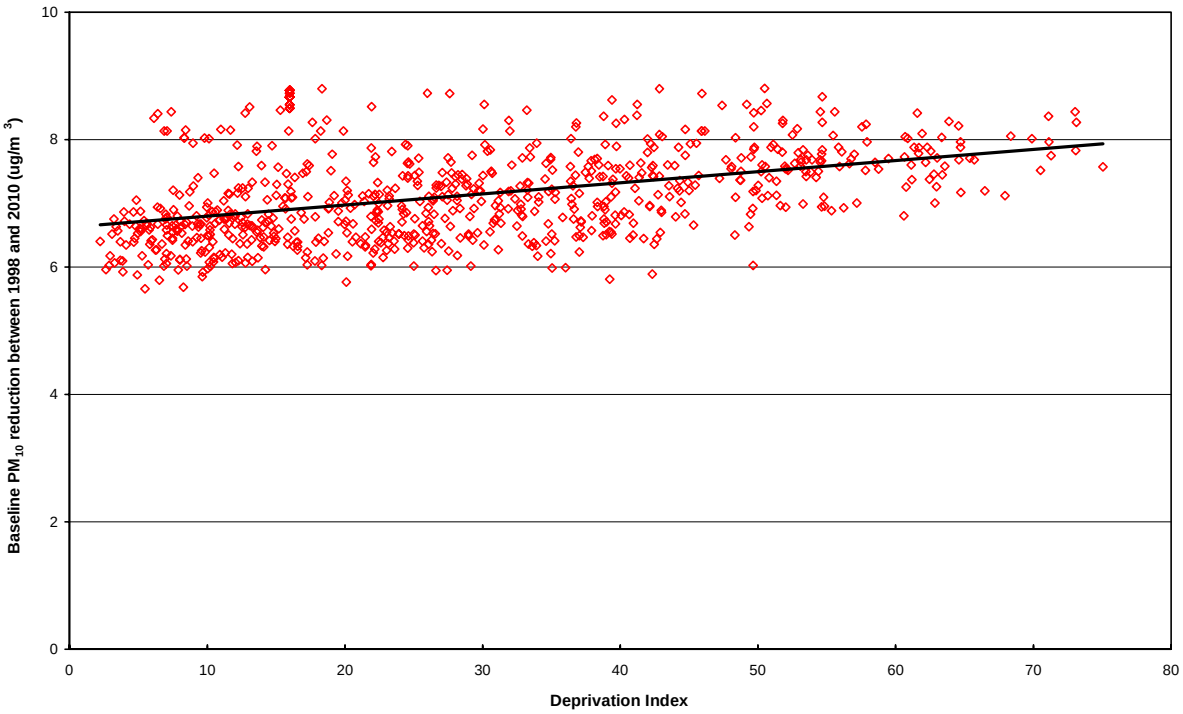


**Figure 28** Greater London annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) reductions between 1998 and 2010




In Annex 4, the Greater Belfast analysis provides a less obvious trend. A positive correlation is apparent for $NO_2$ in terms of reduction between the reference years of 1998 and 2010. The other graphs, which show a large amount of scatter, do not provide any significant evidence of a relationship between the parameters.

The analysis for Cardiff City Council shows a weak negative correlation between pollutant concentration reductions for $NO_2$ between 1998 and 2010 concentrations and levels of deprivation (see Figure 29). This indicates that electoral divisions with lower deprivation will experience more reduction in $NO_2$ concentrations relative to more deprived electoral divisions. Therefore, on the basis of this analysis, policies to reduce $NO_2$ may have a more beneficial impact on less deprived communities. The other graphs for Cardiff do not show any significant correlation between the two parameters.

**Figure 29** Cardiff City Council annual mean $NO_2$ reductions between 1998 and 2010

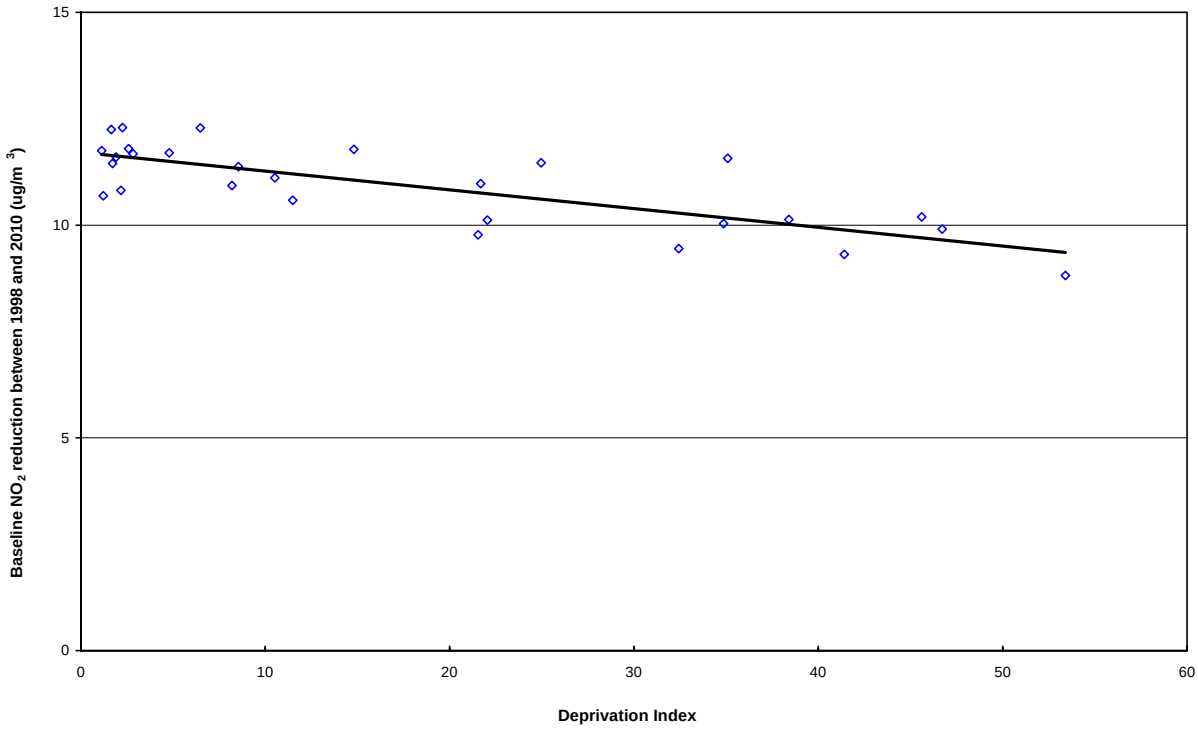
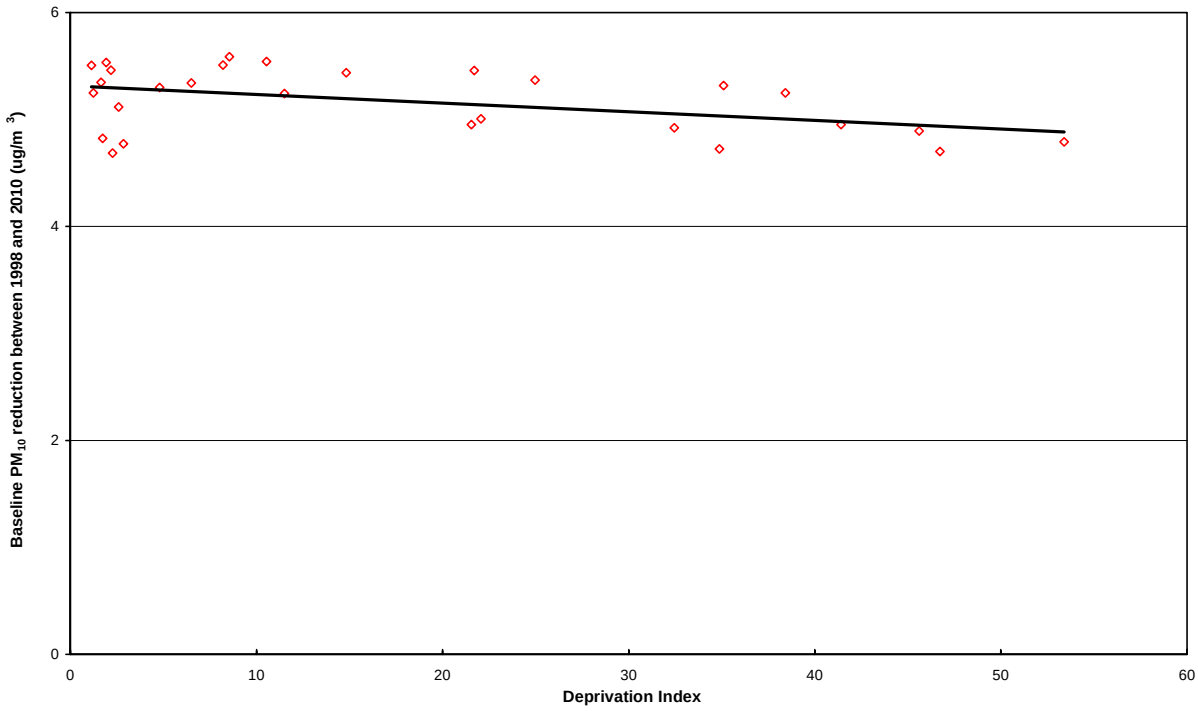



**Figure 30** Cardiff City Council annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) reductions between 1998 and 2010



## 4.6 COMPARISON BETWEEN ED AND WARD LEVEL INDICES

This section of analysis assesses what the effect of different spatial resolutions might be on the relationship between social deprivation and pollutant concentrations. The previous analysis (King and Stedman 2000) showed that the relationship was similar at both enumeration district (ED) and ward levels. In the previous analysis, Birmingham was used as the area for comparison. In this analysis, Belfast has been used as the geographical area for this comparison as the Northern Ireland Index is the only index where data has been produced at the ED level.

The ED multiple deprivation index differs from the ward level index as it is compiled using only two domains – employment and income. Therefore, these two index data sets are not directly comparable. However, employment and income are the two most weighted domains for the ward level index, which increases comparability across the two indices.

Figure 31 and Figure 32 show that the relationship is similar at both levels of spatial analysis, a similar conclusion to that drawn in the previous analysis undertaken (King and Stedman 2000). One of the main features of this analysis, previously mentioned in section 4.1, is that a wide range of pollutant concentrations can be observed at lower deprivation levels. This is particularly evident in Figure 32, which shows the ED analysis. In highly deprived areas, only high $PM_{10}$ concentrations are found. This may point to the use of a limited number of domestic fuels, such as solid fuel, in deprived areas.

**Figure 31** Greater Belfast 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) Ward level data

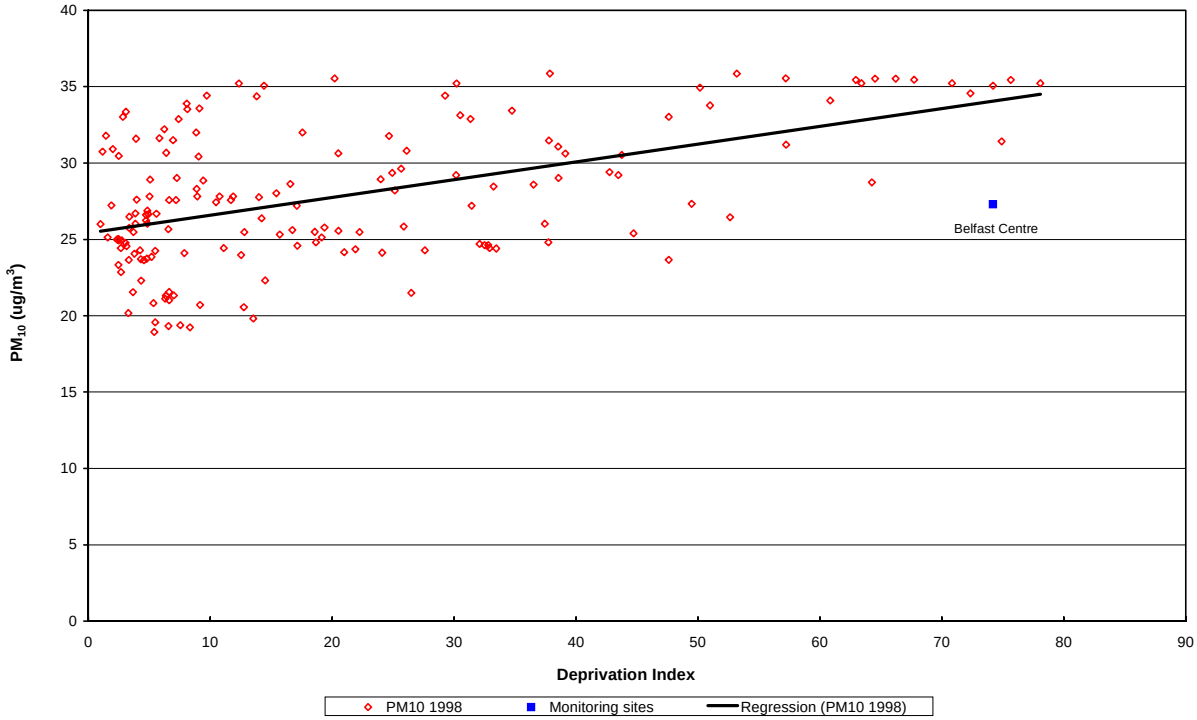
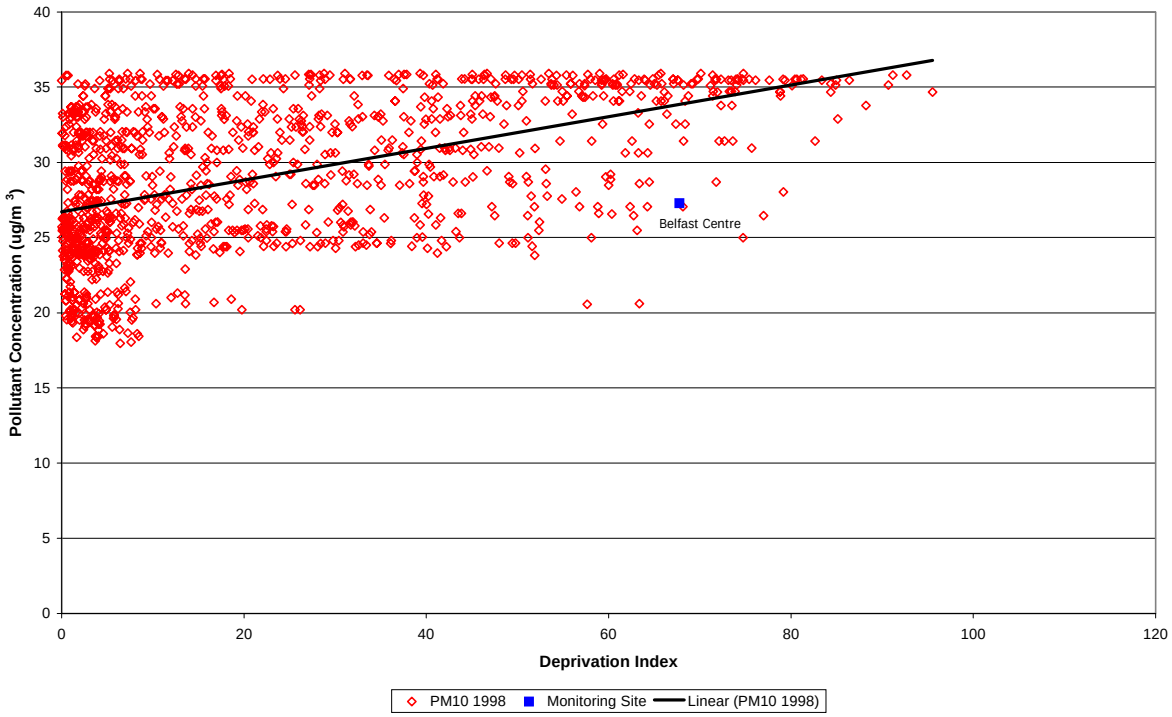


**Figure 32** Greater Belfast 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) Enumeration District (ED) level data




## 4.7 ANALYSIS OF STATISTICAL SIGNIFICANCE

Statistical analysis has been carried out on the relationship between pollutant concentrations and deprivation indexes. Correlation coefficients have been calculated for each of the pairs of data for all of the geographical areas. This is a measure of the degree of linear association between two variables and can take values between –1 and +1. Values close to zero imply a lack of association while a correlation close to 1 implies a close and positive correlation. The correlation coefficients for the Greater London area are shown in Table 4 for illustrative purposes. All of the statistical data can be found in Annex 5 of this report.

**Table 4** Correlation coefficients for the Greater London area

| r | $NO_2$ 1998 | $NO_2$ 2010b | $NO_2$ 2010wm | $PM_{10}$ 1998 | $PM_{10}$ 2010b | $PM_{10}$ 2010wm | $NO_2$ change (1998 – 2010b) | $NO_2$ change (2010b – 2010wm) | $PM_{10}$ change (1998 – 2010b) | $PM_{10}$ change (2010b – 2010wm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Overall Index Score | 0.277 | 0.330 | 0.332 | 0.412 | 0.399 | 0.354 | 0.098 | 0.296 | 0.419 | 0.439 |
| Income | 0.233 | 0.287 | 0.289 | 0.370 | 0.356 | 0.314 | 0.055 | 0.254 | 0.380 | 0.399 |
| Employment | 0.352 | 0.409 | 0.410 | 0.488 | 0.474 | 0.438 | 0.155 | 0.372 | 0.495 | 0.460 |
| Health | 0.211 | 0.256 | 0.258 | 0.318 | 0.314 | 0.272 | 0.063 | 0.219 | 0.319 | 0.369 |
| Education | -0.070 | -0.022 | -0.021 | 0.084 | 0.059 | 0.015 | -0.200 | -0.028 | 0.107 | 0.193 |
| Housing | 0.464 | 0.498 | **0.500** | **0.518** | **0.529** | 0.467 | 0.322 | 0.454 | **0.501** | **0.588** |
| Access | -0.641 | -0.679 | -0.678 | -0.718 | -0.712 | -0.678 | -0.473 | -0.662 | -0.715 | -0.629 |
| Child Poverty | 0.256 | 0.306 | 0.308 | 0.381 | 0.369 | 0.326 | 0.087 | 0.268 | 0.387 | 0.413 |

The five highest positive correlation coefficients have been highlighted. The strongest relationship, however, is found with regard to the domain 'access to geographical services'. This relationship shows a strong negative correlation, with pollutant concentration increasing in wards with low 'access' scores. This trend has been discussed in section 4.3. Employment and housing have the strongest positive correlations, followed by income and health. The education domain does not suggest any significant relationship. Analysis of statistical significance for all geographical areas, including Greater London, can be seen in Annex 5.

Birmingham City District has significant correlation coefficients for most domain variables with 'education' again exhibiting the weakest relationship. Greater Belfast follows this pattern, showing the 'access to geographical services' domain having the strongest correlation, albeit negative. In general, Greater Belfast shows the highest correlation values relative to all the other areas.

For Cardiff City Council, the 'housing' domain interestingly exhibits a significant positive correlation. As is the case with all other analysis areas, 'access to geographical services' domain shows a significant negative correlation. The strongest correlation is found for the reduction in $NO_2$ between 1998 and 2010 for a range of different domains. This may indicate that policies to reduce pollutants will be more beneficial for less deprived areas. However, overall the Cardiff results reflect those seen in all Cardiff analyses that, in general terms, there is no relationship between air pollution and social deprivation. It is important to note that lower significance scores could be reinforced by a small sample size.

## 4.8 POSSIBLE CONFOUNDING FACTOR OF POPULATION DENSITY

In the previous study (King and Stedman 2000), it was recognised that a potential confounding factor of population density might affect the analysis that had been carried out. This remains relevant for this further analysis. 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 emissions mapping is used as an input to the background air concentration mapping. Therefore, there may be overestimated pollutant concentrations in urban areas where population density is high. However, the significance of this confounding factor was not thought to be unduly high. For a more detailed assessment of this factor, see Annex 5 of the previous analysis by King and Stedman (2000).

## 4.9 COMPARISON BETWEEN INITIAL STUDY AND PRESENT ANALYSIS

As stated in the introduction, this study has been undertaken due to the availability of new data sources, particularly new indices of social deprivation, and is therefore essentially an update of the previous analysis (King and Stedman 2000) undertaken. It is important that some comparisons should be made between this analysis and that undertaken previously.

The following general points can be made when comparing both studies:

- For the English and Northern Ireland geographical areas, there seems to be some evidence of a positive correlation between air pollution and social deprivation, a trend which suggests that areas of high deprivation also have higher pollution levels.
- Therefore, it is possible that targeted policies to reduce air pollution concentrations in more deprived areas could have greater marginal benefits relative to less deprived areas. Both studies come to this conclusion.
- Both studies conclude that variation in the spatial scale of analysis does not appear to have a significant effect on the results.
- Similar results are found in both studies with regard to roadside $NO_2$ concentrations.
- Inter-regional comparisons used in this study are far more reliable due to the similar index scales and construction methodologies used.

This analysis has not completely mirrored the previous analysis, with some significant methodological differences. The Welsh analysis area has changed from Port Talbot to Cardiff although the results remain inconclusive for both of these areas. Further analysis has been undertaken with regards to the roadside concentrations, with the inclusion of $PM_{10}$ and the use of an alternative comparable analysis to further explore the relationship between roadside pollutant concentrations and social deprivation.

# 5 Conclusions

There are some general conclusions that can be drawn from this analysis:

- For Greater London, Birmingham City District and Greater Belfast, there appears to be evidence for a positive correlation between $NO_2$ and $PM_{10}$ and social deprivation, with higher concentrations of these pollutants found in areas exhibiting higher levels of deprivation.
- There does not appear to any significant relationship between air pollution and social deprivation for Cardiff City Council, although there are some weak correlations between individual domains and specific pollutants.
- Individual domains within the multiple deprivation index may show very different trends when they are analysed on an individual basis against air pollutant concentrations. However, in general, most domains follow the trend of a positive correlation between pollutant concentration and deprivation index. Important conclusions from this section of analysis include:

    - Income, employment, health and housing domains all have significant positive correlations with pollutant concentrations for Greater London. The 'housing' domain has the strongest positive correlation while the 'access to services' domain has a very strong negative correlation. The education domain does not exhibit a significant correlation with pollutant concentrations.
    - Birmingham City District follows the same pattern to Greater London although the 'education' domain has a more significant relationship.
    - All domains have significant relationships for Greater Belfast, with the 'health' domain possessing the strongest positive correlation coefficient and the 'housing' domain possessing the weakest coefficient. The 'access to services' domain shows a strong negative correlation.
    - The 'housing' and 'access to services' domains show significant correlations for Cardiff District Council. The access to services domain follows the trend seen in other cities, with a negative correlation, while the 'housing' domain shows a strong positive correlation. These trends are not reflected in the overall multiple deprivation index.

  The above points illustrate the importance of looking at individual domains of deprivation, to gain an understanding of the relationship between indicators of deprivation and pollutant concentrations.

- Based on all analysis methodologies undertaken, there appear to be a weak positive relationship between roadside pollution and levels of deprivation.
- Variation in the spatial scale of analysis (ward and enumeration district levels) seems to have limited effect on the results.
- For the English cities, policies to reduce $NO_2$ and $PM_{10}$ could have greater benefits for more deprived communities based on the results from this analysis, and for central urban locations that have highest concentrations of these pollutants. This appears true for Greater Belfast although under the 2010 scenario where additional measures are included, such measures do

not appear to have increased benefits for more deprived areas.[6] This does not appear to be the case for Cardiff City Council, where policies to reduce air pollution could have greater marginal benefits for less deprived communities.

For the areas of Greater London, Birmingham City District and Greater Belfast, it may be likely that targeted policies to reduce $NO_2$ and $PM_{10}$ concentrations in areas where they are high could impact marginally more beneficially in more deprived communities, and therefore move towards reducing the apparent inequity. This inequity can be seen in the general trend that in areas of higher social deprivation, concentrations of $NO_2$ and $PM_{10}$ are higher than in less deprived areas. For the area of Cardiff City Council, this apparent inequity is not observed, and therefore there appears to be no clear relationship between air pollution and social deprivation. The central city areas have the highest pollutant concentrations but relatively low deprivation index scores.

[6] See section 1.2 for full description of 2010 scenarios.

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http://ariadne.aeat.co.uk/netcen/airqual/reports/naqs2001/aeat-env-r-0726.pdf

Stedman, J. R. Bush, T. J., Murrells, T.P. and King, K. (2001*b*) *Projections of $PM_{10}$ and $NO_x$ concentrations in 2010 for additional measures scenarios*, AEA Technology Environment, National Environmental Technology Centre. Report AEAT/ENV/R/0727.
http://ariadne.aeat.co.uk/netcen/airqual/reports/naqs2001/aeat-env-r-0727.pdf

# Annexes

## CONTENTS


| | |
|---|---|
| Annex 1 | Multiple deprivation versus pollutant concentration: Birmingham analysis |
| Annex 2 | Specific domains versus pollutant concentrations |
| Annex 3 | Comparative roadside analysis |
| Annex 4 | Comparison with improvements in air quality |
| Annex 5 | Analysis of statistical significance |

# ANNEX 1 MULTIPLE DEPRIVATION VERSUS POLLUTANT CONCENTRATION: BIRMINGHAM ANALYSIS

**Figure 33** Birmingham City District 1998 annual mean $NO_2$ versus Deprivation Index

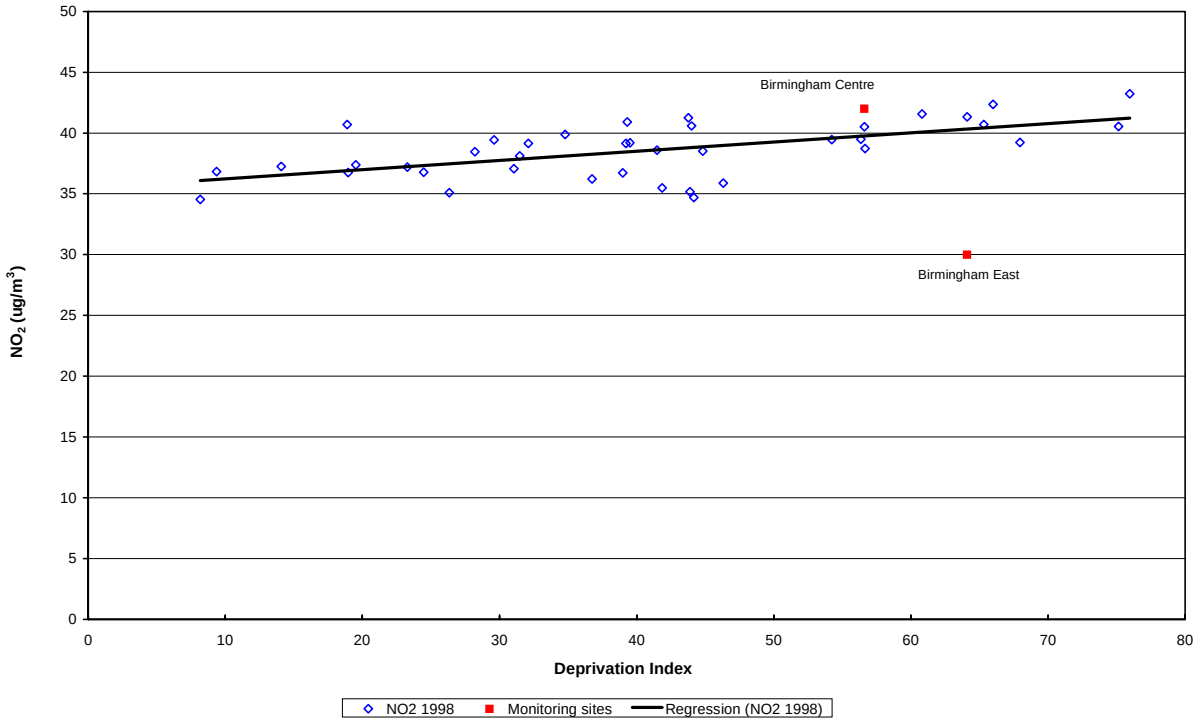



**Figure 34** Birmingham City District 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) versus Deprivation Index

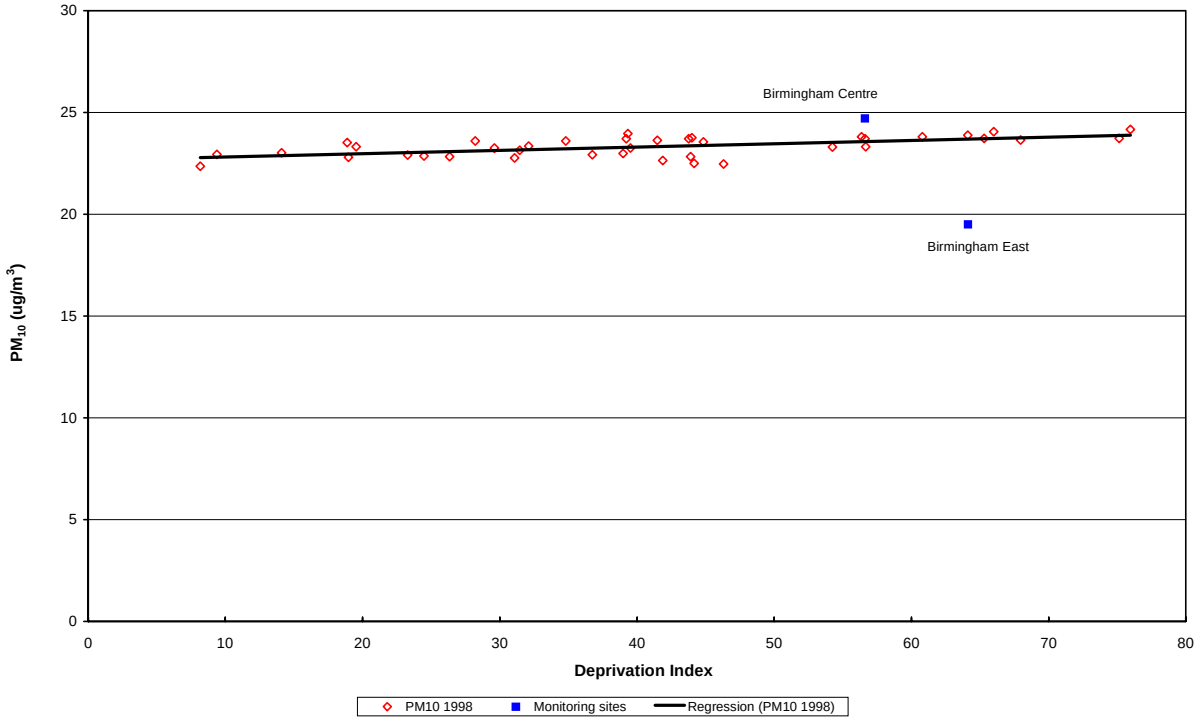
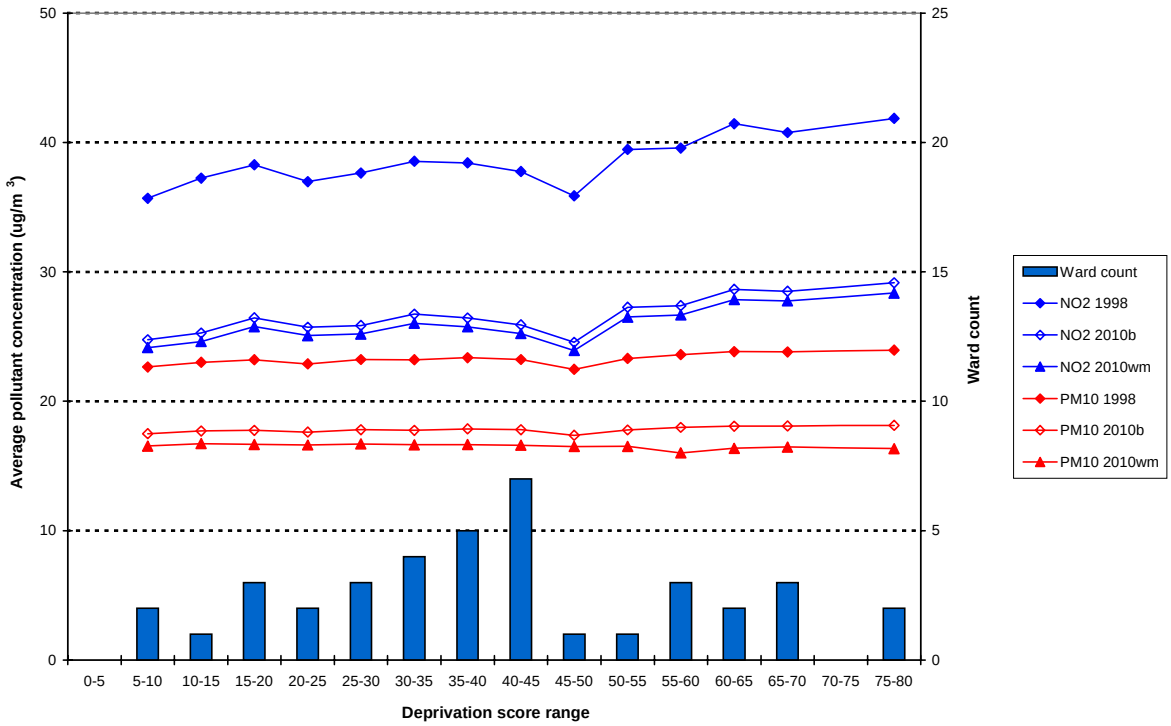


**Figure 35** Birmingham City District: Average annual mean pollution concentrations by deprivation score range



# ANNEX 2 SPECIFIC DOMAINS VERSUS POLLUTANT CONCENTRATIONS

**Figure 36** Greater London 1998 annual mean $NO_2$ versus Income Deprivation domain

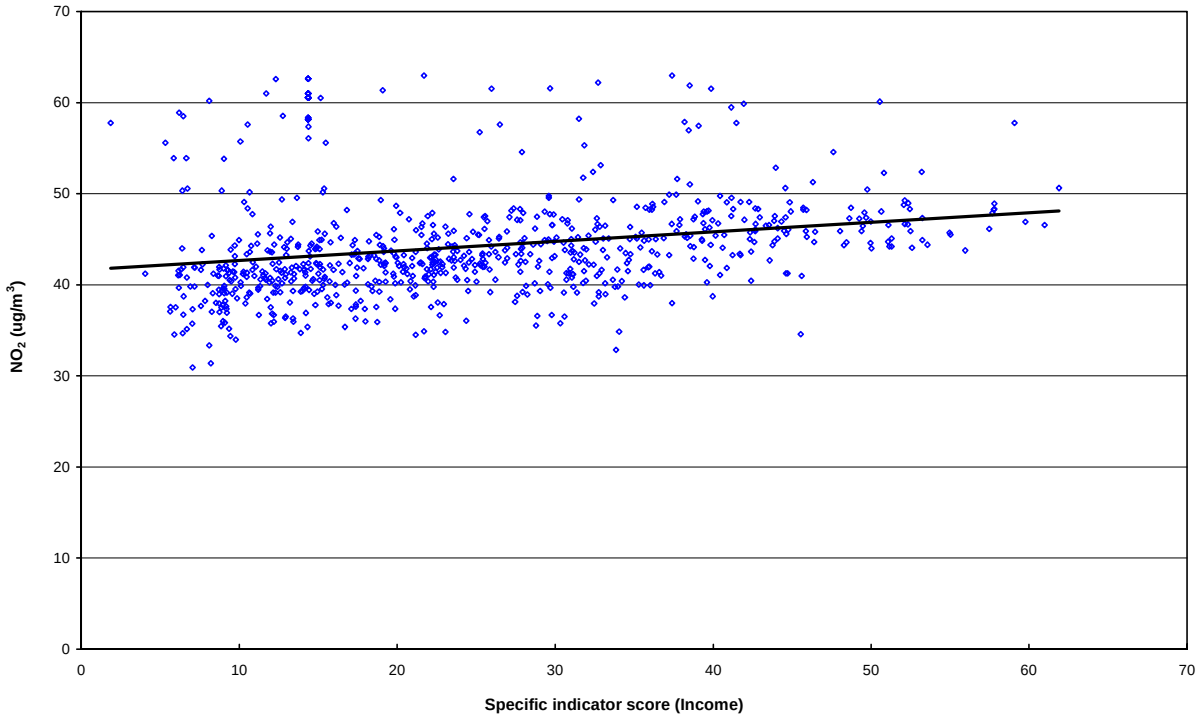



**Figure 37** Greater London 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) versus Income Deprivation domain

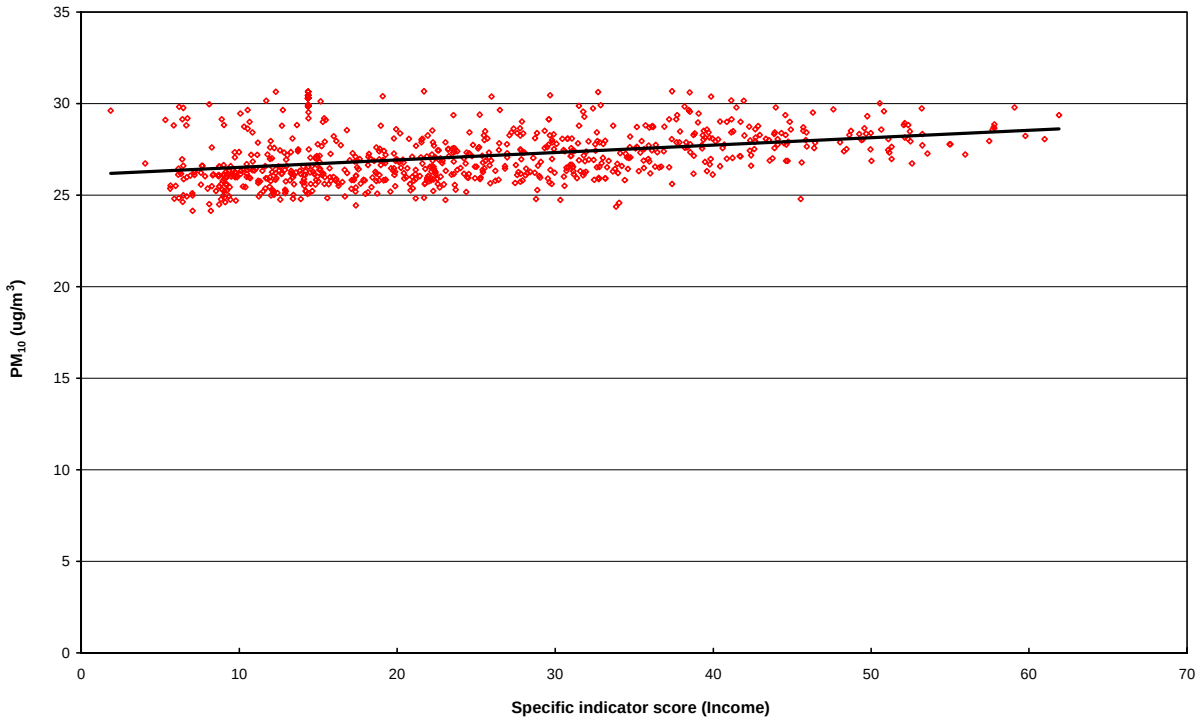


**Figure 38** Greater London 1998 annual mean $NO_2$ versus Employment deprivation domain

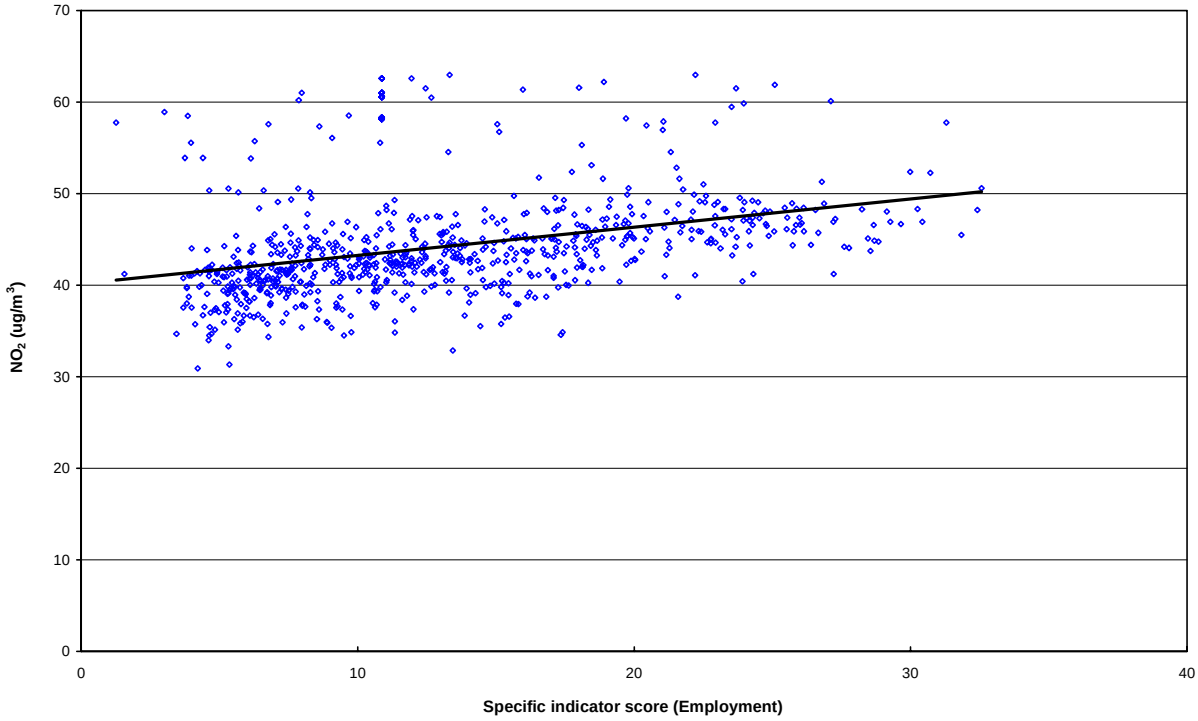



**Figure 39** Greater London 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric) versus Employment Deprivation domain

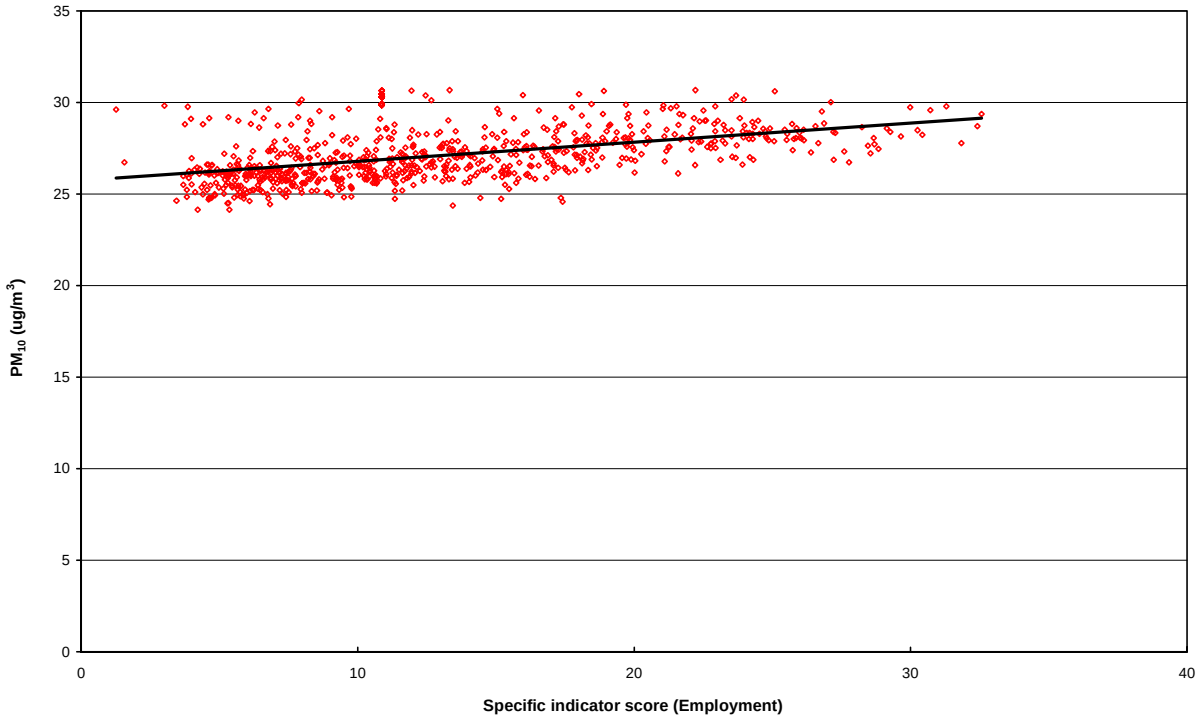


**Figure 40** Greater London 1998 annual mean $NO_2$ versus Health Deprivation domain

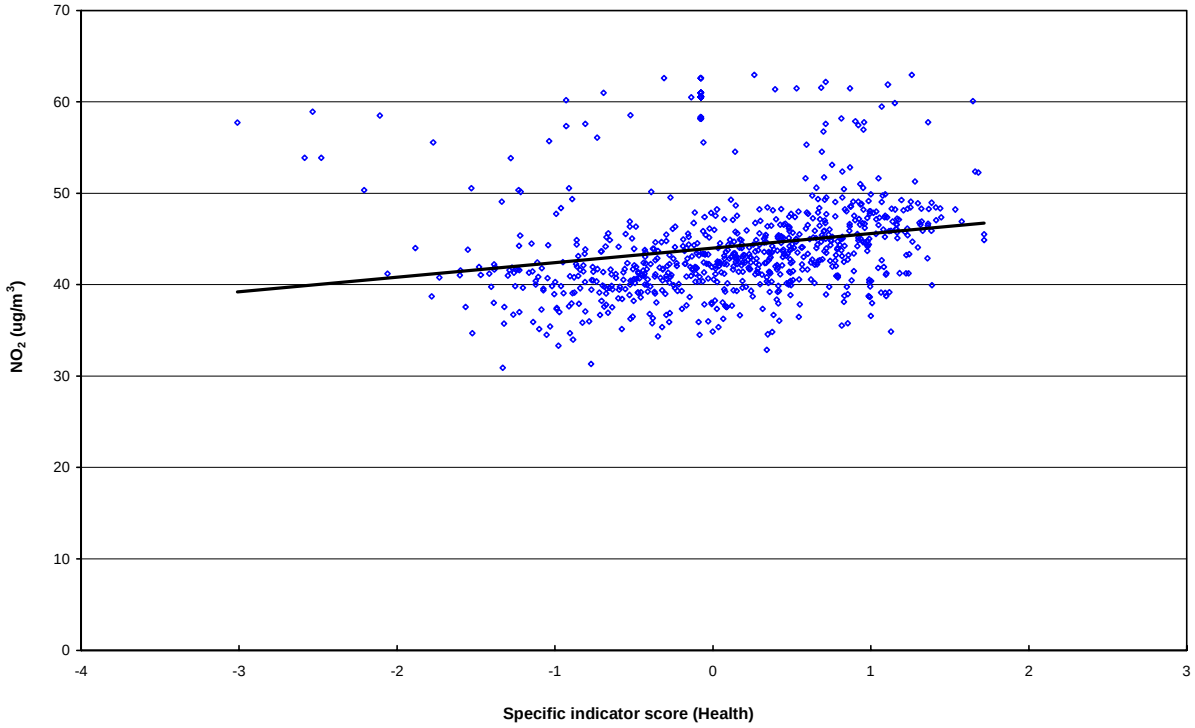



**Figure 41** Greater London 1998 annual mean $NO_2$ versus Education Deprivation domain

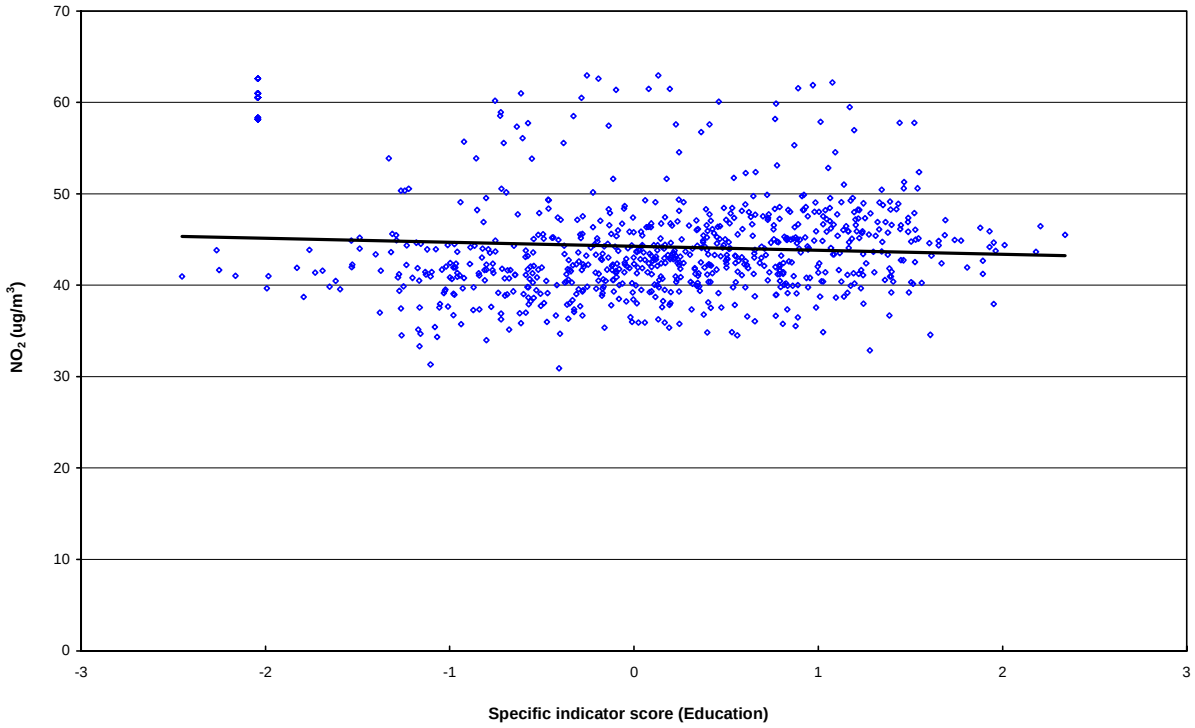


**Figure 42** Greater London 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric) versus Housing Deprivation domain

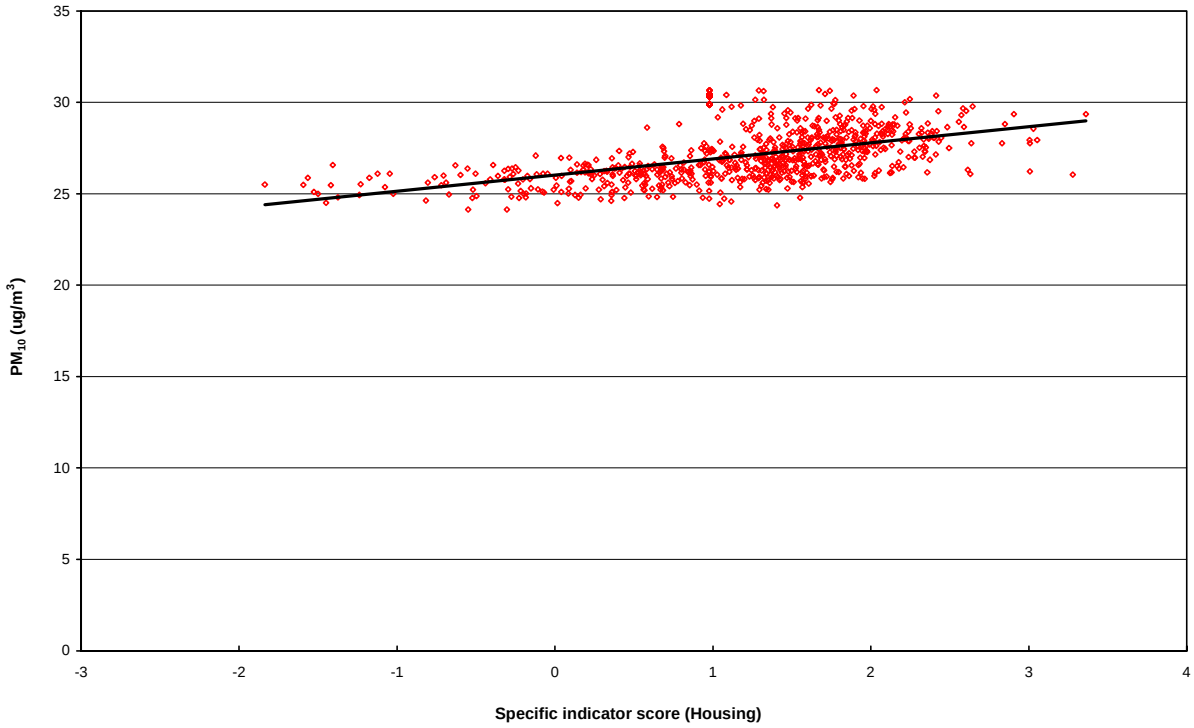



**Figure 43** Greater London 1998 annual mean $NO_2$ versus Access Deprivation domain

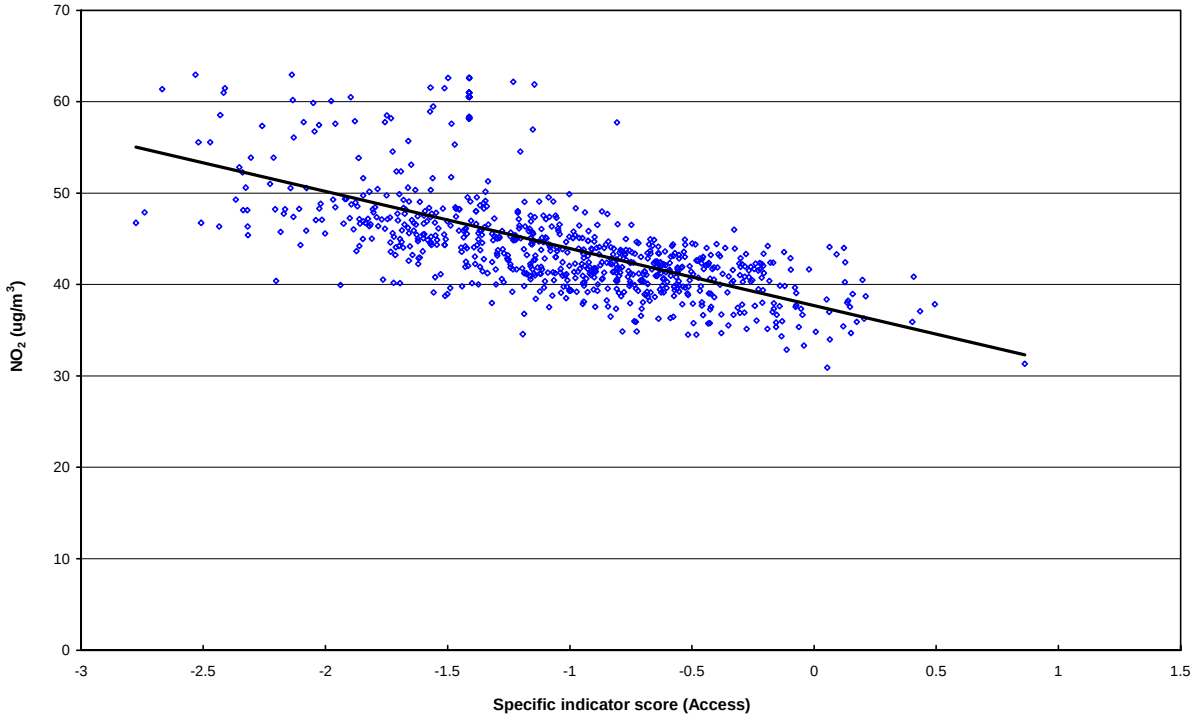


**Figure 44** Greater London 1998 annual mean $NO_2$ versus Child Poverty Deprivation domain

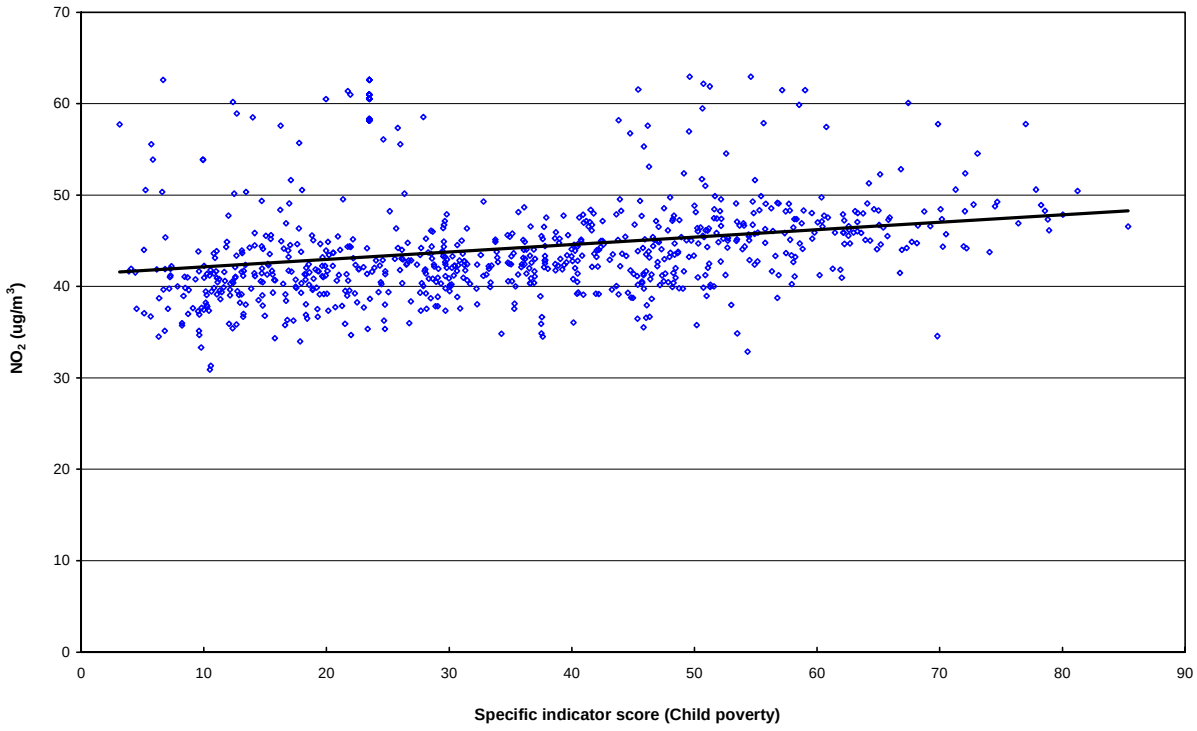
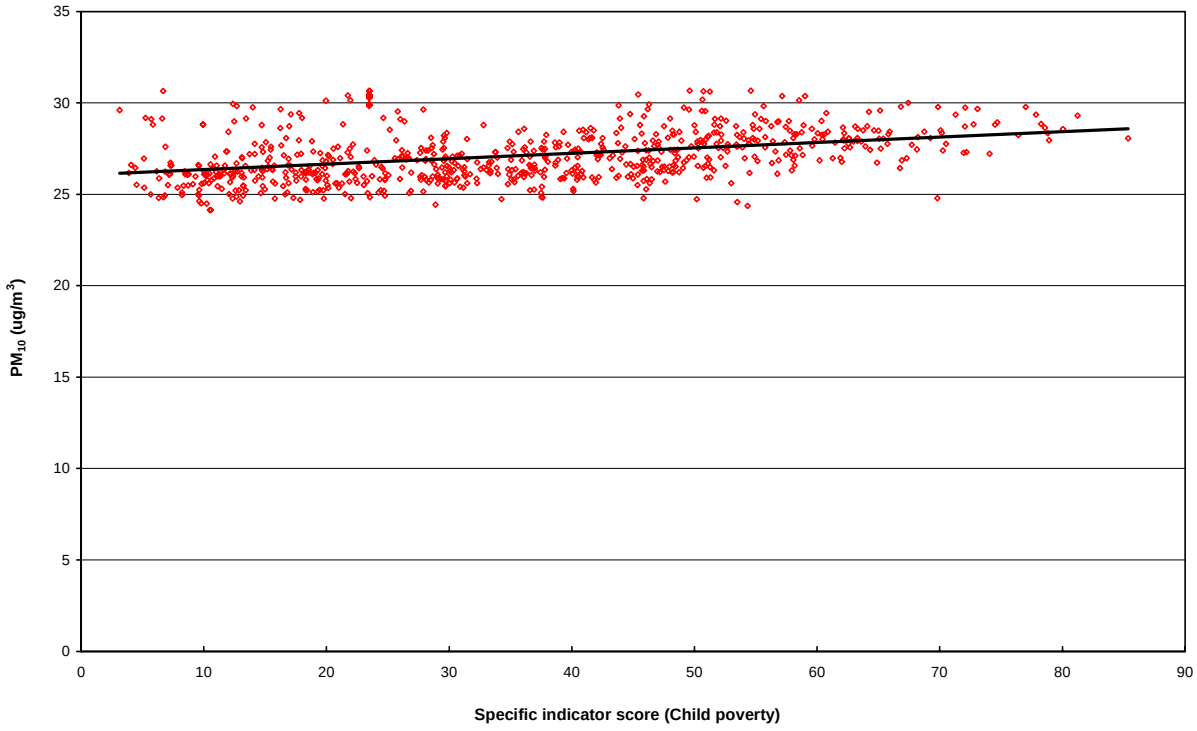



**Figure 45** Greater London 1998 annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric) versus Child Poverty Deprivation domain



# ANNEX 3 COMPARATIVE ROADSIDE ANALYSIS

**Figure 46** Average roadside annual mean $NO_2$ concentrations by deprivation score for Greater London

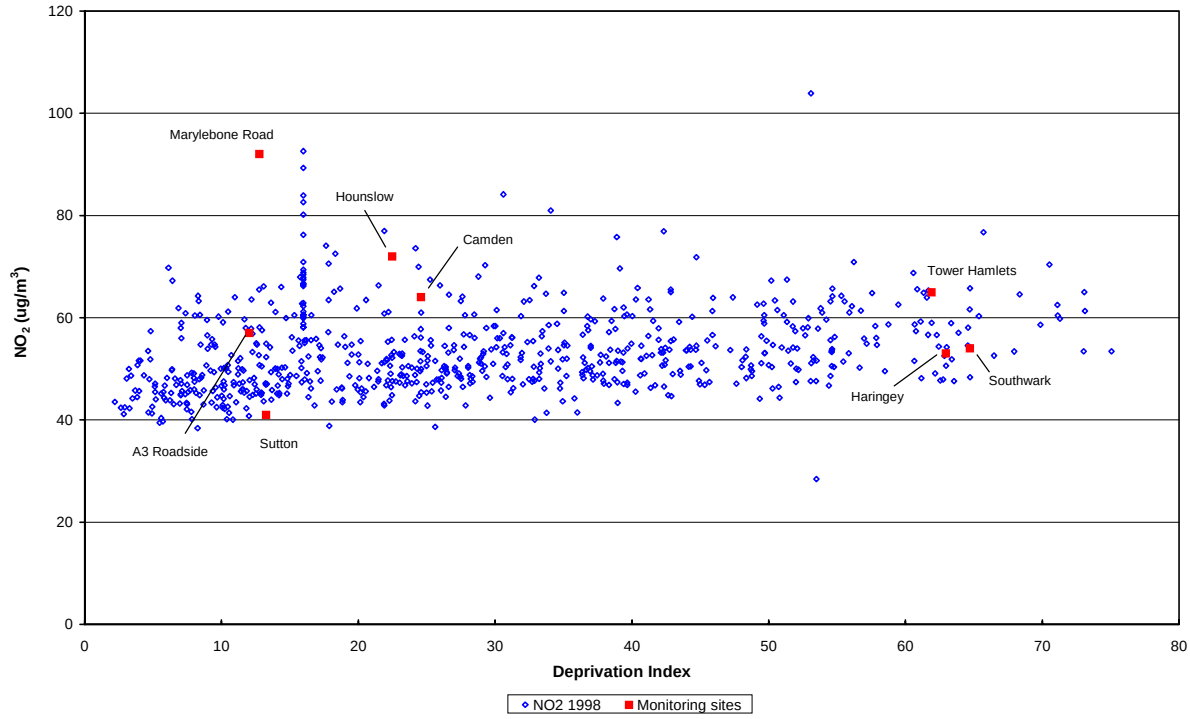
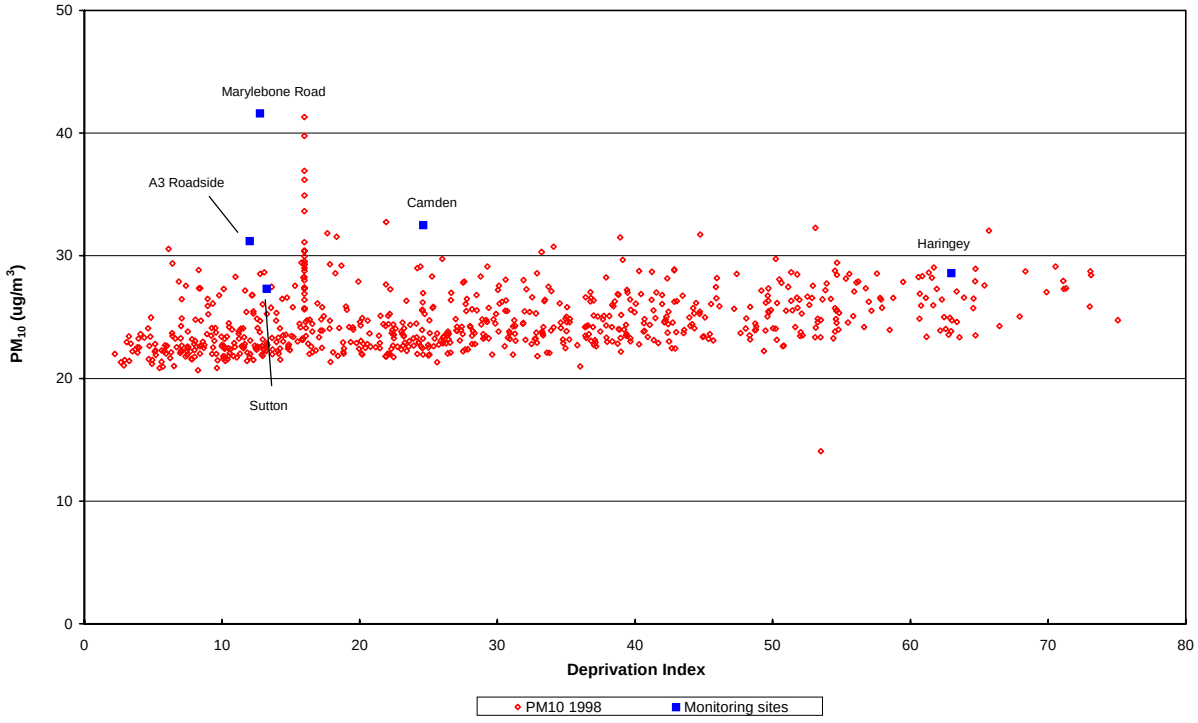



**Figure 47** Average roadside annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) concentrations by deprivation score for Greater London



# ANNEX 4 COMPARISON WITH IMPROVEMENTS IN AIR QUALITY

**Figure 48** Greater London annual mean $NO_2$ reductions between 2010 baseline and 2010 measures scenario

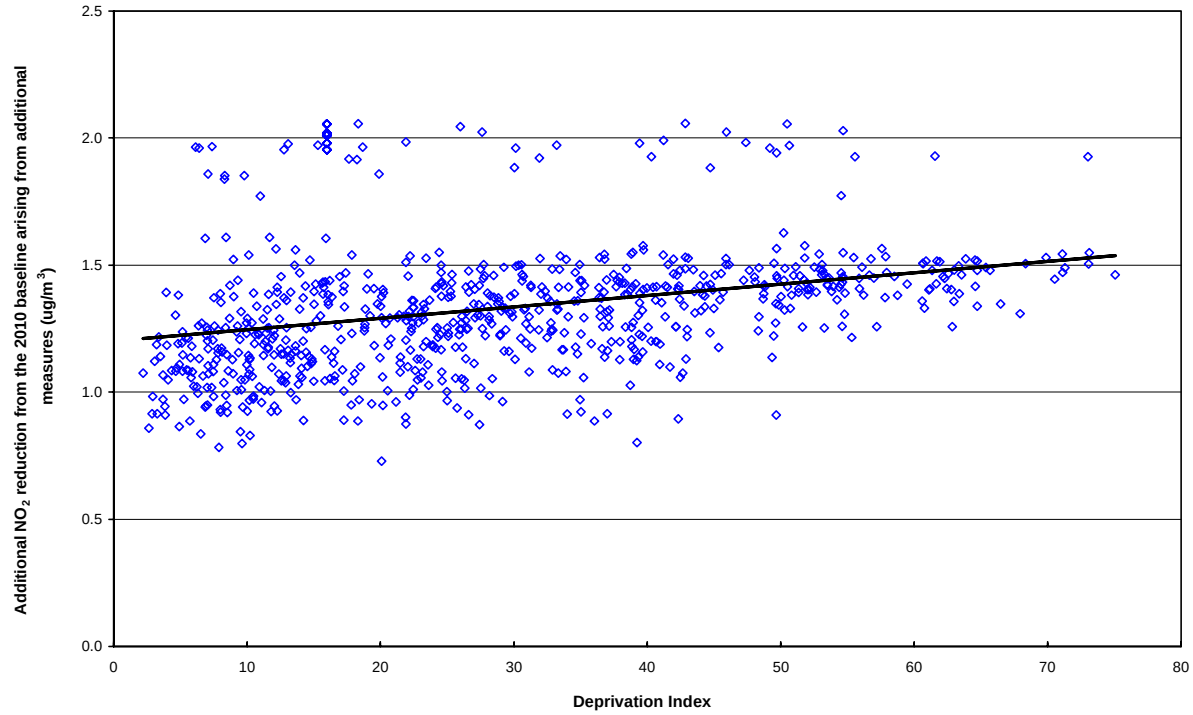



**Figure 49** Greater London annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) reductions between 2010 baseline and 2010 measures scenario

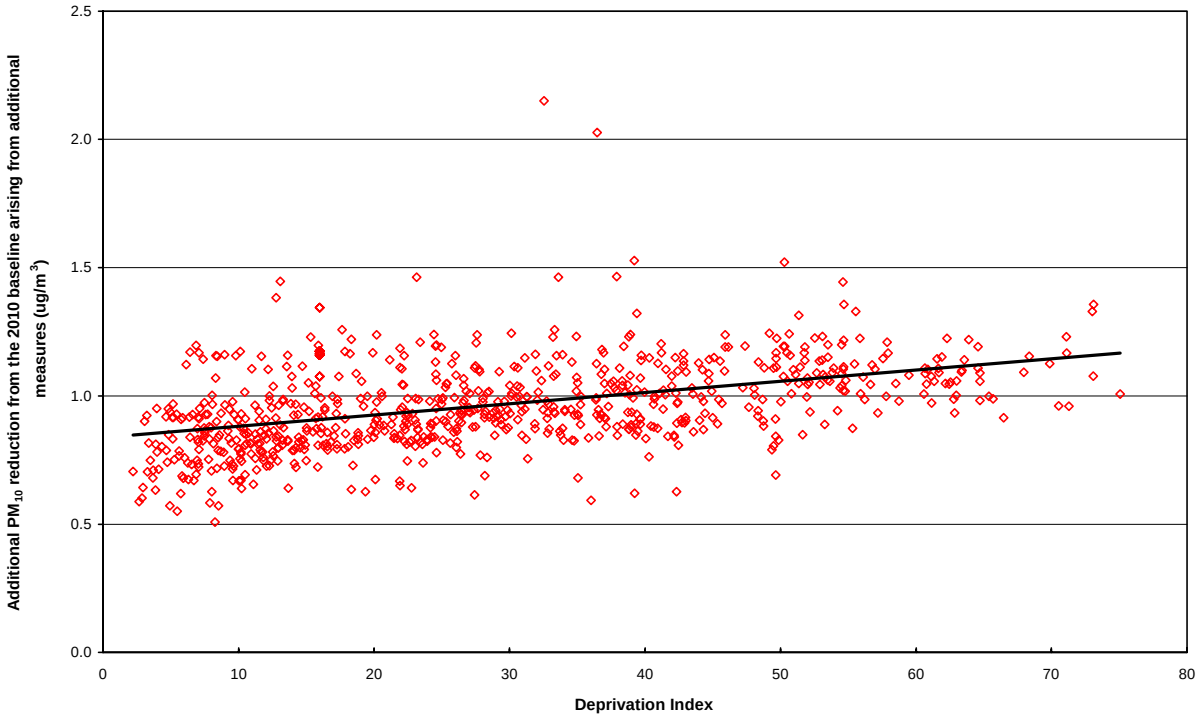


**Table 5a** Greater London wards experiencing increased $NO_2$ reductions between 1998 and 2010

| Ward code | Ward Name | LA Name | Index of Multiple Deprivation Score | Reduction (ug/m3) |
|---|---|---|---|---|
| AAFG | BRIDGE AND BRIDGE WITHOUT WARD | City of London | 15.99 | 18.08 |
| AAFJ | CANDLEWICK WARD | City of London | 15.99 | 18.08 |
| AAFR | DOWGATE WARD | City of London | 15.99 | 18.08 |
| AAFY | QUEENHITHE WARD | City of London | 15.99 | 18.08 |
| AAGA | VINTRY WARD | City of London | 15.99 | 18.08 |
| AAGB | WALBROOK WARD | City of London | 15.99 | 18.08 |
| BEFJ | Cathedral | Southwark | 50.47 | 18.03 |
| BKFW | St. James's | Westminster | 18.33 | 18.03 |
| AYFB | Bishop's | Lambeth | 42.85 | 18.03 |
| BKFX | VICTORIA WARD | Westminster | 25.99 | 17.99 |
| BEFK | Chaucer | Southwark | 54.66 | 17.89 |
| AAFA | ALDERSGATE WARD | City of London | 15.99 | 17.76 |
| AAFF | BREAD STREET WARD | City of London | 15.99 | 17.76 |
| AAFH | BROAD STREET WARD | City of London | 15.99 | 17.76 |
| AAFL | CHEAP WARD | City of London | 15.99 | 17.76 |
| AAFM | COLEMAN STREET WARD | City of London | 15.99 | 17.76 |
| AAFN | CORDWAINER WARD | City of London | 15.99 | 17.76 |
| AAFP | CORNHILL WARD | City of London | 15.99 | 17.76 |
| AAFQ | CRIPPLEGATE WARD | City of London | 15.99 | 17.76 |
| AAFC | Bassishaw | City of London | 15.99 | 17.76 |
| AGFR | HOLBORN WARD | Camden | 45.93 | 17.73 |
| AGFC | Bloomsbury | Camden | 27.61 | 17.73 |
| AAFT | Farringdon Without | City of London | 15.99 | 17.71 |
| AAFK | CASTLE BAYNARD WARD | City of London | 15.99 | 17.71 |
| AAFS | FARRINGDON WITHIN WARD | City of London | 15.99 | 17.71 |
| AYFL | Prince's | Lambeth | 41.22 | 17.62 |
| AAFD | BILLINGSGATE WARD | City of London | 15.99 | 17.59 |
| AAFU | LANGBOURNE WARD | City of London | 15.99 | 17.59 |
| AAFZ | TOWER WARD (Det) | City of London | 15.99 | 17.59 |
| BEFT | NEWINGTON WARD | Southwark | 47.39 | 17.56 |
| AUFB | Bunhill | Islington | 50.64 | 17.55 |
| AUFE | Clerkenwell | Islington | 39.40 | 17.52 |
| BKFU | ST GEORGE'S WARD | Westminster | 15.32 | 17.51 |
| BKFR | Millbank | Westminster | 33.21 | 17.51 |
| BKFZ | West End | Westminster | 21.92 | 17.44 |
| AAFB | ALDGATE WARD | City of London | 15.99 | 17.41 |
| AAFE | BISHOPSGATE WARD | City of London | 15.99 | 17.41 |
| AAFW | LIME STREET WARD | City of London | 15.99 | 17.41 |
| AAFX | Portsoken | City of London | 15.99 | 17.41 |
| BKFE | Cavendish | Westminster | 13.08 | 17.40 |
| BKFC | Belgrave | Westminster | 7.38 | 17.39 |
| BKFM | LANCASTER GATE WARD | Westminster | 18.67 | 17.36 |
| AGFT | King's Cross | Camden | 49.18 | 17.35 |
| AGFD | BRUNSWICK WARD | Camden | 30.12 | 17.35 |
| BKFL | Knightsbridge | Westminster | 6.13 | 17.34 |
| AMFL | Moorfields | Hackney | 55.57 | 17.31 |
| BGFU | WEAVERS WARD | Tower Hamlets | 73.03 | 17.31 |
| AWFL | HANS TOWN WARD | Kensington and Chelsea | 6.41 | 17.28 |
| BEFA | Abbey | Southwark | 49.68 | 17.27 |
| BKFA | BAKER STREET WARD | Westminster | 12.76 | 17.20 |
| AGFZ | Somers Town | Camden | 61.56 | 17.16 |
| AYFK | Oval | Lambeth | 40.30 | 17.15 |
| BKFF | CHURCHILL WARD | Westminster | 31.90 | 17.11 |
| BKFK | Hyde Park | Westminster | 18.24 | 17.00 |
| BKFD | Bryanston | Westminster | 17.64 | 16.96 |
| BJFM | Queenstown | Wandsworth | 30.03 | 16.86 |
| BKFG | CHURCH STREET WARD | Westminster | 44.73 | 16.75 |
| AWFH | Courtfield | Kensington and Chelsea | 8.33 | 16.68 |

| Ward code | Ward Name | LA Name | Index of Multiple Deprivation Score | Reduction (ug/m3) |
|---|---|---|---|---|
| AWFC | BROMPTON WARD | Kensington and Chelsea | 9.80 | 16.68 |
| AWFU | Royal Hospital | Kensington and Chelsea | 7.08 | 16.67 |
| AWFF | CHURCH WARD | Kensington and Chelsea | 19.90 | 16.67 |
| AWFE | CHEYNE WARD | Kensington and Chelsea | 8.31 | 16.53 |
| BKFT | Regent's Park | Westminster | 10.98 | 15.65 |
| BGFP | St. Katherine's | Tower Hamlets | 54.53 | 15.60 |
| ASGC | West Drayton | Hillingdon | 24.61 | 15.31 |

**Table 5b** Greater London wards experiencing increased $NO_2$ reductions between the 2010 reference and 'with measures' scenarios

| Ward code | Ward Name | LA Name | Index of Multiple Deprivation Score | Reduction (ug/m3) |
|---|---|---|---|---|
| AYFB | Bishop's | Lambeth | 42.85 | 2.06 |
| BKFW | St. James's | Westminster | 18.33 | 2.06 |
| BEFJ | Cathedral | Southwark | 50.47 | 2.06 |
| AAFG | BRIDGE AND BRIDGE WITHOUT WARD | City of London | 15.99 | 2.05 |
| AAFJ | CANDLEWICK WARD | City of London | 15.99 | 2.05 |
| AAFR | DOWGATE WARD | City of London | 15.99 | 2.05 |
| AAFY | QUEENHITHE WARD | City of London | 15.99 | 2.05 |
| AAGA | VINTRY WARD | City of London | 15.99 | 2.05 |
| AAGB | WALBROOK WARD | City of London | 15.99 | 2.05 |
| BKFX | VICTORIA WARD | Westminster | 25.99 | 2.05 |
| BEFK | Chaucer | Southwark | 54.66 | 2.03 |
| AGFC | Bloomsbury | Camden | 27.61 | 2.02 |
| AGFR | HOLBORN WARD | Camden | 45.93 | 2.02 |
| AAFK | CASTLE BAYNARD WARD | City of London | 15.99 | 2.02 |
| AAFS | FARRINGDON WITHIN WARD | City of London | 15.99 | 2.02 |
| AAFT | Farringdon Without | City of London | 15.99 | 2.02 |
| AAFC | Bassishaw | City of London | 15.99 | 2.01 |
| AAFA | ALDERSGATE WARD | City of London | 15.99 | 2.01 |
| AAFF | BREAD STREET WARD | City of London | 15.99 | 2.01 |
| AAFH | BROAD STREET WARD | City of London | 15.99 | 2.01 |
| AAFL | CHEAP WARD | City of London | 15.99 | 2.01 |
| AAFM | COLEMAN STREET WARD | City of London | 15.99 | 2.01 |
| AAFN | CORDWAINER WARD | City of London | 15.99 | 2.01 |
| AAFP | CORNHILL WARD | City of London | 15.99 | 2.01 |
| AAFQ | CRIPPLEGATE WARD | City of London | 15.99 | 2.01 |
| AYFL | Prince's | Lambeth | 41.22 | 1.99 |
| BKFZ | West End | Westminster | 21.92 | 1.98 |
| BEFT | NEWINGTON WARD | Southwark | 47.39 | 1.98 |
| AUFE | Clerkenwell | Islington | 39.40 | 1.98 |
| AAFD | BILLINGSGATE WARD | City of London | 15.99 | 1.98 |
| AAFU | LANGBOURNE WARD | City of London | 15.99 | 1.98 |
| AAFZ | TOWER WARD (Det) | City of London | 15.99 | 1.98 |
| BKFE | Cavendish | Westminster | 13.08 | 1.98 |
| BKFR | Millbank | Westminster | 33.21 | 1.97 |
| BKFU | ST GEORGE'S WARD | Westminster | 15.32 | 1.97 |
| AUFB | Bunhill | Islington | 50.64 | 1.97 |
| BKFC | Belgrave | Westminster | 7.38 | 1.97 |
| BKFM | LANCASTER GATE WARD | Westminster | 18.67 | 1.96 |
| BKFL | Knightsbridge | Westminster | 6.13 | 1.96 |
| AWFL | HANS TOWN WARD | Kensington and Chelsea | 6.41 | 1.96 |
| AGFD | BRUNSWICK WARD | Camden | 30.12 | 1.96 |
| AGFT | King's Cross | Camden | 49.18 | 1.96 |
| AAFX | Portsoken | City of London | 15.99 | 1.95 |
| AAFB | ALDGATE WARD | City of London | 15.99 | 1.95 |
| AAFE | BISHOPSGATE WARD | City of London | 15.99 | 1.95 |
| AAFW | LIME STREET WARD | City of London | 15.99 | 1.95 |
| BKFA | BAKER STREET WARD | Westminster | 12.76 | 1.95 |
| BEFA | Abbey | Southwark | 49.68 | 1.94 |
| AGFZ | Somers Town | Camden | 61.56 | 1.93 |
| AYFK | Oval | Lambeth | 40.30 | 1.93 |
| BGFU | WEAVERS WARD | Tower Hamlets | 73.03 | 1.93 |
| AMFL | Moorfields | Hackney | 55.57 | 1.93 |
| BKFF | CHURCHILL WARD | Westminster | 31.90 | 1.92 |
| BKFD | Bryanston | Westminster | 17.64 | 1.92 |
| BKFK | Hyde Park | Westminster | 18.24 | 1.91 |

| Ward code | Ward Name | LA Name | Index of Multiple Deprivation Score | Reduction (ug/m3) |
|---|---|---|---|---|
| BJFM | Queenstown | Wandsworth | 30.03 | 1.88 |
| BKFG | CHURCH STREET WARD | Westminster | 44.73 | 1.88 |
| AWFF | CHURCH WARD | Kensington and Chelsea | 19.90 | 1.86 |
| AWFU | Royal Hospital | Kensington and Chelsea | 7.08 | 1.86 |
| AWFC | BROMPTON WARD | Kensington and Chelsea | 9.80 | 1.85 |
| AWFH | Courtfield | Kensington and Chelsea | 8.33 | 1.85 |
| AWFE | CHEYNE WARD | Kensington and Chelsea | 8.31 | 1.84 |
| BGFP | St. Katherine's | Tower Hamlets | 54.53 | 1.77 |
| BKFT | Regent's Park | Westminster | 10.98 | 1.77 |

**Figure 50** Cardiff City Council annual mean $NO_2$ reductions between 2010 baseline and 2010 measures scenario

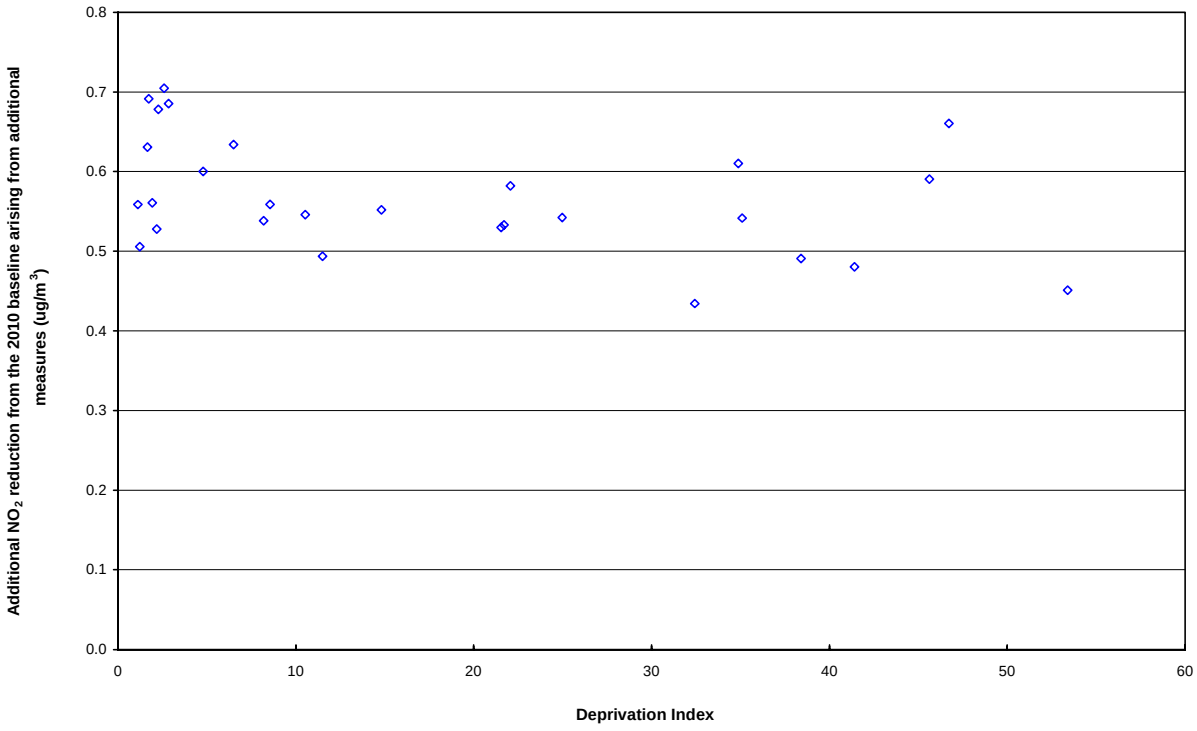



**Figure 51** Cardiff City Council annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) reductions between 2010 baseline and 2010 measures scenario

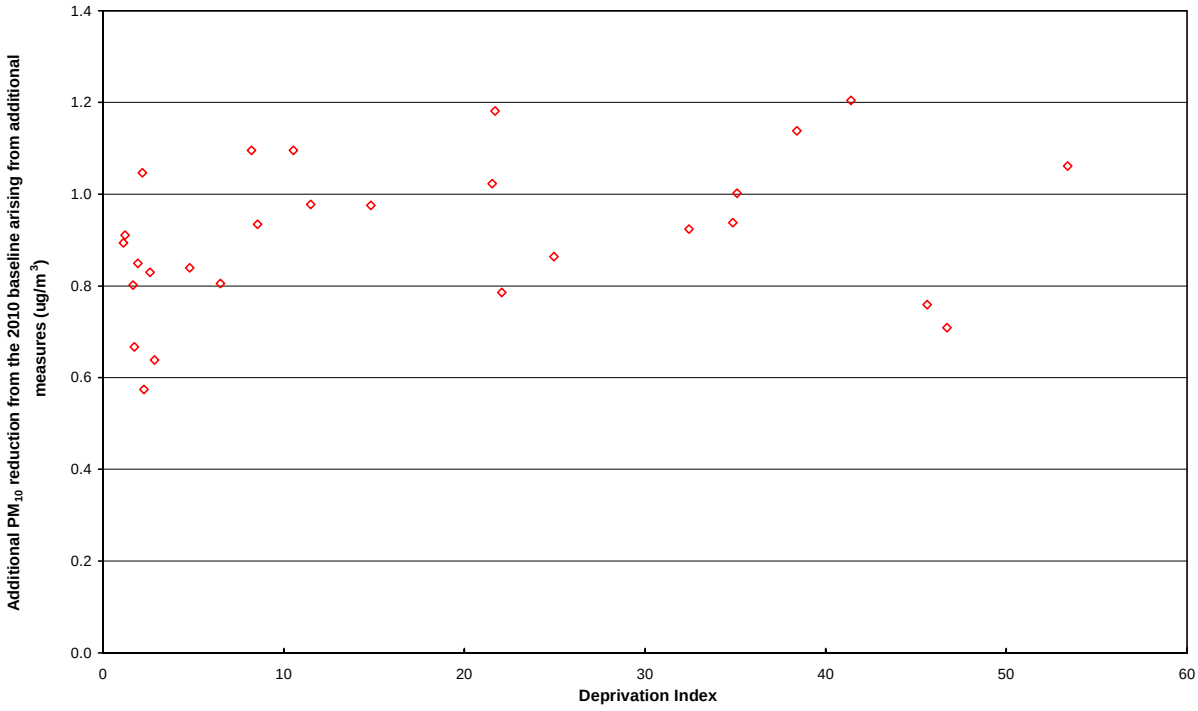


**Figure 52** Greater Belfast annual mean $NO_2$ reductions between 1998 and 2010

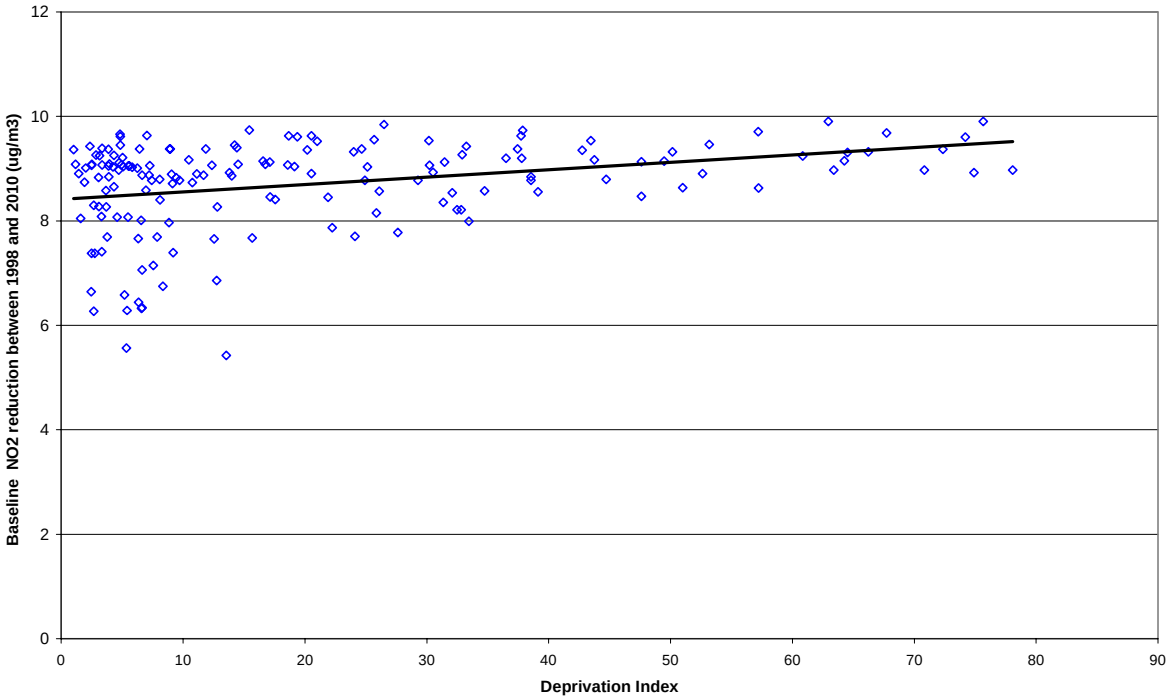



**Figure 53** Greater Belfast annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) reductions between 1998 and 2010

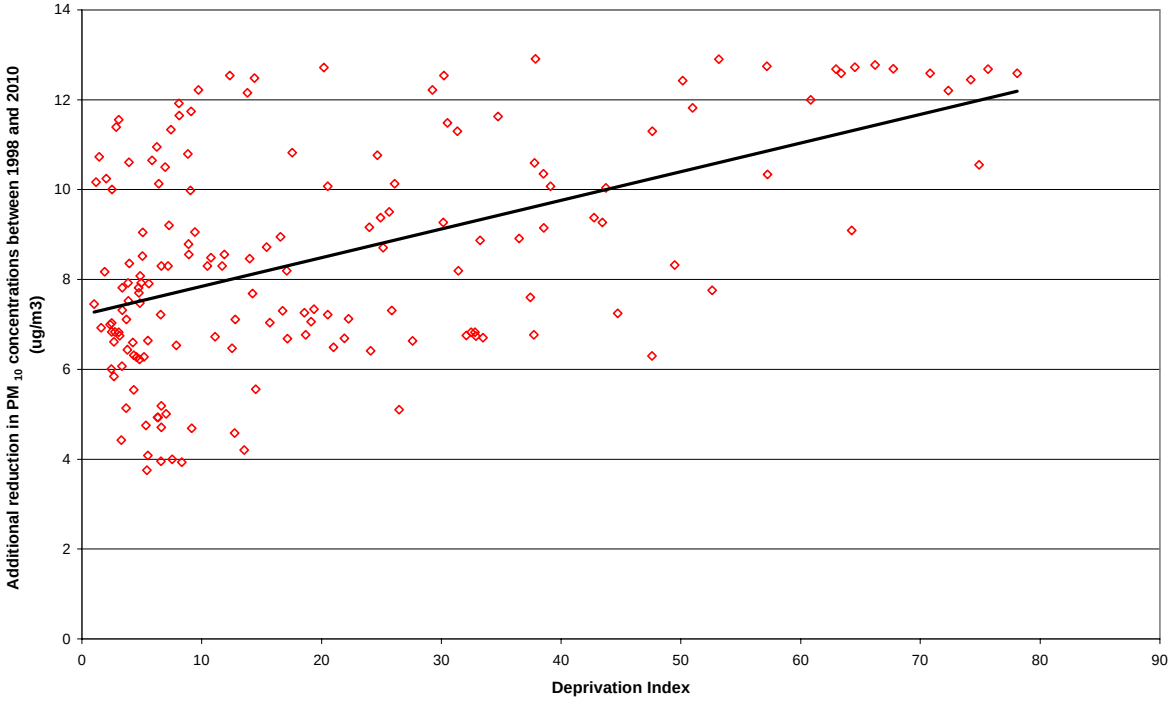


**Figure 54** Greater Belfast annual mean $NO_2$ reductions between 2010 baseline and 2010 measures scenario

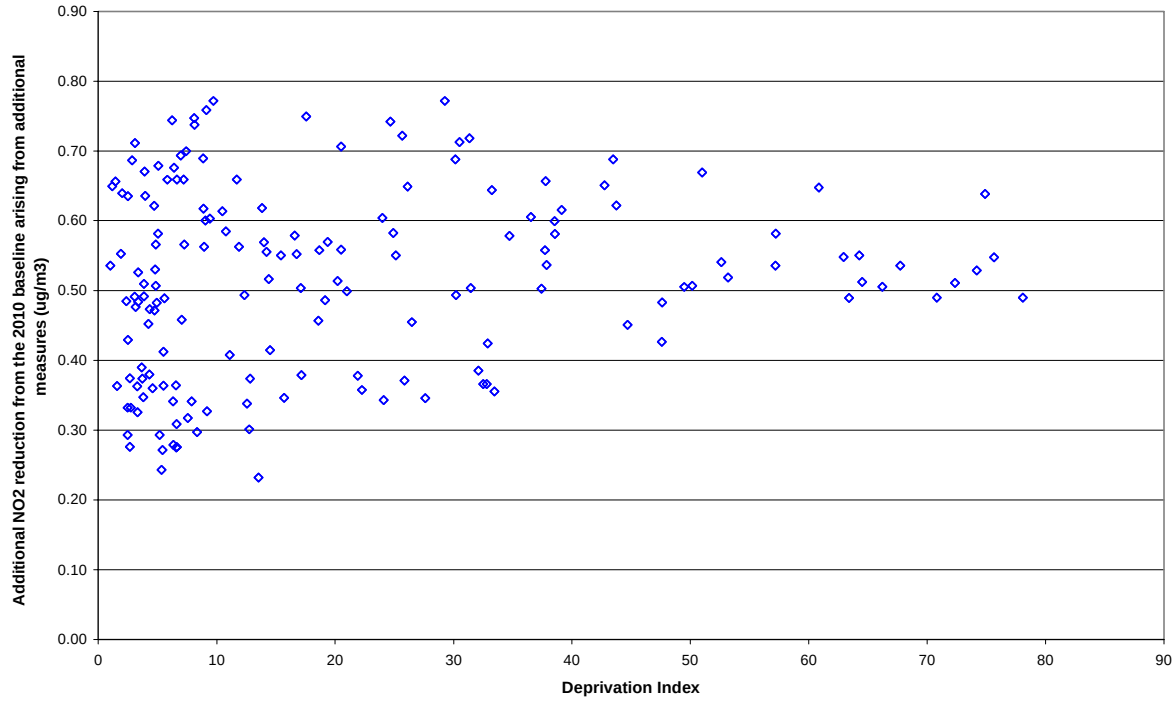
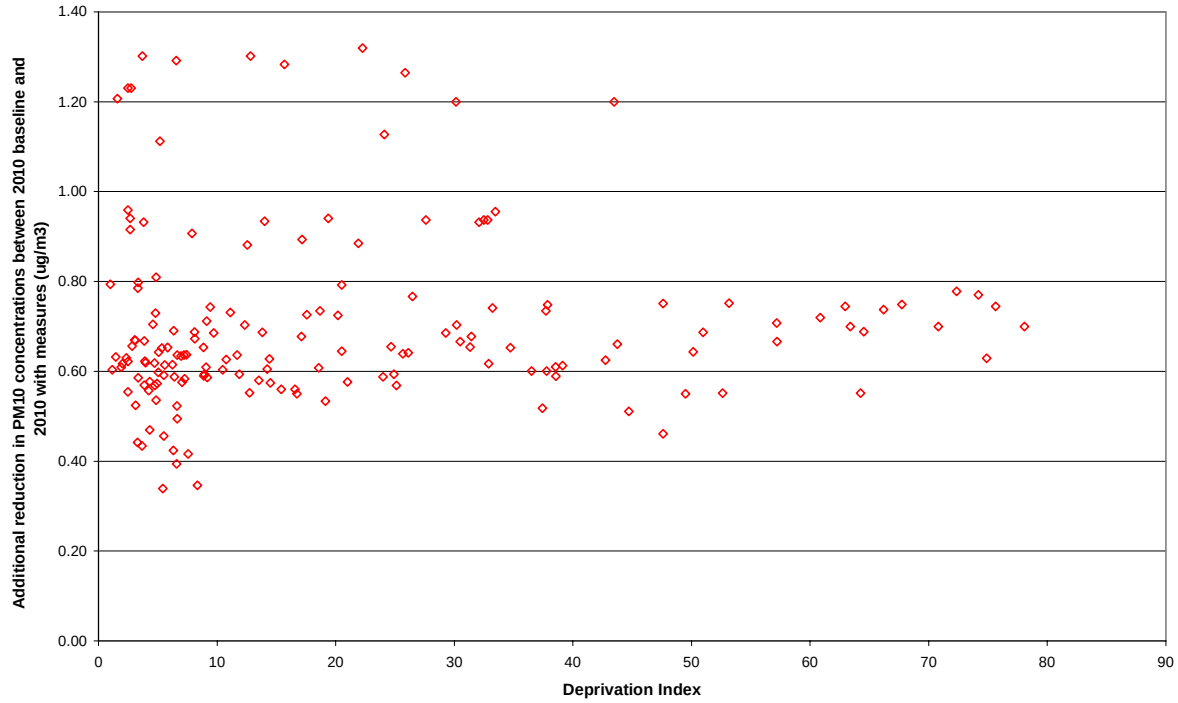



**Figure 55** Greater Belfast annual mean $PM_{10}$ ($\mu gm^{-3}$, gravimetric ) reductions between 2010 baseline and 2010 measures scenario



# ANNEX 5 ANALYSIS OF STATISTICAL SIGNIFICANCE

This Annex provides more detail of the statistical analysis referred to in section 4.7. Testing for statistical significance can be illustrated using the example of Birmingham City District below (Table 6). As in the previous analysis (King and Stedman 2000), the test for statistical independence has been adopted. Testing for significance at the 99% level (p = 0.01) with a sample size of 39, the critical value for r in this case is 0.408. Table 6 illustrates that in the case of Birmingham nearly all of the correlation coefficients are significant (as shown in bold).

**Table 6** Correlation coefficients for the Birmingham City District area

(n = 39; critical r = 0.408) where p = 0.01

| r | $NO_2$ 1998 | $NO_2$ 2010b | $NO_2$ 2010wm | $PM_{10}$ 1998 | $PM_{10}$ 2010b | $PM_{10}$ 2010wm | $NO_2$ change (1998 – 2010b) | $NO_2$ change (2010b – 2010wm) | $PM_{10}$ change (1998 – 2010b) | $PM_{10}$ change (2010b – 2010wm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Overall Index Score | **0.600** | **0.613** | **0.615** | **0.608** | **0.601** | -0.400 | **0.516** | **0.541** | **0.605** | **0.597** |
| Income | **0.606** | **0.622** | **0.624** | **0.611** | **0.605** | -0.338 | **0.511** | **0.548** | **0.608** | **0.558** |
| Employment | **0.597** | **0.623** | **0.626** | **0.598** | **0.597** | -0.356 | **0.481** | **0.529** | **0.590** | **0.566** |
| Health | **0.522** | **0.503** | **0.503** | **0.565** | **0.566** | -0.343 | **0.520** | **0.481** | **0.556** | **0.540** |
| Education | **0.412** | 0.391 | 0.391 | **0.453** | **0.450** | **-0.462** | **0.426** | 0.373 | **0.449** | **0.552** |
| Housing | **0.642** | **0.666** | **0.669** | **0.627** | **0.602** | -0.213 | **0.527** | **0.572** | **0.644** | **0.475** |
| Access | **-0.564** | **-0.594** | **-0.597** | **-0.582** | **-0.574** | 0.336 | **-0.440** | **-0.495** | **-0.581** | **-0.540** |
| Child Poverty | **0.565** | **0.579** | **0.581** | **0.568** | **0.564** | -0.325 | **0.482** | **0.508** | **0.564** | **0.527** |

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

**Table 7** Correlation coefficients for the Greater London area

(n = 774; critical r = 0.09) where p = 0.01

| r | $NO_2$ 1998 | $NO_2$ 2010b | $NO_2$ 2010wm | $PM_{10}$ 1998 | $PM_{10}$ 2010b | $PM_{10}$ 2010wm | $NO_2$ change (1998 – 2010b) | $NO_2$ change (2010b – 2010wm) | $PM_{10}$ change (1998 – 2010b) | $PM_{10}$ change (2010b – 2010wm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Overall Index Score | **0.277** | **0.330** | **0.332** | **0.412** | **0.399** | **0.354** | **0.098** | **0.296** | **0.419** | **0.439** |
| Income | **0.233** | **0.287** | **0.289** | **0.370** | **0.356** | **0.314** | 0.055 | **0.254** | **0.380** | **0.399** |
| Employment | **0.352** | **0.409** | **0.410** | **0.488** | **0.474** | **0.438** | **0.155** | **0.372** | **0.495** | **0.460** |
| Health | **0.211** | **0.256** | **0.258** | **0.318** | **0.314** | **0.272** | 0.063 | **0.219** | **0.319** | **0.369** |
| Education | -0.070 | -0.022 | -0.021 | 0.084 | 0.059 | 0.015 | **-0.200** | -0.028 | **0.107** | **0.193** |
| Housing | **0.464** | **0.498** | **0.500** | **0.518** | **0.529** | **0.467** | **0.322** | **0.454** | **0.501** | **0.588** |
| Access | **-0.641** | **-0.679** | **-0.678** | **-0.718** | **-0.712** | **-0.678** | **-0.473** | **-0.662** | **-0.715** | **-0.629** |
| Child Poverty | **0.256** | **0.306** | **0.308** | **0.381** | **0.369** | **0.326** | 0.087 | **0.268** | **0.387** | **0.413** |

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

**Table 8** Correlation coefficients for the Cardiff City area

(n = 28; critical r = 0.374) where p = 0.05

| r | $NO_2$ 1998 | $NO_2$ 2010b | $NO_2$ 2010wm | $PM_{10}$ 1998 | $PM_{10}$ 2010b | $PM_{10}$ 2010wm | $NO_2$ change (1998 – 2010b) | $NO_2$ change (2010b – 2010wm) | $PM_{10}$ change (1998 – 2010b) | $PM_{10}$ change (2010b – 2010wm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Overall Index Score | -0.291 | 0.028 | 0.040 | -0.236 | -0.059 | -0.267 | **-0.769** | **-0.406** | **-0.451** | 0.316 |
| Income | -0.271 | 0.035 | 0.047 | -0.210 | -0.044 | -0.251 | **-0.738** | **-0.398** | **-0.414** | 0.326 |
| Employment | -0.260 | 0.063 | 0.076 | -0.210 | -0.030 | -0.243 | **-0.777** | **-0.445** | **-0.433** | 0.344 |
| Health | -0.262 | 0.050 | 0.063 | -0.213 | -0.047 | -0.248 | **-0.749** | **-0.448** | **-0.416** | 0.311 |
| Education | 0.048 | 0.352 | 0.361 | 0.115 | 0.274 | 0.090 | **-0.717** | **-0.539** | -0.113 | **0.526** |
| Housing | 0.356 | **0.537** | **0.541** | **0.406** | **0.525** | **0.402** | -0.414 | -0.537 | 0.202 | **0.611** |
| Access | **-0.568** | **-0.701** | **-0.701** | **-0.601** | **-0.643** | **-0.609** | 0.288 | **0.516** | **-0.481** | **-0.549** |
| Child Poverty | -0.139 | 0.165 | 0.175 | -0.072 | 0.099 | -0.104 | **-0.726** | **-0.446** | -0.296 | **0.426** |

Figures in **bold** are significant (p = 0.05) while those underlined show the highest five correlation coefficients.

**Table 9** Correlation coefficients for the Greater Belfast area

(n = 164; critical r = 0.22) where p = 0.01

| **r** | $NO_2$ 1998 | $NO_2$ 2010b | $NO_2$ 2010wm | $PM_{10}$ 1998 | $PM_{10}$ 2010b | $PM_{10}$ 2010wm | $NO_2$ change (1998 – 2010b) | $NO_2$ change (2010b – 2010wm) | $PM_{10}$ change (1998 – 2010b) | $PM_{10}$ change (2010b – 2010wm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Overall Index Score | **0.499** | **0.502** | **0.509** | **0.517** | **0.515** | **0.511** | **0.323** | 0.155 | **0.518** | 0.036 |
| Income | **0.484** | **0.482** | **0.488** | **0.487** | **0.486** | **0.480** | **0.332** | 0.202 | **0.488** | 0.056 |
| Employment | **0.489** | **0.496** | **0.502** | **0.515** | **0.515** | **0.502** | **0.298** | 0.179 | **0.516** | 0.120 |
| Health | **0.587** | **0.592** | **0.596** | **0.583** | **0.581** | **0.582** | **0.372** | **0.308** | **0.584** | -0.021 |
| Education | **0.368** | **0.353** | **0.358** | **0.347** | **0.346** | **0.340** | **0.322** | 0.139 | **0.348** | 0.052 |
| Access | **-0.753** | **-0.758** | **-0.761** | **-0.801** | **-0.807** | **-0.780** | **-0.484** | **-0.479** | **-0.795** | **-0.269** |
| Social Environment | **0.469** | **0.474** | **0.477** | **0.468** | **0.466** | **0.466** | **0.287** | **0.273** | **0.470** | -0.001 |
| Housing | 0.204 | **0.233** | **0.240** | **0.298** | **0.297** | **0.282** | -0.006 | -0.043 | **0.299** | 0.152 |
| Child Poverty | **0.491** | **0.482** | **0.487** | **0.487** | **0.486** | **0.476** | **0.377** | 0.217 | **0.487** | 0.094 |

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