Environmental Quality and Social Deprivation Phase II: National Analysis of Flood Hazard, IPC Industries and Air

R&D Technical Report E2-067/1/PR2

Environmental Quality and Social Deprivation

Phase II: National Analysis of Flood Hazard, IPC Industries and Air Quality

R&D Project Record E2-067/1/PR2

Dr Gordon Walker, John Fairburn, Graham Smith, Dr Gordon Mitchell

Research Contractor
University of Staffordshire
University of Leeds

Publishing Organisation
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol BS32 4UD
Tel: 01454 624400 Fax: 01454 624409

ISBN 1 844322 246

Dissemination Status
Internal: Released to Regions
External: Publicly Available

Statement of Use
This Project Record contains national analysis of the relationship between social deprivation and flood hazard, IPC industries and air quality. The information contained in this document is intended to support policy development to help promote environmental equality.

Keywords:
Environmental quality, social exclusion, deprivation, equality, equity, environmental justice, flood, IPC, air quality.

Research Contractors

Dr Gordon Walker, John Fairburn and Graham Smith
Institute of Environmental and Sustainability Research
The School of Geography
The University of Staffordshire
Stoke on Trent, ST4 2DE

Dr Gordon Mitchell
The School of Geography and the Institute for Transport Studies
The University of Leeds
Leeds, West Yorkshire
LS2 9JT

Project Manger
The Environment Agency's Project Manager for Project E2-067/1 was Helen Chalmers, Social Policy Development Officer, Head Office, Bristol.

Further copies of this report are available from:
Environment Agency R&D Dissemination Centre, c/o
WRc, Frankland Road, Swindon, Wilts SN5 8YF

tel: 01793-865000 fax: 01793-514562 e-mail: publications@wrcplc.co.uk

ACKNOWLEDGEMENTS

We would like to thank Prof. Danny Dorling, of the School of Geography at the University of Leeds, for valuable discussions throughout the project.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS, NOTATION AND TERMS

ANOVA	Analysis of Variance
AQMA	Air Quality Management Area (NAQS)
BEN	Black Environmental Network
CO	Carbon monoxide
COMAH	Control of Major Accident Hazard
COMEAP	Committee of Medical Experts on Air Pollution (DoH)
CRI	Chemical Release Inventory
Decile	A tenth - in our analyses deciles are population weighted, and initially contain an equal share of national population
DEFRA	Department of the Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions
DoH	Department of Health
DVLA	Driver Vehicle Licensing Agency
DWI	Drinking Water Inspectorate
ED	Enumeration district
EJ	Environmental justice
EPA	Environmental Protection Agency (USA)
ESRC	Economic and Social Science Research Council
EU	European Union
FoE	Friends of the Earth
GIS	Geographic Information System
Gini IC	Gini Index of Concentration, a measure of equality within a distribution, calculated as the area between a Lorenz curve and a line of equal distribution.
GQA	General Quality Assessment (water quality)
HSE	Health and Safety Executive
IPC	Integrated Pollution Control
IMD	Index of Multiple Deprivation
Lorenz curve	The cumulative distribution of a variable
LULU	Locally unwanted land use (USA)
MAUP	Modifiable area unit problem
mg/m^3	Milligrams per cubic metre
NAQS	National Air Quality Strategy
NETCEN	National Environmental Technology Centre

NHEXAS	National human exposure assessment study (USA)
NO_X	Nitrogen oxides
NO_2	Nitrogen dioxide
NPL	National Priority List (of USA contaminated 'superfund' sites)
NRU	Neighbourhood renewal unit (Office of Deputy Prime Minister)
NGO	Non-governmental organisation
ONS	Office of National Statistics
PM_{10}	Particles less than 10 microns in diameter
$PM_{2.5}$	Particles less than 2.5 microns in diameter
Quintile	A fifth - (see also decile)
SDC	Sustainable Development Commission
SEPA	Scottish Environmental Protection Agency
SFVI	Social Flood Vulnerability Index
SME	Small and medium sized enterprises
SO_2	Sulphur dioxide
SURPOP	Surface population (modelling)
STW	Sewage treatment works
TRI	Toxic Release Inventory (USA). See also CRI
TSDF	Transfer, storage and disposal facilities (USA)
ug/m^3	Micrograms per cubic metre

1 INTRODUCTION

1.1 Aims and Objectives

This report describes work completed under Environment Agency R&D Project E2-067/1 on Environmental Quality and Social Deprivation Data Analysis. The aim of the research was to 'improve the Environment Agency's understanding of the relationship between environmental quality and social deprivation in order to inform the Environment Agency's policy position on environmental quality'. The objectives of the study were to:

1. Evaluate existing data and research for the relationship between environmental quality – with particularly reference to the Agency's environmental priorities (e.g. air and water quality, flooding) and social deprivation (as measured by the Index of Multiple Deprivation);

2. Identify gaps in the current evidence base, which restrict the development of an Agency policy on environmental equality;

3. Critically appraise the existing methodology used by the Environment Agency to explore the extent to which environmental conditions vary across socially deprived wards (as identified by the Index of Multiple Deprivation);

4. Identify the value of, and priorities for, more detailed quantitative analysis of environmental data sets and propose appropriate methodologies for conducting this analysis;

5. Conduct statistical analysis of data sets associated with areas for which the Environment Agency has regulatory responsibility and those relating to deprivation; and

6. Make appropriate recommendations for Agency policy responses and further research.

The first four objectives are addressed in the Phase I Project Record (Mitchell and Walker, 2003a), whilst the latter two objectives are addressed in this Phase II Project Record. A technical summary of the full project is also available.

1.2 Report Structure

Chapter 1 of the report (this chapter) describes the aims and objectives of the project, and the report structure. The context for the analysis is outlined, including the process by which the three theme areas of flooding, IPC sites and air quality were selected for detailed analysis. Aspects of the methodology common to these theme areas are also described.

Chapter 2 describes the results of, and specific recommendations arising from, the analysis of the relationship between social deprivation and coastal and fluvial flood risk.

Chapter 3 describes the results of, and specific recommendations arising from, the analysis of the relationship between social deprivation and Integrated Pollution Control sites.

Chapter 4 describes the results of, and specific recommendations arising from, the analysis of the relationship between social deprivation and air quality.

Chapter 5 presents our overall conclusions, and our general recommendations for development of Environment Agency policy and practice to address environmental inequality in England and Wales. Further research needs are also identified.

1.3 Selection of Issues and Scope of Analysis

The outcome of the stakeholder workshop held on 3 April 2003 (Chalmers 2003) was to recommend that we focus the Phase II data analysis on a few environmental equity issues, studied in depth, rather than attempt to analyse a broader range of issues more superficially. Three specific issues were identified as particularly relevant to the remit of the Agency and most appropriate for analysis within this project:

- Flood hazard;
- Integrated Pollution Control sites; and
- Air quality.

Whilst limited to only three issues, the analysis we have undertaken incorporates at least elements of seven of the nine high priority issues we identified prior to the workshop in our Phase I report (Mitchell and Walker 2003). Our air quality analysis covers both concentrations and exceedences, and the IPC analysis includes indicators relevant to incidents, Agency enforcement and inspection priorities.

For each of these analyses, we used a common approach to spatially link environmental data to social deprivation data. In all cases we have used the ward level Index of Multiple Deprivation (IMD 2000) (DETR 2000a) as the social variable, as specified in the tender document. As the IMD for England is constructed on a different basis from that for Wales (see 1.3), all of the analyses have been undertaken separately for the two areas. The scope of the analysis undertaken for each environmental issue is as follows:

(a) Flood Hazard

Indicative floodplain maps produced by the Agency have been used to relate flood hazard to ward deprivation data. The maps show 1 in 100 year peak water level return periods for rivers and 1 in 200 year floods for coasts or the highest known water level. A sophisticated method has been used to ensure that only the population within wards that is also within the indicative flood area is counted within the analysis. Many wards will have rivers running through their area but no people resident within the indicative flood hazard area, particularly in rural wards. Results are reported that show the percentage of population for each deprivation decile that lives within indicative flood hazard areas.

(b) IPC Sites

The spatial distribution of IPC sites has been evaluated against deprivation using two methods – 'spatial coincidence' which counts the number of sites with grid references falling within wards, and 'population proximity' where the population within a buffer drawn around each site form the basis of the analysis. As well as counting sites we have also used data on number of authorised processes and emission sources at each site. In addition, we have introduced differentiation into the analysis by examining deprivation characteristics within different industrial sectors; for emissions to air alone; for specific substances (NO_2, PM_{10}); groups of substances (carcinogens); and for authorisations approved at different dates. Finally, the Agency Operator Pollution and Risk Appraisal (OPRA) scores for authorised processes have also been used to take account of the level of pollution hazard from each process and the performance of site operators.

(c) Air Quality

Five variables have been analysed using 2001 annual mean concentration data available on a 1km^2 grid: NO_2, PM_{10}, SO_2, CO and benzene. Two of these variables NO_2 and PM_{10} have also been analysed for predicted levels in 2010, in order to assess how the expected changes in concentration differentially affect more or less deprived groups. As well as analysing annual mean concentrations we have conducted separate analyses of exceedences of standards. In addition to single pollutant analyses we have attempted to identify the cumulative inequity pattern through application of an air quality index.

Each of the analyses we have undertaken in these three theme areas inevitably has limitations arising from the quality and resolution of source data sets, the spatial scale at which analysis has been undertaken and the complexity of real world environmental variables which can only partially be captured. We have undertaken an environmental equity analysis which is more advanced methodologically than any existing work in the UK and on a par with the better quality research undertaken in the US. However, in the discussion that follows we have also been fully open about the limitations of analysis and, where necessary, cautious with the conclusions that can reasonably be made.

1.4 Methodological Approach

As discussed in the Phase I Project Record (Mitchell and Walker 2003), the methodological issues raised by environmental equity and justice studies are numerous and involved. As the three environmental issues that we focus on in our data analysis are distinct in terms of the form of data utilised and spatial characteristics, the methods utilised for each part of the analysis are discussed separately. However, there are aspects to the methodology, related to the use of social data, that apply across all of the analysis. These are described below.

1.4.1 Ward Population and Deprivation Data

The spatial unit of analysis used for social data is the census ward, of which there are 8,414 wards in England and 865 in Wales. Wards are designed to contain roughly equal numbers of electors within local authority districts, thus ward size is density dependent, with small wards in urban centres and large wards in rural areas.

Deprivation was represented using the Index of Multiple Deprivation 2000 (IMD 2000) (DETR 2000a). This has become the most widely used official data set on deprivation and was identified in the project tender document as the indicator that the Agency wished us to use. The IMD is based on six separate domains (income, employment, health deprivation and disability, education, skills and training, housing and geographical access to services), addressed by 33 separate indicators. The physical environment is also considered an important element of deprivation, and there is widespread support for a physical environment domain addressing issues such as air, water and land quality in a future index. Note however, that the physical environment is not represented in the IMD 2000, and hence there is no danger of auto-correlation in the environmental equity analysis.

For each ward a score is produced for each indicator and then domain, and domain scores are standardised to a uniform metric by ranking, and by applying an exponential transformation. Individual domain scores are then weighted and summed to create an overall score, which forms the basis for the final ranking of wards by deprivation (DETR 2000a). This procedure ensures that bias in the identification of deprivation is minimised as far as possible. Note, however, that because of the method of calculation, a ward with an IMD rank of 100 is not necessarily twice as deprived as a ward with a rank of 200.

Given the nature of the IMD, we uniformly present the deprivation data in this project in the form of deciles which maintain the ranked ordinal form of the data. The IMD calculation method also precludes combination of the IMD 2000 data sets for England and Wales, which were derived separately. An index value for a ward in Wales can not be taken as equivalent to the same index value for England, hence throughout the analysis we have considered Wales and England separately.

A number of the data processing tasks required the use of ward population data. We obtained our population data from the Neighbourhood Statistics Branch of the Office for National Statistics. The data are mid-1998 estimates for wards in England and Wales, produced by the Social Disadvantage Research Group of Oxford University. The data relate to ward boundaries as of 1st April 1998, and are rounded to the nearest 100. The data are not official ONS population estimates, but were developed to act as denominators for Neighbourhood Statistics, including the DETR IMD 2000. The data are controlled to ONS Local Authority District estimates for 1998, and are preferred to 1991 census observations, as much of our environmental data addresses more recent years (e.g. air quality data is for 2001). Observed data from the 2001 census data were not available at the time of writing.

1.4.2 Creation of ward deprivation deciles

In order to create ward deprivation deciles, data were first ranked in terms of deprivation, and the ranked wards placed into deciles of equal population (within 0.2% for England, and 2.7 % for Wales) see Tables 1.1 and 1.2. Deciles of equal population are preferred to those of equal ward count as the analysis then gives a population based, not area based distribution of pollution, which is more meaningful for the purposes of equity analysis. In all cases, decile 1 is the most deprived and decile 10 the least deprived.

It is important to understand exactly what these deciles represent. Essentially, decile 1 has the largest *concentration* of deprived people, while decile 10 has the smallest concentration of deprived people. Population weighted deprivation deciles of this form are often referred to using shorthand terminology but their precise definition needs to be remembered: in this way decile 1 is not the 'poorest 10 % of the population', as some of the poorest people will live in pockets within wards that are less deprived overall, nor is it 'the most 10 % deprived wards', as a population weighting has been applied.

Table 1.1: Population weighted deprivation deciles for wards in England

Decile	Population Range (cumulative ward pop.)	Ward Count	IMD Ranks	Median IMD Rank
1	0 – 4,943,000	540	1 - 541	271
2	4,955,000 – 9,897,400	574	542 - 1116	829
3	9,907,200 – 14,837,400	647	1117 - 1764	1441
4	14,860,200 – 19,783,800	741	1765 - 2506	2136
5	19,797,600 – 24,739,300	811	2507 - 3318	2913
6	24,744,500 – 29,686,200	929	3319 - 4248	3784
7	29,695,400 – 34,630,500	994	4249 - 5243	4746
8	34,644,600 – 39,585,900	1082	5244 - 6326	5785
9	39,613,500 – 44,537,400	1109	6327 - 7436	6882
10	44,542,900 – 49,497,000	977	7437 - 8414	7926

Table 1.2: Population weighted deprivation deciles for wards in Wales

Decile	Population Range (cumulative ward pop.)	Ward Count	IMD Ranks	Median IMD Rank
1	0 - 295,756	66	1 to 66	34
2	300,400 - 599,317	71	67 to 137	102
3	605,444 - 899,686	81	138 to 218	178
4	902,768 - 1,199,047	88	219 to 306	263
5	1,209,018 - 1,499,475	87	307 to 393	350
6	1,504,098 - 1,800,586	111	394 to 504	449
7	1,802,408 - 2,099,720	111	505 to 615	560
8	2,103,587 - 2,399,454	105	616 to 720	668
9	2,401,943 - 2,693,588	79	721 to 799	760
10	2,702,386 - 3,001,829	66	800 to 865	833

It follows that the population within a ward and within a decile will vary in their characteristics; the index of deprivation provides an indicator of deprivation across a spatial area, not a precise measure of the deprivation level of everyone living within that ward. This is a general and inevitable limitation in area based rather than individual data often referred to as the 'ecological fallacy' (see section 4.5.1 of Mitchell and Walker 2003), which requires a caveat to be placed on the analysis undertaken in such analyses.

This limitation is particularly relevant to methods used to characterise populations within flood hazard areas or IPC site buffers, where population counts are accurate, but where deprivation characteristics reflect the deprivation score for the ward (see section 2.2), which may not be the same.

1.4.3 Statistical analysis

There are no standard empirical methodologies for investigating environmental equity issues, and techniques used range from visual comparison of mapped data (Stevenson *et al*. 1998, 1999; Pennycook *et al.* 2001), to simple statistical tests (bivariate correlation, t-test, Chi-squared: see examples in Bowen, 2002), and multivariate regression (McLeod *et al.* 2000, Jerrett *et al.* 2001; Brainard *et al.* 2002).

Bowens (2002) review of the US environmental equity literature reveals that many of the more sophisticated analyses have not allowed firm conclusions to be drawn, due to a lack of rigour. In particular, highly significant regression equations are often cited, but with very low r^2 values. Although not a reason to reject a model, this is indicative of much unexplained variance, and a need for further tests for omitted variables and incorrect functional forms. Bowen (2002) cites Kriesel *et al.* (1996), for example, showed race to be a significant variable in explaining environmental risk in Georgia and Ohio when race and poverty were the only variables entered into a regression model, but not when a broader range of variables on education, transport and industrial location were included.

We chose not to conduct regression modelling, given the necessity to gather data on a very wide range of possible explanatory variables, at ward level for the nation. This is the basis of a causality study, and is beyond the scope of this scoping project. Rather, we chose to apply bivariate descriptive statistics. Of these we considered, but rejected correlation, which is a widely used technique for equity analysis. Parametric correlation (e.g. product-moment) was rejected as the Index of Multiple Deprivation data is ranked, and ordinal data cannot be used with parametric tests. Non-parametric correlation (e.g. Spearman Rank) is a valid technique, but we made little use of this test for three reasons.

Firstly, from previous experience we suspected that the relationship between deprivation and air quality was not linear. Preliminary visual inspection of the data confirmed this, and suggested that no simple transformation would render the data linear and hence suitable to correlation. Secondly, we note that for non-parametric correlation, both data sets must be in rank order (i.e. air quality data must also be ranked). With two such large data sets, we inevitably find that many matched pairs of observations are tied, that is, there are many common air quality values which are then given the same rank. Tied observations can be addressed (although a very laborious process with so many observations), but we did not do so because of the obvious non-linearity in the data. In order to maintain consistency of approach between flood, IPC and air quality analysis, we felt it better not to conduct correlation for the IPC and flood analysis. Finally, however, we note that non-parametric correlation is a generally weak test and that other more descriptive tests were preferable. Thus we based our analysis upon simple descriptive statistics, including the Gini Index of Concentration (see below).

Note that we have not conducted more sophisticated significance tests, such as bivariate testing of differences in means by deprivation decile. Such inferential statistics (e.g. Z-tests on means, or ANOVA between deciles) are predicated upon assessing whether population means differ between groups (deciles in this case) based upon samples of the population. For our analysis, we were in the unusual, but fortunate position of having access to the entire population data, There is therefore no necessity to conduct difference tests as we are able to draw conclusions based on the population means, rather than make inferences about those means based upon samples of the population. Our analysis was therefore simple, but powerful. Note that in addressing the entire country, we avoid the difficulties of selecting appropriate comparison areas.

We have for some of our analysis calculated Gini Concentration Index (CI) values to provide a comparative statistical indicator of inequality. The CI is closely related to the simpler Gini coefficient which has been widely adopted as a measure of income and health inequalities (Wagstaff *et al*. 1991) and also recently applied to environmental equity research (Lejano *et al*. 2002). To calculate a Gini coefficient, data are plotted as a Lorenz curve (cumulative distribution) and the area between the curve and a line of equal distribution calculated by integration.

Whereas a Gini coefficient is used to calculate the distribution of a variable across a constant unit (e.g. income by population), Gini CI values are used to investigate the distribution of a variable with respect to a second, usually socio-economic, variable (e.g. disease by socio-economic status). A modified form of the Gini calculation method is used, in which CI values range from 1 to -1. A value of zero indicates complete equality (e.g. in our application the proportion of the population within a floodplain area would be identical for all deprivation deciles) whilst values of 1 and -1 indicate extreme inequality in positive or negative relationships with deprivation.

The CI does not provide an indicator of the *significance* of inequality which will always be an ethical and political judgement and is best used in a comparative setting (see e.g. the comparison of current and future air quality in section 4). It is useful to note however that values for income inequality in the UK over the period from 1979 to 2001 have ranged from 0.25 to 0.35 (Shephard 2003). Gini values for income inequality in the USA, by comparison, are currently around 0.45.

Each of the analyses we have undertaken inevitably have limitations arising from the quality and resolution of source data sets, the spatial scale at which analysis has been undertaken and the complexity of real world environmental variables which can only partially be captured. We have undertaken an environmental equity analysis which is as advanced methodologically as any existing national scale work in the UK and, we believe, on a par with the better quality research undertaken in the USA (although we note that national scale analyses are absent in the USA). However, in the discussion that follows we have sought to be fully open about the limitations of analysis and, where necessary, cautious with the conclusions that can be reasonably be made.

2 FLOOD HAZARD

2.1 Introduction

Flooding is a key area of responsibility for the Environment Agency which has a statutory responsibility under the 1991 Water Resources Act to identify areas that are at risk from flooding. Recent flood events, for example of Easter 1998, have highlighted the need for the improved management of flood hazard, including the control of new development on floodplains and enhanced systems for warning and preparing the public. The likely impacts of climate change on the frequency and severity of floods and the potential for coastal flooding through sea level rise provide an overarching context for current Agency policy and action on flooding.

As discussed in Part 1 of the Project Record (Mitchell and Walker 2003), we were able to identify few existing studies examining flood hazard from an equity perspective. The need to incorporate social vulnerability into the hazard appraisal process has been increasingly recognised and a number of exploratory steps have been taken in the UK to develop social vulnerability maps incorporating a range of demographic and social variables (Tapsell *et al*. 2002). However, to our knowledge, no research has been conducted that specifically assesses the demographic characteristics of populations within UK flood hazard areas from an equity perspective. Our analysis will therefore provide the first view of the overall pattern of social distribution of flood hazard.

Our objectives in undertaking the equity analysis for flood hazard are to:

- provide coverage of England and Wales (although for reasons discussed in section 1.4.1 separate analyses have to be undertaken);
- analyse fluvial and tidal flooding separately;
- use a method which provides a good estimation of the population living within the floodplain outlines provided by the Agency.

2.2 Data Sources and Methods

2.2.1 Data Sources

The key source of data used in the flood hazard analysis, in addition to the ward deprivation and population data discussed in section 1.4.1 was the Indicative Floodplain Map (IFM). This was made publicly available by the Agency in 2000 (through access over the Internet) but was produced out of a process initiated in 1994 by the then National Rivers Authority. A £25 million programme of floodplain mapping was initiated across England and Wales to meet the requirement of land use planning guidance, particularly focusing on 821 hotspot locations where land use development pressures were most acute. By 2000 the programme of mapping was not complete but there was strong pressure to produce a national map even in a relatively unrefined state. To produce the map at this point in time a number of sources of data were combined – work carried out in hotspot areas, historical records of floods that had occurred and a study carried out by the Institute of Hydrology using a flood estimation model.

The IFM shows 1 in 100 year peak water level return periods for rivers and 1 in 200 year floods for coasts or the highest known water level. The map is currently updated to reflect improved local knowledge on an annual basis. Our analysis made use of the map current as of May 2003. Whilst the best publicly available floodplain map for England and Wales, it has a number of key limitations:

- most crucially, it takes no account of flood defences and therefore presents a precautionary view of the area potentially at risk from flooding; and

- the data produced from the Institute of Hydrology flood estimation model is very coarse and where this has been used it produces a blocky, rasterised outline for the floodplain area.

Because of these limitations, our analysis can only provide an indication of the deprivation characteristics of those people living in areas potentially at risk from flooding. The floodplain outlines indicate where flooding from rivers, streams, watercourses or the sea is possible, but do not provide an indication of the level of risk (which will be higher in undefended low-lying areas near rivers or the sea and lower in areas where flood defences offer some protection) or the hazard which is dependent on factors such as velocity and depth of flow.

A strategy for upgrading the quality of flood maps available for England and Wales has been developed by the Agency and substantial changes are to be seen over the next two years. Whilst our project has been unable to make use of the new mapping products being developed, they are relevant to the policy implications arising from our analysis (see section 2.6).

2.2.2 Estimating the population within the floodplain

The one aspect of the flood hazard equity analysis which requires detailed explanation is the process by which we derived the deprivation characteristics of people living within the floodplain area delineated by the IFM. When calculating the population living within a floodplain (or within the buffer of an IPC site; see section 3.2.2) it is not sufficient to simply use the overall ward population that the floodplain falls within. The floodplain will typically only occupy a small part of a ward and it is quite often the case that no people actually live within this area - particularly in large rural wards where floodplains cover only agricultural land. If we simply took the deprivation characteristics of any ward that a floodplain happened to cross into, we would therefore be assigning a flood hazard to people that didn’t exist (flood hazard being a combination of an elevated water level *and* the vulnerability of people living within the floodplain area).

The solution we identified to this problem was to use unit postcode centroids (points) and associated house counts to identify the spread of population across a ward. This is superior to other methods often used in equity studies such as calculating the proportion of the ward area that is occupied by the floodplain and using this to estimate the proportion of the population. This latter method assumes that the ward population is evenly distributed across the entire ward area which is grossly inappropriate for many large wards.

Unit postcodes have a typical size of 15 to 20 delivery points (addresses) and through using Codepoint data we are able to calculate the number of these delivery points which are private households. Using this data to assign a population to the postcode resolves two issues. It takes account of the variation in size between the postcodes within a ward and ensures that commercial postcodes are discounted. Figure 2.1 gives an example of a pattern of unit postcode points in relation to ward boundaries and the indicative flood map area. Using Codepoint data does not provide a perfect distribution of the population in a ward, as postcode unit areas vary in shape and some of the records on the nature of each delivery point (domestic or commercial) are recognised as being of low quality. However, for the purposes of our analysis it provides a good estimation of the proportion of the residential population within a ward that is within and outside of the floodplain.

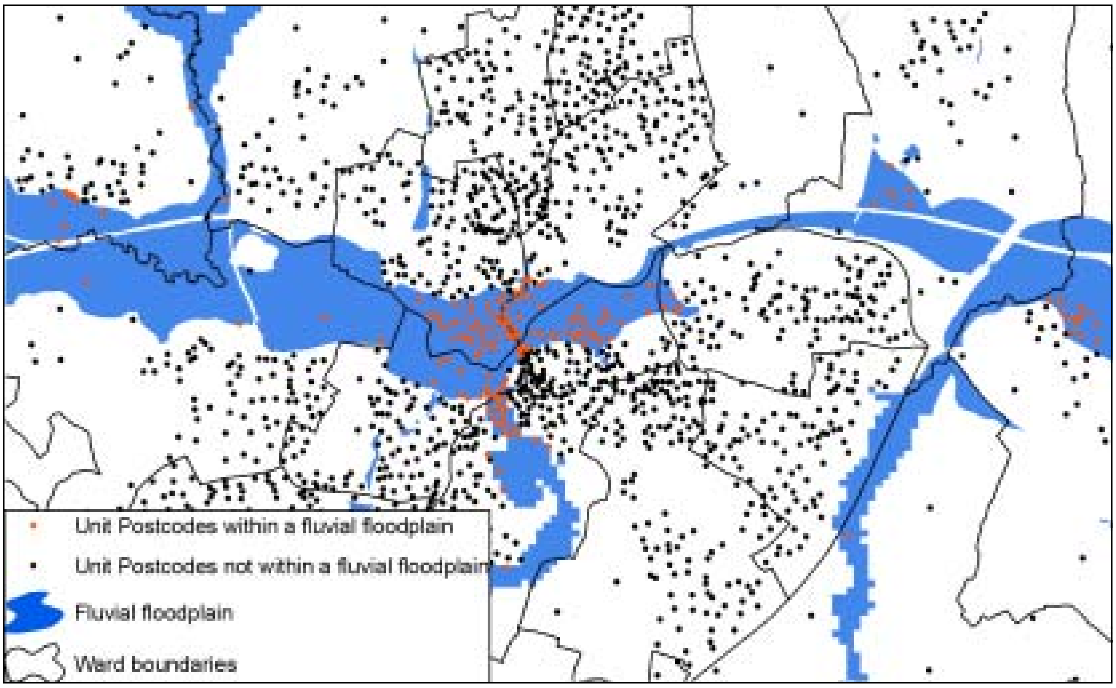


Figure 2.1: Postcode unit distribution within and outside a fluvial floodplain

The process we followed to estimate the population within the flood area involved first calculating the average number of residents per address within each individual ward. Next, the total number of residents for each individual postcode is assigned as well as the decile into which the individual postcode falls.

The indicative floodplain maps can be used to determine which unit postcodes within a ward are located on a floodplain. Using the populations assigned to the unit postcodes, the population of the ward within a floodplain can now be estimated and resulting summary data produced.

This method also provides a good estimation of the proportion of the population of each ward (and therefore each deprivation decile) that lives within floodplain areas. Whilst therefore improving the spatial distribution of population it is important to note that it *cannot* provide a more detailed picture of the deprivation characteristics of that population. It is necessary to assume that all people within the ward share the same deprivation characteristics, even though in practice these may vary considerably from one part of the ward to another. This problem, known as the '*ecological fallacy*', can only be addressed by using smaller scale spatial units. In the context of this project this option was not available and thus the limitations of using ward-level deprivation data have to be accepted.

2.3 Flood Hazard and Deprivation in England

The estimated population from wards in the ten deprivation deciles and living within IFM floodplain area is shown in Table 2.1. Whilst seemingly precise population figures are given it is important to remember that these are estimates and that of most significance are the *relative* proportions of population in and outside of the floodplain between the ten deciles.

Table 2.1: Population (total, percent) living in a floodplain by population weighted ward deprivation decile for England.

Decile	**Total Population**	**Population Living in a Floodplain**	**Percentage of Population Living in a Floodplain**
1	4,943,800	478,448	13.5
2	4,953,600	459,790	13.0
3	4,940,000	371,445	10.5
4	4,947,900	463,358	13.1
5	4,948,200	416,489	11.7
6	4,952,700	330,433	9.3
7	4,938,400	313,600	8.8
8	4,955,400	256,501	7.2
9	4,951,500	239,702	6.8
10	4,959,600	216,390	6.1
England	49,491,100	3,546,154	100

At first sight, and as shown in Figure 2.2 there appears to be a general relationship between deprivation and the proportion of the population in wards in each decile living within a floodplain. Of the population living in a floodplain 13.5 % are in the most deprived decile, compared to 6.1 % in the least deprived decile, and the concentration index value of 0.14 indicates a weak bias towards the deprived deciles.

However, when the data is disaggregated into fluvial and tidal floodplain populations (Table 2.2) it becomes clear that the overall relationship with deprivation observed in the aggregated data is coming entirely from the tidal floodplain element.

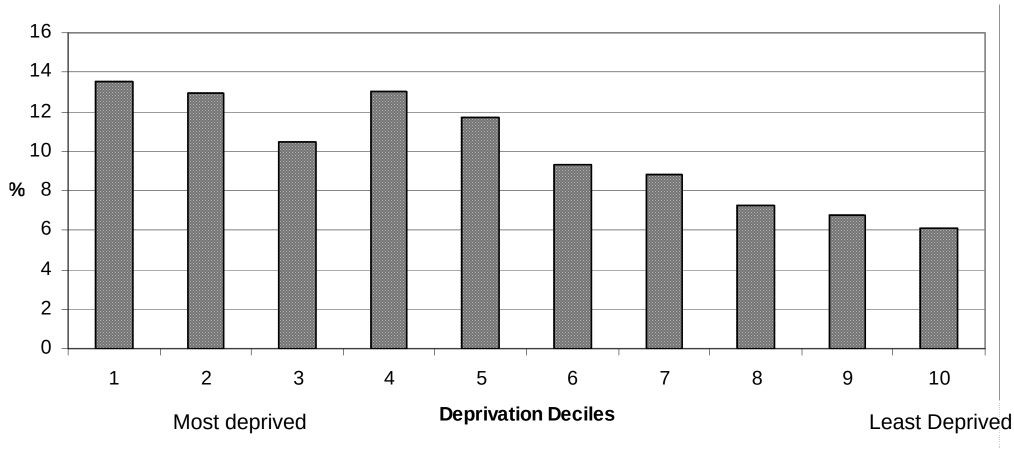


Figure 2.2: Percentage of population living in a floodplain by population weighted ward deprivation decile for England (Concentration Index = 0.14)

Table 2.2: Total and percentage population living in fluvial and tidal floodplains by population weighted ward deprivation decile for England

Decile	Population Living in a Fluvial Floodplain	%	Population Living in a Tidal Floodplain	%	Population Living in a Fluvial and Tidal Floodplain	%
1	104,052	6.9	380,814	18.4	6,418	22.2
2	94,005	6.2	366,280	17.7	494	1.7
3	107,014	7.1	264,886	12.8	456	1.6
4	137,175	9.1	330,439	16.0	4,256	14.7
5	174,574	11.6	253,287	12.3	11,372	39.4
6	177,222	11.7	155,643	7.5	2,432	8.4
7	183,567	12.2	133,278	6.4	3,246	11.2
8	192,831	12.8	63,669	3.1	0	0.0
9	166,326	11.0	73,376	3.6	0	0.0
10	171,550	11.4	45,055	2.2	215	0.7
	1,508,315	100	2,066,727	100	28,888	100

For the tidal floodplain (Figure 2.3) there is a clear relationship with deprivation with a more marked tailing off in the least deprived deciles. Of the population living within the tidal floodplain, 18.4 % are in the most deprived decile compared to only 2.2 % in the least deprived. The proportion of the population in the floodplain in the most deprived decile is eight times that of the least deprived decile, and the CI value of 0.33 indicates a substantial inequality.

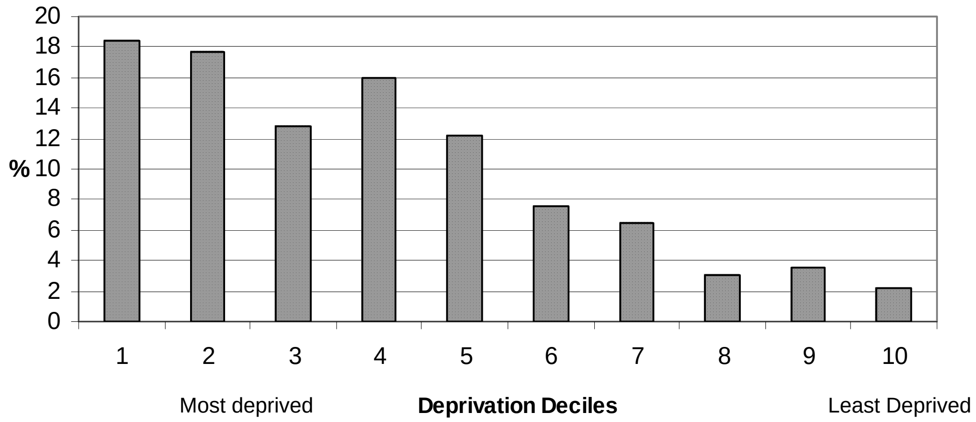


Figure 2.3: Percentage of population living in a tidal floodplain by population weighted ward deprivation decile for England. (Concentration Index = 0.33)

In contrast, for the fluvial floodplain (Figure 2.4) there is an inverse relationship with deprivation, although of lesser strength (CI value of -0.11), with a higher proportion of the population within the floodplain in the less deprived compared to the more deprived deciles. Comparing quintiles, 13 % of the population within a fluvial floodplain comes from the 20 % most deprived wards, compared to 22 % from the 20 % least deprived.

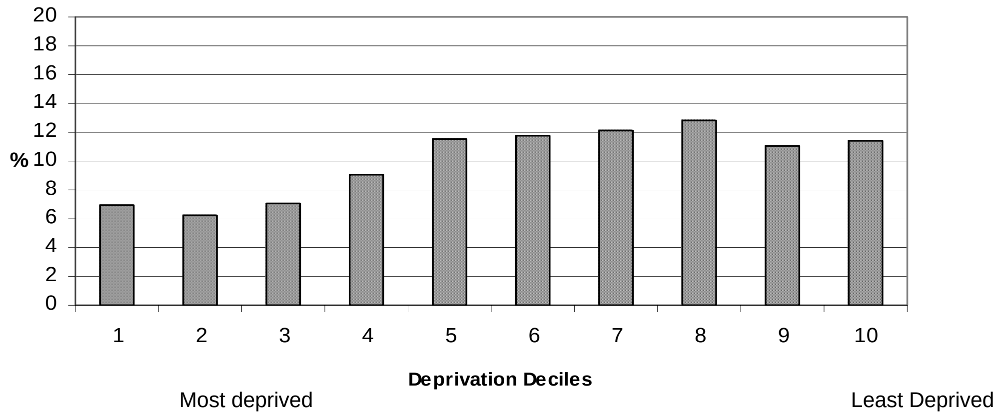


Figure 2.4: Percentage of population living in a fluvial floodplain by population weighted ward deprivation decile for England. (Concentration Index = -0.11)

2.4 Flood Hazard and Deprivation in Wales

The pattern of social distribution of floodplain populations in Wales is less distinct but shows some similarities to England (Table 2.4, Figure 2.5). The overall floodplain population is most concentrated into deciles 3 and 5. Comparing quintiles, the most deprived 20 % have 17.9 % of population within the overall floodplain compared to 7.9% in the least deprived decile, indicating a bias towards deprived wards. The CI value of 0.15 is similar to that for England but the focus of the disparity is less orientated towards the *most* deprived deciles.

Table 2.3: Total and percentage population living in fluvial and tidal floodplains by population weighted ward deprivation deciles for Wales

Decile	Total Pop.	Population Living in a Floodplain	%	Population Living in a Fluvial Floodplain	%	Population Living in a Tidal Floodplain	%
1	295,756	24,724	11.0	8,500	7.3	16,224	14.9
2	303,561	15,660	6.9	7,784	6.7	7,876	7.2
3	300,369	37,084	16.5	27,290	23.4	9,795	9.0
4	299,361	26,475	11.7	8,278	7.1	18,197	16.7
5	300,428	49,985	22.2	19,184	16.5	30,801	28.3
6	301,111	19,015	8.4	11,560	9.9	7,455	6.8
7	299,134	13,604	6.0	6,824	5.9	6,780	6.2
8	299,734	20,914	9.3	14,991	12.9	5,923	5.4
9	294,134	8,765	3.9	4,685	4.0	4,080	3.7
10	308,241	9,111	4.0	7,323	6.3	1,788	1.6
Wales	3,001,829	225,337	100	116,418	100	108,919	100

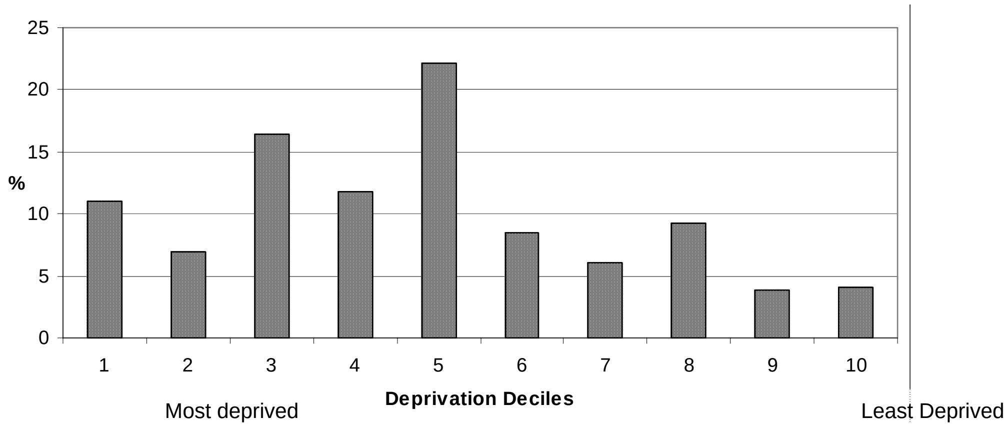


Figure 2.5: Percentage of population living in a floodplain by population weighted ward deprivation decile for Wales (Concentration Index = 0.15)

After disaggregation into fluvial and tidal areas the patterns against deprivation (Figures 2.6 and 2.7) become complex. For fluvial floodplains there are peaks in deciles 3 and 5 whilst the proportions in the least deprived and most deprived deciles are very similar. The CI value of 0.09 indicates a low comparative level of inequality, but no overall bias towards the less deprived deciles as in England. For tidal floodplains there is a peak in decile 5, but the proportion in the most deprived decile (14.9 %) is much higher than in the least deprived (1.6 %). The balance of disparity is towards the more deprived deciles (1-5) although the CI value of 0.21 is not as strong as for England.

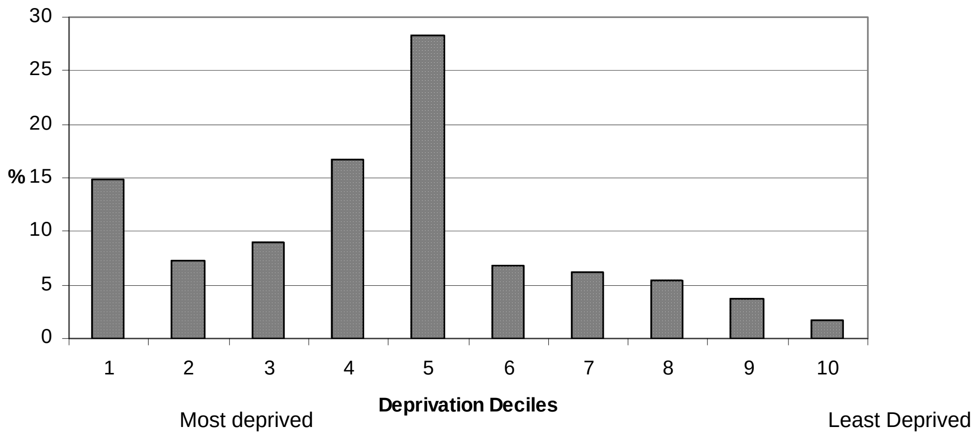


Figure 2.6: Percentage of population living in a tidal floodplain by population weighted ward deprivation decile for Wales. (Concentration Index = 0.21)

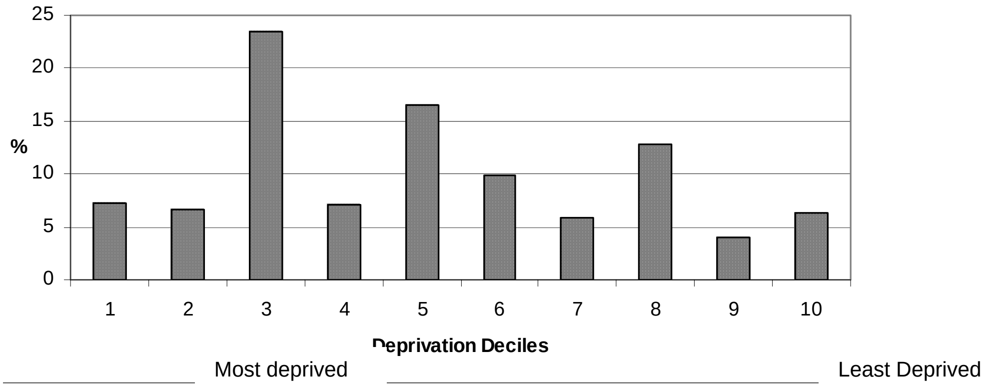


Figure 2.7: Percentage of population living in a fluvial floodplain by population weighted ward deprivation decile for Wales. (Concentration index = 0.09)

2.5 Discussion of Flood Hazard Equity Analysis

The social equity patterns revealed in the data for England and Wales are in part predictable and in part more surprising. That fluvial floodplain populations show some weak bias for England towards the more affluent deciles is to be expected given that much of the floodplain area is rural rather than urban in character and rural wards are generally more affluent than urban wards. Riverside locations generally also have a premium value in terms of property prices - although this very local social patterning is unlikely to be picked up in ward level data, and may serve on the ground to further accentuate the proportion of the better-off population living within fluvial floodplains.

The strong relationship between deprivation and location in tidal floodplains for England, and weaker for Wales, is less expected and does not have an immediately obvious explanation. Examining the pattern of distribution of the most deprived quintile (deciles 1 and 2) for England shown in Figure 2.8 the populated poor areas potentially at risk are focused on London and the Thames Estuary, Hull and the Humberhead Levels, the Lincolnshire coast and Teesside; with further pockets in South

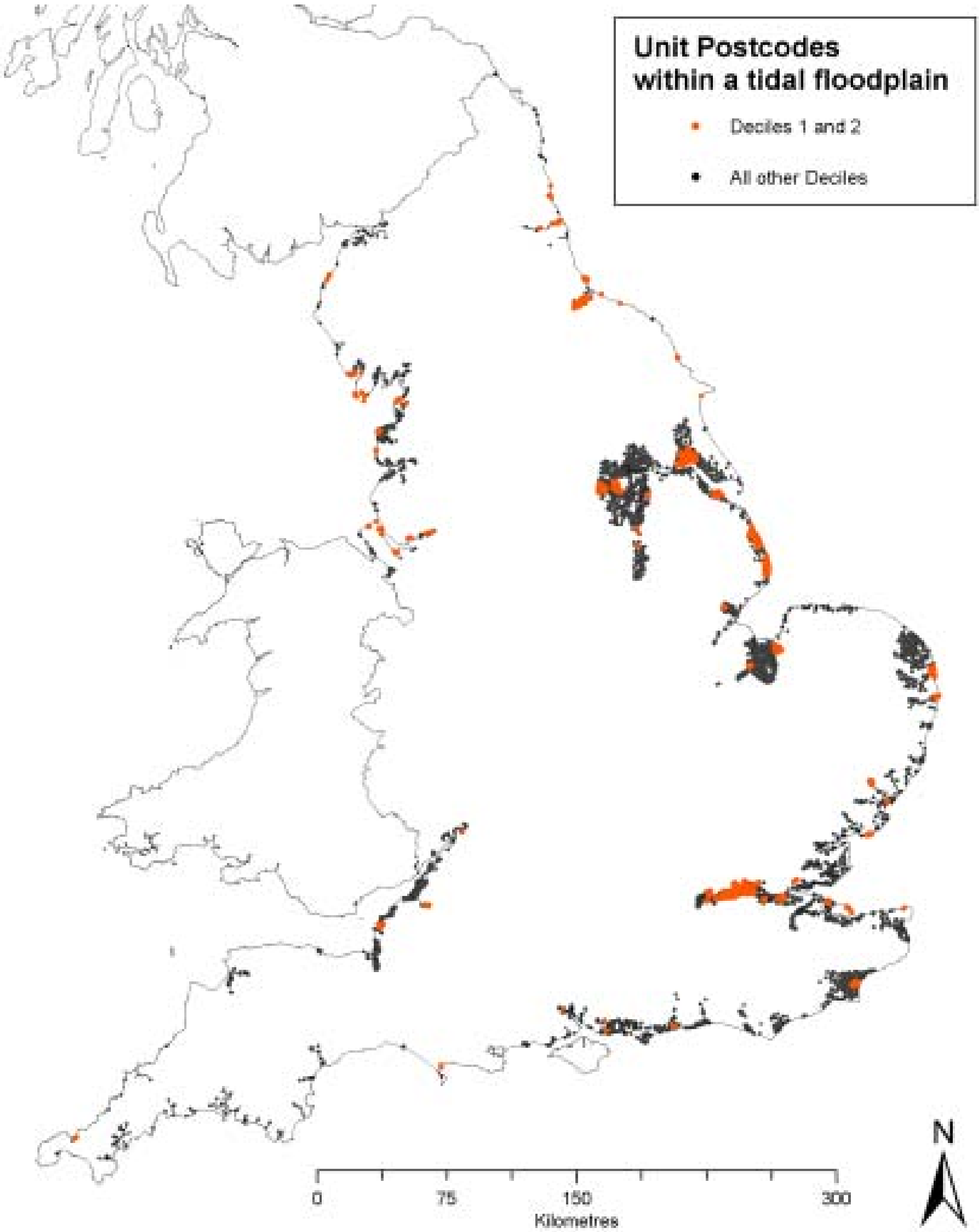


Figure 2.8: Areas within the Tidal Floodplain for England highlighting wards in deciles 1 and 2

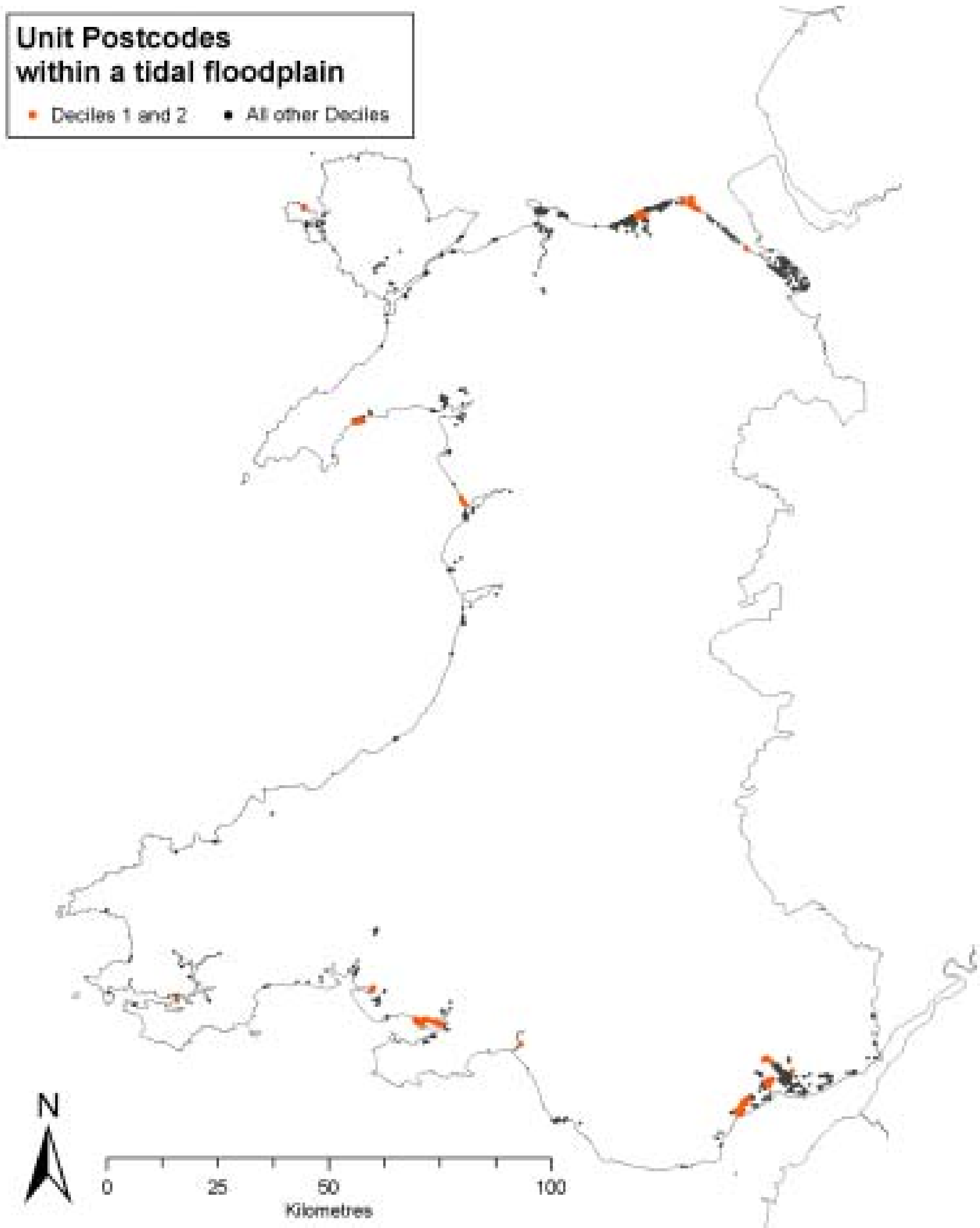


Figure 2.9: Areas within the Tidal Floodplain for Wales highlighting wards in deciles 1 and 2

Kent, various locations along the North West coastline and Tyneside. A regional breakdown of the population within this quintile particularly highlights the size of the population at risk in London and the Thames Estuary. Of the 747,000 estimated people living within the tidal floodplain in the most deprived 20 % of wards, 438,000 (59 %) are in the Agency Thames region, followed by the North East region at 134,000 (18 %) and the Anglian region at 117,000 (16 %).

For Wales (Figure 2.9) the most significant populations within deciles 1 and 2 are located in Cardiff extending northwards, near to Llanelli, various locations along the North Wales coastline and north of Deeside, Barmouth and Pwllheli.

An important caveat on our analysis stems from the limitations of the Indicative Floodplain Map used for the floodplain outlines (discussed in section 2.2). Most importantly this does not take into account flood defences which will clearly have a strongly differential impact on the flood risk in different areas.

2.6 Recommendations

The analysis we have undertaken provides a first broad view of national patterns of floodplain outlines against social deprivation. It has been produced at a time when there are significant changes taking place in the Agency's approach to both flood mapping and flood management, many of which are recognising the social vulnerability dimensions of flood hazard. In this evolving context we can point to four recommendations for Agency action arising from our analysis:

1. Over the next few years significantly more precise and complex flood mapping products are to be released by the Agency, differentiating flood potential, from flood hazard and risk within a GIS environment that includes relatively detailed postcode based information. The first major step in this direction is expected to be realised in March 2004. Such maps will provide the opportunity to build on the initial analysis we have undertaken to explore whether or not the patterns of association with deprivation are maintained when additional flood-estimation variables are added into the mapping process. It may be, for example, that when the *risk* of being flooded is estimated and mapped, the pattern of coastal flooding linked to major inundation's and deprived populations becomes less significant; or that rivers in particular catchments begin to dominate and highlight particular deprived or wealthy communities within the analysis. To examine such questions in some detail we therefore recommend <u>that the Agency undertake further equity analysis using new flood maps in order to compare the results obtained to those we have produced in this project</u>.

2. Decisions on past flood protection investments have traditionally been driven by economic considerations which balance the cost of the investment with the estimated economic loss from flood events. This has been criticised as inequitable leading to a marginalisation of areas for flood protection which contain poor communities and only low value economic activity. This is an environmental equity issue that we have not been able to explore in this project due to the current lack of a national dataset on the location of flood protection measures. However the new mapping products to be released by the Agency will identify the location of flood protection measures and the areas in the floodplain that are protected. Therefore, <u>we recommend that new flood maps are particularly used to investigate the question as to whether or not populations that have been protected by flood defence investments are indeed the 'better off</u>. Such analysis could be undertaken at both national and regional levels.

3. Where there are associations between flood hazard and deprivation it can reasonably argued that particular population vulnerabilities may exist. Deprivation may contribute to people being more vulnerable to harm (for example, through the association between deprivation and long term ill health) and less able to cope and recover from flood events than those with more substantial material resources.

These social dimensions to vulnerability are being increasingly recognised by the Agency in various aspects of flood hazard management. The identification of floodplain areas that contain deprived populations, which our analysis and the further analysis suggested above can enable, would allow a targeting of Agency intervention to reduce vulnerability. Whether or not such targeting is appropriate is a matter of judgement as to the degree to which deprivation is seen as an important variable (other social variables such as age may be considered more significant) and the relative priority to be given to economic and other forms of loss. It is also subject to the generic question of whether or not an unequal pattern of exposure to flood hazard constitutes an injustice or inequity justifying a policy response to *reduce* the pattern of inequality. We however recommend that the Agency considers the case for targeting flood management measures towards those deprived communities that are at risk from flooding.

4. The evidence that tidal flooding potential is biased towards areas of deprived population suggests at first sight that the potential impacts of increased coastal flood risk due to climate change (through sea level rise and greater frequency of extreme storm events) will be felt more acutely by the poor in England and to a lesser extent in Wales. This observation links to the framing of climate change impacts at a global level as a case of international environmental injustice, with the most severe impacts experienced by poor countries as a result of greenhouse gas emissions produced largely by the rich. Following this reasoning there may therefore be a case on social justice grounds for particular attention to be given to the management of future tidal flood risk in deprived areas; and, more generally, an additional argument for the reduction of greenhouse gas emissions as a precautionary measure. However, given the limitations of the IFM and of the scale of analysis we have undertaken, we recommend that the Agency undertake further analysis of the social distribution of tidal flood risk in order to inform the development of climate change related policy measures. This analysis could use more sophisticated flood maps which take account of coastal flood defences (as discussed above); involve analysis of both current and future flood hazard under climate change scenarios to see how future patterns in the social distribution of hazard are likely to evolve; and incorporate a range of social variables relevant to flood vulnerability

3 INTEGRATED POLLUTION CONTROL SITES

3.1 Introduction

The regulation of Integrated Pollution Control (IPC)[1] sites is a key responsibility of the Environment Agency. Included within the remit of the IPC regime are the most substantial sources of pollution from industrial and related sources in England and Wales. Each IPC site must obtain authorisations to emit specified substances, undergo inspection by Agency staff and make annual returns on actual emission levels to the pollution inventory database operated by the Agency. The emissions from each site are extremely diverse and combine with pollution from other sources, such as transport and smaller scale businesses regulated by local authorities, to influence overall air, water and land quality.

As noted in the literature review in Part 1 of the project record (Mitchell and Walker 2003) sources of industrial pollution and risk have been a major focus of research on environmental equity and justice. In the US many studies have examined the equivalent of IPC sites, analysing their spatial distribution at different scales in relation to patterns of both ethnicity and deprivation. In the UK there have been three published equity studies examining IPC site locations in relation to deprivation, two undertaken by Friends of the Earth (2000, 2001) and the third by the Environment Agency (2002). These three studies have each shown a strong relationship between site location and indicators of deprivation.

The IPC analysis we have undertaken in this project has sought to build on and significantly extend the analysis in these existing studies. We have used a methodology that has followed best practice guidance from the substantial body of US research, whilst introducing innovations which, where practicable, introduce a greater degree of sophistication and differentiation than has been seen in studies to-date. Our objectives in undertaking this work are to:

- provide coverage of England and Wales (although for reasons discussed in section 1.4 separate analyses must be undertaken);
- use two methods for assessing spatial relationships with deprivation (‘site in ward’ counting and population proximity analysis);
- differentiate in the analysis between industrial sectors;
- undertake an analysis just for sites producing emissions to air in order to focus on greatest potential human health risks;
- analyse Operator and Pollution Risk Appraisal (OPRA) scores to examine patterns of operator performance and the distribution of pollution hazard by deprivation;
- investigate any differences between the patterns of social deprivation associated with recent authorisations compared to more long standing authorisations;
- analyse patterns in the level of emissions from IPC sites for specific substances - those included in the National Air Quality Strategy and carcinogenic emissions.

[1] We have used the term IPC in this report although a transition is taking place towards regulation under the new Integrated Pollution Prevention and Control (IPPC) system. For 2001, the year of the dataset we have utilised, 95% of sites were still regulated under IPC.

3.2 Data Sources and Methods

3.2.1 Data sources

The sources of data used in the IPC analysis, in addition to the ward deprivation and population data discussed in section 1.4, are:

- *IPC pollution inventory database*. This was supplied by the Agency for 2001, the latest year for which emissions data has been collected and verified. The inventory database includes details of sites (name, address, grid reference, industry sector etc.), authorised processes (nature of process, date of authorisation) and emissions from these processes (including level and route). Each IPC site can have more than one polluting process (for example, a chemical site operating an organic chemical process and inorganic chemical manufacturing) and each of these processes must have a separate authorisation. Each authorisation then has a sometimes-long list of authorised emissions of different substances to different environmental media. The significance of these elements of the database can be seen in that there were a total of 1,139 sites in England and Wales on the 2001 pollution inventory database, with a total of 1,620 authorisations and 12,886 emission sources. The IPC database required some cleaning before it was ready for use, including the correction of grid references and elimination of duplicate site records.

- *OPRA score database*. This was supplied by the Agency for 2001 therefore matching the pollution inventory data. Scores are given to authorised processes rather than for sites, so in some cases there are more than one set of scores for each site. The OPRA scores are divided into two main parts, providing an Agency field inspector appraisal of the pollution hazard from the authorised process and of the quality of the operator performance. These scores are described further in section 3.2.3 below. There were a significant number of authorisations which did not have OPRA scores in the database. These gaps were explained by the Agency as being largely ones where field inspectors did not consider it necessary to distinguish between the scores for different processes on the same site.

- *Codepoint*. This postcode based dataset of numbers of residential households was used to identify populations within buffers around IPC sites (see also discussion of flooding method in section 2.2, which also uses Codepoint data)

Additional datasets were examined to see if they could add further value and differentiation to the analysis. However, in each case limitations in the data or the availability of better alternatives meant that the following were not used:

- *Agency inspection rates*. The possibility of analysing rates of inspection to investigate if these displayed a bias towards or away from deprived areas was raised at the stakeholder workshop as part of a package of analysis for IPC sites. Whilst reasonably thorough information on inspection rates under IPC was available for 2002-3, the interpretation of data was felt to be too problematic for simple analysis. For example, the occurrence of particular incidents within the year would lead to multiple visits and dominate the overall pattern of inspection. Low inspection rates for particular authorisations could also be due to plant being covered by multiple permits and the transition from the IPC to PPC regime. It was also noted that inspection priorities are guided by OPRA scores.

- *Pollution Incident Data*. The national pollution incident database held by the Agency for 2001 was considered by the Agency to be reliable and consistent enough for analysis. However, whilst there is a field indicating if an incident is linked to an IPC site we were advised that this was not necessarily completed consistently. It was also noted that the OPRA scores provide a longer term rating by field inspectors of a company's performance on incidents.

- *Enforcement database*. Information was potentially available from an internal Agency database on enforcement actions. There was not however time available within the project to utilise this. Again the OPRA scores, to an extent, reflect the degree to which enforcement actions have been required for each authorised process.

3.2.2 Spatial Analysis Methods

Much of the recent US literature has emphasised the importance of the choice of spatial analysis methods in environmental justice research. As discussed in Part 1 of the Project Record, the choice of spatial units for analysing social variables is particularly significant, with some studies finding substantial differences in results produced using different approaches to relating site locations to area-based social data.

The IPC equity studies undertaken in the UK to date have used simple 'spatial coincidence' methods. Industrial site locations are related to standard areas for which socio-economic data are available – wards in the case of the early Agency work (Environment Agency 2002) and the FoE study on carcinogenic emissions (FoE 2001) and postcode sectors for the initial FoE IPC study (2000).

To enable some comparison with these studies and to provide an initial view of the data we also first undertook a 'spatial coincidence' analysis counting sites in wards (and associated authorisations and emissions). As this approach to spatial analysis has a number of limitations (discussed in Mitchell and Walker 2003, and further below) we in addition followed a more sophisticated method of buffering each IPC to produce a consistently sized circle within which population deprivation characteristics could be estimated. Each of these methods are explained further and discussed below.

Site in Ward Counting Method

The choice of ward as the spatial unit for this method (rather than say postcode areas or enumeration districts) was predetermined by the use of the Index of Multiple Deprivation as the social indicator which is available at a ward level but not below. The method is simple to implement involving the counting of sites within each ward, which is then ranked according to deprivation score across the ten deciles. There are specific and generic problems with using this method. First, there is one grid reference for each site within the Agency database (rather than a site area), this point being located at the site entrance. Large industrial sites may extend across or adjoin a number of different wards but will only have a single spatial reference to assign the site to a ward. Second, and more generically, are problems associated with the highly variable size and shape of wards and the use of the ward area to link a specific population to the site. The contrast between urban and rural areas is particularly important here as wards in rural areas are typically much larger than in urban areas, so the land area and associated population 'attached' to each site will be highly divergent. Where sites are located near to ward boundaries this also means that people living near a site, but not within the same ward as the site, are not identified through this method as being proximate to it. The use of buffers is a way of addressing this problem.

Population Proximity within Buffer Method
This method involves using a GIS to draw a circle of specified radius around each IPC site location, and then using this area to examine the deprivation characteristics of the nearby population. Under this method each site is treated consistently in terms of the size and shape of spatial unit that is 'attached' to the site.

When a circle is drawn around a site it clearly has the potential to cut across a number of different ward boundaries. When this occurs a number of methods can be used to allocate populations and social characteristics to the buffer area; Lui (2001) identifies polygon containment, centroid containment and buffer containment as the most widely used alternatives. The approach we adopted is identical to that used for the flooding analysis (see section 2.2 for detailed discussion) involving the use of Codepoint data to determine the proportion of a wards population that is inside or outside the buffer. This is a more sophisticated and precise approach to allocating population to a buffer than used in any other environmental justice studies we have identified in the literature. An example of how Codepoint data points relate to ward areas and site buffers in shown in Figure 3.1, where a 1 km buffer is used. The key value of using Codepoint data in this way is that the populations counted as within 1 km of a site have not been artificially distributed across an entire ward. For example, where sites have no people living within 1 km they will have no influence on the results produced which relate site location to deprivation. Under other methods, for example assuming a constant distribution of population across a ward (not therefore allowing for empty spaces, or areas of industry), a population presence within 1 km would have been artificially created.

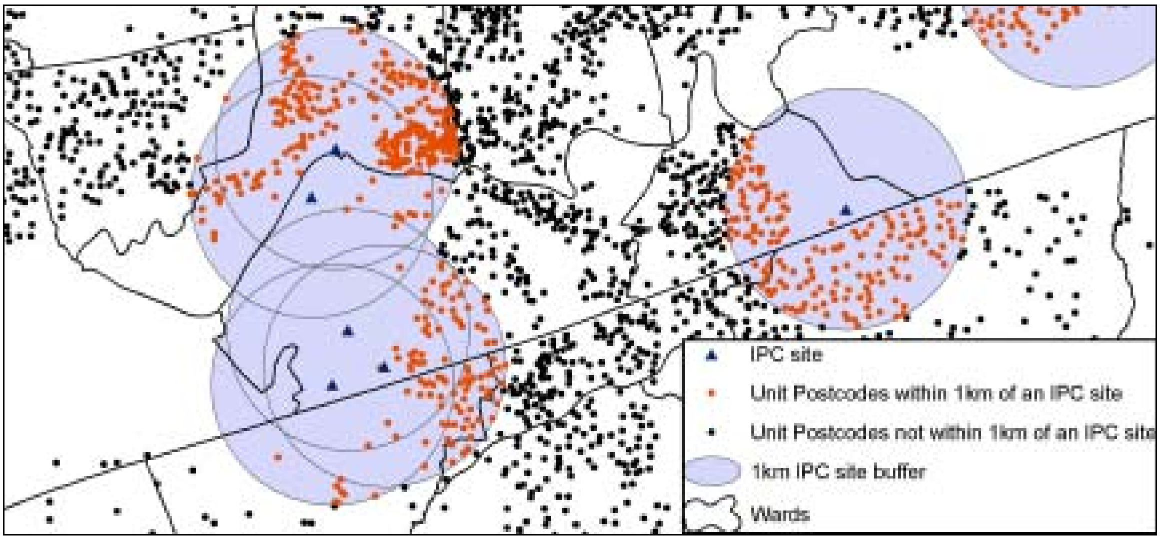


Figure 3.1: Example of unit postcodes and 1 km buffers around IPC sites

Despite its strengths there are a number of issues in applying this method:

Site grid reference – as discussed above, each site in the Agency pollution inventory database is located by a site grid reference positioned at the site entrance. This means that a circular buffer will be drawn around this point, which for large sites may be some distance from actual emission sources. Ideally buffers would be drawn around individual sources or around the entire site area, but the spatial information needed to undertake this was not available in the Agency national databases.

Size of buffer – ideally if the objective of analysis is to examine potential impacts on people living near an IPC site, then a buffer would reflect the distribution of estimated potential impact. This could take the form of a risk contour, a plume grounding area for emissions from stacks, a visual impact area, or noise contour depending on the impact of concern. None of these are likely to be simple circles of fixed radius. However, such detailed and site specific information on exposure patterns is complex and highly resource intensive to produce and is unavailable on a national basis. For large sites with multiple emissions it would also involve taking into account the many different forms and scales of exposure and potential impact. For this reason it is only possible to use a buffer as a measure *not* of actual exposure or impact, but as a way of *characterising* the deprivation profile of people living around the site. The size of the buffer must then be determined, and in many equity studies this decision has been recognised as rather arbitrary (Liu 2001). Following discussion with the Agency, our approach was to explore the impact of varying buffer size by undertaking an initial analysis using four buffer sizes: 500 m, 1 km, 2 km and 4 km. This range of buffer sizes was suggested by the Agency as encompassing, at 4 km, the greatest likely extent of impact from emission source. The graduations below 4 km then provide a range of alternatives for exploring the significance of buffer size on the results of equity analysis. In later aspects of analysis we chose 1 km as a standard buffer size on the following grounds:

- the analysis of population data reported in section 3.3.2 below for England and 3.4.2 for Wales shows that there is little proportional difference between the relationship with deprivation for the 500 m, 1 km and 2 km buffers sizes. The choice of buffer size would therefore appear not to be critical in influencing the degree of inequality revealed;

- when planning authorities are making decisions on planning applications for new, sensitive developments near to IPC sites, a 1 km distance has been used as a guideline radius within which impacts could potentially be of significance, and planning applications therefore may need to be sent to the Agency for advice;

- for emissions to air, published guidance on stationary pollution sources has look up charts to estimate the distance to maximum ground level concentration and the amount of maximum concentration for various types and heights of chimneys. This guidance shows that for most stacks (between 40-100 m high) the maximum annual average ground level concentration occurs within 1-1.5 km.

Buffer overlaps – once a buffer layer is created within the GIS it amalgamates all areas within 1 km of at least one IPC site. This amalgamated buffer therefore hides situations where buffers overlap, and people are living within 1 km of more than one IPC site. To investigate situations of multiple proximity or site concentration the GIS was used to identify areas where 2, 3, 4 and more buffers overlapped and then derive the population characteristics of populations within these overlap areas. An example of buffer overlaps is shown in Figure 3.2

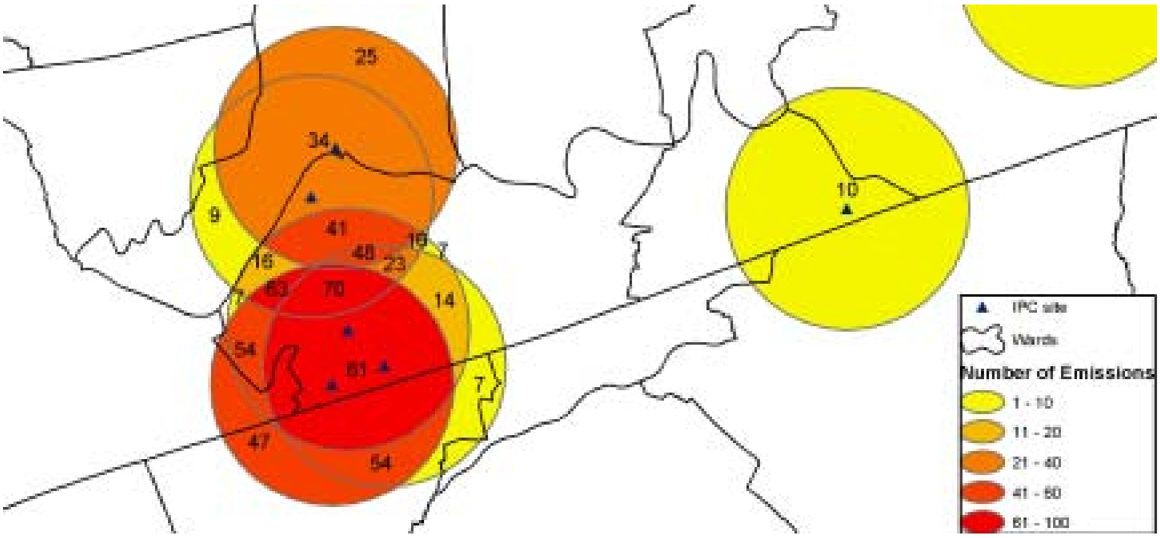


Figure 3.2: Example of overlapping 1km buffers around IPC and calculation of numbers of emissions within overlaps

3.2.3 OPRA Scores

The Operator and Pollution Risk Appraisal system was formally introduced by the Agency in 1997 as part of a wider move towards risk-based assessment and regulation. The system has been developed to be simple to use and able to produce rapid results, whilst being 'underpinned by sound, logical practices' (Environment Agency 1997). The OPRA system has two parts each with multiple component parts.

Pollution Hazard Appraisal (PHA) measures the inherent environmental risks of processes. The PHA score is reviewed at least every four years but usually remains the same unless there is significant modification to a process. PHA comprises the following attributes:

- presence of hazardous substances – what is stored;
- scale of hazardous substances – what could be emitted;
- frequency and nature of hazardous operations – how complicated the process is;
- technologies for hazard prevention and minimisation – how the hazard is controlled at source;
- technologies for hazard abatement – how environmental emissions are reduced;
- location of process – how sensitive the local environment is to pollution; and
- offensive characteristics – whether emissions are likely to cause local annoyance (such as smell).

Operator Performance Appraisal (OPA) - measures the operator's ability to manage the environmental risks of processes. The OPA score is reviewed at least annually and is based on regulation of the process in the previous year. OPA comprises the following attributes:

- recording and use of information;
- knowledge and implementation of authorisation requirements;
- plant maintenance;
- management and training;
- process operation;
- incidents, complaints and non-compliance events; and
- recognised environmental management systems.

For the authorised process at IPC sites, the individual attributes within the PHA and OPA are given a score by Agency field inspectors based on their knowledge of the process and how it is being operated. The allocations of scores is based on detailed guidance to encourage compatibility between inspectors (Environment Agency 1997). The attribute scores are summed and this total score banded to give total scores and bandings for each authorisation.

OPRA is intended by the Agency to complement authorisations and support inspections by providing information about IPC processes and their performance against the authorisation on a regular basis. This information is seen as helping the Agency 'to assign regulatory effort in proportion to the environmental risk of the process on a more consistent and transparent basis' (Environment Agency 1997).

For the purposes of this study, the PHA score in particular provides a way of differentiating sites in terms of their pollution hazard, rather than treating all sites equally. This differentiation is achieved in a qualitative but informed and holistic manner – account is taken not only of total emissions but also factors such as toxicity, the nature of operations and the existence of pollution control systems. Attempting to differentiate sites solely on the basis of data in the pollution inventory would inevitably be far cruder. At the same time it must be recognised that the PHA and OPA is based on the judgement of the regulator and despite attempts to ensure consistent scoring between inspectors this may be difficult to achieve. The method for producing OPRA scores is being revised under the IPCC regime and is expected to ensure greater consistency and reliability of scores.

3.2.4 Selection and Analysis of Specific Substances

Information is available within the pollution inventory database on the levels of pollutants emitted from each authorised process. There are a large number of substances reported to the inventory and a separate analysis of each of these could not be undertaken within this project. However, to illustrate the scope for substance specific mapping against deprivation the following analyses were undertaken:

NO_2 and PM_{10}. These are two important air pollutants included within the UK National Air Quality Strategy. Mapping their distribution provides scope for interrelating the

IPC deprivation analysis with that of air quality. For NO_2 the pollution inventory entry used was substance code 1062 'Nitrogen Oxides (except N_2O) reported as NO_2'.

Carcinogens. The release of carcinogenic substances and resulting health risks have been the subject of particular concern and attention. Friends of the Earth (FoE 2001) specifically focused on carcinogenic emissions to air in the second of their environmental equity analyses. We also chose to focus on carcinogens in order to compare our results with those of FoE and to provide an example of analysis of a substance group. The definition of carcinogenic substance was that adopted by the Agency following guidance from the Department of Health and includes substances that are carcinogenic or mutagenic. This definition is different from that used by FoE which was based on the US State of California definition known as 'Proposition 65'. The DoH definition covers 67 substances within the pollution inventory 35 of which were released to air by IPC sites in 2001. All emissions of these substances to air were selected (on the basis that emissions to air have the most direct link to health concerns) and the number of emissions and total mass released (kg) aggregated. Aggregating different substances together in this way is not ideal as it takes no account of the relative degree of hazard or risk posed by each substance. It does, however, provides a simple initial indicator of degree of hazard and enables comparison with the FoE research which also aggregated mass released for different substances.

3.3 IPC Sites and Deprivation in England

The discussion of results for England begins with an overview of the general patterns of IPC site distribution without differentiating between different types of sites or site characteristics. Different forms of differentiation and approaches to analysis are then introduced, including the use of OPRA scores to explore possible relationships between pollution hazard and operator performance and the social profile of site locations.

3.3.1 Numbers of Sites, Authorisations and Emissions in Wards

For sites, authorisations and emissions Table 3.1 and Figure 3.3 show a strong relationship with deprivation, with wards in the most deprived decile providing the location for five times as many sites and authorisations and seven times as many emission sources as the wards in the least deprived decile. There are only 92 sites and 656 emission sources in the 20 % least deprived wards (deciles 9 and 10), compared to 316 sites and 3,782 emission sources in the 20 % most deprived wards (deciles 1 and 2). As indicated by the concentration index (CI) values, counting sites provides the marginally weaker relationship with deprivation, whilst counting emission sources provides the strongest, indicating that the sites in the more deprived wards have a greater number of emissions per site (on average) than sites in the less deprived wards.

Table 3.1: Sites, Authorisations and Emissions by population weighted ward deprivation decile for England using 'site in ward' counting method.

Decile	Number			%		
	Sites	Authorisations	Emissions	Sites	Authorisations	Emissions
1	154	231	1751	15	16	15
2	162	226	2031	16	15	18
3	142	248	1644	14	17	14
4	130	173	1464	13	12	13
5	97	125	1036	9	9	9
6	92	121	1080	9	8	9
7	85	122	1017	8	8	9
8	77	101	805	7	7	7
9	56	71	401	5	5	3
10	36	49	255	3	3	2
Totals	1031	1467	11484	100	100	100

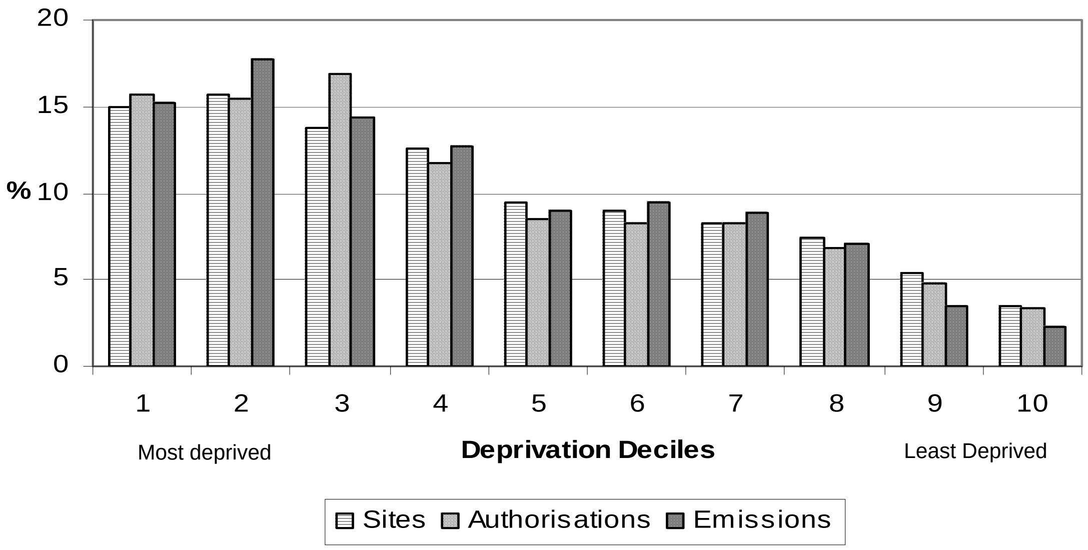


Figure 3.3: Percent of Sites, Authorisations and Emissions by population weighted deprivation decile for England using 'site in ward' counting method. Gini CI values = 0.22 (sites), 0.25 (authorisations) and 0.26 (emissions)

This data shows a broadly similar relationship with deprivation to the Agency's own IPC site analysis. The Agency analysis (Environment Agency 2002) used a measure of IPC site density (no of sites per km^2) to take account of the different sizes and population densities of wards across the deciles. Consequently the graph produced in this analysis shows a steeper decline from the least deprived decile to the middle deciles and a small upturn for the least deprived deciles 9 and 10 compared to 8.

3.3.2 Population Proximity to IPC Sites

Undertaking a similar analysis using the population proximity within a buffer method; which as noted in section 3.2.2 provides a more consistent method for characterising the deprivation characteristics of people living near to sites, produces a similar but more accentuated relationship with deprivation. Table 3.2 and Figure 3.4 show populations within each deprivation decile living within four different distances from IPC sites – 500 m, 1 km, 2 km and 4 km (the choice of these distances is explained in section 3.2.2 above). Given that there are very nearly equal numbers of people in each decile, if IPC sites were evenly distributed then we would expect an equal proportion of the population within each deprivation decile to live within each buffer distance.

This population proximity data produces a stronger and more consistent relationship between deprivation and site location than using 'site in ward' counts. The disproportionate concentration of the most deprived populations near to IPC sites is highlighted with the highest percentage consistently in the most deprived decile for all four buffer distances, followed by an almost universally consistent fall through to the least deprived decile. The ratio between most and least deprived wards is also higher than that produced using the ward count method. The CI values for the 500 m, 1 km and 2 km buffers all indicate a greater inequality than the CI value of 0.22 for the site in ward count method. For the ward count method the ratio between least and most deprived ward decile is 4:1, that is, there are four times more IPC sites in decile 1 compared to decile 10. For the site buffer method the ratios are between 5:1 and 6:1 for the buffer distances 500 m, 1 km and 2 km. Out of the 3.6 million estimated people living within 1 km of an IPC site, there are six times more people from decile 1, the most deprived, as from decile 10, the least deprived.

Table 3.2: Total and Percentage Populations living within 500m, 1km, 2km and 4km of an IPC site by population weighted deciles for England.

Decile	**Total Pop. (Million)**	**Population within 500 m of an IPC Site**		**Population within 1 km of an IPC Site**		**Population within 2 km of an IPC Site**		**Population within 4 km of an IPC Site**	
		Total	%	Total	%	Total	%	Total	%
1	4.9438	162,948	20.1	761,064	21.1	2,166,331	18.4	4,025,003	15.0
2	4.9536	124,390	15.4	582,092	16.1	1,872,031	15.9	3,719,323	13.9
3	4.9400	136,445	16.9	521,329	14.5	1,682,984	14.3	3,434,683	12.8
4	4.9479	106,566	13.2	450,845	12.5	1,460,468	12.4	3,169,473	11.8
5	4.9482	84,763	10.5	355,828	9.9	1,167,286	9.9	2,893,713	10.8
6	4.9527	47,973	5.9	257,231	7.1	928,658	7.9	2,415,685	9.0
7	4.9384	38,314	4.7	218,868	6.1	868,910	7.4	2,102,571	7.9
8	4.9554	39,429	4.9	185,528	5.1	677,725	5.7	1,969,142	7.4
9	4.9515	37,764	4.7	149,044	4.1	561,447	4.8	1,621,068	6.1
10	4.9596	30,342	3.8	123,058	3.4	410,065	3.5	1,408,857	5.3
	49.491	808,933	100	3,604,888	100	11,795,904	100	26,759,518	100

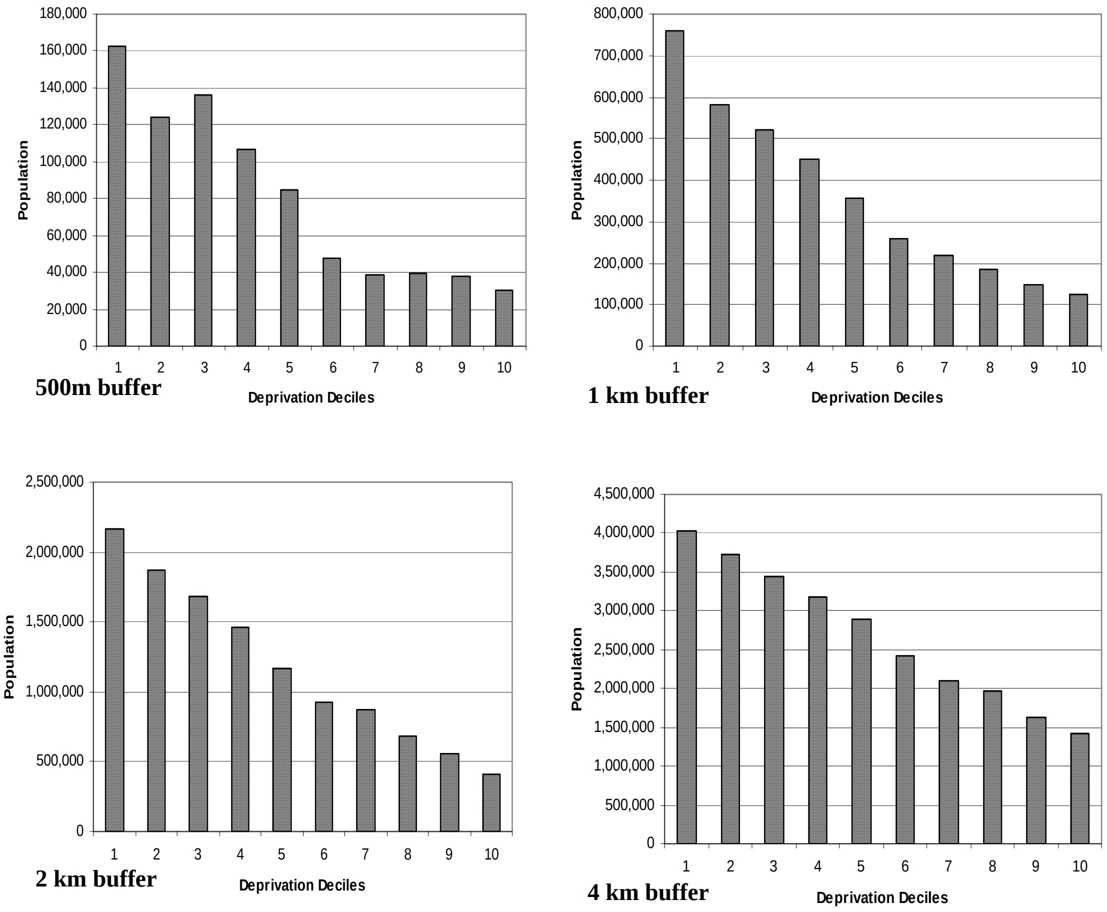


Figure 3.4: Total populations estimated to live within 500 m, 1 km, 2km and 4km of an IPC site by population weighted ward deciles for England (Gini CI = 0.31 for 500m and 1km, 0.27 for 2km, 0.18 for 4km)

The significance of changing the buffer distance can also be assessed from the gradients of the bars in Figure 3.4 and the Gini CI values. For the 500m, 1 km and 2 km buffers the gradient is broadly similar and the CI values vary little (0.31 and 0.27). The shallower curve and lower CI value (0.18) for the 4 km buffer is to be expected given that the larger the buffer the more of the total variation in the population is contained - as shown in Table 3.2 over 50 % of England's population lives within 4 km of an IPC site.

These patterns can also be seen in Figure 3.5 which charts an indexed ratio for each buffer distance. The index is derived by setting the value for the least deprived ward decile at 1 in each case. The relationship between IPC site location and the deprivation characteristics of wards near to IPC sites is again very clear as is the close correlation between the 500 m, 1 km and 2 km profiles. These results, together with the argument presented in section 3.2.2, leads us to select the 1 km buffer distance for subsequent analyses.

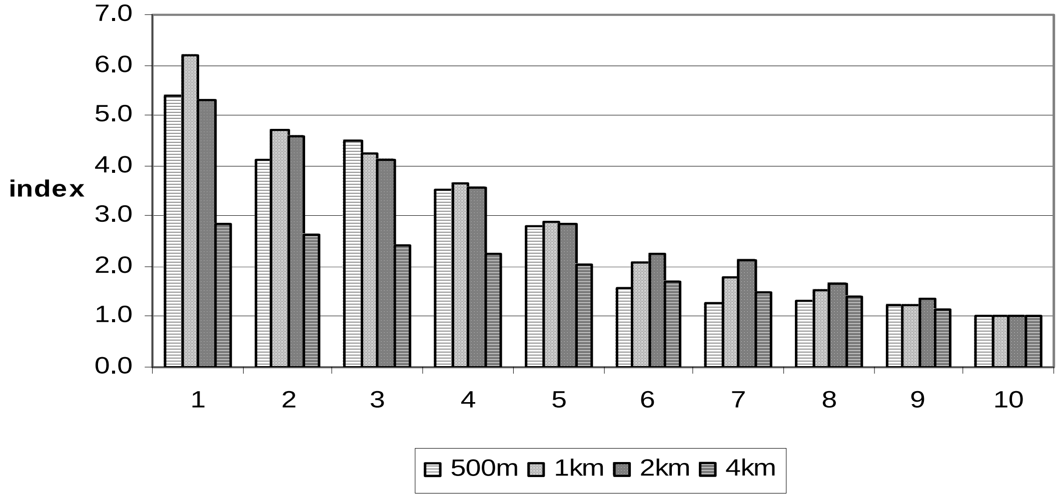


Figure 3.5: Index ratio between the proportion of people living in the least deprived deciles (=10) and other deciles for four distances from IPC sites in England (500 m, 1 km, 2 km and 4 km).

3.3.3 Population Proximity to Multiple Sites, Authorisations and Emissions

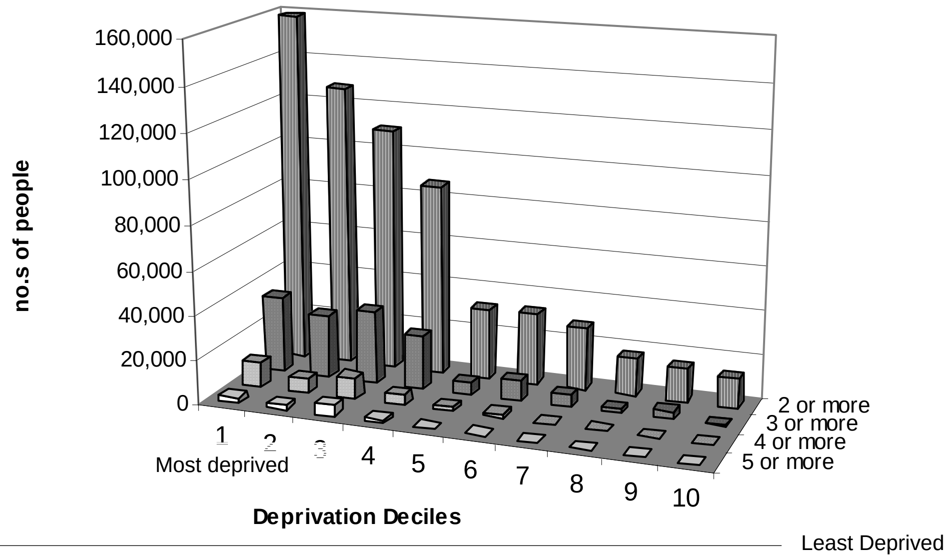
The results from the 'counting people' in buffer method give no indication of whether people are living within 1 km of more than one site (i.e. where buffers overlap) and therefore whether or not IPC sites are clustered in areas of higher levels of deprivation. The analysis has also been restricted to sites, rather than taking account of multiple authorisations and emissions at each site.

A further, more involved analysis was therefore conducted to assess the deprivation characteristics of people living within 1 km of more than one IPC site (i.e. where buffers overlap). Contrasting the most and least deprived deciles in Table 3.3 and Figure 3.6 we find that there are 159,031 people in the most deprived decile living near to 2 or more sites, and only 13,301 in the least deprived decile resident near multiple sites. There are *no* people living near to four or more sites in the least deprived decile, compared to 11,523 in the most deprived. As the number of sites within 1 km rises, the bias towards the more deprived deciles becomes more acute, as indicated by the graduation of CI values rising from 0.31 to 0.59.

The analysis for proximity to multiple authorisations and multiple emission sources shown in Figures 3.7 and 3.8 displays a similar but more accentuated relationship with deprivation. For multiple emission sources in particular, the concentration in the least deprived decile is highlighted.

Table 3.3: Number of people living within 1 km of multiple sites by population weighted ward deprivation deciles for England.

Decile	5 or more sites	4 or more sites	3 or more sites	2 or more sites	1 or more sites
1	2,613	11,523	34,878	159,031	761,064
2	2,077	6,469	28,915	127,984	582,092
3	4,865	9,544	32,710	110,211	521,329
4	1,212	4,424	23,890	86,773	450,845
5	47	1,793	5,111	32,023	355,828
6	248	1,586	8,893	32,860	257,231
7	18	80	5,226	28,236	218,868
8	0	0	1,630	16,948	185,528
9	0	0	3,392	15,486	149,044
10	0	0	272	13,301	123,058
England	11,079	35,419	144,917	622,854	3,604,888



No of Sites	5 + sites	4 sites	3 sites	2 sites	1 site
Gini Concentration Index	0.59	0.59	0.48	0.44	0.31

Figure 3.6: Numbers of people living within 1km of multiple IPC sites by population weighted deprivation deciles for England

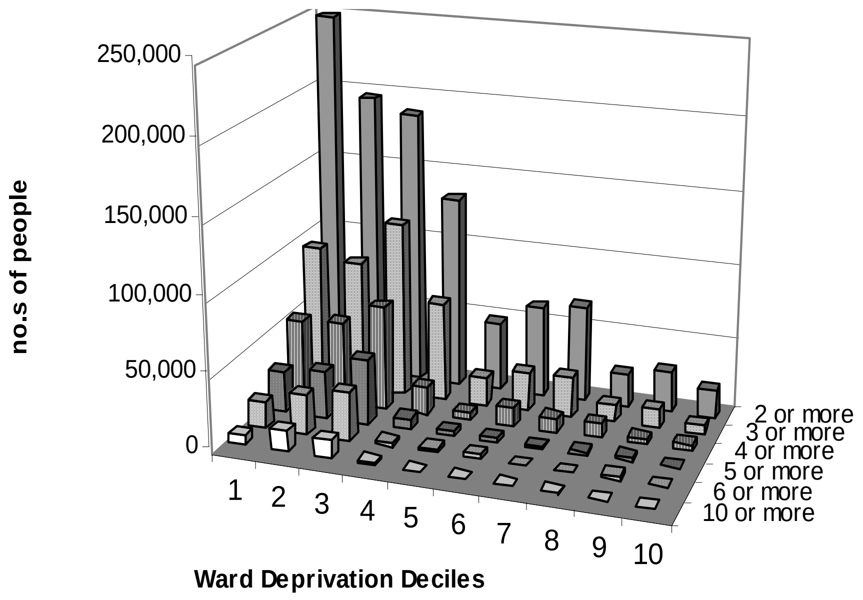
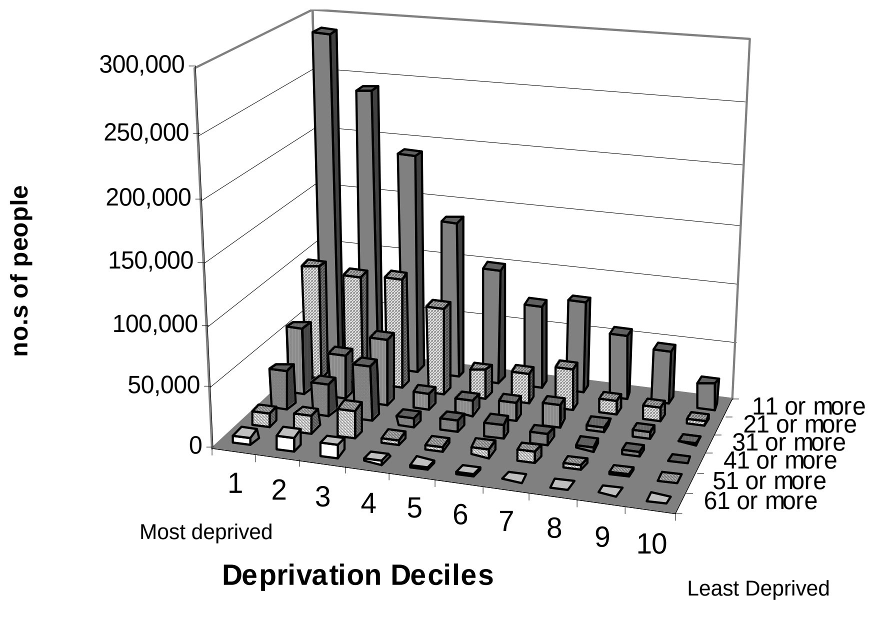


Figure 3.7: Number of people living within 1 km of multiple IPC authorised processes by population weighted ward deprivation deciles for England.



No. of IPC processes	>61	>51	>41	>31	>21	>11	1
Gini Concentration Index	0.50	0.36	0.44	0.43	0.41	0.36	0.31

Figure 3.8: Numbers of people living within 1km of multiple IPC emission sources by population weighted ward deprivation deciles for England.

3.3.4 Analysis by Industry Sector

Within the IPC regime and pollution inventory, sites are categorised into one of six industry sectors: chemical, fuel and power, metal, mineral, waste and other. In order to examine if there are differences in the distribution of sites in relation to deprivation between these sectors, the site in ward count and 1 km population proximity analysis was undertaken for each sector in turn. Table 3.4 shows total and percent figures for the site in ward count and Figure 3.9 the percent data clustered by sector. For each of the industry sectors there is a broad gradient following the pattern for all sites, indicating a higher number of sites in the more deprived ward deciles. The exception is the mineral sector, which shows a weak inverse pattern with more of the sites in the less deprived deciles 6, 7, and 8, although this pattern does not extend to the least deprived wards as there are no mineral sites in decile 10. The minerals' pattern is contrary to the general trend and may be explained by the predominantly rural location of mineral operations. The waste sector is also highlighted by the highest concentration of sites in the most deprived decile 10, which is not the case for sectors such as fuel and metals.

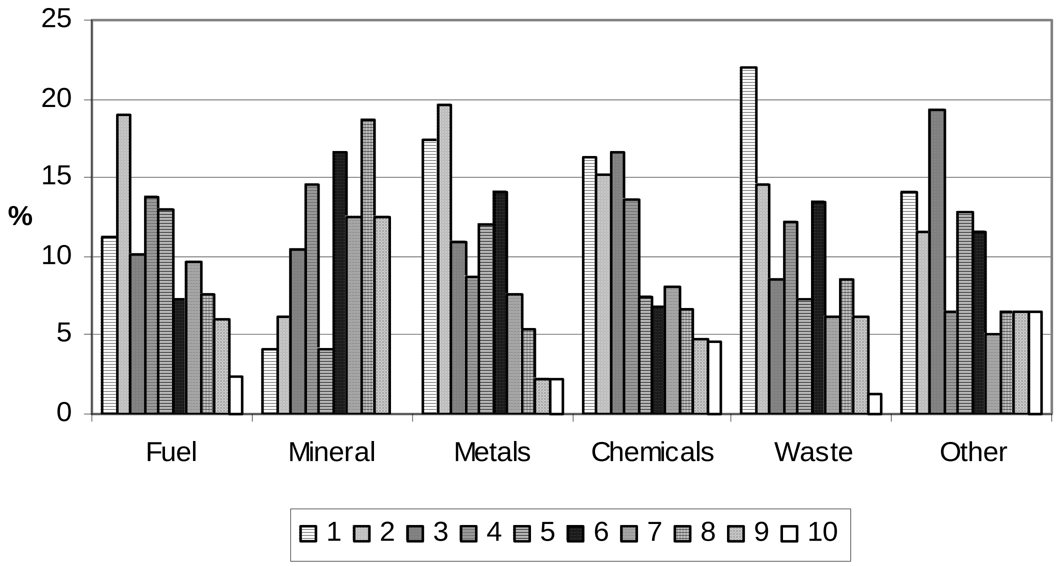


Figure 3.9: Sites (%) in different industry sectors by population weighted deprivation deciles in England.

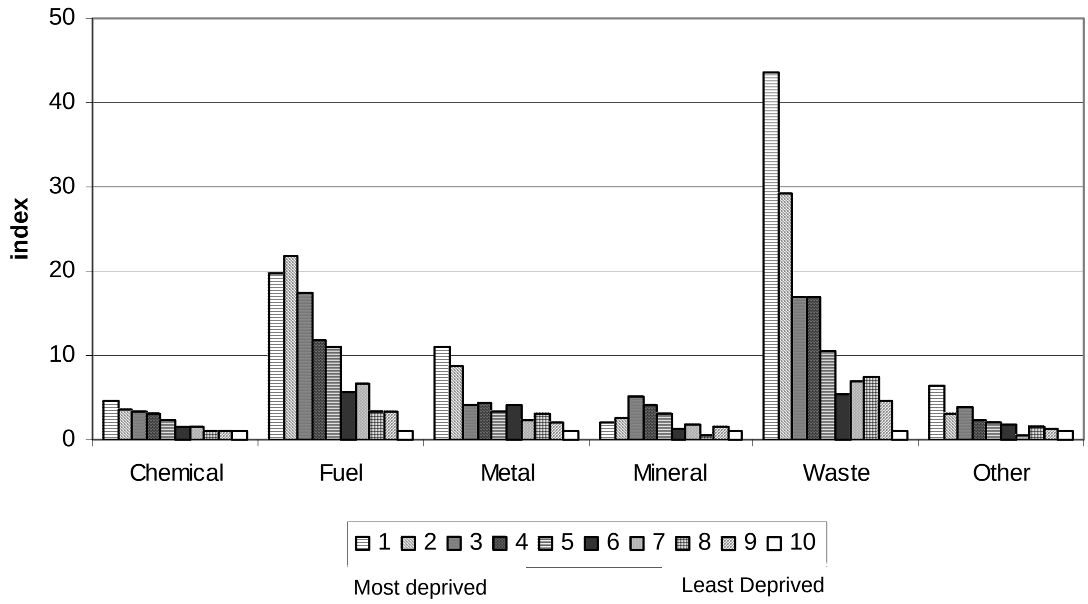
These patterns across the industry sectors are to an extent mirrored in the 1 km buffer population proximity analysis, but some significant differences are also revealed (Table 3.5). Figure 3.10 charts an index ratio based upon the lowest decile in each sector (the lowest decile is given a value of 1). This enables a comparison of the difference between the least deprived decile and other deciles sector by sector.

Table 3.4: Total numbers and percentages of sites in industry sectors by population weighted deprivation deciles for England

Decile	Total Sites	Fuel	%	Mineral	%	Metals	%	Chemicals	%	Waste	%	Other	%
1	154	28	11	2	4	16	17	79	16	18	22	11	14
2	162	47	19	3	6	18	20	73	15	12	15	9	12
3	142	25	10	5	10	10	11	80	17	7	9	15	19
4	130	34	14	7	15	8	9	66	14	10	12	5	6
5	97	32	13	2	4	11	12	36	7	6	7	10	13
6	92	18	7	8	17	13	14	33	7	11	13	9	12
7	85	24	10	6	13	7	8	39	8	5	6	4	5
8	77	19	8	9	19	5	5	32	7	7	9	5	6
9	56	15	6	6	13	2	2	23	5	5	6	5	6
10	36	6	2	0	0	2	2	22	5	1	1	5	6
	1031	248	100	48	100	92	100	483	100	82	100	78	100

Table 3.5: Total and percentage of population within 1km of IPC sites for industrial each sector by population weighted deprivation deciles for England.

Decile	Population within 1km of an IPC Site	Fuel	%	Mineral	%	Metals	%	Chemical	%	Waste	%	Other	%
1	761,064	123,400	19.5	13,878	9.2	113,707	25.2	20.0	20.0	113,768	30.6	104,800	27.1
2	582,092	136,192	21.5	17,126	11.3	91,590	20.3	15.3	15.3	76,343	20.5	50,998	13.2
3	521,329	108,332	17.1	33,258	22.0	41,739	9.2	14.5	14.5	43,934	11.8	63,802	16.5
4	450,845	72,769	11.5	26,482	17.5	45,708	10.1	13.3	13.3	44,326	11.9	37,754	9.8
5	355,828	68,713	10.8	20,159	13.4	33,241	7.4	10.0	10.0	27,451	7.4	32,139	8.3
6	257,231	35,736	5.6	8,175	5.4	41,875	9.3	7.1	7.1	14,359	3.9	27,763	7.2
7	218,868	41,167	6.5	11,686	7.7	23,054	5.1	6.9	6.9	17,995	4.8	7,120	1.8
8	185,528	20,729	3.3	3,376	2.2	30,668	6.8	4.8	4.8	19,254	5.2	22,945	5.9
9	149,044	20,897	3.3	10,355	6.9	19,967	4.4	3.9	3.91	11,882	3.2	22,733	5.9
10	123,058	6,250	1.0	6,496	4.3	10,377	2.3	4.3	4.28	2,619	0.7	16,227	4.2
	3,604,888	634,186	100	150,992	100.0	451,927	100.0	100.0	100	371,931	100.0	386,282	100.0



Site type	All sites	Chemical	Fuel	Metal	Mineral	Waste	Other
Gini CI values	0.31	0.29	0.38	0.34	0.21	0.45	0.34

Figure 3.10: Index of ratio between least deprived and other ward deciles for proportion of population within 1 km of IPC sites in different industry sectors (index = 1 for decile 10, apart from minerals where 1 = decile 9)

In a similar manner to the all site analysis (section 3.2.2) analysing population proximity, rather than counting sites in wards, accentuates the bias towards the most deprived decile (decile 1) and the general gradient against deprivation (compare Figure 3.9 and 3.10). In Figure 3.10 all of the sectors, including minerals, show an inequality bias towards the more deprived deciles with the differential in the waste sector standing out as particularly extreme (Gini CI value of 0.45). The proportion of the population in the most deprived decile living within 1 km of an IPC waste site is 43 times higher (113,768 people) than in the least deprived decile (2,619 people).

3.3.5 Differentiation by Scale of Pollution Hazard

In order to differentiate IPC sites in terms of the level of pollution hazard they present, the Pollution Hazard Appraisal scores assigned to each authorisation by Agency inspectors were used. These scores, explained in section 3.2.3, provide a multidimensional indicator of the level of pollution hazard from each authorised process.

For ease of analysis, the scores for each authorisation were related to ward deprivation deciles by the ‘ward counting’ rather than ‘site buffer’ method, and the PHA bandings were used rather than the overall scores. Band A indicates that the authorisation has a low pollution hazard appraisal, and band E a high pollution hazard appraisal.

Table 3.6: Pollution Hazard Appraisal (PHA) scores for authorisations falling within population weighted ward deciles for England

Decile	Authorisations		low				PHA Band				high	
	Total	%	A	%	B	%	C	%	D	%	E	No Record [1]
1	231	16	2	9	44	11	136	18	28	16	0	21
2	226	15	4	18	66	17	121	16	27	16	0	8
3	248	17	0	0	46	12	133	18	51	30	0	18
4	173	12	5	23	47	12	86	11	20	12	0	15
5	125	9	1	5	39	10	44	6	20	12	0	21
6	121	8	3	14	29	8	64	9	9	5	0	16
7	122	8	0	0	35	9	62	8	9	5	0	16
8	101	7	4	18	37	10	43	6	4	2	0	13
9	71	5	2	9	30	8	33	4	2	1	0	4
10	49	3	1	5	10	3	30	4	2	1	0	6
Eng	1467	100	22	100	383	100	752	100	172	100	0	138

1. S see section 3.2.3 for explanation of missing PHA scores

The majority of authorisations fall into PHA band C with very few in the lowest hazard band A, and none in the highest band E. This concentration of authorisations towards the middle hazard bands therefore makes differentiation of hazard by deprivation difficult to identify. However, higher hazard band C and D authorisations are more prevalent in the more deprived deciles in absolute and relative terms (Figure 3.11), whilst band A and B authorisations are more evenly distributed. There are 55 sites with the highest pollution hazard rating in the most deprived 20 % of wards, compared to only four in the 20 % least deprived. The graduation in Gini CI values, from 0.07 for Band A to 0.4 for Band D, also demonstrates the more equal distribution of low hazard sites and the bias towards more deprived deciles for high hazard sites. We can therefore conclude that there are more IPC sites and more high hazard IPC sites in deprived wards compared to more affluent wards.

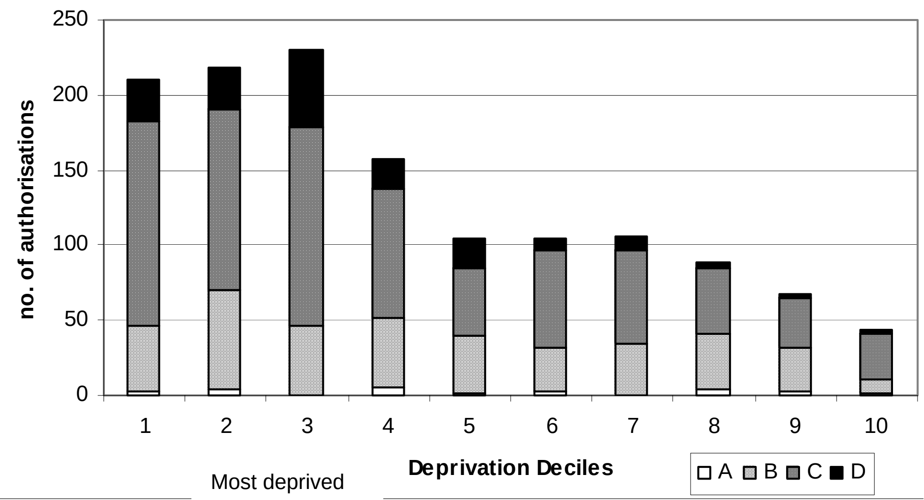
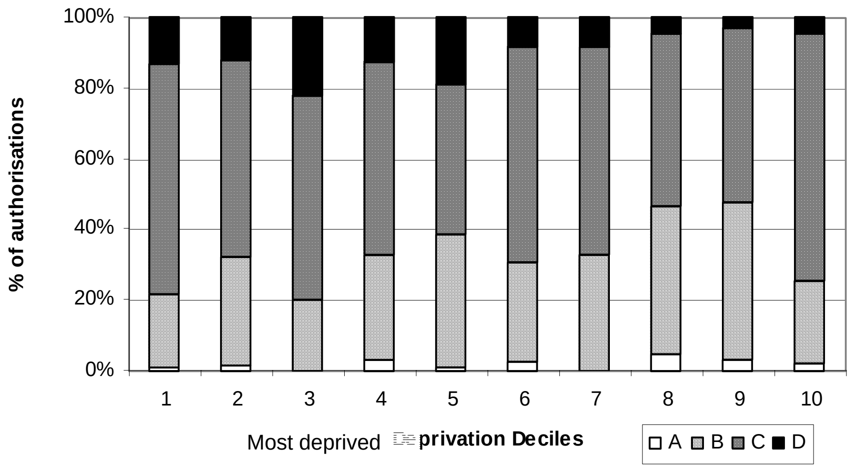


Figure 3.11: Pollution Hazard Appraisal (PHA) scores of authorisations located in population weighted deprivation deciles (A = low pollution hazard, D = high)



PHA Hazard Band	A	B	C	D	All
Gini CI index	0.07	0.17	0.28	0.4	0.26

Figure 3.11: (cont.) Pollution Hazard Appraisal scores of authorisations located in population weighted deprivation deciles (A = low pollution hazard, D = high).

One element of the PHA rating which is particularly relevant to the day to day experience of living near to an IPC site is the score given to 'offensive characteristics' that are likely to give 'local annoyance'. This is measured over a range of 1 to 5. The distribution of scores for this element of PHA is shown in Table 3.7 and Figure 3.12.

Table 3.7: Authorisation Scores for offensive characteristics by population weighted ward deprivation deciles for England

Decile	**Authorisations**	**1 low**	**%**	**2**	**%**	**3**	**%**	**4**	**%**	**5 high**	**%**
1	231	34	12	65	15	58	16	32	25	21	18
2	226	55	19	72	17	55	15	22	17	14	12
3	248	31	11	65	15	87	24	18	14	29	25
4	173	33	11	56	13	39	11	23	18	7	6
5	125	33	11	29	7	17	5	4	3	21	18
6	121	29	10	33	8	31	9	3	2	9	8
7	122	18	6	39	9	30	8	9	7	10	9
8	101	27	9	32	7	18	5	8	6	3	3
9	71	19	7	26	6	17	5	4	3	1	1
10	49	9	3	18	4	7	2	7	5	2	2
Total	1467	288		435	100	359	100	130	100	117	100

In absolute terms there are many more authorisations with offensive characteristics in the high deprivation bands than in the lower ones. For the scores for highest offensiveness (bands 4 and 5), there are 52 authorisations in wards in the most deprived decile, compared to only nine in the least deprived decile. In relative terms, there is a bias towards the more deprived, with a Gini CI value for authorisations in band 5 of 0.34 indicating a stronger inequality than a Gini CI value of 0.26 for all authorisations.

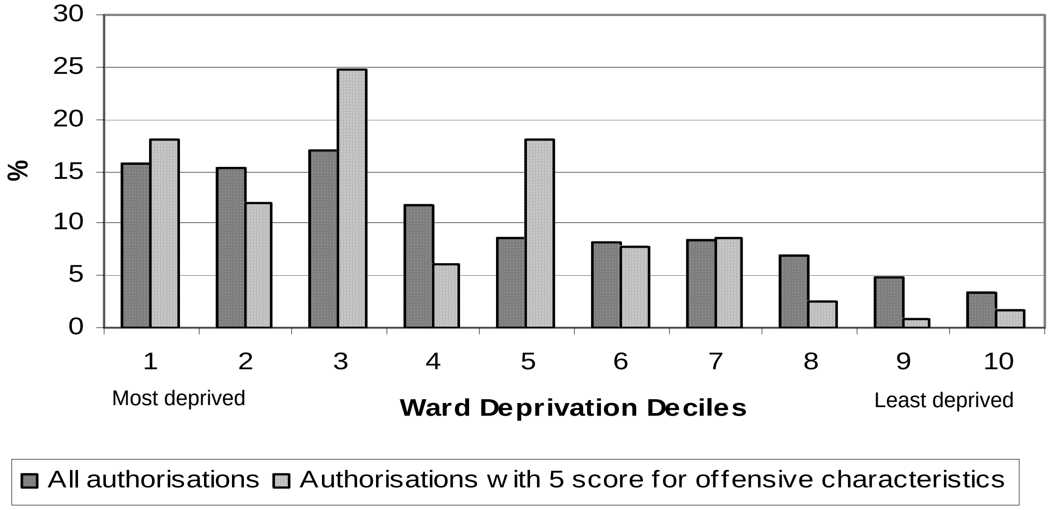


Figure 3.12: Authorisations (% of all, % of most offensive) against population weighted ward deprivations deciles for England (Gini CI: all authorisations = 0.25; 'most offensive' 5 score = 0.34).

3.3.6 Operator Performance at IPC sites

An indicator of operator performance, or how well a site is being run, is provided by the Operator Performance Appraisal score within the OPRA framework. These scores are explained in section 3.3.2. Examining the spatial pattern of operator performance provides an indicator of whether or not the quality of operator performances is potentially related to the social characteristics of the nearby population – one hypothesis might be that sites in 'better off' areas are subject to more articulate and politically powerful lobbying than in more deprived areas and that they may consequently make a greater effort to keep up pollution control standards and avoid pollution incidents.

Table 3.8 shows the total and % of sites in each operator performance appraisal (OPA) band. If OPA scores were proportionately distributed across the deprivation deciles they would match the % distribution of all authorisations. Looking at the best run sites falling into band A, there is a disproportionate number of well run sites in the most deprived decile (25 % of band A sites compared to 16 % of all sites) but *also* in the *least* deprived decile (8 % of band A sites against 3 % of all sites). In between these extremes there is no clear relationship between operator performance and deprivation – for example, in the worst run categories D and E there is are an approximately proportionate numbers of sites in the least and most deprived deciles but excesses in the middle deciles 5 and 6. This data therefore provides no evidence of a consistent association between operator performance and deprivation.

Table 3.8: Operator Performance Appraisal Scores against population weighted ward deprivation deciles for England

Decile	Authorisations		Good		OPA Band						Poor		
	Total	%	A	%	B	%	C	%	D	%	E	%	No Record
1	231	16	26	25	57	12	115	17	12	15	0	0	21
2	226	15	12	12	70	15	125	18	11	14	0	0	8
3	248	17	10	10	73	16	135	20	12	15	0	0	18
4	173	12	6	6	70	15	75	11	7	9	0	0	15
5	125	9	7	7	33	7	49	7	15	19	0	0	21
6	121	8	18	18	31	7	47	7	9	11	1	50	15
7	122	8	9	9	38	8	51	8	8	10	0	0	16
8	101	7	2	2	50	11	34	5	2	3	1	50	12
9	71	5	4	4	28	6	33	5	2	3	0	0	4
10	49	3	8	8	18	4	15	2	2	3	0	0	6
Total	1467	100	102	100	468	100	679	100	80	100	2	100	136

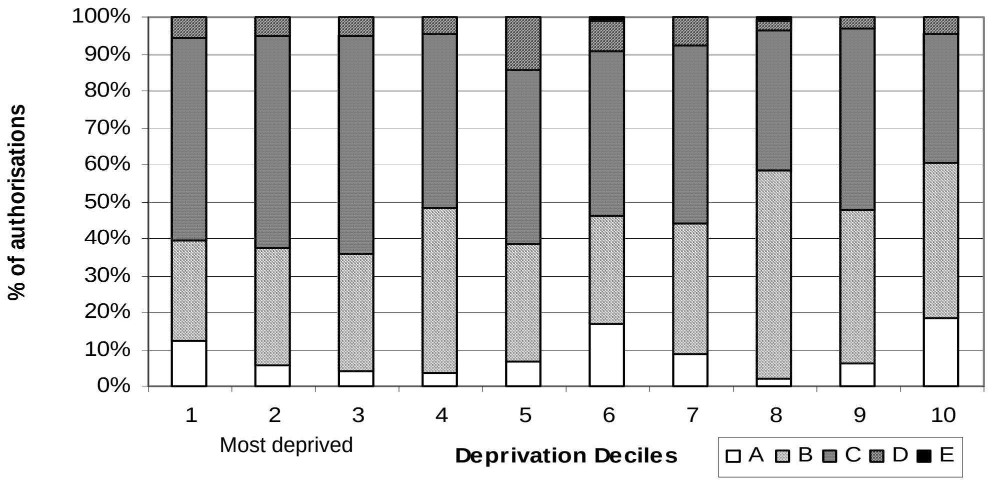


Figure 3.13: Percentage Operator Performance Appraisal (OPA) Bandings for IPC Authorisations within population weighted ward deprivation deciles (A = good performance, E = poor).

A specific measure within the operator performance appraisal, which provides a measure of 'incidents and complaints' at a site was also examined. A score of 5 on this indicator indicates a good performance, a score of 1 a bad performance. Figure 3.14 shows that the pattern of scores on this variable is broadly consistent with the number of authorisations in each decile and no consistent relationship with deprivation is apparent. The only comparison which stands out in Figure 3.14 is in the 5 category indicating good performance on complaints and incidents: 5 % of the sites in the least deprived decile have a 5 score, compared to 15 % in the most deprived.

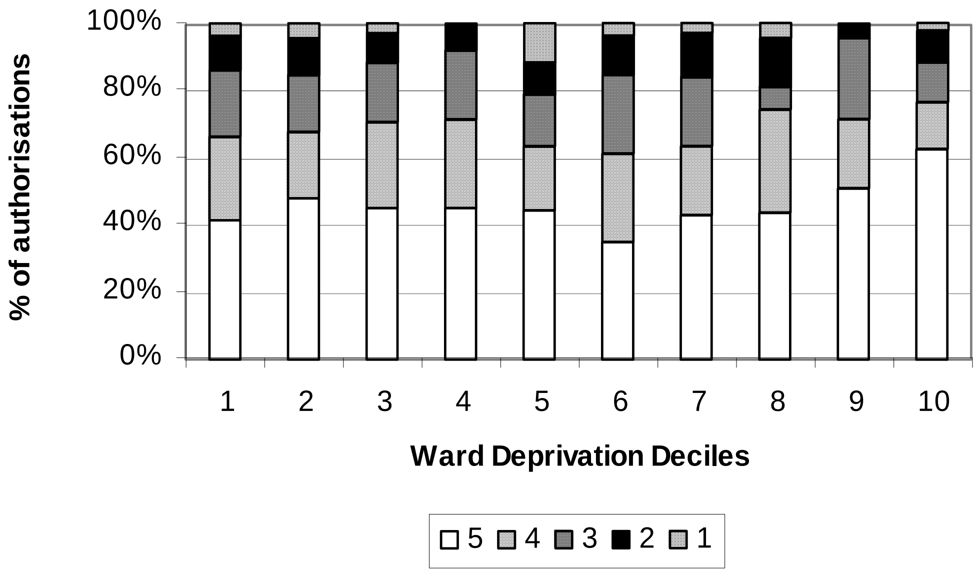


Figure 3.14: Incidents and Complaints OPRA score (%) for IPC authorisations in population weighted ward deprivation deciles (5 = good performance, 1 = poor)

3.3.7 IPC sites producing emissions to air

So far, our analysis has used data for all IPC sites regardless of the environmental media into which emissions are made. However, it can be argued that emissions made to water or solid waste that is disposed of on-site or transported to waste disposal facilities off-site, have less relevance to local people than emissions to air. This is particularly the case if impacts on health are the primary concern. For this reason the analysis undertaken over preceding sections was repeated for emissions to air only, and excluding sites and authorisations which made no such emissions. Rather than reproducing all the results the discussion below details the general pattern of distribution and highlights where there are significant differences with the 'all site' results.

In total, of the 1,031 IPC sites in England, 873 (85 %) made at least one emission to air in 2001. Of the total 11,484 authorised emissions from IPC sites 5,915 (52 %) were made to air. The latter figure is significantly lower in proportional terms, and emphasises the need to consider just the pattern of emissions to air.

The ward count data (Table 3.9) displays little difference between the social distribution of all sites, authorisations and emissions and those just involving emissions to air. The same is true of the 1km buffer population data shown in Table 3.10. The observation that the relationship with deprivation is broadly the same for all IPC sites and for those making emissions to air is also confirmed by the Gini CI values shown in Table 3.11.

It is concluded that, across the main variables examined, the relationship with deprivation is broadly the same between all IPC sites, and for those only making emissions to air.

Table 3.9: Social distribution of sites, authorisations and emissions (all, and emission to air sub-set) for population weighted ward deciles for England

Decile	All Sites	No. of Sites with emissions to air	All Authori-sations	Authorisations with at least one emission to air	All Emissions	Emissions to Air
1	15	15	16	16	15	15
2	16	16	15	16	18	18
3	14	14	17	17	14	13
4	13	13	12	12	13	12
5	9	9	9	8	9	9
6	9	9	8	8	9	10
7	8	8	8	8	9	10
8	7	7	7	6	7	8
9	5	6	5	5	3	4
10	3	3	3	3	2	2
Total	15	100	100	100	100	100

Table 3.10: Population (%) living within 1 km of an IPC site, and within 1km of IPC site producing emissions to air.

Decile	Population (%) within 1 km of an IPC site	Population (%) within 1 km of an IPC site with at least 1 emission to air
1	21.1	21.2
2	16.1	16.6
3	14.5	15.0
4	12.5	12.7
5	9.9	9.6
6	7.1	6.5
7	6.1	6.6
8	5.1	4.3
9	4.1	4.3
10	3.4	3.3
England	100.0	100.0

Table 3.11: Comparison of Concentration Index Values for All Sites and Sites with at least One Emission to Air

	Sites	Authorisations	Emissions	1 km buffer	>2 sites within 1km	PHA Band D
All Sites	0.22	0.25	0.26	0.31	0.44	0.40
Sites with emissions to air	0.23	0.26	0.25	0.32	0.41	0.40

3.3.8 IPC sites and date of authorisation

It has been hypothesised that unequal social distributions of IPC sites may be attributed to past authorisations practices (see later discussion). Table 3.12 compares authorisations during two time periods, 1991-1996 and 1997-2001. The first period has by far the greater number of authorisations as it encompasses the years during which the IPC regulations were first introduced and pre-existing processes were granted authorisations. The second period has a much lower number of authorisations reflecting the year by year addition of new processes to existing sites and development of new sites. The CI value for the earlier period of 0.25 is little different to that of the later period of 0.20, and the slightly higher value if anything indicates a stronger bias in the earlier when compared to the later period.

Table 3.12: Totals and percentages of authorisations per population weighted ward deprivation decile for 1991-91 and 1997-2001 for England

Decile	All authorisations		1991-96		1997-2001	
	No.	%	No.	%	No.	%
1	231	16	200	15.6	31	17.0
2	226	15	200	15.6	26	14.3
3	248	17	226	17.6	22	12.1
4	173	12	152	11.8	21	11.5
5	125	9	114	8.9	11	6.0
6	121	8	96	7.5	25	13.7
7	122	8	108	8.4	14	7.7
8	101	7	85	6.6	16	8.8
9	71	5	63	4.9	8	4.4
10	49	3	41	3.2	8	4.4
Total	1467	100	1285	100	182	100

3.3.9 NO_2, PM_{10} and Carcinogenic Emissions

Two significant air pollutants and a group of substances with potential carcinogenic impacts on humans were investigated both in terms of the locations of emission sources and the total amounts released to air. The rationale for selecting these substances for analysis is discussed in section 3.2.4 above. The locations of the emission sources were linked to deprivation through the 'site in ward' counting method. Results are presented as quintiles rather than deciles to smooth the data and better present relationships.

Table 3.13: NO_2 emission (sources and total mass released) from IPC sites in England by location in population weighted ward deprivation quintiles.

Quintile	Total Number of IPC NO_2 Sources	Percentage of IPC NO_2 sources	Total mass (kg) of NO_2 released from IPC sites	Percentage of total NO_2 released from IPC sites
1	140	34.6	94,471,636	28.1
2	104	25.7	43,892,455	13.0
3	64	15.8	38,141,127	11.3
4	71	17.5	139,401,559	41.4
5	26	6.4	20,664,737	6.1
England	405	100	94,471,636	100

Emissions of nitrogen dioxide (Table 3.13) by count of sources show a broadly consistent gradient against deprivation with the most sources in the most deprived quintile, and least in the least deprived. By mass released, however, (Figure 3.15) there is a strong peak in the third quintile due to the influence of a few very large emission sources (this quintile has 17.5 % of emission sources by number, but 41.4 % of total emissions by mass) and this balances with the substantial emissions in the lowest quintile to produce a low Gini CI score.

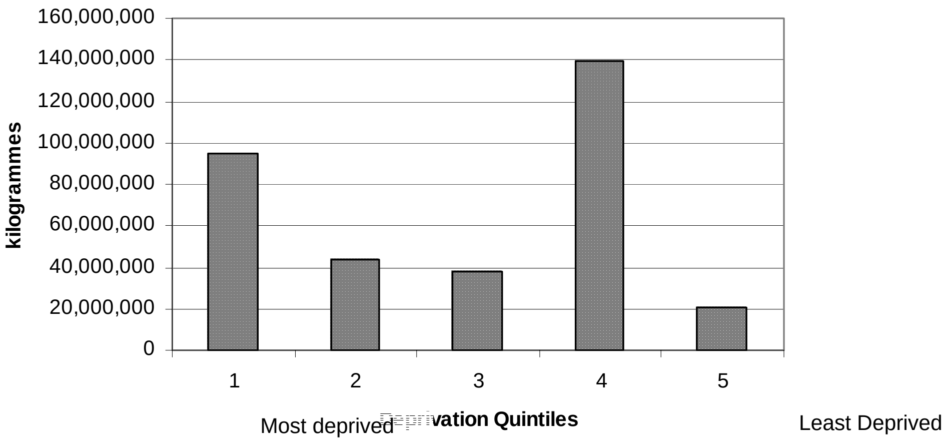


Figure 3.15: Total Emission of NO_2 from IPC sites in England by population weighted ward deprivation quintile (Gini CI = 0.07).

Emissions of fine particulates (PM_{10}) show a strong relationship with deprivation (Table 3.14 and Figure 3.16). The highest emissions (absolute and %) are in the lowest quintile. The most deprived 20 % of wards are the location for 42 % of the total tonnage of PM_{10} emissions from IPC sites in England, whilst the least deprived 20 % of wards are the location for less than 0.5 %. That there are substantial emissions in the more deprived wards is relevant to the air quality 'pollution-poverty' hot spot analysis discussed in section 4.6.

Table 3.14: PM_{10} emission sources and total released from IPC sites in England against location in population weighted ward deprivation quintiles.

Deprivation quintile	**Total Number of IPC PM_{10} Sources**	**Percentage of IPC PM_{10} sources**	**Total Kg of PM_{10} released from IPC sites**	**Percentage of total PM_{10} released from IPC sites**
1	30	31.9	7702469	42.1
2	17	18.1	3309871	18.1
3	23	24.5	2987480	16.3
4	18	19.1	4215719	23.1
5	6	6.4	65844	0.4
England	94	100	18,281,383	100

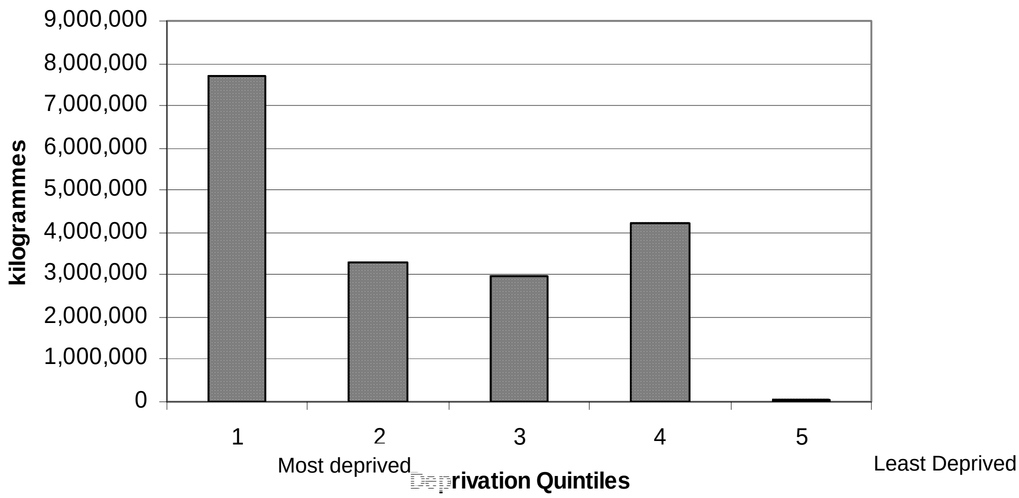


Figure 3.16: Total Emissions of PM_{10} from IPC sites in England by population weighted ward deprivation quintile (CI = 0.28).

Carcinogenic emissions cover 35 substances released to air from at least one site in 2001 (see section 3.2.4 for discussion of definition and make-up of this category). Aggregating the mass emission of these substances is clearly very different from aggregating mass emission of one substance alone, as no account is taken of comparative levels of toxicity or risk between substances. Total carcinogen emission can therefore only be used as a basic indicator of potential carcinogen hazard. Table 3.15 and Figure 3.17 show a strong relationship of carcinogen emission with deprivation. The most deprived 20 % of wards is the location for half of all carcinogen emissions from IPC sites, compared to just 8.6 % of all emission in the least deprived wards. We note that of the carcinogen emissions in the most deprived quintile, most are in the second deprivation decile (45.4% emission in decile 2, 4.5 % in decile 1).

Table 3.15: Carcinogenic emission sources to air and total released from IPC sites in England against location in population weighted ward deprivation quintiles.

Quintile	**Total Number of IPC sources of carcinogens emitted to air**	**%**	**Total kg of IPC sources of carcinogens emitted to air**	**%**
1	379	35.0	3,686,532	49.9
2	233	21.5	784,097	10.6
3	232	21.4	1,089,725	14.8
4	190	17.5	1,187,127	16.1
5	49	4.5	637,805	8.6
England	1083	100	7,385,286	100

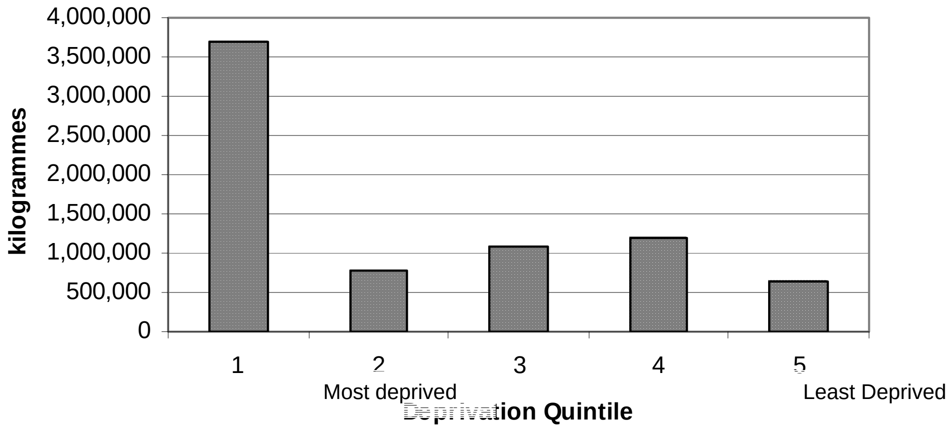


Figure 3.17: Total Emissions of Carcinogenic Substances to air from IPC sites in England by population weighted deprivation quintile (CI = 0.28).

These results are not as acute as those produced by Friends of the Earth (FoE 2001). FoE found that 82 % of carcinogenic emissions were released in the least deprived 20 % of wards compared to 49.9 % in our analysis. The differences are likely explained by the use of different data (we used 2001 rather than 1999), our use of population weighted deprivation deciles, and the different definitions of 'carcinogenic emissions'.

3.4 IPC Sites and Deprivation in Wales

The discussion of results for Wales mirrors that for England beginning with an overview of the general pattern of IPC site distribution without differentiating between types of site or site characteristics. Types of differentiation and approaches to analysis are then introduced, including the use of OPRA scores to explore possible relationships between pollution hazard and operator performance and the social profile of site locations.

Table 3.16: Sites, Authorisations and Emissions (Total, %) by population weighted ward deprivation decile for Wales (using 'site in ward' counting method)

	Number of Sites			%		
Decile	Sites	Authorisations	Emissions	Sites	Authorisations	Emissions
1	5	5	24	5	3	2
2	12	20	120	11	13	9
3	9	13	99	8	8	7
4	18	25	239	17	16	17
5	6	8	74	6	5	5
6	10	14	79	9	9	6
7	17	28	383	16	18	27
8	11	17	145	10	11	10
9	7	7	126	6	5	9
10	13	16	113	12	10	8
Wales	108	153	1402	100	100	100

3.4.1 Numbers of Sites, Authorisations and Emissions in Wards

There are 108 IPC sites in Wales, one tenth the number in England. These sites contain a 153 authorisations and 1,402 emissions, compared to 1,467 and 12,886 in England.

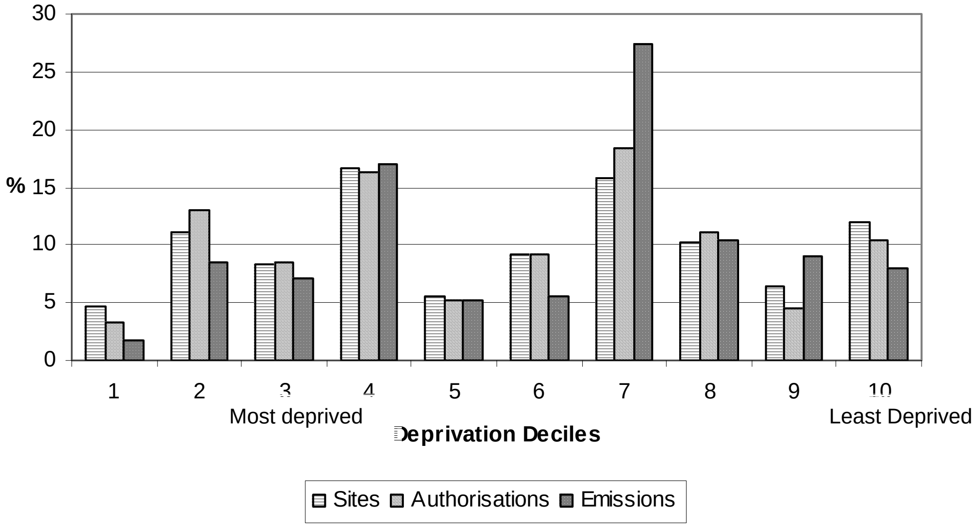


Figure 3.18: Percentage of Sites, Authorisations and Emissions by population weighted ward deprivation decile for Wales (using 'site in ward' counting method) Gini CI values = -0.04 (sites) -0.03 (authorisations) -0.11 (emissions).

The site in ward counts for sites, authorisations and emissions show no clear relationship with deprivation with the highest numbers in the deciles four and seven and the lowest numbers in the most deprived decile (one). The CI values indicate a very marginal bias towards the *less* deprived deciles and is slightly less marginal for emissions.

This data shows some similarity to the Friends of the Earth analysis (FoE 2000) which examined the relationship between IPC site locations and income data at regional and national levels. For Wales, it was found that there was little numerical relation with poverty, with average income in postcode sectors with IPC sites nearly identical to that of sectors without IPC sites.

3.4.2 Population Proximity to IPC Sites

Using the population proximity within a buffer method produces evidence of a relationship with deprivation. Table 3.17 and Figure 3.19 show populations within each deprivation decile living within four buffer distances. For the 500 m and 1 km buffers the Gini CI values of 0.26 and 0.18 indicate an overall bias towards the lower deciles, but to a lesser degree than for England which had equivalent Gini CI values of 0.31. Gini CI values decline further for the larger buffers, with a value of 0.02 for the 4 km buffer, indicating little or no bias. The inequality is also less skewed in Wales towards the *most* deprived decile. This disparity between methods suggest that the population proximity data is addressing populations near to IPC sites, but not those located within the same wards as the sites.

Table 3.17: Populations (total, %) living within 500m, 1 km, 2 km and 4 km of an IPC site by deprivation deciles for Wales.

Decile	Total Pop.	Population within 0.5km of an IPC Site		Population within 1km of an IPC Site		Population within 2km of an IPC Site		Population within 4km of an IPC Site	
		Total	%	Total	%	Total	%	Total	%
1	295,756	4,593	11.4	19,790	9.2	67,055	10.2	140,464	9.5
2	303,561	6,159	15.3	37,506	17.4	91,094	13.9	176,942	12.0
3	300,369	9,996	24.8	37,521	17.4	98,428	15.0	168,553	11.4
4	299,361	5,595	13.9	32,855	15.2	87,044	13.3	161,407	10.9
5	300,428	3,359	8.3	17,619	8.2	57,159	8.7	139,057	9.4
6	301,111	3,306	8.2	18,529	8.6	57,116	8.7	124,059	8.4
7	299,134	665	1.6	6,102	2.8	30,345	4.6	95,292	6.5
8	299,734	3,649	9.0	17,536	8.1	54,180	8.3	156,419	10.6
9	294,134	1,056	2.6	15,265	7.1	57,802	8.8	175,307	11.9
10	308,241	1,999	5.0	12,890	6.0	54,089	8.3	139,389	9.4
	3,001,829	40,377	100	215,614	100	654,312	100	1,476,889	100

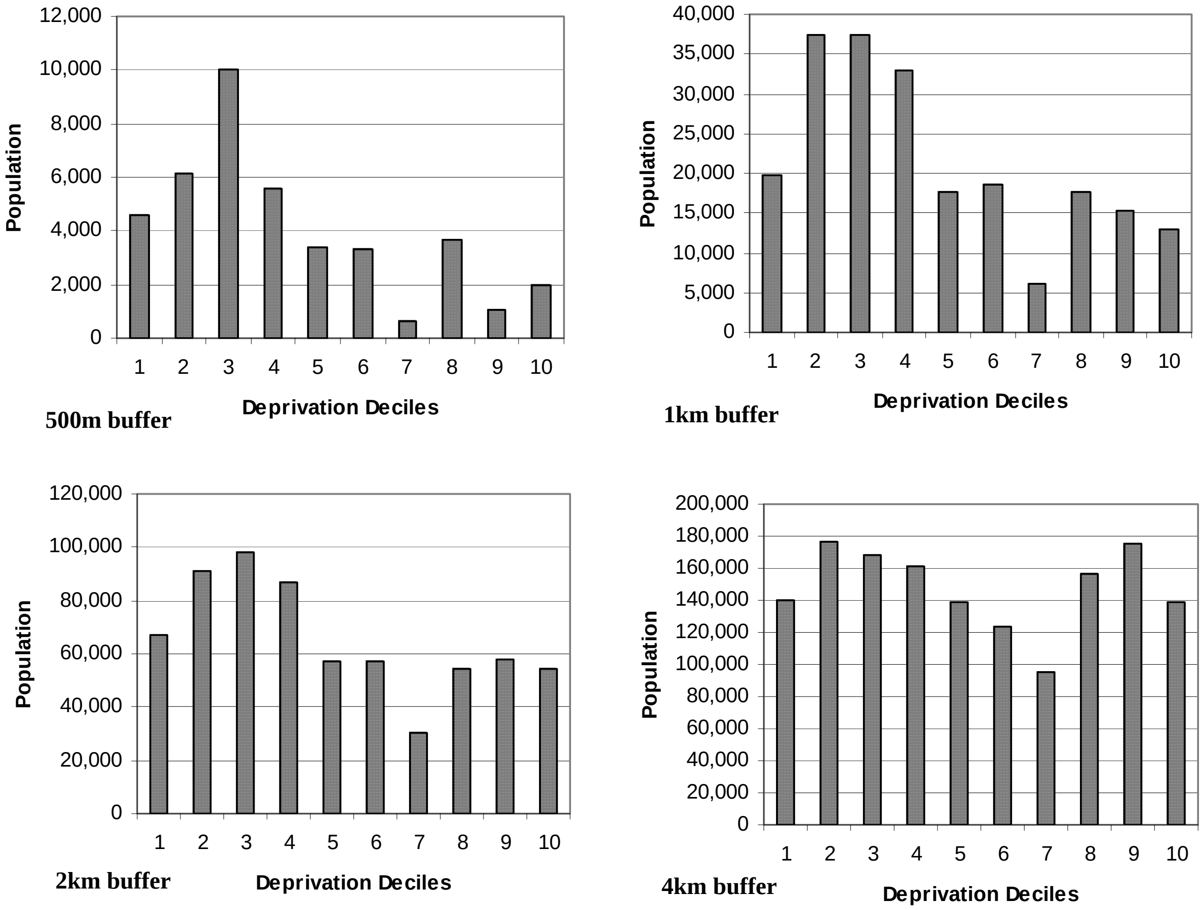


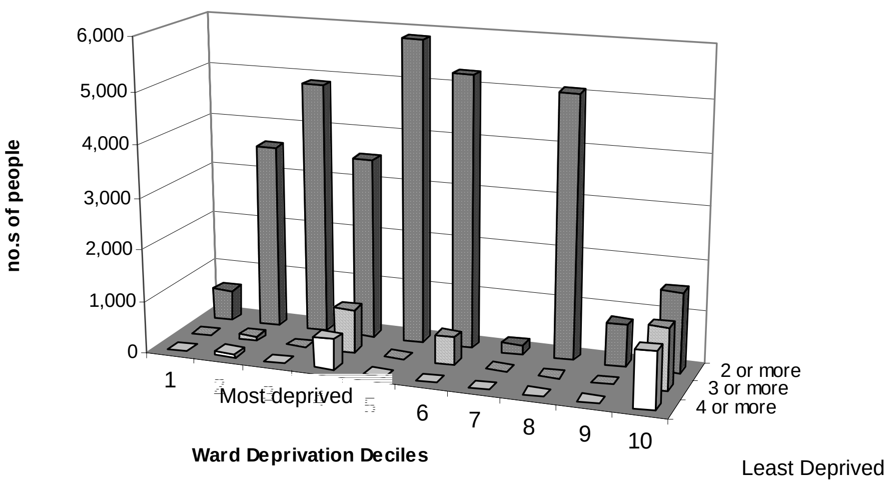
Figure 3.19: Total populations living within 500m, 1 km, 2 km and 4 km of an IPC site by population weighted ward deprivation deciles for Wales. (CI values = 0.26 for 500m, 0.18 for 1km, 0.11 for 2km, 0.02 for 4km)

3.4.3 Population Proximity to Multiple Sites, Authorisations and Emissions

The number of people living in proximity to multiple sites and the concentration of multiple sites in Wales is significantly lower than in England (Table 3.18, Fig 3.20). There is also little evidence of multiple sites being disproportionately located in the more deprived deciles, indeed the Gini CI values show a bias towards the *less* deprived deciles as proximity to multiple sites increases. The proportions of population within a decile living within 1 km of two or more sites is highest in deprivation bands 5, 6, 3 and 8 with a low figure in band 1, the most deprived. For proximity to 'four or more' sites the total population involved is low but greatest in the *least* deprived decile. A similar overall pattern with deprivation was found for authorisations and emissions.

Table 3.18: Numbers of people living within 1 km of multiple sites by population weighted ward deprivation deciles for Wales

Decile	Total Population	Number of Sites			
		4 or more	3 or more	2 or more	1 or more
1	295,756	0	0	596	19,790
2	303,561	70	89	3,576	37,506
3	300,369	0	0	4,871	37,521
4	299,361	593	842	3,502	32,855
5	300,428	0	0	5,866	17,619
6	301,111	0	538	5,269	18,529
7	299,134	0	11	181	6,102
8	299,734	0	0	5,067	17,536
9	294,134	0	0	802	15,265
10	308,241	1,085	1,191	1,547	12,890
Wales	3,001,829	1,748	2,672	31,277	215,614



No of Sites	5 + sites	4 sites	3 sites	2 sites	1 site
Gini Concentration Index	N/A	-0.43	-0.30	0.07	0.18

Figure 3.20: Number of people living within 1km of multiple IPC sites by population weighted deprivation deciles for Wales.

Table 3.19: Sites (total and %) in industry sectors by population weighted deprivation deciles for Wales

Decile	Total Sites	Fuel	%	Mineral	%	Metals	%	Chemicals	%	Waste	Other
1	5	1	3	0	0	1	6	3	3	0	0
2	12	4	11	0	0	1	6	7	17	0	0
3	9	2	6	1	13	1	6	5	10	0	0
4	18	6	17	1	13	4	29	6	13	0	1
5	6	0	0	2	25	0	0	4	7	0	0
6	10	2	6	0	0	2	18	5	9	0	1
7	17	10	37	0	0	3	29	4	12	0	0
8	11	0	0	2	25	1	6	5	13	2	1
9	7	2	6	2	25	0	0	2	2	0	1
10	13	4	14	0	0	0	0	9	13	0	0
Wales	108	31	100	8	100	13	100	50	100	2	4

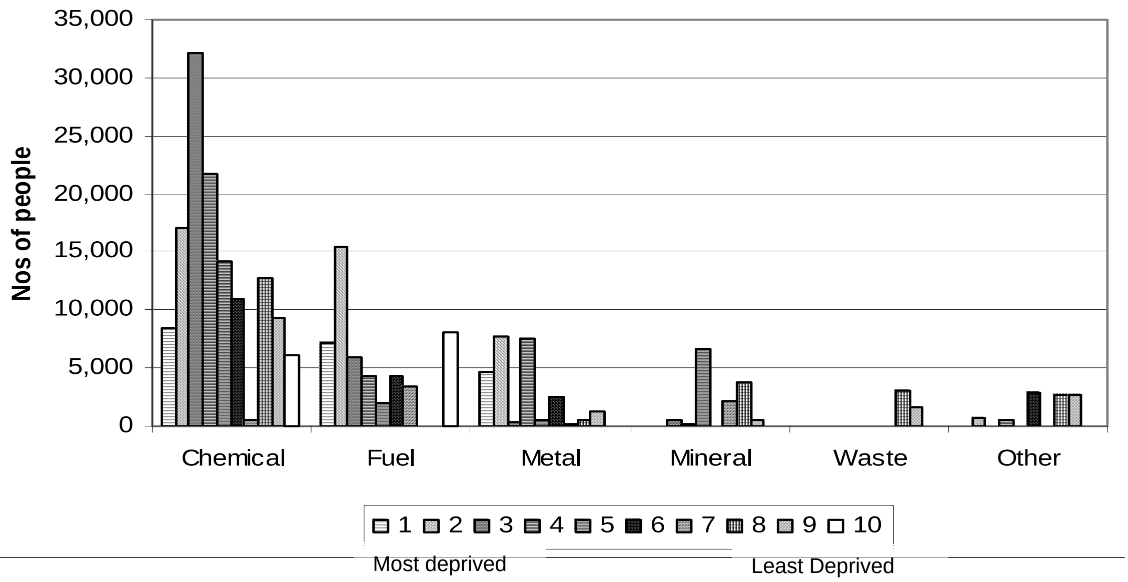
Table 3.20: Population (total and %) within 1km of IPC sites for industrial sector by population weighted deprivation decile for Wales.

Decile	Total Pop.	Population within 1km	%	Fuel	%	Minerals	%	Metals	%	Chemicals	%	Waste	%	Other	%
1	295,756	19,790	9.2	7,138	14.1	0	0.0	4,749	18.7	8,474	6.4	0	0.0	0	0.0
2	303,561	37,506	17.4	15,364	30.3	0	0.0	7,780	30.6	17,086	12.8	0	0.0	695	7.4
3	300,369	37,521	17.4	5,908	11.7	572	4.1	418	1.6	32,134	24.1	0	0.0	0	0.0
4	299,361	32,855	15.2	4,302	8.5	251	1.8	7,563	29.7	21,729	16.3	0	0.0	471	5.0
5	300,428	17,619	8.2	2,017	4.0	6,667	47.8	594	2.3	14,222	10.7	0	0.0	0	0.0
6	301,111	18,529	8.6	4,340	8.6	0	0.0	2,475	9.7	11,006	8.3	0	0.0	2,862	30.4
7	299,134	6,102	2.8	3,398	6.7	2,149	15.4	145	0.6	488	0.4	0	0.0	0	0.0
8	299,734	17,536	8.1	0	0.0	3,744	26.8	484	1.9	12,679	9.5	3,082	65.0	2,615	27.8
9	294,134	15,265	7.1	80	0.2	561	4.0	1,252	4.9	9,318	7.0	1,613	34.0	2,760	29.4
10	308,241	12,890	6.0	8,091	16.0	15	0.1	0	0.0	6,019	4.5	47	1.0	0	0.0
Wales	3,001,829	215,614	100	50,637	100	13,958	100	25,462	100	133,154	100	4,742	100	9,402	100.0

3.4.4 Analysis by Industry Sector

The analysis of data by industry sector for Wales is constrained by the low number of sites in some sectors. For the waste sector there are only two sites, minerals eight and for metals just 13. For the two sectors where there are a greater number of sites (chemicals and fuel) there is no evident relationship with deprivation through a count of site locations in wards. For chemicals there are nine sites each in deciles of low and high deprivation (10 and 2). The two waste sites in Wales are in both decile 8.

These patterns across the industry sectors are not fully maintained in the 1 km buffer analysis which reveals more distinct patterns, as it did in the English analysis. In Table 3.20 and Figure 3.21 there are biases towards more deprived deciles for chemical, fuel and metal sectors, and towards the less deprived for mineral, waste and other industries. For the two waste sites the entire population within 1 km is to be found in the more affluent deciles (8, 9 and 10). The chemical sector shows significantly greater numbers of people in deprived deciles (2, 3 and 4) and comparatively few people in decile 10, a pattern out of proportion to the distribution of sites (shown in Table 3.19). This suggests that the buffer analysis selects sites located in wards in decile 10 that have a low population density within 1 km when compared to sites in other wards. A different pattern is however found in the fuel sector where the second highest number of people within 1 km of IPC sites is in the least deprived decile.



Site type	All sites	Chemical	Fuel	Metal	Mineral	Waste	Other
Gini CI values	0.18	0.18	0.25	0.43	-0.14	-0.57	-0.31

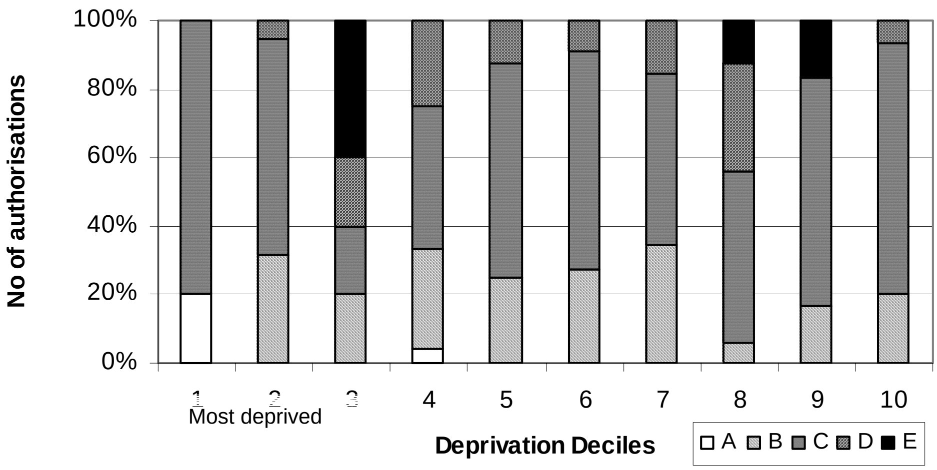
Figure 3.21: Population resident within 1 km of IPC sites by industry for Wales

3.4.5 Differentiation by Scale of Pollution Hazard

Using the Pollution Hazard Appraisal scores to differentiate IPC sites in terms of the level of pollution hazard they present produced no clear pattern with deprivation (Table 3.21 and Figure 3.22). The low number of authorisations in some categories makes interpretation using percentages unproductive, whilst the absolute numbers show no clear pattern across the deciles. The highest hazard sites (band E) occur in deciles 4, 8 and 9 and the Gini CI values are all close to zero, indicating an equal social distribution.

Table 3.21: Pollution Hazard Appraisal (PHA) scores for authorisations falling within population weighted ward deciles for Wales

Decile	Total Authorisations	PHA Band					
		A	B	C	D	E	No Record
1	5	1	0	4	0	0	0
2	20	0	6	12	1	0	1
3	13	0	2	2	2	4	3
4	25	1	7	10	6	0	1
5	8	0	2	5	1	0	0
6	14	0	3	7	1	0	3
7	28	0	9	13	4	0	2
8	17	0	1	8	5	2	1
9	7	0	1	4	0	1	1
10	16	0	3	11	1	0	1
Wales	153	2	34	76	21	7	13



PHA Hazard Band	A	B	C	D	E	All
Gini CI index	N/A	0.02	-0.06	-0.05	0.04	- 0.03

Figure 3.22: Pollution Hazard Appraisal (PHA) scores of authorisations in Wales by deprivation deciles (A = low pollution hazard, E = high)

One element of the PHA rating which is particularly relevant to the day to day experience of living near to an IPC site is the score given to ‘offensive characteristics’ that are likely to give ‘local annoyance’. The distribution of scores for this element of PHA is shown in Table 3.22.

Table 3.22: Authorisation Scores for 'offensive characteristics' against population weighted ward deprivation deciles for Wales

Decile	Total Authorisations	Offensive Characteristics Score (PHA)					
		1	**2**	**3**	**4**	**5**	**No Record**
1	5	2	2	0	1	0	0
2	20	4	7	5	3	0	1
3	13	1	3	2	0	4	3
4	25	9	4	6	3	2	1
5	8	3	4	0	1	0	0
6	14	2	3	3	2	1	3
7	28	6	8	6	3	3	2
8	17	3	0	5	3	5	1
9	7	1	2	2	0	1	1
10	16	2	6	6	1	0	1
Wales	153	33	39	35	17	16	13

Again it is hard to discern a pattern but focusing on authorisations with the highest score of 5 there are marginally greater proportions of these towards the less deprived deciles, but the trend is not strong.

3.4.6 Operator Performance at IPC sites

Table 3.23 shows total authorisations in operator performance appraisal (OPA) bands. Again it is hard to discern any pattern. All the best run sites (Band A) are in decile 4, and the worst run (band D) (there are none in Band E in Wales) are distributed across the mid range of deciles, not at either extreme. This data therefore provides no evidence of a clear relationship between operator performance and deprivation.

Table 3.23: Operator Performance Appraisal Scores against population weighted ward deprivation deciles for England

Decile	Total Authorisations	*Good*	OPA Band			*Poor*	
		A	**B**	**C**	**D**	**E**	**No Record**
1	5	0	4	1	0	0	0
2	20	0	6	13	0	0	1
3	13	0	1	8	1	0	3
4	25	6	7	9	2	0	1
5	8	0	0	7	1	0	0
6	14	0	2	6	3	0	3
7	28	0	15	11	0	0	2
8	17	0	0	13	3	0	1
9	7	0	3	2	1	0	1
10	16	0	6	9	0	0	1
Wales	153	6	44	79	11	0	13

Figure 3.23: Percentage Operator Performance Appraisal (OPA) Bandings for IPC authorisations within deprivation deciles (A = good performance, E = poor).

3.4.7 IPC sites producing emissions to air

In total out of the 108 IPC sites in Wales, 96 sites made at least one emission to air. Of the total of 1,402 authorised emissions from IPC sites, 702 were made to air. As in England, the patterns against deprivation deciles are very similar for sites making emissions to air as they are for all sites for both site in ward counts (Table 3.24) and population within 1 km (Table 3.25).

Table 3.24: Social distribution of sites, authorisations and emissions (all, and emission to air sub-set) for population weighted ward deciles for Wales.

Decile	All Sites	Sites with at least one emission to air	All Authoris-ations	Authorisations with at least one emission to air	All Emissions	Emissions to Air
1	5	5	3	4	2	1
2	11	11	13	15	9	10
3	8	8	8	9	7	5
4	17	17	16	16	17	17
5	6	6	5	5	5	7
6	9	7	9	7	6	4
7	16	16	18	19	27	27
8	10	9	11	9	10	9
9	6	6	5	5	9	11
10	12	14	10	12	8	10
Wales	100	100	100	100	100	100

Table 3.25: Population (%) living within 1 km of an IPC site, and within 1 km of an IPC site producing at least 1 emission to air against, by population weighted ward deprivation deciles for Wales (CI = 0.18 for both)

Decile	% Population within 1km of an IPC Site	% Population within 1km of an IPC Site with at least 1 emission to air
1	9.2	10.0
2	17.4	18.3
3	17.4	18.1
4	15.2	10.2
5	8.2	8.9
6	8.6	8.5
7	2.8	3.0
8	8.1	8.8
9	7.1	7.7
10	6.0	6.3
	100	100

3.4.8 IPC sites and date of authorisation

Due to the relatively small number of authorisations in Wales over the period 1997-2001 it is difficult to discern any general pattern of authorisations against deprivation. However, the data in Table 3.26 shows that there has been no particular bias towards the lower deprivation deciles with the highest percent of new authorisations in deciles 4 and 7, and no new authorisations all the most deprived decile (1).

Table 3.26: Totals and percentages of authorisations per population weighted ward deprivation decile for 1991-91 and 1997-2001 for Wales

Decile	All authorisations		1991-96		1997-2001	
	Totals	%	Totals	%	Totals	%
1	5	3.3	5	2.1	0	0.0
2	20	13.1	24	9.9	1	4.2
3	13	8.5	32	13.2	0	0.0
4	25	16.3	31	12.8	7	29.2
5	8	5.2	25	10.3	1	4.2
6	14	9.2	19	7.9	2	8.3
7	28	18.3	34	14.0	5	20.8
8	17	11.1	35	14.5	4	16.7
9	7	4.6	18	7.4	2	8.3
10	16	10.5	19	7.9	2	8.3
Wales	153	100	242	100	24	100

3.4.9 NO_2, PM_{10} and Carcinogenic Emissions

NO_2 emissions are unevenly distributed by deprivation quintiles with release amounts reflecting the influence of a small number of major emission sources. By far the greatest emission level is released in quintile five, the least deprived (58.4 % of total) with only very small emission levels in the most deprived deciles. The bias towards the least deprived is also indicated by the high negative Gini CI value of -0.43.

Table 3.27: NO_2 emission sources and total released from IPC sites in Wales against location in population weighted ward deprivation quintile.

Quintile	Total Number of IPC NO_2 Sources	Percentage of IPC NO_2 sources	Total mass (kg) of NO_2 released from IPC sites	Total (%) NO_2 released from IPC sites
1	7	14.6	428,090	0.9
2	12	25.0	8,111,699	16.4
3	5	10.4	222,000	0.4
4	15	31.3	11,800,583	23.8
5	9	18.8	28,920,457	58.4
Wales	48	100	49,482,829	100

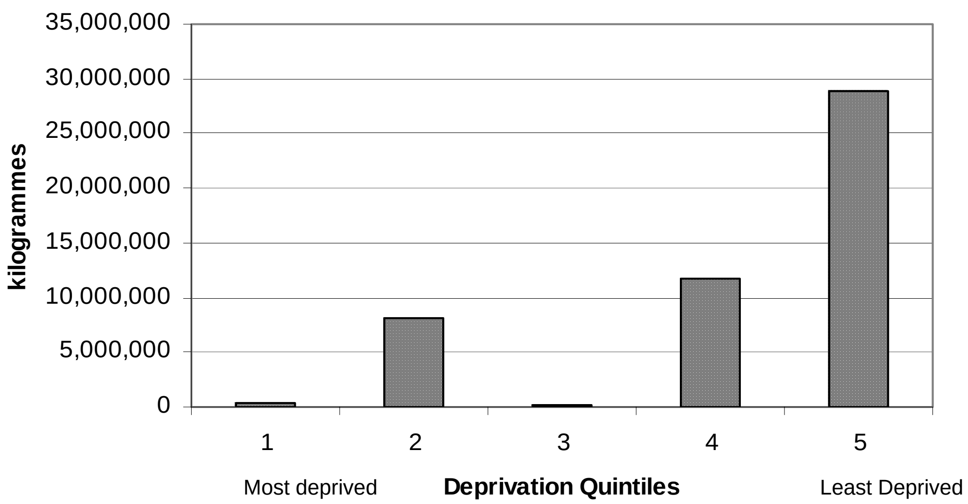


Figure 3.24: Total Emissions of NO_2 from IPC sites in Wales by population weighted ward deprivation quintile (CI = -0.43).

There are only 21 emissions of PM_{10} from IPC sites in Wales with a few large sources dominating and these are unevenly distributed across the quintiles. There is an uneven association with level of deprivation with the greatest emissions in quintile two. As indicated by the negative Gini CI value (-0.16) there is an inverse bias with higher emissions in the less deprived wards.

Table 3.28: PM_{10} emission sources and total released from IPC sites in Wales against location in population weighted ward deprivation quintile.

Quintile	Total Number of IPC PM_{10} Sources	Percentage of IPC PM_{10} sources	Total mass (Kg) of PM_{10} released from IPC sites	Percentage of total PM_{10} released from IPC sites
1	1	4.8	73000	1.87
2	4	19.0	1568100	40.17
3	2	9.5	39900	1.02
4	8	38.1	1050350	26.91
5	6	28.6	1172100	30.03
Wales	21	100	3903450	100

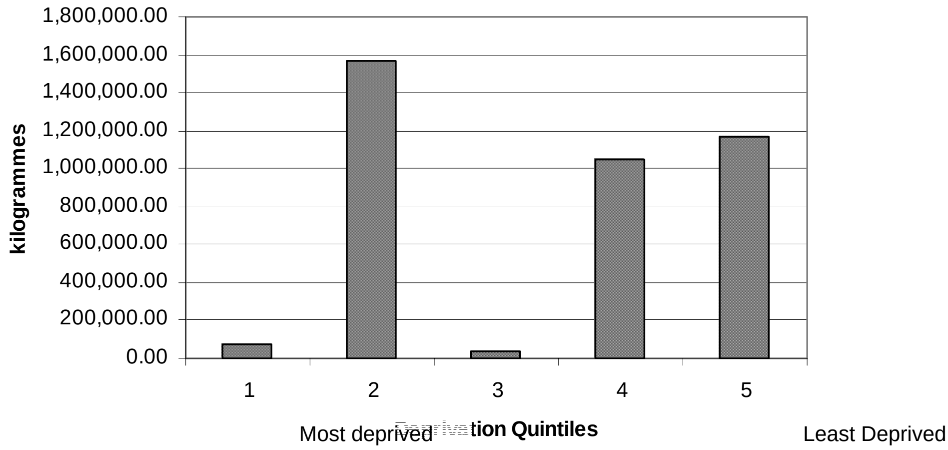


Figure 3.25: Total Emissions of PM_{10} from IPC sites in Wales by population weighted deprivation quintile (CI = -0.16).

Carcinogenic emissions are greater in number in Wales with 176 separate sources. The highest level of emission is in quintile four and the negative CI value (-0.27) again shows an inverse relationship with deprivation. There are only 0.8 % of total emissions in the most deprived quintile, compared to 26.3% in the *least* deprived.

Table 3.29: Carcinogenic emission sources to air and total released from IPC sites in Wales against location in wards in population weighted deprivation quintiles.

Quintile	Total Number of IPC sources of carcinogens emitted to air	Percentage of IPC sources of carcinogenic emissions emitted to air	Total Kilograms of carcinogenic emissions to air	Percentage of total amount of carcinogenic emissions to air
1	12	6.8	3,053	0.8
2	43	24.4	65,871	16.9
3	17	9.7	39,281	10.1
4	67	38.1	179,415	46.0
5	37	21.0	102,633	26.3
Wales	176	100	390,523	100

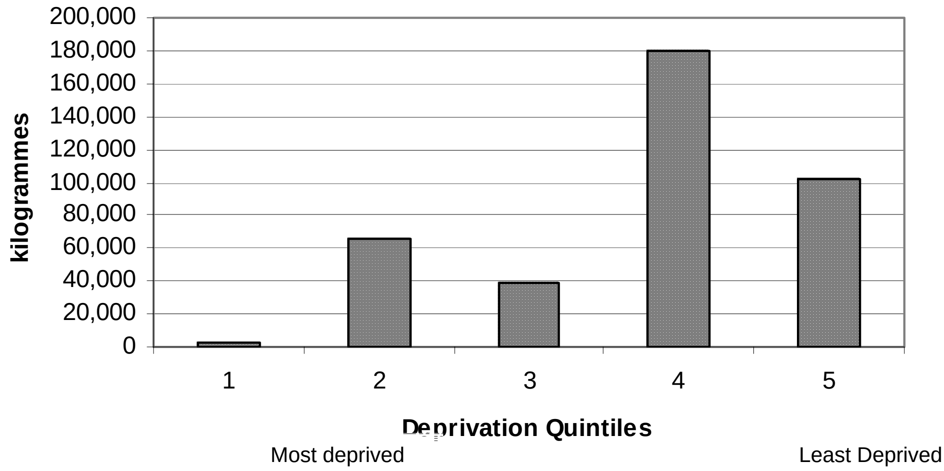


Figure 3.26: Total Emissions of Carcinogenic Substances to air from IPC sites in Wales by population weighted deprivation quintile (CI = -0.27).

3.5 Discussion

3.5.1 The social distribution of IPC sites

The analysis we have undertaken for IPC sites has examined the available national data sets in a number of different ways. This depth of analysis was intended to add value and understanding to the results already available from existing research. The results for England and for Wales are first summarised before questions of causality and possible policy response are considered.

The social distribution of IPC sites in England

There is compelling evidence of a socially unequal distribution of IPC sites in England. These significant sources of pollution are disproportionately located in more deprived areas - as measured both through counting locations of sites in wards and through analysing the deprivation characteristics of populations living within 1 km of each site. There are four times as many sites in the most deprived ward decile, compared to the least deprived; and six times more people living within 1 km of a site. IPC sites are also more clustered in deprived areas, with the proportion of people living within 1 km of multiple sites higher than in more wealthy areas. IPC sites in deprived areas on average produce greater numbers of emissions and present a greater potential pollution hazard, as indicated by the Agency in authorisation OPRA scores. They also produce more 'offensive' pollutants in deprived areas which are likely to have an impact on the day-to-day quality of life for people living nearby. Levels of PM_{10} emissions to air from IPC sites are disproportionately high in more deprived wards and to a lesser extent also emissions of NO_2.

Waste sites in particular stand out as being disproportionately located in more deprived areas with the proportion of the population living within 1 km 39 times higher in the most deprived decile compared to the least deprived. This raises particular issues for waste policy regarding the social distribution of local impacts from incinerators at a time when a substantial programme of new incinerator construction is planned.

A detailed analysis of where in England particular associations between IPC sites and deprivation are occurring has not been possible within the remit of this project. However, Figure 3.27, which maps the locations of IPC sites in relation to the lower and upper quintiles, visually shows both the association between deprived wards and site location and where in the country sites are most concentrated. Many tight clusters of sites in industrial-urban areas can be identified – including the North West in the area running from Liverpool through to Manchester, Leeds and Bradford, Sheffield, Birmingham, Teesside, Tyneside and in London along the Thames estuary.

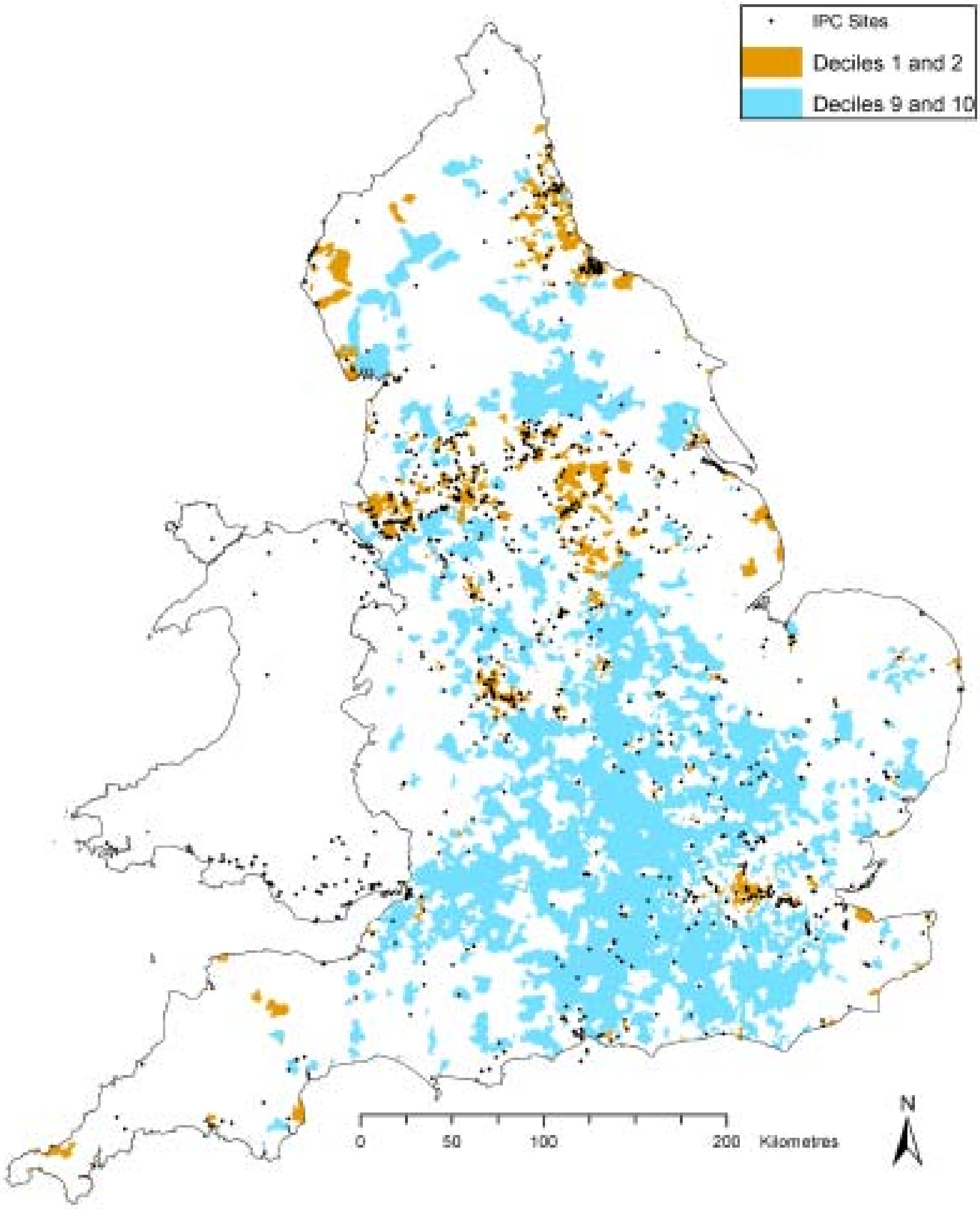


Figure 3.27: The spatial distribution of IPC sites in England and wards in deciles 1 and 2 (most deprived) and 9 and 10 (least deprived)

The social distribution of IPC sites in Wales

In contrast to England the patterns of distribution of IPC sites in Wales shows little relation to deprivation. The locations of sites in wards analysis shows no association with deprivation, although the population within 1 km of an IPC site does exhibit some bias towards more deprived deciles (but not the *most* deprived). There is little evidence of multiple sites being disproportionately located in more deprived areas or of a greater concentration of emission sources or processes producing a greater pollution hazard. The 1 km buffer analysis reveal that chemical sites tend to have more deprived than less deprived people living near to them, but the converse is true for the fuel sector and for waste sites (although there are only two of the latter in Wales). Emissions of NO_2, PM_{10} and carcinogens are all biased towards the less deprived wards. An explanation for the social pattern of sites in Wales and the differences between England and Wales merits further investigation. However, the reasons appear to be in part associated with the geography of deprivation in Wales. Figure 3.28 shows that the most deprived wards particularly in the South Wales valleys have few IPC sites, explained by the particular industrial history of these areas.

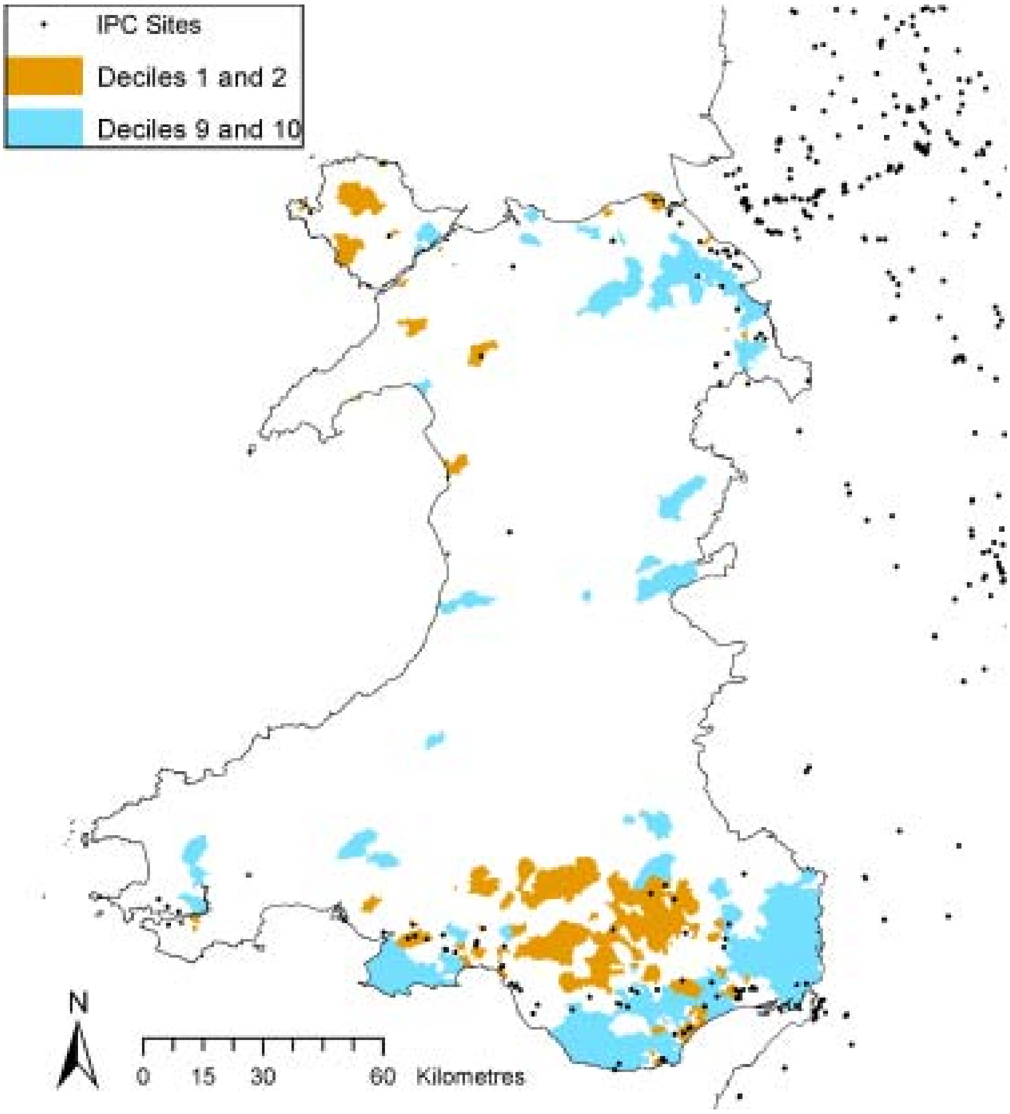


Figure 3.28: The spatial distribution of IPC sites in Wales and wards in deciles 1 and 2 (most deprived) and 9 and 10 (least deprived)

3.5.2 Inequality, Inequity and Causality

Whilst there is strong evidence that in England there is a distributional inequality in the location of IPC sites, the extent to which this is seen as inequitable and unfair and in need of redress is a question of judgement. There are a number of dimensions to this judgement, each of which may be evaluated in different ways by different stakeholders. These include:

- the extent to which proximity to sites and emission sources is considered to produce undesirable impacts of various forms. Proximity is only a surrogate for impacts. For some impacts, such as visual impacts and 'place stigma' it may be considered a good surrogate, for others such as health, proximity may be considered a cruder indicator;

- the extent to which the spatial and social distribution of the benefits gained from IPC sites, such as employment, is considered to be able to provide a balancing factor against unequal impacts;

- the extent to which 'informed choice' is considered to have been exercised by people in living in areas near to IPC sites - are they choosing to live 'at risk' in order to gain other benefits?;

- whether there are particular decision-making processes operated by public or private bodies that make sites in deprived areas more potentially or actually hazardous;

- whether there are particular discriminatory decision-making processes operated by public or private bodies which have created or are reinforcing the unequal distributions of sites

In our analysis we have only been able to begin to touch on some of these questions through the examination of national data sets. In particular, issues of causality, why the association between deprivation and site location exists, are very difficult to address through a national level statistical analysis (see Mitchell and Walker 2003 for discussion) and may need to be explored through alternative and more locally focused research methods. However, we have been able to establish that:

- for emissions to air, which are more directly linked to health impacts, the social distribution of site locations is largely the same as for all IPC sites;

- there is no evidence from the scores given by the Agency for operator performance that sites are worse run in deprived areas and therefore are presenting a greater level of risk due to poor site management. This provides some rebuttal of the hypothesis that companies will be more responsive to concerns expressed by more wealthy, articulate and politically influential communities, rather than more marginalised communities, albeit from evidence only on a macro national scale;

- there is no evidence from our analysis that the Agency's site inspection priorities discriminate against deprived areas. As inspection priorities are guided by OPRA scores the higher pollution hazard ratings in deprived areas should *rather* focus attention on sites in more deprived areas; and

- there is no evidence that authorisations applied for and granted more recently are disproportionately biased towards more deprived areas. Whilst this provides some rebuttal of the hypothesis that companies have become more sensitive to NIMBY reactions and could therefore be deliberately targeting less organised and mobilised communities in new site investments, it also shows that patterns of new authorisations are not becoming more equitable than they have been in the past. In other words past patterns are being maintained, probably largely because new processes tend to be established at existing site locations or in areas where other polluting industry already exists.

Whilst these aspects of the analysis therefore provide some evidence of relevance to judgements of inequity and unfairness and the causes of unequal distributions in site locations, they cannot provide definitive answers. Some of the recommendations we make for further research below are intended to focus on analyses that may improve our information base and understanding in the future.

3.5.3 The range of responses

One line of argument emerging from the considerations outlined above could be to argue that, whilst there is an inequality, there is either too little known about the causes of the inequality, or its impacts to justify taking action; or more fundamentally that the fact that deprived people live in undesirable areas is just a fact of life, 'the way things are', and that making a policy response is therefore unnecessary.

If, however, we assume that the many dimensions of the unequal distribution of IPC sites *can* reasonably lead us to a conclusion that this situation is unfair and needs to be addressed in some way, what potential responses exist? The range of possibilities are numerous, but could include (ordered from the more radical to less so):

1. *Directing new IPC sites away from deprived areas.* Whilst not addressing the situation that currently exists, such a policy would ensure that the inequality of distribution did not increase. Such a response could in theory be achieved through land use planning policy but would go against typical current planning presumptions that polluting industry (or other undesirable activities) should be clustered together in areas of poor environmental quality rather than 'spread around'. Many further questions are raised by this form of response. By what criteria could such a policy be applied: is greater distributional equity being sought at a national, regional or local scale; what if deprived communities want to attract new industry to create jobs; is it politically realistic to direct say new incinerators into leafy suburbs?

2. *Applying higher standards in deprived areas in particular with multiple sites or emissions* The only way of addressing the current unequal situation (unless wholesale site relocation is advocated) is to take measures that disproportionately seek to reduce the impacts from IPC sites in deprived areas. A targeted approach could for example particularly focus on areas where there are multiple sites and multiple hazardous/offensive emissions and deprived populations. However, a number of difficult questions also need to be addressed here. How much of a concentration of sites or emissions or perhaps 'degree of cumulative risk' warrants a particular claim of injustice? How should impacts of 'applying higher standards' be

measured, through reductions in numbers of emissions, levels of emissions, or perhaps improvement in environmental management standards?

3. *Providing information on deprivation within decision-making processes.* Rather than laying down a general siting policy as above, an alternative is to develop decision-making processes that are informed about deprivation implications. Information on deprivation (and other social characteristics of affected populations) is not routinely produced within, for example, project or strategic environmental assessments, but could be seen as a relevant addition to other information supporting planning and policy decisions. Sharing such information with the local community could be seen as a particularly important dimension of local engagement.

4. *Developing compensatory benefits for deprived communities*. The concept of compensation derives from an economic view of the need to balance the unequal distribution of cost and benefit, and has been proposed particularly as a solution to problematic siting processes for 'locally unwanted land uses'. If particular communities are taking the burden of costs for the wider societal good, then they should receive compensatory benefits which in some form match the costs. Arguments for compensation may be particularly strong where deprived communities are taking the burden of costs whilst benefits are gained more by the wealthy. Compensation can take a range of forms beyond monetary, including, for example, greater investment in public services such as health and education and improvements in general environmental quality.

5. *Strengthen general emission and operator performance standards*. If IPC sites are disproportionately located in deprived areas it can be argued that across the board action to reduce emissions and improve operator performance will therefore help the poor more than others. An additional social justice argument is thus added to the case for investment of resources into environmental regulation and management more generally.

3.6 Recommendations

3.6.1 Recommendations for policy and practice

1. <u>The Agency should consider whether or not a targeting of regulatory attention on IPC sites in more deprived areas is warranted by the overall pattern of association between deprivation and site location in England</u>. This could be implemented in a number of ways such as an adjustment to OPRA scores, which are used to prioritise a number of Agency actions, to reflect deprivation data.

2. Whilst the Agency does not have decision-making powers over land use planning decisions it should <u>consider entering into dialogue with the ODPM and local planning authorities over possible planning and siting responses to the inequity of IPC site location</u> (as discussed above).

3. The fact that IPC sites are agglomerating particularly in deprived areas raises the question of whether sufficient significance is being given to the accumulation and

concentration of multiple emissions in such areas. If there is evidence that deprivation makes people more susceptible to experiencing health impacts from air pollutants in particular, then the case for being concerned about concentration of emissions is particularly strong. We therefore recommend that the Agency considers whether the evidence of social inequality in site distribution should stimulate further attention to be given to assessing the risks of cumulative and synergistic exposure to emissions from IPC sites.

4. Our analysis of air quality data has identified particular ‘poverty-pollution’ hot spots. One of the contributory sources to pollution in these areas could be emissions from IPC sites, providing a direct way in which the Agency can work with local authorities and others to address local air quality problems. We therefore recommend that the Agency undertakes further work to examine the relationship between poor air quality and IPC emissions in these ‘hot spot’ areas.

5. The generation of information on the social characteristics of communities living near to polluting sites has been one of the key responses made by the EPA in the US to the commitment to build environmental justice concerns into its policy and operating practices. That information is then used in a number of ways to inform decision-making and work with local communities. We recommend that the Agency considers similar action by developing techniques for social equity appraisal for IPC sites that can be used within the Agency and by other key partners such as local planning authorities.

3.6.2 Recommendations for additional research

Whilst our research has provided a more detailed and wide ranging analysis of the social equity dimensions of IPC site locations, emissions, hazards and operator performance than previously available, there are still inevitably unanswered questions and ways in which the analysis could be extended. Areas for further specific IPC related research include:

- undertaking analysis in relation to other social variables (such as age, ethnicity, health);
- more intensive regional or local analysis (perhaps focused on agglomerations of polluting sites) which takes account of further contextual variables and pollution sources extending beyond IPC;
- analysis of processes of causation through more detailed longitudinal case studies of the sequencing of locational decisions (between sites and nearby development) and changes in the social make-up of local communities;
- analysis of the distribution of a wider range of emitted substances and groups of substances;
- investigation of patterns of site inspection and other aspects of Agency intervention in relation to the influence of local activism and political influence;

- use of improved spatial information such as site boundaries within analysis and the finer grained social information available from the 2001 census; and

- analysis of pollution incident data including the pattern of incidents at IPC sites.

4 AIR QUALITY

4.1 Introduction

Within the UK, air quality has been the subject of more environmental equity research than any other environmental issue, at least ten studies to date. We found this body of evidence to be insufficient to draw any firm conclusions on the relationship between air quality and social characteristics of resident populations (Mitchell and Walker 2003). The studies (described in Mitchell and Dorling 2003, Mitchell and Walker 2003) have addressed a range of pollutants (nitrous oxides, fine particulates, sulphur dioxide and carbon monoxide); scales (country, region, city); spatial units (local authority district, ward, enumeration district, grid cell, buffer zone); social characteristics (deprivation, ethnicity, age, population density); and analytical method.

It is apparent that these studies, particularly given their diverse nature, represent a small, heterogeneous body of research. Collectively, there is an indication that more deprived communities are located in areas of poorest air quality, but this finding is by no means consistent between studies examining common parameters. Two studies find an inverse association between pollutant concentration and deprivation (McLeod *et al.* 2000; King and Stedman 2000), whilst two studies report no association (Pye *et al.* 2001; Lyons *et al.* 2002). This has led to diametrically opposed conclusions for air quality management intended to address environmental equity. McLeod *et al.* (2000:p84) conclude that "measures taken to reduce air pollution in areas of similar population density, for example a city, may actually decrease equity and produce injustice". In contrast, Pye *et al.* (2001:p iv) conclude that "…targeted policies to reduce air pollution concentration in areas where they are high could impact marginally more beneficially in more deprived communities, and therefore move towards reducing the apparent inequity".

The confusion arising from these studies arises largely due to different treatments of space. The national study of McLeod *et al.* (2000) has good spatial coverage, but the spatial unit of analysis, the local authority district, is arguably too large to enable the highly variable distribution of air quality to be adequately addressed. Conversely, those studies that address smaller spatial units, such as wards, have largely addressed just a few cities, and hence do not provide a large enough sample of the UK population from which to determine more general trends. Hence both approaches prove to be of limited use in developing nationally relevant environmental equity policy.

Only two studies have investigated the social distribution of air quality at the national scale using a small area analysis (Environment Agency 2002; Mitchell and Dorling 2003). Both studies found that air quality is worse than average in more deprived areas, but that there is no simple linear relationship between deprivation and air quality. The purpose of the analysis reported here is to conduct further national-small area analysis of the relationship between air quality and deprivation, and in particular, further develop the earlier Environment Agency analysis.

Following our earlier work on issue scoping and review of methods (Mitchell and Walker 2003), and discussion at the stakeholder conference in April, the specific objectives of this part of the study are to conduct further national, ward level analyses of air quality and deprivation that:

- Addresses poverty using the Index of Multiple Deprivation (IMD 2000), the preferred governmental measure of deprivation (DETR, 2000a);
- Extends the analysis to cover Wales, as well as England;
- Increases the range of atmospheric pollutants previously studied by the Agency;
- Attempts equity analysis that addresses multiple pollutants collectively; and finally
- Investigates how environmental equity patterns vary over time.

4.2 Data and Methods

4.2.1 Study area and spatial unit of analysis

The study addressed England and Wales (as separate countries, see section 1.2), using the ward as the spatial unit of analysis. There are 8,414 wards in England and 865 in Wales. Wards are designed to contain roughly equal numbers of electors within local authority districts, thus ward size is density dependent, with small wards in urban centres and large wards in rural areas. This is a fortunate occurrence as air pollutant concentration gradients are generally high in urban centres and low in rural areas. Having small wards in urban centres thus minimises the range of pollutant values coincident with the ward area, and provides a more confident representation of mean air quality for that ward. Conducting a ward scale national study thus provides a resolution in which urban scale patterns can be resolved, but where potential bias of a small sample size incurred by city level studies can be overcome.

4.3 Atmospheric Pollutants

The study addressed five atmospheric pollutants: nitrogen dioxide (NO_2), fine particulates (PM_{10}), sulphur dioxide (SO_2), carbon monoxide (CO), and benzene, the latter commonly used as an indicator of total volatile organic carbon (VOC). These pollutants were selected so as to address concerns expressed in the UK National Air Quality Strategy (NAQS) (DETR, 2000b) developed in response to the 1995 Environment Act and the EU Air Quality Framework Directive (96/62/EC).

The NAQS objectives are shown in Table 4.1, which includes recent amendments (DEFRA 2003). These objectives are designed to protect human health, the principal aim of the NAQS (alternative standards are presented for protection of vegetation). Note that we have not addressed lead or 1,3-butadiene due to a lack of adequate small area national data. Ozone is also excluded from the analysis as it is a secondary pollutant, formed by reactions between VOC's, oxides of nitrogen and sunlight. These chemical reactions take place over hours or days, during which the pollutant can be transport many hundreds of kilometres. This means that ozone is not amenable to local level management, and hence is not included in the local air quality management regulations under the NAQS. Furthermore, ozone is not yet well modelled and mapped at fine spatial scale (regional models make estimates at 10 km grid scale for Europe). For these reasons, we chose not to address ozone in the equity analysis.

Table 4.1: National Air Quality Strategy Objectives

Pollutant	Objective concentration	Measured as	Achieved by
Benzene	16.25 μg/m^3 (5 ppb) 5.0 μg/m^3 (1.54 ppb) [1,2]	Running annual mean	31 Dec 2003 31 Dec 2010
1,3-butadiene	2.25 μg/m^3 (1 ppb)	Running annual mean	31 Dec 2003
Carbon monoxide	11.6 mg/m^3 (10 ppm) 10.0 mg/m^3 (8.6 ppm) [2]	Running 8 hour mean	31 Dec 2003 31 Dec 2010
Lead	0.50 μg/m^3	Annual mean	31 Dec 2004
	0.25 μg/m^3	Annual mean	31 Dec 2008
PAH's	0.25 ng/m3	24 hour mean	31 Dec 2010
Nitrogen dioxide	200 μg/m^3 (105 ppb) not to be exceeded > 18 times a year	1 hour mean	31 Dec 2005
	40 μg/m^3 (21 ppb)	Annual mean	31 Dec 2005
Particulates (PM_{10})	50 μg/m^3 not to be exceeded >35 times a year	24 hour mean	31 Dec 2004
	40 μg/m^3 20 μg/m^3 [3]	Annual mean	31 Dec 2004 31 Dec 2010
Sulphur dioxide	350 μg/m^3 (132 ppb) not to be exceeded > 24 times a year	1 hour mean	31 Dec 2004
	125 μg/m^3 (47 ppb) not to be exceeded > 3 times a year	24 hour mean	31 Dec 2004
	266 μg/m^3 (100 ppb) not to be exceeded > 35 times a year	15 minute mean	31 Dec 2005

Source: DEFRA (2003)

Notes:
1. A different objective applies to Scotland
2. A different objective applies to Northern Ireland
3. A different objective applies to London

4.3.1 Air quality data: derivation and limitations

Annual mean pollutant concentration maps for the UK in 2001 were provided by the National Environmental Technology Centre. The data are of annual mean concentrations for each 1 km^2 grid cell centroid in the UK. Data are available for 2001 (NO_2, PM_{10}, CO, SO_2 and benzene) and 2010 (NO_2 and PM_{10}). The maps can be viewed at the NETCEN website (www.airquality.co.uk).

The pollutant concentration maps are based upon emissions recorded in the National Atmospheric Emission Inventory (Goodwin *et al.* 2000). The inventory provides an estimate of total pollutant emission in a base year for a 1 x 1 km grid, based upon estimated emission in over 140 secondary sectors and nine principal sectors: residential, services, industry, road transport, off road vehicles, shipping, rail, aviation, and other. Emissions for future years are estimated by scaling base year emissions at the secondary sector level. Road traffic emissions, for example, are scaled using projected changes in vehicle activity and emission characteristics under a central growth scenario assuming current transport policies. Change in vehicle activity (kilometres travelled per year; vehicle speed by road type) is derived from national trip forecast models, and the change in emission characteristics of the vehicle fleet is a product of changing fleet composition (31 classes defined by vehicle type, age, fuel used) and changing emission factors by vehicle type.

Atmospheric concentrations are calculated from emissions by application of a dispersion box model. For secondary pollutants additional modelling is required. For example, in the case of oxides of nitrogen (NO_X), which are oxidised in the atmosphere to form NO_2 (the only nitrogen oxide for which an NAQS objective applies) the model applies a dispersion coefficient derived from regression of NO_X emissions in the vicinity of monitoring sites, against the difference between measured NO_X at the monitoring site, and background NO_X taken from a nearby rural site. Annual mean NO_2 concentrations are then calculated using non-linear functions relating atmospheric annual mean NO_X to annual mean NO_2 for geographical areas with characteristically different atmospheric chemistry: rural areas, urban areas and areas within 3 km of the centre of London. Note that road traffic is estimated to account for 50 % of total UK NO_X emission, rising to 75 % in urban areas (Goodwin *et al.* 2000).

The data upon which the box model functions are based were collected from 1990 to 1999 using the national automated monitoring network. Verification of the modelled concentrations using an independent set of measured data collected from 1996 to 1999 shows generally good agreement between observed and estimated concentrations (Stedman and Handley 2001). Further details of the air quality modelling procedures are described in Stedman *et al.* (1997) and Stedman *et al.* (2001a; 2001b).

Note that this modelled data addresses the annual mean only, and that there is no data for other averaging times (e.g. 8 or 24 hour mean). For each pollutant, descriptive statistics, including the ward mean, were calculated using a Geographic Information System (GIS) point in polygon analysis (i.e. analysis of all points falling within a ward). A small number of wards (3 %) had no air quality data within their boundary, as they are small, and fall between points in the 1 km^2 air quality grid. These wards were allocated an air quality value from the air quality point nearest the ward centroid.

In correlating annual mean air quality with demographic data an assumption is made that an individual's exposure occurs entirely within the relevant ward. Clearly this is a gross assumption and population movement (e.g. commuting), introduces a potentially significant bias in pollution exposure, a problem recognised in the air quality equity literature. The extent of this bias may differ between population groups depending upon their mobility. However, it is thought the effects of within-day population movement will be less significant when conducting a national scale analysis, as opposed to a more local study. Local studies tend to be of large cities within which population movement during the day due to commuting, travel to school and so on are greatest.

4.3.2 Air quality index

The air quality equity studies described earlier (Mitchell and Dorling 2003; Mitchell and Walker 2003) have all addressed individual pollutants, with no attempt to address several pollutants collectively. If pollutants can be addressed collectively within an appropriately structured index, then there is an opportunity to investigate the social distribution of air quality, rather than simply that of individual pollutants. This is potentially important as health responses to atmospheric pollution are made to a mixture of air pollutants, and not solely individual pollutants.

We used a simple air quality index, also used by Wheeler (*in press*), based on an index developed by Sol *et al.* (1995). For each pollutant, the atmospheric concentration is related to a guideline or standard value. Annual mean standards are available under the NAQS for PM_{10}, NO_2 and benzene (Table 4.1), but no annual mean health based standards are available for SO_2 or CO. We therefore used the WHO guideline value for annual mean SO_2 , which is 50 ug/m^3 (WHO 2000). All standards for CO are based on short averaging times, hence CO was not included in the index.

In addressing the health effects of pollutant mixtures, the Department of Health Committee on the Medical Effects of Air Pollution (COMEAP) concluded that the available evidence on pollutant mixtures, although limited, points to health impacts that are the result of an additive, rather than synergistic effect, although the additive effects are thought to be relatively weak (DoH 1998: p59). This conclusion is reflected in the index, which has the following form:

$$AQI_j = \sum_{i}^{4} (C_{ij} / S_{ij})$$

Where: AQI_j is the air quality index for ward j
C_{ij} is the concentration of pollutant i in ward j
S_{ij} is the standard or guideline value for pollutant i

Some authors recommend the use of parameter weights in air quality indices, so as to recognise the extent of divergence from air quality goals (i.e. additional weight is given to cases where pollution is farthest from the desired standard). However, such weights are difficult to derive, and their use not widely agreed upon, hence we chose not to use them.

The index is most sensitive to NO_2 and PM_{10}, which generally have higher concentrations that are closer to permitted standards than is the case for benzene or SO_2. Note that the index is unitless, with values ranging from, in theory, zero to infinity. In practice values are unlikely to exceed four, the equivalent of a site where concentrations of all four pollutants were at their respective standards.

4.3.3 Analytical method

For individual pollutants, and the air quality index, we examined the social distribution (pollutant distribution by deprivation) of: (a) ward annual mean air quality; (b) ward mean exceedences of NAQS standards; and (c) the distribution of wards with the poorest air quality, irrespective of standards. These analysed, conducted for both England and Wales, were developed as follows:

(a) Cross sectional analysis.

The cross sectional analysis produces a description of the basic pattern of environmental equity, a prerequisite for any subsequent more detailed analysis. The analyses are conducted as follows:

1. All data was sorted and placed into equal population deprivation deciles (see section 1.2).

2. For each decile, mean air quality is calculated (arithmetic mean of all ward means) and decile plots with 5-95 percentile bars are presented. Note that we do not need to present 95 % confidence intervals around the mean, as we are working with the whole population, not a sample.

3. Next, we investigate the social distribution of wards with poorest air quality. Clearly, somebody has to experience the highest pollution concentrations. However, are high values distributed independently of social characteristic, or do deprived communities bear a greater burden of the high concentrations?

   Using population weighted deprivation decile plots, our investigation focuses on two types of extreme value. First, we examine the social distribution of exceedences of NAQS mean annual air quality standards. Second, we examine the social distribution of the worst 5, 10 and 20 % of wards in air quality terms, so as to investigate pollutants for which exceedences do not occur. This 'non-exceedence' analysis is conducted as:

   - Our air quality values are ward means, and may mask localised within-ward exceedences of the annual mean standard. We assume that the frequency of occurrence of such within-ward exceedences correlates with the ward mean;

   - We assume that the frequency of exceedences of standards over shorter averaging periods (e.g. 24 hour mean), for which we have no spatially adequate data, also correlate with the ward mean; and

   - Compliance with an air quality standard does not guarantee health protection from exposure, as standards are currently set considering both health and economic objectives. Epidemiological evidence suggests that adverse health effects do occur at levels below current standards. We note that COMEAP concludes there is no concentration threshold below which there are no adverse health effects of exposure, and that recommended dose-response relationships are linear and through the origin (DoH 1998).

- Air quality objectives are periodically revised and are not constant throughout the UK (see Table 4.1) whilst new knowledge (e.g. of chronic effects) is likely to lead to tighter standards. The 'non-exceedence ' analysis therefore provides an insight into the potential equity implications of revising air quality standards.

(b) Longitudinal analysis

Longitudinal (time-series) analysis is conducted by applying the cross sectional techniques described above, to two discrete time periods, so as to provide a preliminary assessment of possible change in the national pattern of environmental equity, with respect to air quality. We make the following observations:

- The longitudinal analysis is constrained by available data. We are able to address NO_2 and PM_{10}, for the years 2001 and 2010. Thus the analysis does not assess how equity patterns may have changed in the past, but provides insight into how future equity patterns may develop in the absence of any intervention;

- The air quality data for 2010 is modelled, and differs from the modelled 2001 data in terms of emission estimates, based on projected changes in technology and economic activity. We do not have 2010 estimates of deprivation, and hence relate air quality for both years to the same deprivation data set. This is a simplification, but we note that patterns of deprivation change very slowly, and that, whilst actual levels of deprivation may change significantly from 2001-2010, the national spatial pattern is not expected to change significantly.

- The analysis is not intended to address issues of causality. To understand reasons for inequality requires research beyond the scope of this study (e.g. multivariate analysis; participatory or qualitative research).

4.4 Results: England

4.4.1 Introduction

Results of the cross sectional analysis are presented below. Note that our use of statistics has been limited to descriptive statistics, and that we have not conducted more sophisticated statistical tests. This is because our analyses are of the entire population, not a sample, hence we do not need to conduct inferential difference tests based on samples (see 1.3).

We present the following results for England:

- A summary of the principal observations;
- Summary descriptive statistics of the social distribution of air quality (Tables 4.2 to 4.4);
- Graphical plots of deprivation against air quality (as mean, exceedence and extreme values) for five pollutants, and the air quality index (Figures 4.1 to 4.6);
- Graphical plots of the change in the social distribution of NO_2 and PM_{10} over the period 2001-2010 (Figures 4.7 to 4.10).

4.4.2 Principal observations

(a) Social distribution of ward mean air quality.

- For all pollutants studied, air quality is poorest for the most deprived 10 % of the population (more precisely, the 10 % of the national population that are resident in the most deprived wards in England). Ward mean concentrations for this most deprived decile are up to 76 % greater than concentrations experienced by people of average means;
- The least deprived 10 % of the population also experience above average concentrations, but to a lesser extent than the most deprived 10 %. Ward mean concentrations for the least deprived are no more than 13 % greater than concentrations experienced by people of average means;
- The greatest differential in air quality occurs with respect to benzene (76 % higher amongst the most deprived than people of average means), followed by NO_2 (41 %), CO (38 %), SO_2 (27 %) and PM_{10} (11 %).

(b) Social distribution of air quality standard exceedences.

- For those pollutants for which there are NAQS annual mean concentration standards (NO_2, PM_{10}, benzene), 2001 ward mean concentrations only exceed the standard for NO_2;

- 2.5 million people in England (5.1 % of total population) are resident in wards with mean NO_2 concentrations in excess of the NAQS standard. Of these people, one third are amongst the most deprived 10 % of the population, and over half (53 %) amongst the most deprived 20 % of the population;

- Of the 2.5 million people in a ward with mean NO_2 in excess of the NAQS standard, only 1 % are resident in the least deprived wards.

(c) Social distribution of highest pollutant concentrations.

- The highest pollutant concentrations occur disproportionately amongst the most deprived wards for all pollutants studied, with, for most pollutants, over half of the most exposed 5 % of the population (2.5 million people) resident in the 20 % most deprived wards;

- Of the 2.5 million people in England with the greatest exposure to:

  - NO_2, 53 % are in the most deprived 20 % of the population (cf. 14 % in average deprivation quintile and only 4 % for least deprived quintile - 4 and 13 times less respectively);

  - PM_{10}, 58 % are in the most deprived 20 % of the population (cf. 9 % in average deprivation quintile and only 4% for least deprived quintile - 4 and 13 times less respectively);

  - SO_2, 30 % are in the most deprived 20 % of the population (cf. 20 % in average deprivation quintile and only 8% for least deprived quintile - 1.5 and 4 times less respectively);

  - CO, 52 % are in the most deprived 20 % of the population. (cf. 12 % in average deprivation quintile and only 4 % for least deprived quintile - 4 and 12 times less respectively);

  - Benzene 51 % are in the most deprived 20 % of the population (cf. 11 % in average deprivation quintile and only 5 % for least deprived quintile - 4 and 11 times less respectively);

- A quarter of a million people in England are resident in wards with an Air Quality Index value > 2 (equivalent to all four pollutants in the index at half the guide or NAQS standard). Of these, 46 % are in the 20 % most deprived wards, and only 9 % in the least deprived wards. There are 7.5 million people resident in wards with an index value > 1.5, of which 42 % are in the most deprived quintile.

(d) Longitudinal analysis

- The social distribution of air quality (as mean ward NO_2 and PM_{10}) in 2001 and 2010 appear very similar. This occurs as the differences in the air quality modelling for each year lie in factors which are aspatial (e.g. emission coefficients) or which vary very little spatially (e.g. busiest roads remain busiest roads; land use change not modelled);

- In 2001, 2.5 million people are resident in wards with a mean NO_2 in excess of the permitted 40 ug/m^3 NAQS standard, compared to just 0.37 million people in 2010. Of these person exceedences 53 % are in the most deprived quintile in 2001, and 54 % in 2010. Whilst the social distribution of exceedences is largely unchanged, the benefits of NO_2 reduction fall more greatly to the poor (both absolutely and relatively).;

- In 2001, 0.65 million people are resident in wards with a mean ward PM_{10} > 20 ug/m^3 although there are no ward mean exceedences of the current NAQS standard of $40ug/m^3$. However, the standard is to be tightened to $20ug/m^3$, to be introduced in 2010, bringing 25,000 people into an exceedence zone. Of these people, 75 % are in the most deprived 20 % of the population, and all of them in the 30 % most deprived population.

Table 4.2: Social distribution of mean air quality in England

Air quality parameter [1]	**Year**	**Mean air quality** [2]		
		Most deprived (Decile 1)	**Average deprivation (Deciles 5 & 6)**	**Least deprived (Decile 10)**
Nitrogen dioxide	2001	32.3	22.9	25.9
	2010	25.2	17.3	19.4
Particulates (PM_{10})	2001	16.6	14.9	15.5
	2010	14.6	13.2	13.7
Sulphur dioxide	2001	4.58	3.60	3.48
Carbon monoxide	2001	0.40	0.29	0.31
Benzene	2001	0.67	0.38	0.41
Air Quality Index	2001	1.36	1.04	1.13

Notes:
1. All unit are ug/m3, except CO (mg/m3) and the Air Quality Index (no units);
2. Air quality is modelled as the annual mean concentration for every 1 km^2 grid point in England. These values are used to determine a ward mean air quality, from which the mean air quality for each deprivation decile is calculated. Deciles have equal population.

Table 4.3: Social distribution of mean air quality in England, standardised to mean deprivation

Air quality parameter [1]	Year	Standardised against average deprivation [3]		
		Most deprived (IMD decile 1)	Average deprivation (IMD deciles 5&6)	Least deprived (IMD decile 10)
Nitrogen dioxide	2001	141	100	113
	2010	146	100	112
Particulates (PM_{10})	2001	111	100	104
	2010	110	100	103
Sulphur dioxide	2001	127	100	97
Carbon monoxide	2001	138	100	108
Benzene	2001	176	100	109
Air Quality Index	2001	130	100	109

Notes:
1. All unit are ug/m^3, except CO (mg/m3) and the Air Quality Index (no units);
2. Air quality is modelled as the annual mean concentration for every 1 km^2 grid point in England. These values are used to determine a ward mean air quality, from which the mean air quality for each deprivation decile is calculated. Deciles have equal population.
3. Average deprivation set to 100

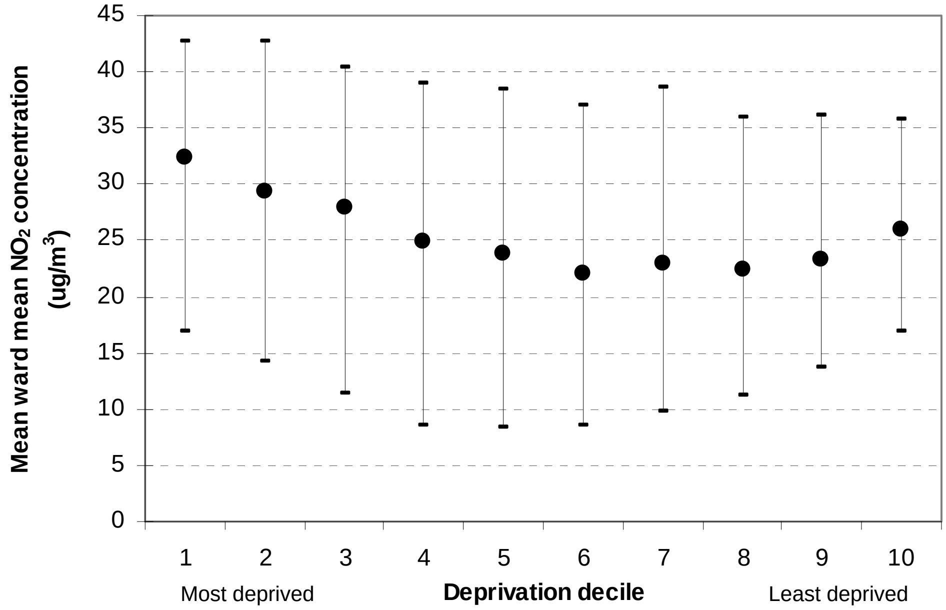
Table 4.4: Social distribution of greatest air quality concentrations in England

Air quality parameter [1]	Year	Per cent of population in deprivation quantile that are resident in wards with highest pollutant concentration [2]				
		Q1 (Most deprived quantile)	Q2	Q3	Q4	Q5 (Least deprived quantile)
Nitrogen dioxide	2001	47 [3]	22	16	10	5
	2010	47	24	14	9	5
Particulates (PM_{10})	2001	50	26	10	9	5
	2010	54	24	10	7	4
Sulphur dioxide	2001	33	26	20	12	9
Carbon monoxide	2001	47	26	14	9	5
Benzene	2001	45	27	13	9	6
Air Quality Index	2001	48	23	15	9	4

Notes:
1. All unit are ug/m^3, except CO (mg/m^3) and the Air Quality Index (no units);
2. High pollutant concentration defined as the top 10 % highest concentrations for each pollutant;
3. This shows, for example, that of all the people living in wards where pollutant concentrations are highest (top 10 %) 4 7 % live in the most deprived quantile.

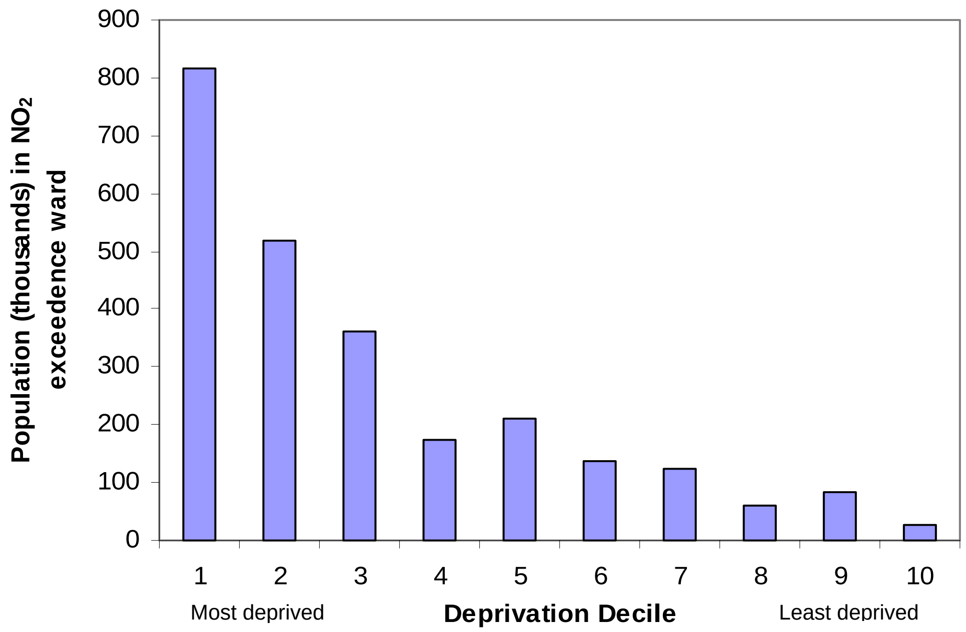
4.4.3 Cross sectional Analysis

(a) Distribution of ward mean NO_2



Notes:
1. Bars denote 5-95 percentile range, N=8,414.
2. Each decile represents the average of ward mean NO_2, measured as an annual mean.

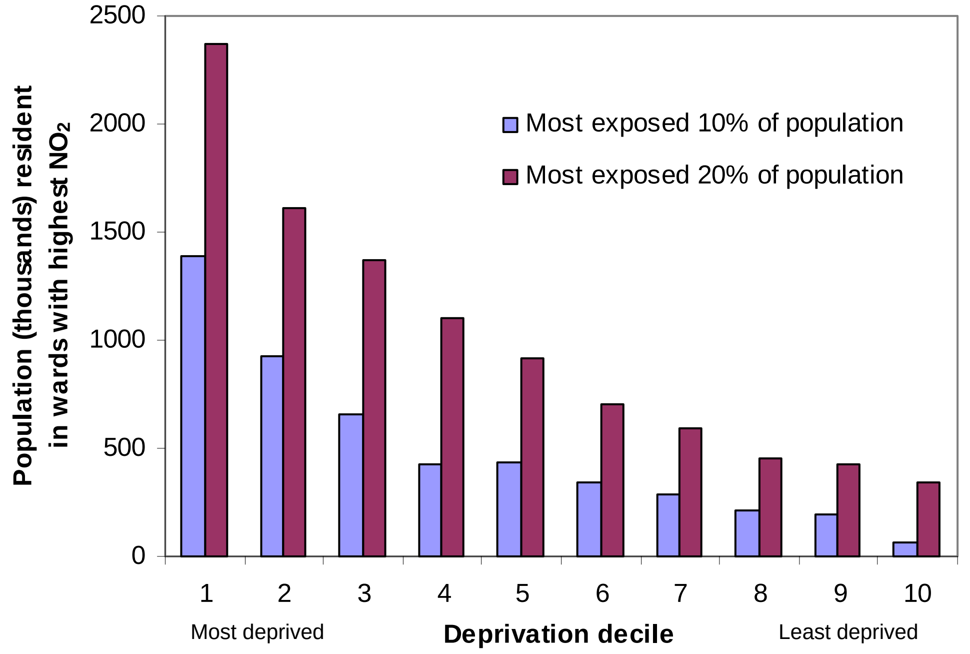
(b) Distribution of ward mean NO_2 exceedences (2001)



Notes:
1. Annual mean standard is 40 ug/m^3, applied as a ward average.
2. Decile 1 is most deprived (see section 1.2). All deciles have 4.9 million people.
3. 2.51 million people are in an NO_2 exceedence ward, 5.1 % of the population of England.
4. 53 % of all person exceedences are in the most deprived quantile

Figure 4.1: Social distribution of Nitrogen dioxide in England, 2001

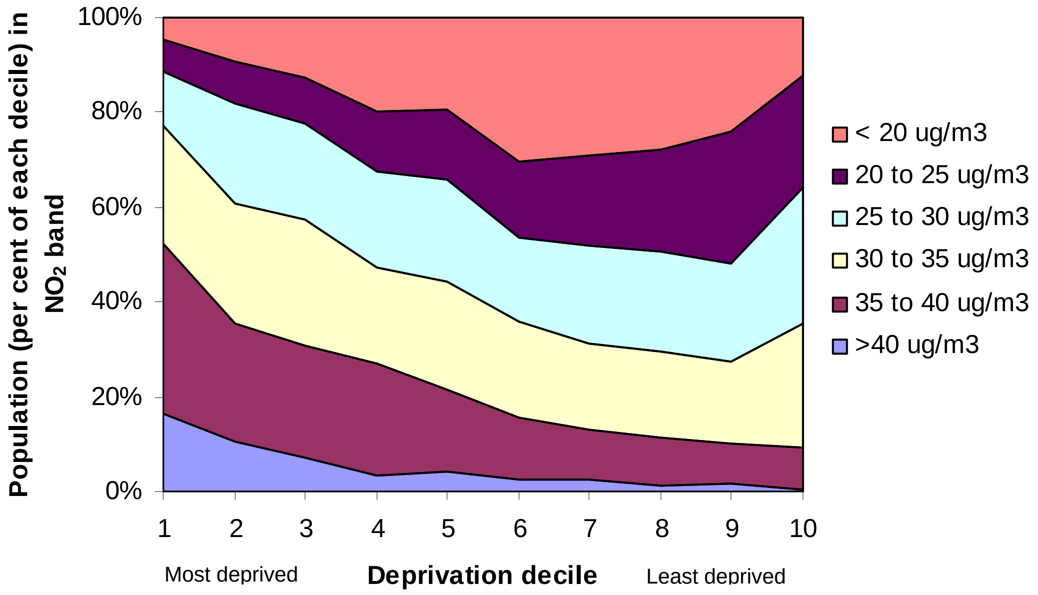
(c) Distribution of highest ward mean NO_2 values (2001)



Notes:

1. The most exposed 10 % of the population (4.95 million people), experience a mean ward level (annual mean) NO_2 concentration of 42.3 ug/m^3 (cf. national annual mean NO_2 of 24.8 ug/m^3).
2. The most exposed 20 % of the population (9.89 million people), experience a mean ward level (annual mean) NO_2 concentration of 39.7 ug/m^3.

(d) Distribution of high to low ward mean NO_2 concentrations by deprivation



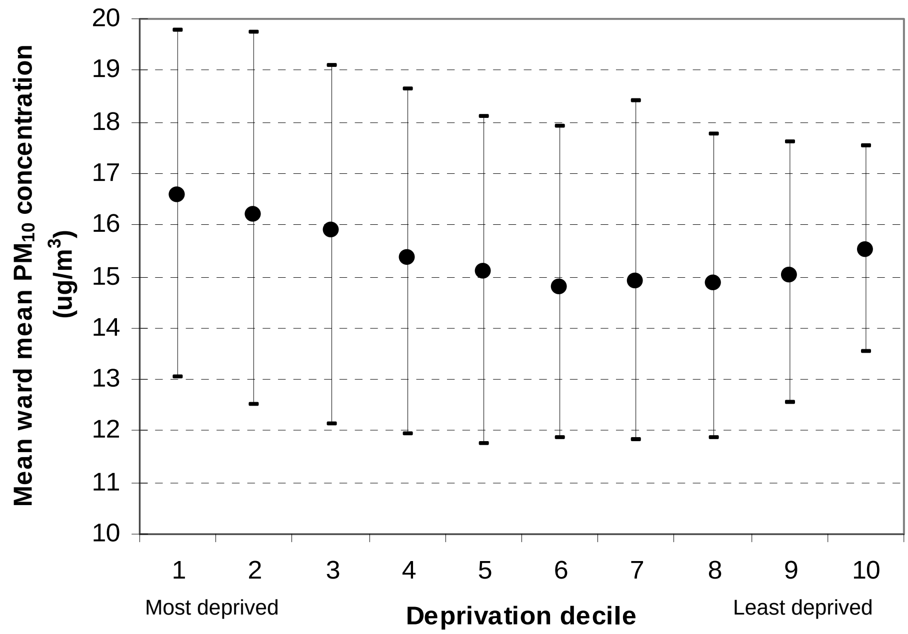
Notes:

1. Each decile has 4.95 million people.

2. Plot shows that highest concentrations (>35, >40 ug/m^3 NO_2) are disproportionately borne by poorest deciles, who also have the smallest share of cleanest air (<20ug/m^3).

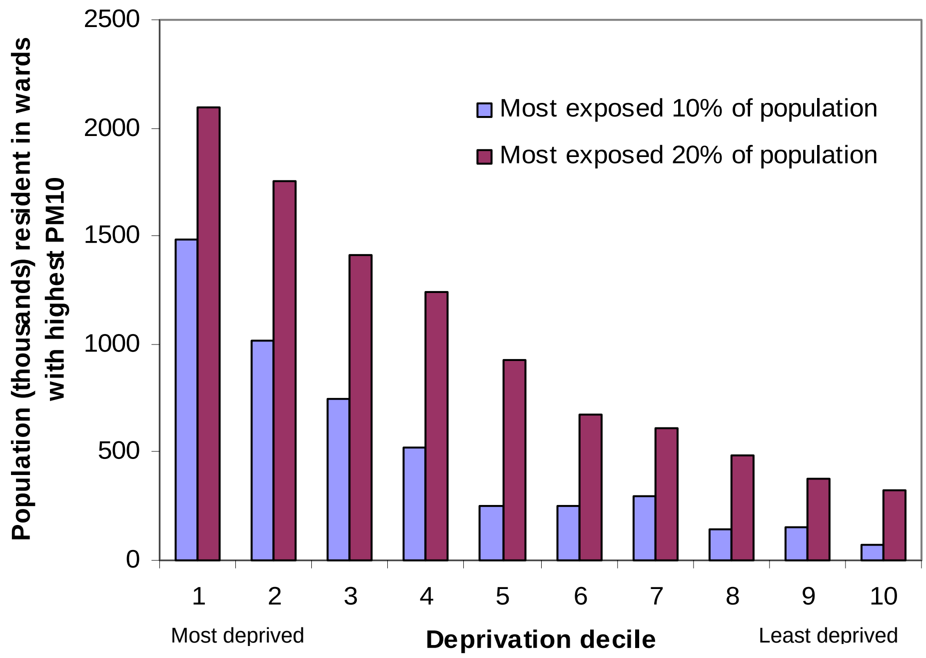
Figure 4.1: (cont) Social distribution of Nitrogen dioxide in England, 2001

(a) Distribution of ward mean PM_{10}



Notes:
1. Bars denote 5-95 percentile range, N=8,414.
2. Each decile represents the average of ward mean PM_{10}, measured as an annual mean.

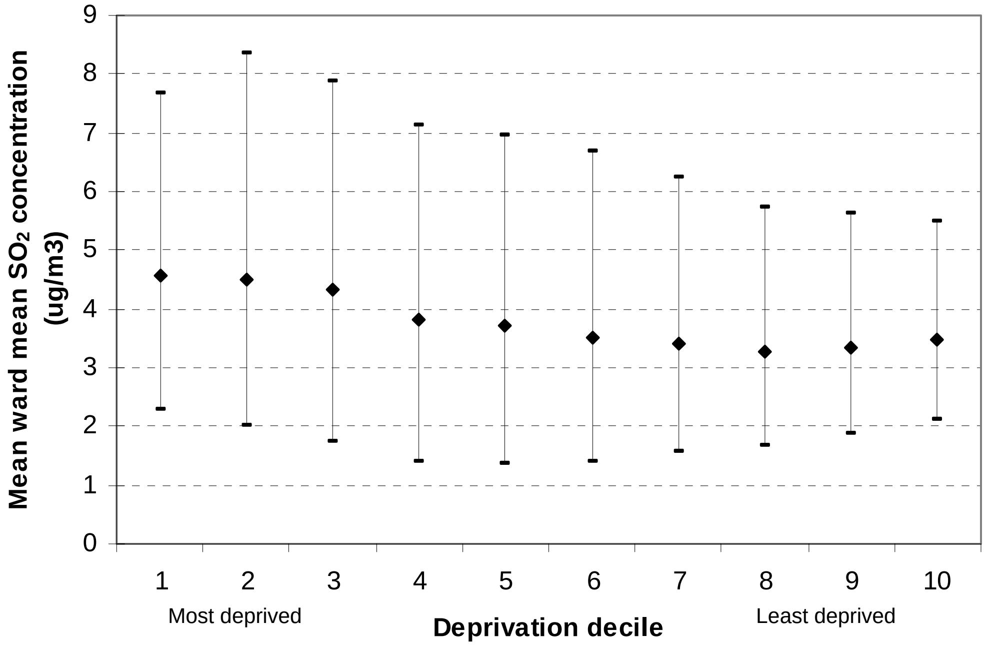
(b) Distribution of highest ward mean PM_{10} concentrations (2001)



Notes:
1. The most exposed 10 % of the population (4.95 million people), experience a mean ward level (annual mean) PM_{10} concentration of 19.3 ug/m^3 (cf. national annual mean 15.3 ug/m^3).
2. The most exposed 20 % of the population (9.90 million people), experience a mean ward level (annual mean) PM_{10} concentration of 18.6 ug/m^3.
3. There are no ward mean exceedences of the annual mean PM_{10} standard of 40 ug/m^3.

Figure 4.2: Social distribution of fine particulates (PM_{10}) in England, 2001

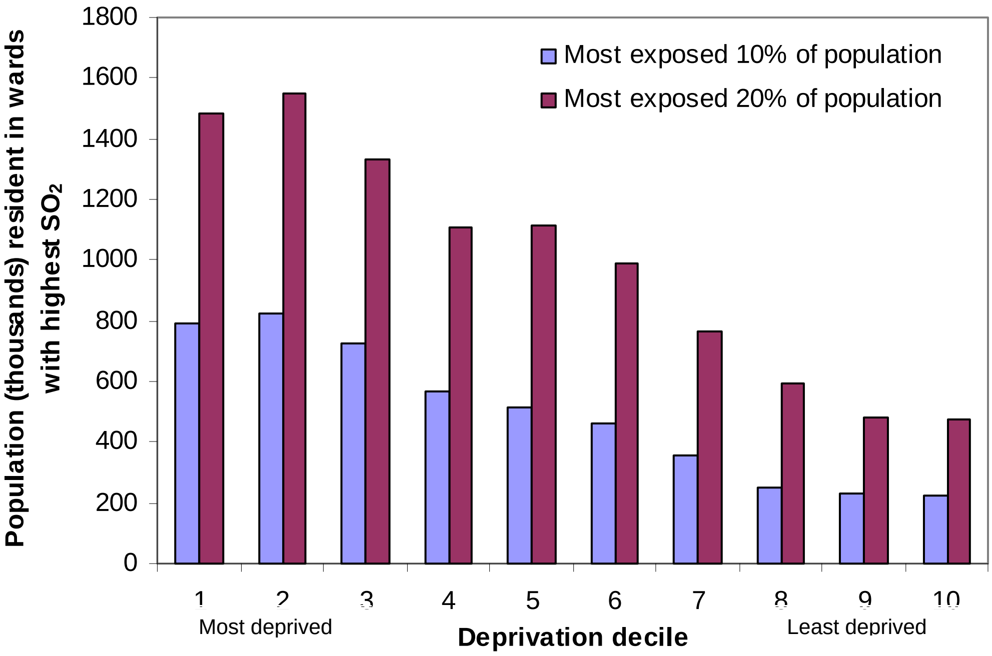
(a) Distribution of ward mean SO_2



Notes:

1. Bars denote 5-95 percentile range, N=8,414.
2. Each decile represents the average of ward mean SO_2, measured as an annual mean.

(b) Distribution of highest ward mean SO_2 concentrations (2001)

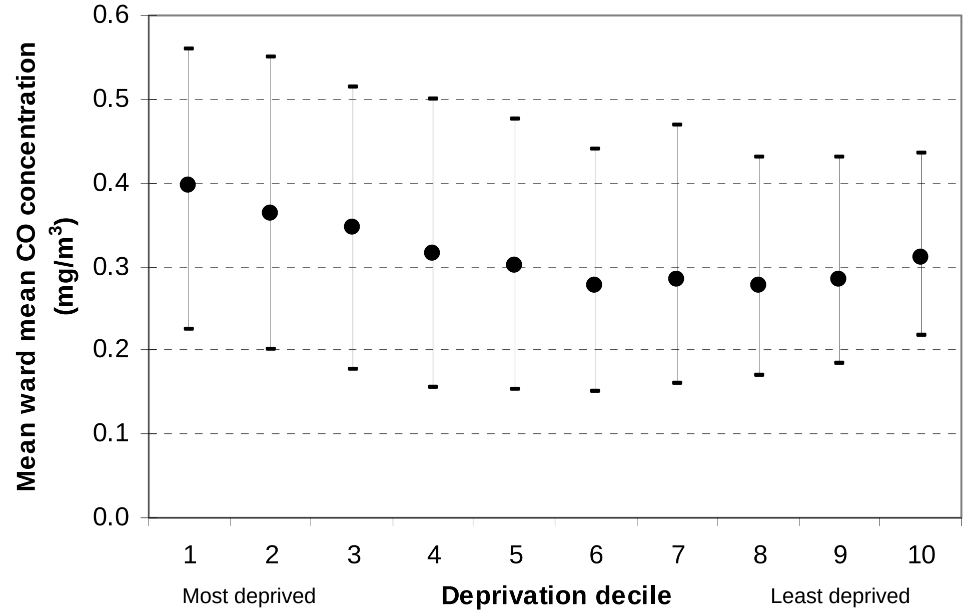


Notes:

1. The most exposed 10 % of the population (4.95 million people), experience a mean ward level (annual mean) SO_2 concentration of 7.7 ug/m^3 (cf. national annual mean NO_2 of 3.68 ug/m^3).
2. The most exposed 20 % of the population (9.89 million people), experience a mean ward level (annual mean) SO_2 concentration of 6.6 ug/m^3.
3. There is no annual mean standard for SO_2 (WHO guideline value is 50 ug/m^3)

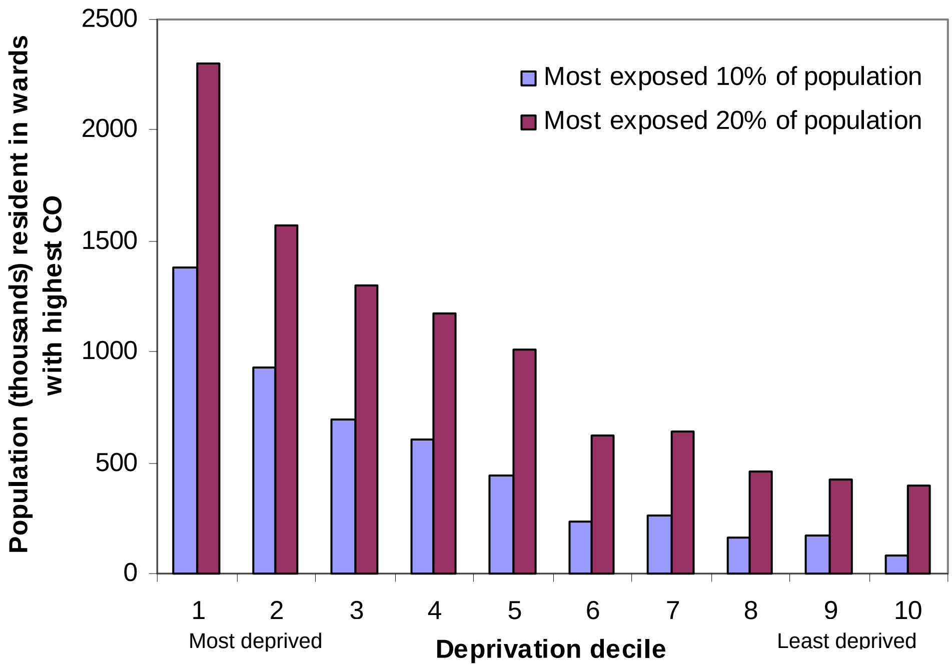
Figure 4.3: Social distribution of Sulphur dioxide in England, 2001

(a) Distribution of ward mean CO



Notes:
1. Bars denote 5-95 percentile range, N=8,414.
2. Each decile represents the average of ward mean SO_2, measured as an annual mean.

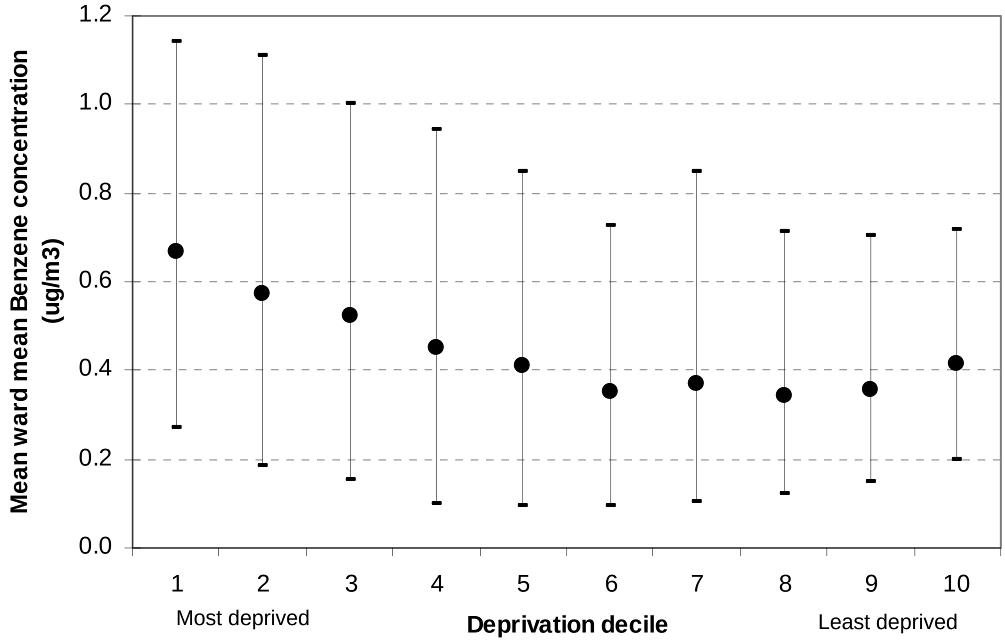
(b) Distribution of highest ward mean CO concentrations (2001)



Notes:
1. The most exposed 10 % of the population (4.95 million people), experience a mean ward level (annual mean) CO concentration of 0.53 mg/m^3 (cf. national annual mean CO of 0.31 mg/m^3).
2. The most exposed 20 % of the population (9.89 million people), experience a mean ward level (annual mean) CO concentration of 0.49 ug/m^3.
3. There is no annual mean standard for CO (or WHO guideline value).

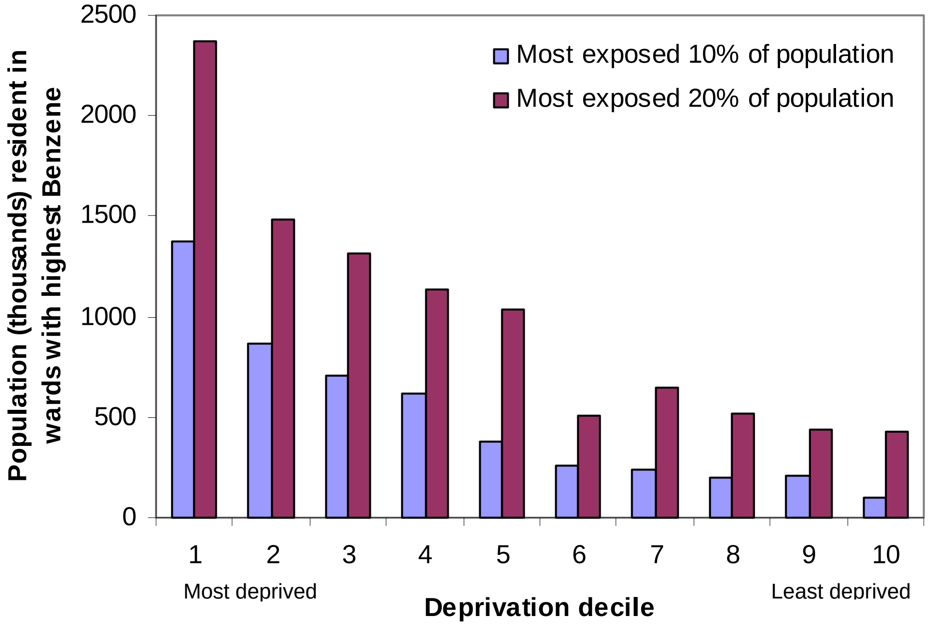
Figure 4.4: Social distribution of Carbon monoxide in England, 2001

(a) Distribution of ward mean Benzene



Notes:
1. Bars denote 5-95 percentile range, N=8,414.
2. Each decile represents the average of ward mean SO_2, measured as an annual mean.

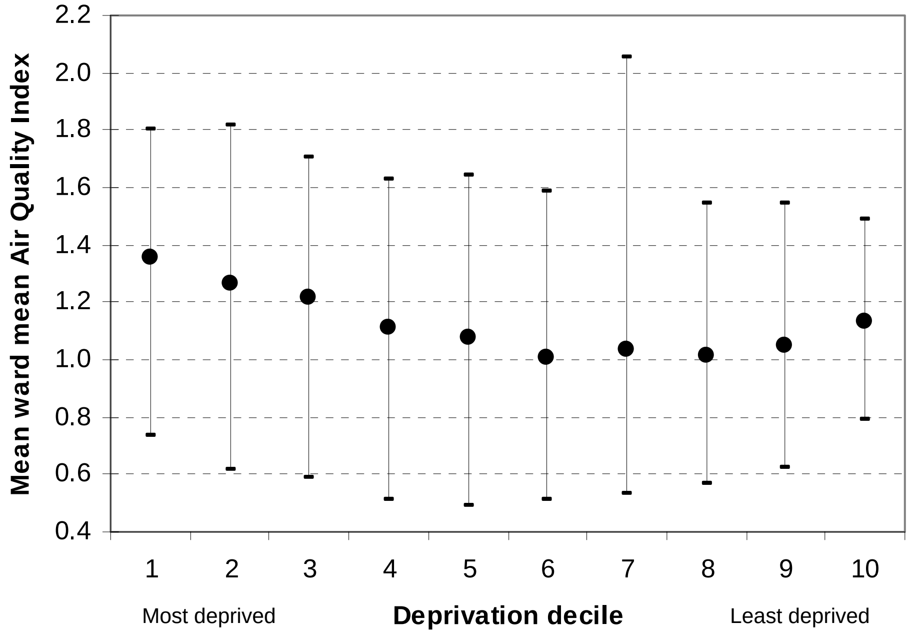
(b) Distribution of highest ward mean Benzene concentrations (2001)



Notes:
1. The most exposed 10 % of the population (4.95 million people), experience a mean ward level (annual mean) benzene concentration of 1.05 ug/m^3 (cf. national annual mean CO of 0.42 mg/m^3).
2. The most exposed 20 % of the population (9.89 million people), experience a mean ward level (annual mean) benzene concentration of 0.92 ug/m^3.
3. There are no ward mean exceedences of the annual mean Benzene standard of 16.25 ug/m^3.

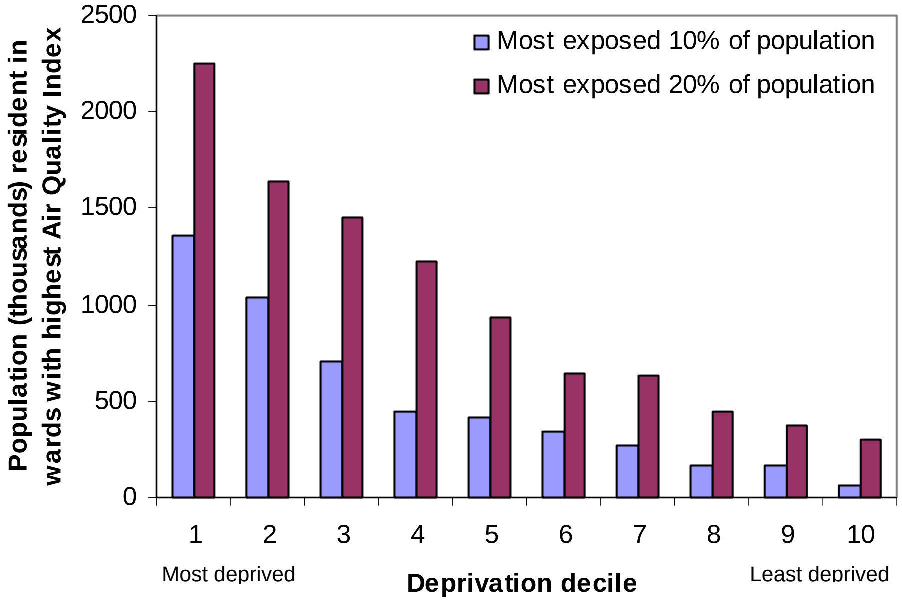
Figure 4.5: Social distribution of Benzene in England, 2001

(a) Distribution of ward mean Air Quality Index



Notes:
1. Bars denote 5-95 percentile range, N=8,414.
2. Each decile represents the average of ward mean SO_2, measured as an annual mean.

(b) Distribution of highest ward mean Air Quality Index (2001)



Notes:
1. The most exposed 10 % of the population (4.95 million people), experience a mean ward level AQI of 1.69 (cf. national annual mean AQI of 1.10).
2. The most exposed 20 % of the population (9.89 million people), experience a mean ward level AQI of 1.6.
3. Exceedences cannot be applied to the air quality index

Figure 4.6: Social distribution of the Air Quality Index in England, 2001

4.4.4 Longitudinal analysis: England

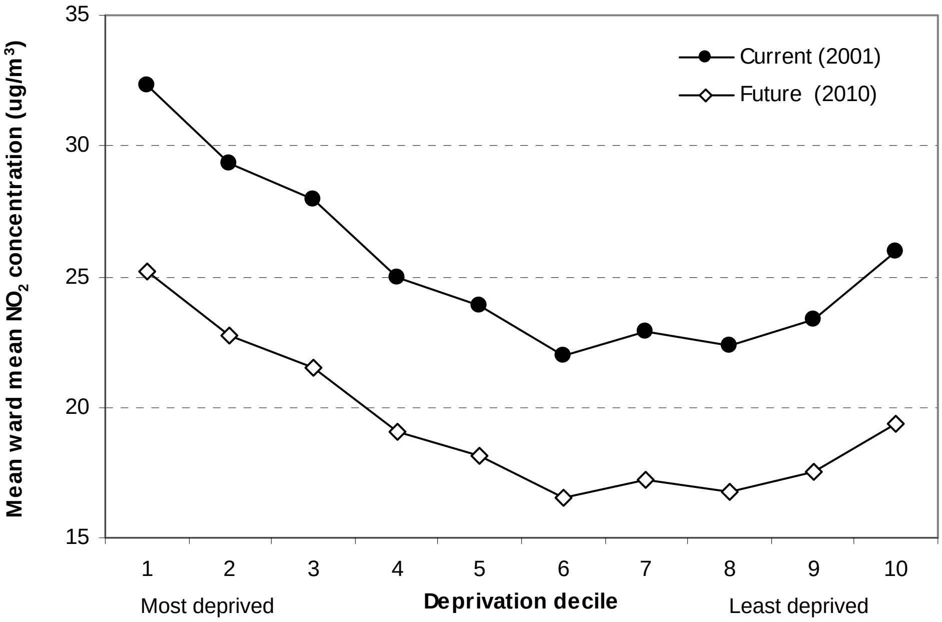
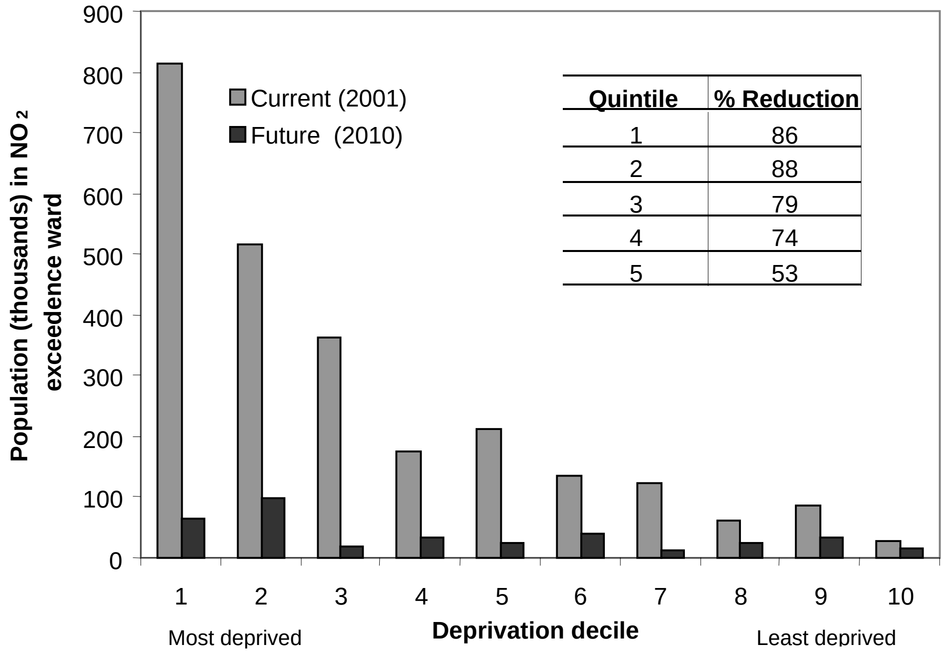


Figure 4.7: Change in social distribution of ward mean NO_2, 2001-2010



Notes:

- Annual mean standard is 40 ug/m^3, applied as a ward average.
- Decile 1 is most deprived (see section 1.2). All deciles have 4.9 million people.
- 2.51 million people are in an NO_2 exceedence ward, in 2001, of which 53% are in the most deprived quintile
- In 2010, 54 % of person NO_2 exceedences are in the most deprived wards, but the number of people in an exceedence ward has fallen to 0.37 million.

Figure 4.8: Change in population in an NO_2 exceedence ward, 2001-2010

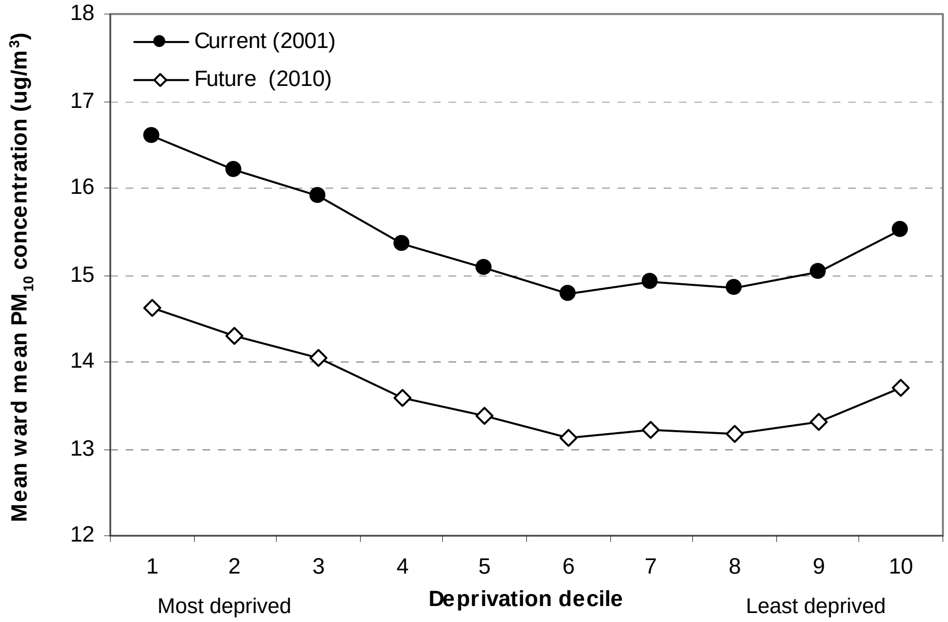
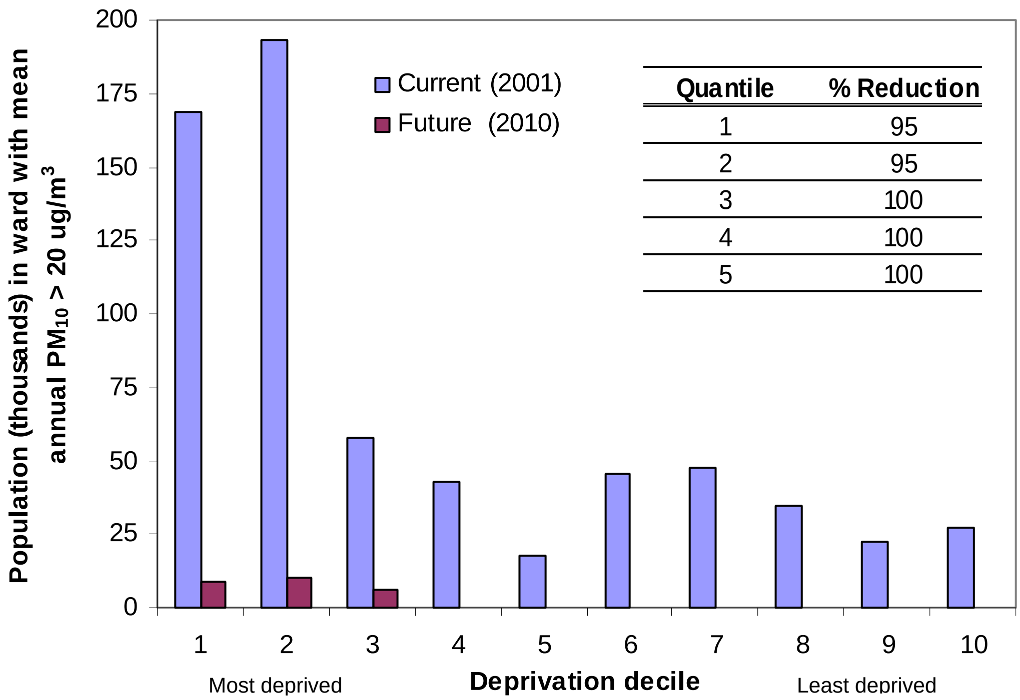


Figure 4.9: Change in social distribution of ward mean PM_{10}, 2001-2010



Notes:

1. Annual mean standard is 40 ug/m^3, applied as a ward average.
2. Decile 1 is most deprived (see section 1.2). All deciles have 4.9 million people.
3. 657,000 people are in wards with mean annual PM_{10} > 20ug/m^3 in 2001, of which 55 % are in the most deprived quantile.
4. In 2010, only 25,000 people are in wards with mean annual PM_{10} > 20ug/m^3 , but 75 % are in the most deprived quintile, and 100 % in the three most deprived deciles.
5. Note that in 2010, the PM_{10} standard will be 20ug/m^3, hence when exceedence of the new standard will be very strongly associated with deprivation.

Figure 4.10: Change in population in a ward exceeding 20 ug/m^3 PM_{10}, 2001-2010

4.5 Results: Wales

4.5.1 Introduction

Results of the cross sectional analysis for Wales are presented below, including:

- A summary of the principal observations;
- Summary descriptive statistics of the social distribution of air quality (Tables 4.5 to 4.7);
- Graphical plots of deprivation against air quality (as mean, exceedence and extreme values) for five pollutants, and the air quality index (Figures 4.11 to 4.16);
- Graphical plots of the change in the social distribution of NO_2 and PM_{10} over the period 2001-2010 (Figures 4.17 to 4.20).

Note that our use of statistics has been limited to descriptive statistics, given the constraints of the available data (variables, measurement scale), and because we are using the entire population (see 4.3.3 above).

4.5.2 Principal observations

(a) Social distribution of ward mean air quality.

- Air quality in Wales is much better than that of England, with significantly lower mean and peak concentrations (e.g. mean ward NO_2 concentration is 41 % lower in Wales than England; $PM_{10,}$ SO_2, CO and benzene are 15 %, 22 %, 35 % and 48 % lower respectively);
- The social distribution of air quality in Wales displays a U-shaped distribution similar to that for England, with above average concentrations experienced by both the least and most deprived;
- For all pollutants studied (SO_2 excepted), air quality is worst for the *least* deprived 10 % of the population (more precisely, the 10 % of the national population that are resident in the least deprived wards in Wales). Ward mean concentrations for the least deprived are up to 58 % greater than concentrations experienced by people of average means;
- The most deprived 10 % of the population also experience above average concentrations, but to a lesser extent than the least deprived decile. Ward mean concentrations for the most deprived are up to 55 % greater than concentrations experienced by people of average means.
- The greatest differential in air quality occurs with respect to benzene (59 % higher amongst the least deprived than people of average means), followed by NO_2 (58 %), CO (30 %), SO_2 (23 %) and PM_{10} (12 %).

(b) Social distribution of air quality standard exceedences.

- Ward mean concentrations do not exceed the NAQS standards for any pollutant for which there are annual mean concentration standards (NO_2, PM_{10}, benzene). Note that exceedences may occur for standards over other averaging periods (e.g. 24 hr mean), but that there is no national small area data to support this analysis;

(c) Social distribution of highest pollutant concentrations.

- The highest pollutant concentrations occur disproportionately amongst the least deprived wards for all pollutants studied, with the exception of SO_2, for which there is no clearly discernible pattern. For the remaining pollutants, at least one third of the most exposed 10 % of the population (0.6 million people) are resident in the 20 % least deprived wards;

- Of the 0.6 million people in Wales with the greatest exposure to:

  - NO_2, 41 % are in the least deprived 20 % of the population (cf. 11 % in average and least deprivation quintiles - 4 times less);

  - PM_{10}, 34 % are in the least deprived 20 % of the population (cf. 19 % in average deprivation quintile, 17 % for most deprived quintile - half that of the least deprived);

  - SO_2, no quantile bears more than 25 % of the population, indicating that the highest SO_2 values have a roughly even social distribution;

  - CO, 43 % are in the least deprived 20 % of the population. (cf. 7 % in average deprivation quintile and only 11 % for most deprived quintile - 6.5 and 4 times less respectively);

  - Benzene, 42 % are in the least deprived 20 % of the population (cf. 8 % in average deprivation quintile and only 13 % for least deprived quintile - 5 and 3 times less respectively);

- The most deprived quintile bears a lower proportion of the top 10 % peak pollutant concentrations. An even social distribution would see 20 % of peak values in each quantile, but in Wales, the most deprived quintile has only 11-17 % of peak values (21 % for SO_2);

- Nearly 300,000 people in Wales are resident in wards with an Air Quality Index value >1.25 (Max AQI in Wales is 1.49). Of these people 35 % are in the 20 % least deprived wards, and 14 % in the most deprived wards. Nearly one million people are resident in wards with an index value > 1.0 (equivalent to concentrations of all 4 pollutants in the index at one quarter of permitted standard), of which 31 % are in the least deprived quintile.

(d) Longitudinal analysis

- The social distribution of air quality (as mean ward NO_2 and PM_{10}) in 2001 and 2010 appear very similar. This occurs as the differences in the air quality modelling for each year lie in factors which are aspatial (e.g. emission coefficients) or which vary very little spatially (e.g. busiest roads remain busiest roads; land use change not modelled).

- In 2001, 0.2 million people are resident in wards where NO_2 exceeds 30 ug/m^3 (no exceedences of NAQS 40 ug/m^3 threshold), of which 48 % are in the least deprived 20 % of the population. By 2010, only 36,000 people will be resident in wards with > 30 ug/m^3 NO_2, of which all are in the most deprived 30 % of the population. Note however, that this comprises just four wards.

- In 2001, 15,000 people are resident in wards with a mean ward PM_{10} > 20 ug/m^3, although there are no exceedences of the current NAQS standard of 40 ug/m^3. However, the standard is to be tightened to 20 ug/m^3, to be introduced in 2010, putting 15,000 people into an exceedence zone. Of these people, all are in the most deprived 30 % of the population, but are all resident in just two wards.

Table 4.5: Social distribution of mean air quality in Wales.

Air quality parameter [1]	**Year**	**Mean air quality** [2]		
		Most deprived (Decile 1)	**Average deprivation (Deciles 5 & 6)**	**Least deprived (Decile 10)**
Nitrogen dioxide	2001	17.4	12.6	20.0
	2010	12.9	9.3	15.1
Particulates (PM_{10})	2001	13.8	12.5	14.1
	2010	12.4	11.3	12.6
Sulphur dioxide	2001	3.57	2.78	3.43
Carbon monoxide	2001	0.22	0.19	0.24
Benzene	2001	0.29	0.19	0.30
Air Quality Index	2001	0.87	0.70	0.94

Notes:
1. All unit are ug/m^3, except CO (mg/m^3) and the Air Quality Index (no units);
2. Air quality is modelled as the annual mean concentration for every 1 km^2 grid point in England. These values are used to determine a ward mean air quality, from which the mean air quality for each deprivation decile is calculated. Deciles have equal population.

Table 4.6: Social distribution of mean air quality in Wales, standardised to average deprivation.

Air quality parameter [1]	Year	Standardised against average deprivation [3]		
		Most deprived (Decile 1)	Average deprivation (Deciles 5 & 6)	Least deprived (Decile 10)
Nitrogen dioxide	2001	138	100	158
	2010	139	100	162
Particulates (PM_{10})	2001	110	100	112
	2010	109	100	111
Sulphur dioxide	2001	128	100	123
Carbon monoxide	2001	119	100	130
Benzene	2001	155	100	159
Air Quality Index	2001	125	100	135

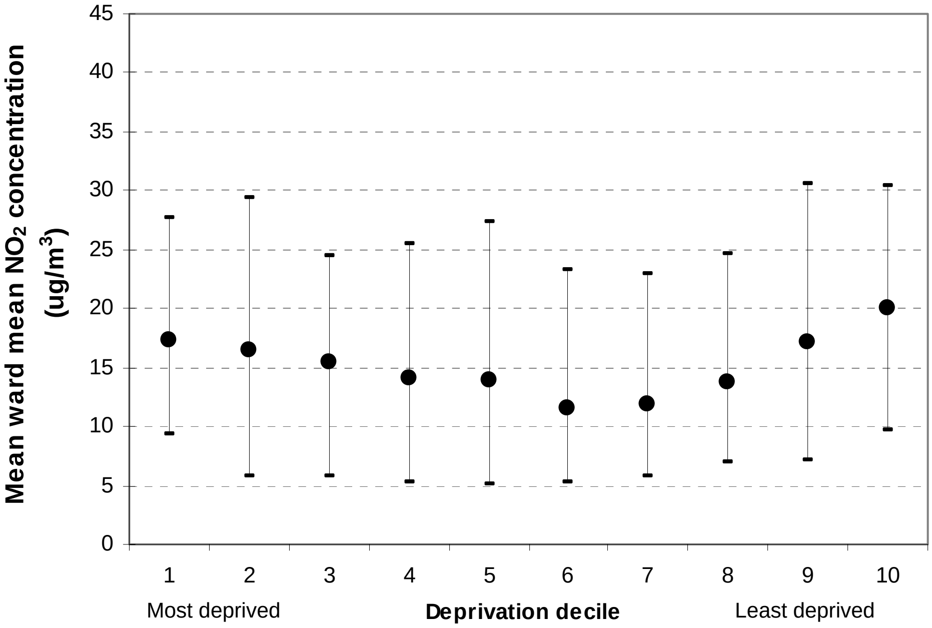
Notes:
1. All unit are ug/m^3, except CO (mg/m^3) and the Air Quality Index (no units);
2. Air quality is modelled as the annual mean concentration for every 1 km^2 grid point in England. These values are used to determine a ward mean air quality, from which the mean air quality for each deprivation decile is calculated. Deciles have equal population.
3. Average deprivation set to 100.

Table 4.7: Social distribution of greatest air quality concentrations in Wales

Air quality parameter [1]	Year	Per cent of population in deprivation quantile that are resident in wards with highest pollutant concentration [2]				
		Q1 (Most deprived quantile)	Q2	Q3	Q4	Q5 (Least deprived quantile)
Nitrogen dioxide	2001	11	13	11	24	41
	2010	16	11	14	23	36
Particulates (PM_{10})	2001	17	11	19	19	34
	2010	18	11	20	21	29
Sulphur dioxide	2001	21	16	25	18	19
Carbon monoxide	2001	11	15	7	23	43
Benzene	2001	13	12	8	24	42
Air Quality Index	2001	14	13	13	24	35

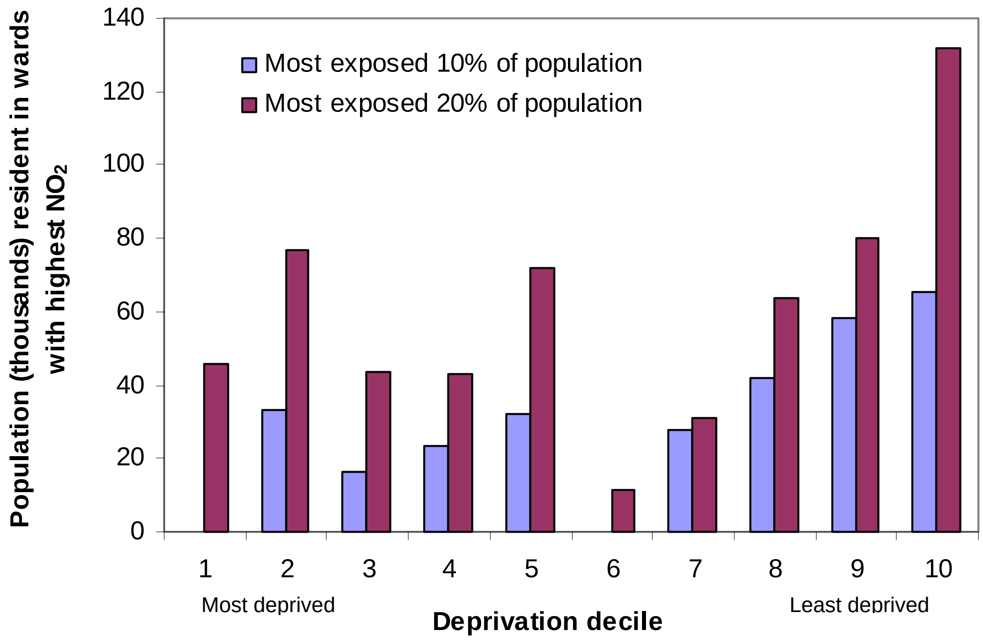
Notes:
1. All unit are ug/m^3, except CO (mg/m^3) and the Air Quality Index (no units);
2. High pollutant concentration defined as the top 10% highest concentrations for each pollutant
3. This shows, for example, that of all the people living in wards where pollutant concentrations are highest (top 10 %) 11 % live in the most deprived quintile.

(a) Distribution of ward mean NO_2



Notes:
1. Bars denote 5-95 percentile range, N=865.
2. Each decile represents the average of ward mean NO_2, measured as an annual mean.
3. Decile 1 is most deprived (see section 1.2). All deciles have 300,000 ± 6,000 people.

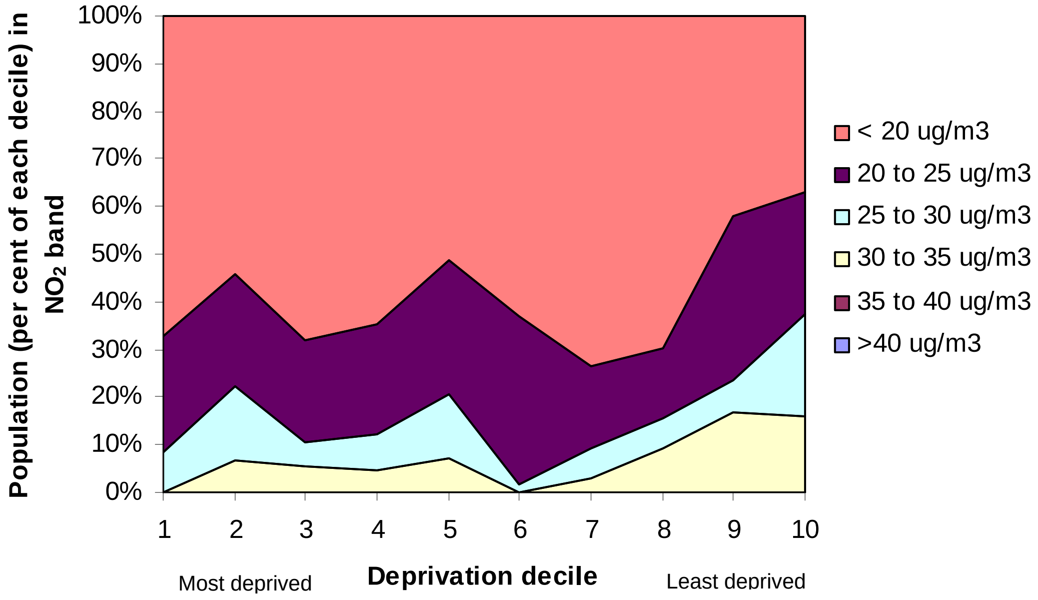
(b) Distribution of highest ward mean NO_2 values (2001)



Notes:
1. The most exposed 10 % of the population (0.3 million people), experience a mean ward level (annual mean) NO_2 concentration of 31.4 ug/m^3 (cf. national annual mean NO_2 of 14.7 ug/m^3).
2. The most exposed 20 % of the population (0.6 million people), experience a mean ward level (annual mean) NO_2 concentration of 27.4 ug/m^3.
3. There are no ward mean exceedences of the annual mean PM_{10} standard of 40 ug/m^3.

Figure 4.11: Social distribution of Nitrogen dioxide in Wales, 2001

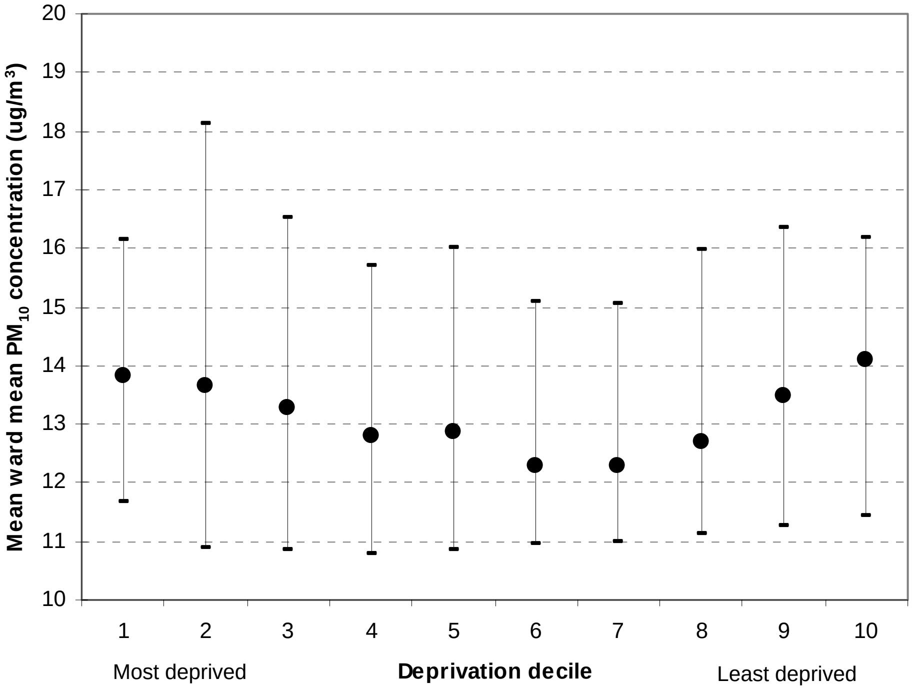
(c) Distribution of high to low ward mean NO_2 concentrations by deprivation



Notes:
1. Each decile has 0.3 million people;
2. There are no occurrences of the highest concentrations (>35, >40 ug/m^3 NO_2);
3. The highest concentrations tend to be borne by people resident in the least deprived wards, although the overall association between air quality and deprivation is weak.

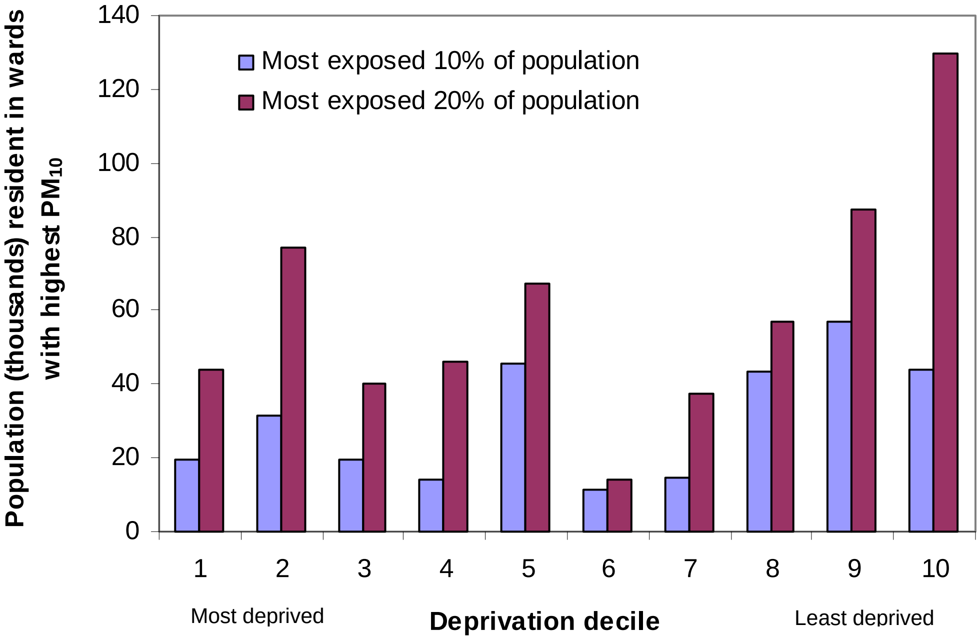
Figure 4.11: (cont) Social distribution of Nitrogen dioxide in Wales, 2001

(a) Distribution of ward mean PM_{10}



Notes:
1. Bars denote 5-95 percentile range, N=865
2. Each decile represents the average of ward mean PM_{10}, measured as an annual mean.

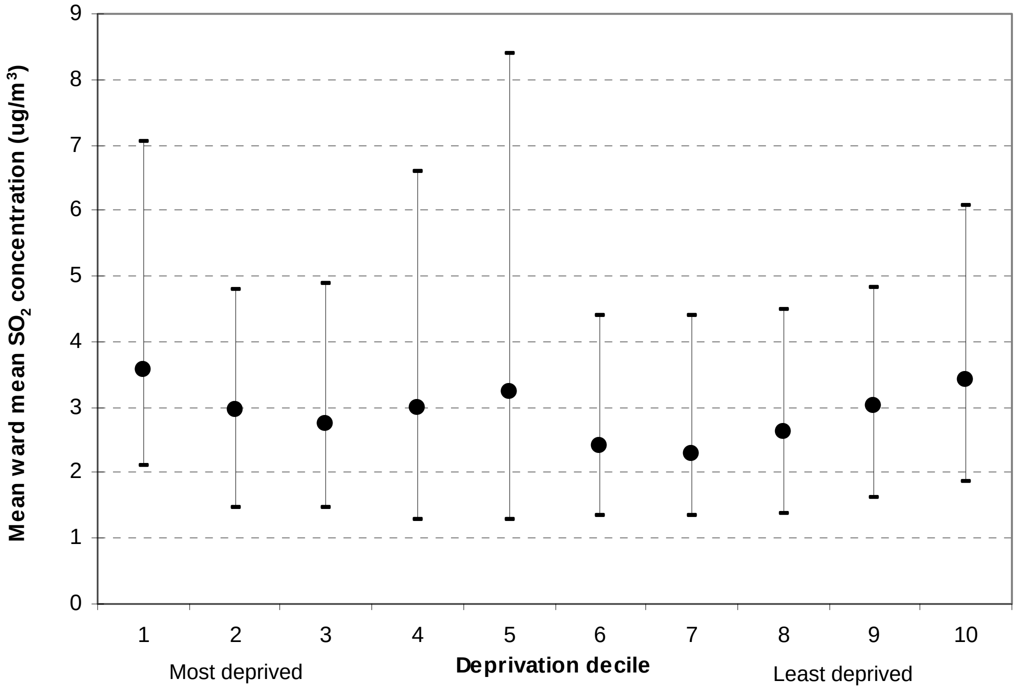
(b) Distribution of highest ward mean PM_{10} concentrations (2001)



Notes:
1. The most exposed 10 % of the population (0.3 million people), experience a mean ward level (annual mean) PM_{10} concentration of 17.2 ug/m^3 (cf. national annual mean 13.0 ug/m^3).
2. The most exposed 20 % of the population (0.6 million people), experience a mean ward level (annual mean) PM_{10} concentration of 16.4 ug/m^3.
3. There are no ward mean exceedences of the annual mean PM_{10} standard of 40 ug/m^3.

Figure 4.12: Social distribution of fine particulates (PM_{10}) in Wales, 2001

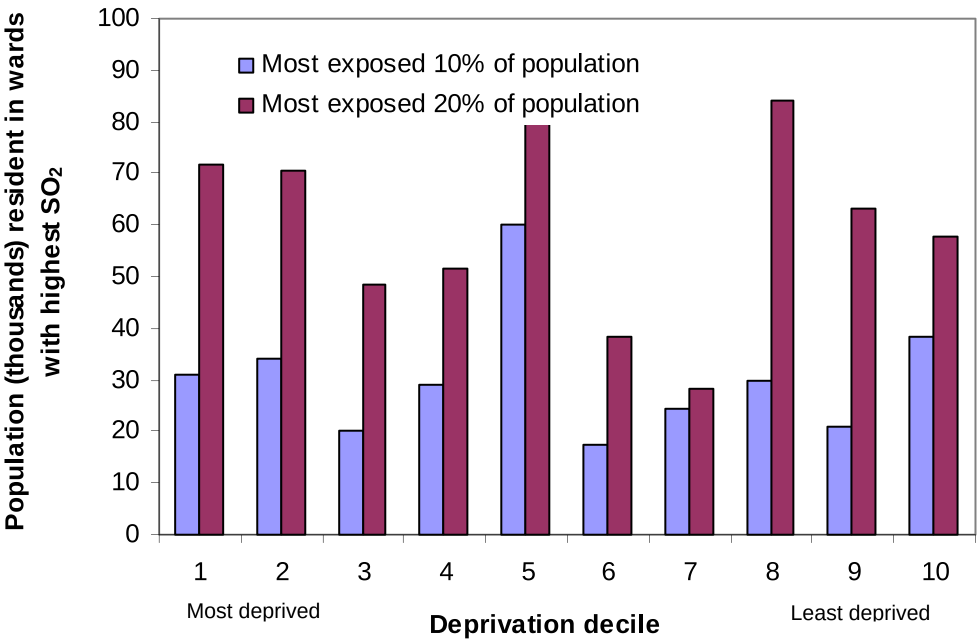
(a) Distribution of ward mean SO_2



Notes:

1. Bars denote 5-95 percentile range, N=865.
2. Each decile represents the average of ward mean SO_2, measured as an annual mean.

(b) Distribution of highest ward mean SO_2 concentrations (2001)

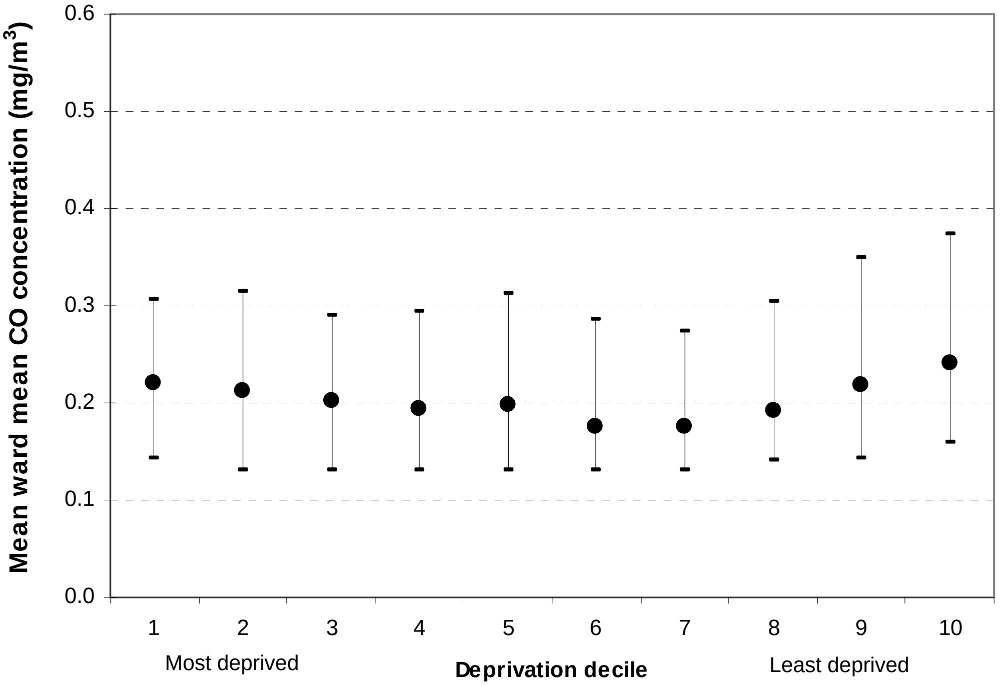


Notes:

1. The most exposed 10 % of the population (0.3 million people), experience a mean ward level (annual mean) SO_2 concentration of 6.8 ug/m^3 (cf. national annual mean NO_2 of 2.86 ug/m^3).
2. The most exposed 20 % of the population (0.6 million people), experience a mean ward level (annual mean) SO_2 concentration of 5.8 ug/m^3.
3. There is no annual mean standard for SO_2 (WHO guideline value is 50 ug/m^3)

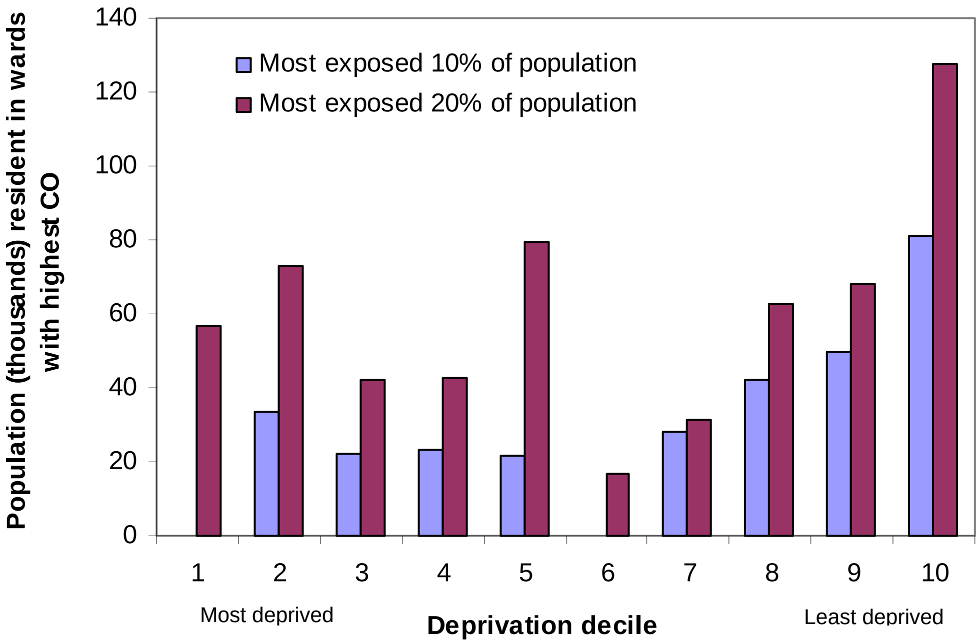
Figure 4.13: Social distribution of Sulphur dioxide in Wales, 2001

(a) Distribution of ward mean CO



Notes:
1. Bars denote 5-95 percentile range, N=865.
2. Each decile represents the average of ward mean SO_2, measured as an annual mean.

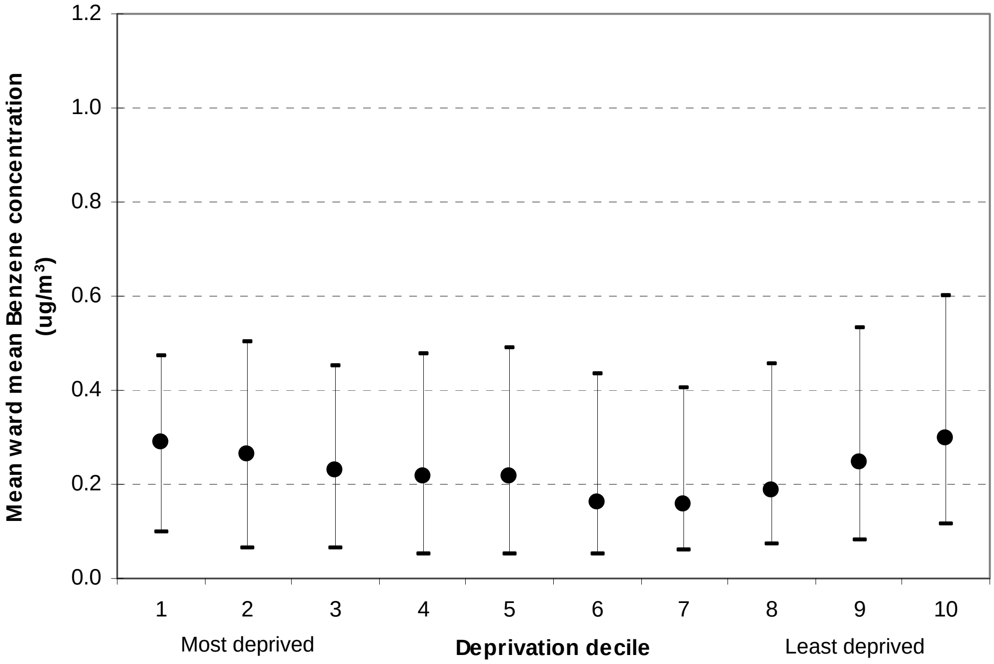
(b) Distribution of highest ward mean CO concentrations (2001)



Notes:
1. The most exposed 10 % of the population (0.3 million people), experience a mean ward level (annual mean) CO concentration of 0.36 mg/m^3 (cf. national annual mean CO of 0.20 mg/m^3).
2. The most exposed 20 % of the population (0.6 million people), experience a mean ward level (annual mean) CO concentration of 0.32 ug/m^3.
3. There is no annual mean standard for CO (or WHO guideline value).

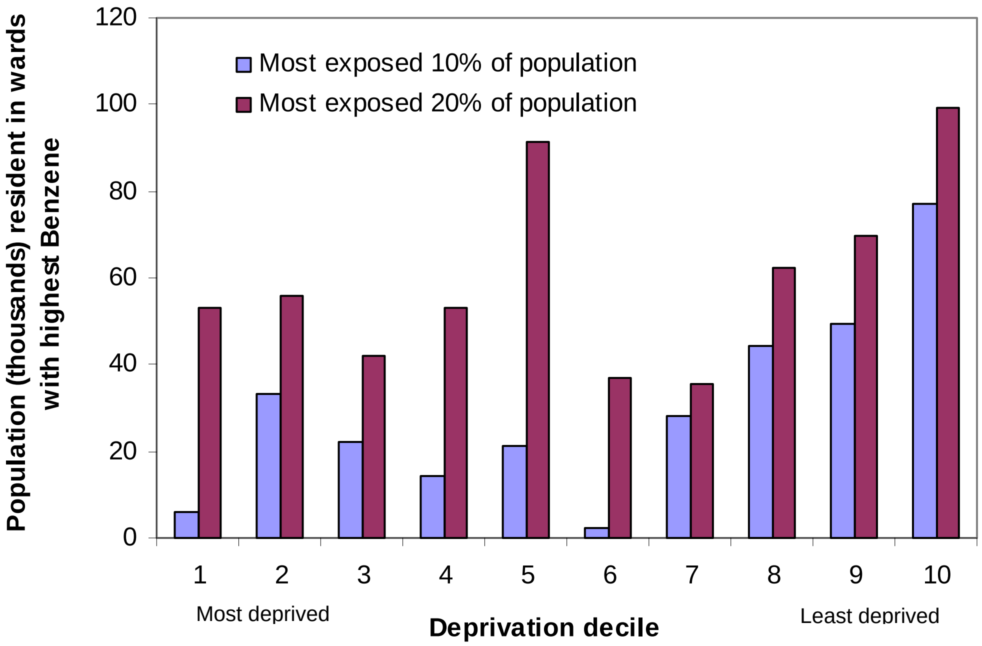
Figure 4.14: Social distribution of Carbon monoxide in Wales, 2001

(a) Distribution of ward mean Benzene



Notes:
1. Bars denote 5-95 percentile range, N=865.
2. Each decile represents the average of ward mean SO_2, measured as an annual mean.

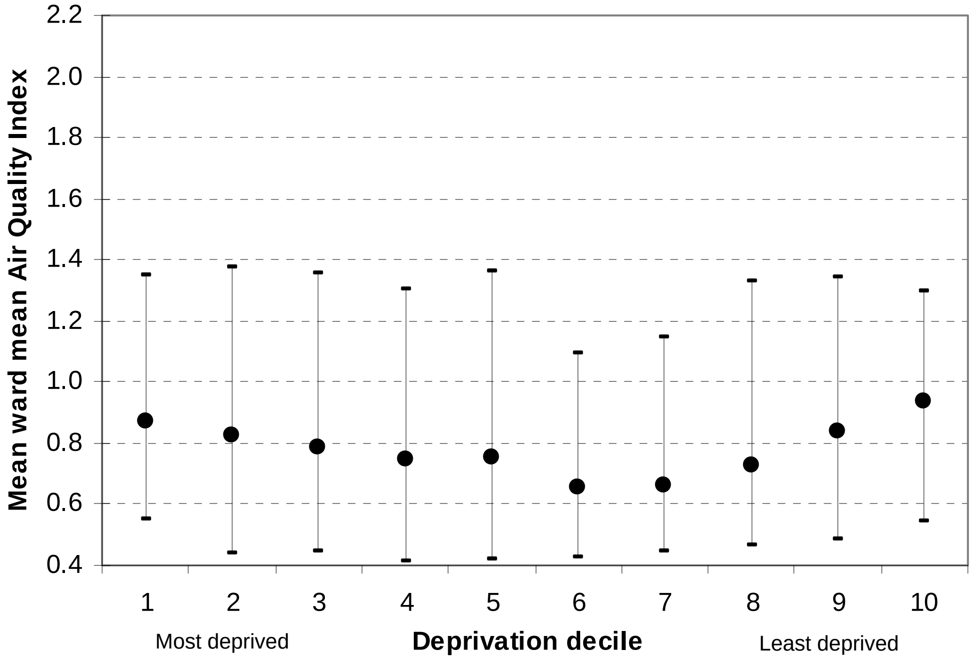
(b) Distribution of highest ward mean Benzene concentrations (2001)



Notes:
1. The most exposed 10 % of the population (0.3 million people), experience a mean ward level (annual mean) benzene concentration of 0.58 ug/m^3 (cf. national annual mean CO of 0.21 mg/m^3).
2. The most exposed 20 % of the population (0.6 million people), experience a mean ward level (annual mean) benzene concentration of 0.49 ug/m^3.
3. There are no ward mean exceedences of the annual mean Benzene standard of 16.25 ug/m^3.

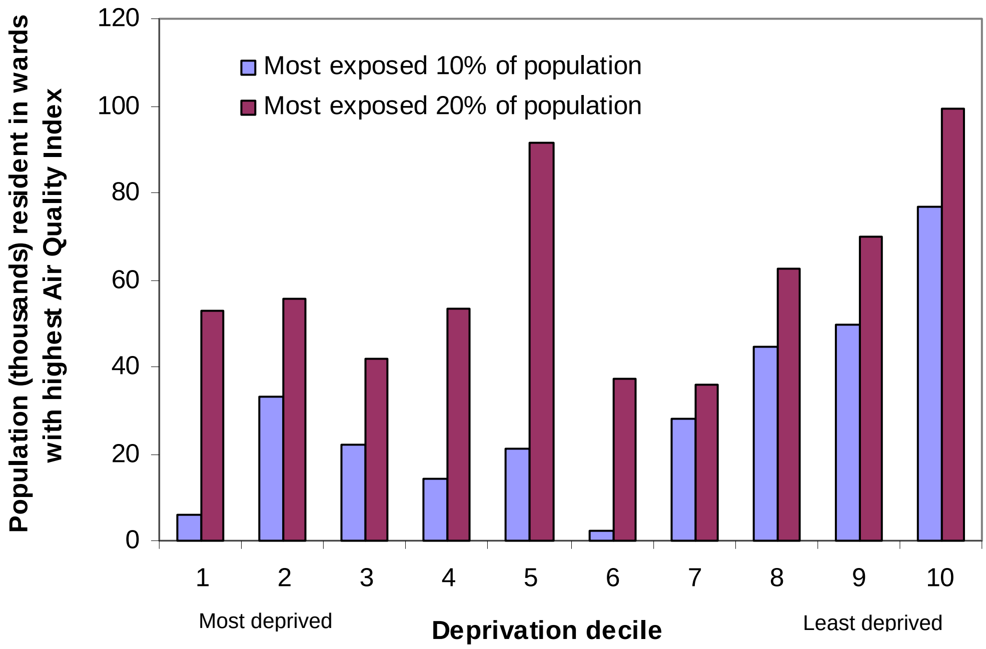
Figure 4.15: Social distribution of Benzene in Wales, 2001

(a) Distribution of ward mean Air Quality Index



Notes:
1. Bars denote 5-95 percentile range, N=865.
2. Each decile represents the average of ward mean Air Quality Index

(b) Distribution of highest ward mean Air Quality Index (2001)



Notes:
1. The most exposed 10 % of the population (0.3 million people), experience a mean ward level AQI of 1.34 (cf. national annual mean AQI of 0.76).
2. The most exposed 20 % of the population (0.6 million people), experience a mean ward level AQI of 1.23.
3. Exceedences cannot be applied to the air quality index

Figure 4.16: Social distribution of the Air Quality Index in Wales, 2001

4.5.3 Longitudinal analysis: Wales

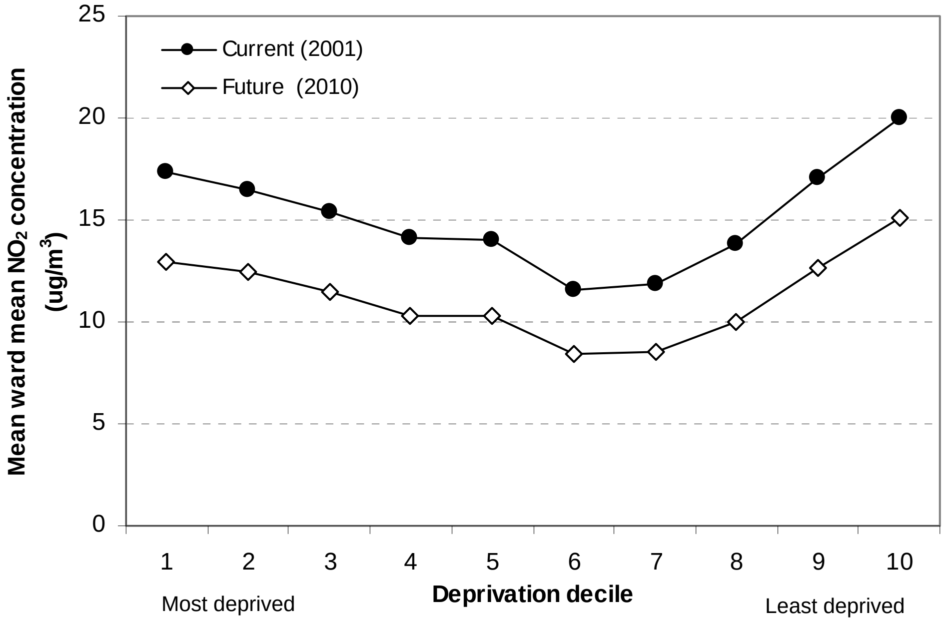
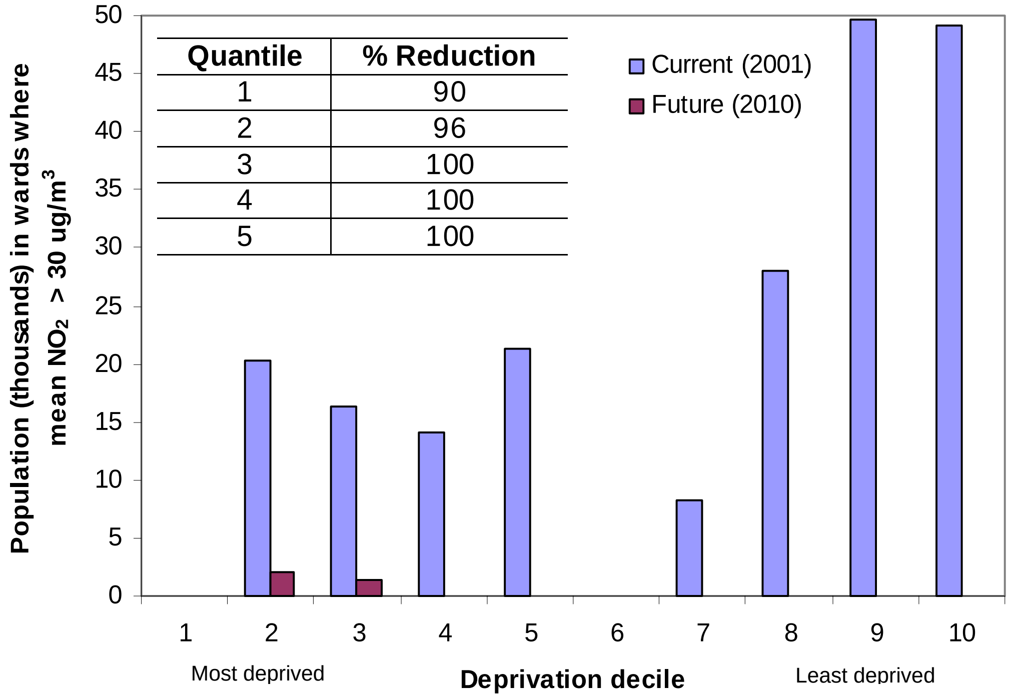


Figure 4.17: Change in social distribution of ward mean NO_2, 2001-2010



Notes:

1. Annual mean standard is 40 ug/m^3, of which there are no exceedences.
2. Decile 1 is most deprived (see section 1.2). All deciles have 0.3 million people;
3. In 2001, 207,000 people are in a ward where mean NO_2 > 30 ug/m^3, of which 65% are of below average deprivation (i.e. more affluent), and 48% are in the least deprived quintile;
4. In 2010, all ward mean NO_2 concentrations > 30 ug/m^3 are in the most deprived 30% of wards, although none are in the most deprived 10% of wards. The total number of people in wards where NO_2 > 30 ug/m^3 has fallen to just 36,000.

Figure 4.18:Change in population in wards where mean NO_2 exceeds 30 ug/m^3, 2001-2010

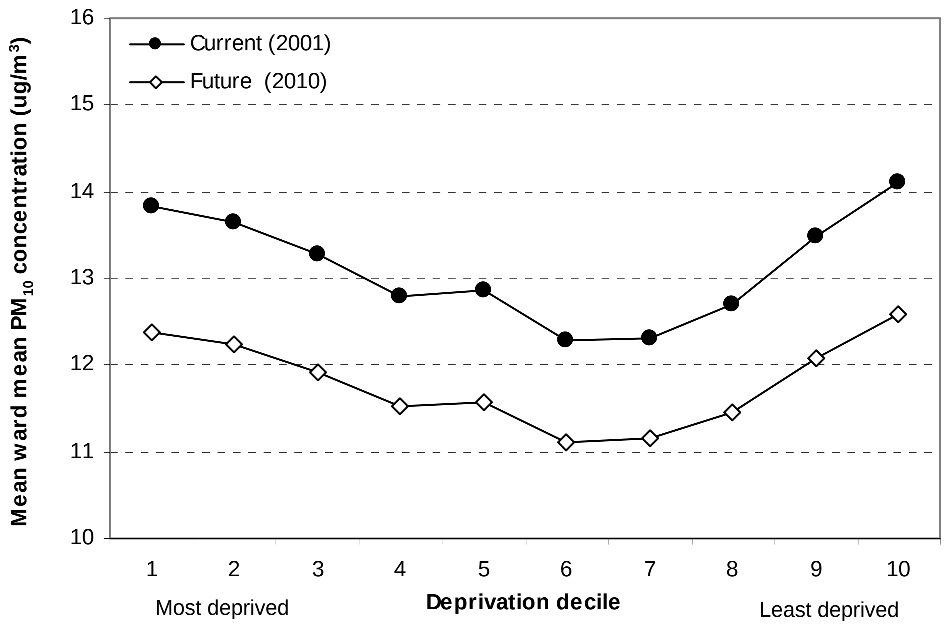
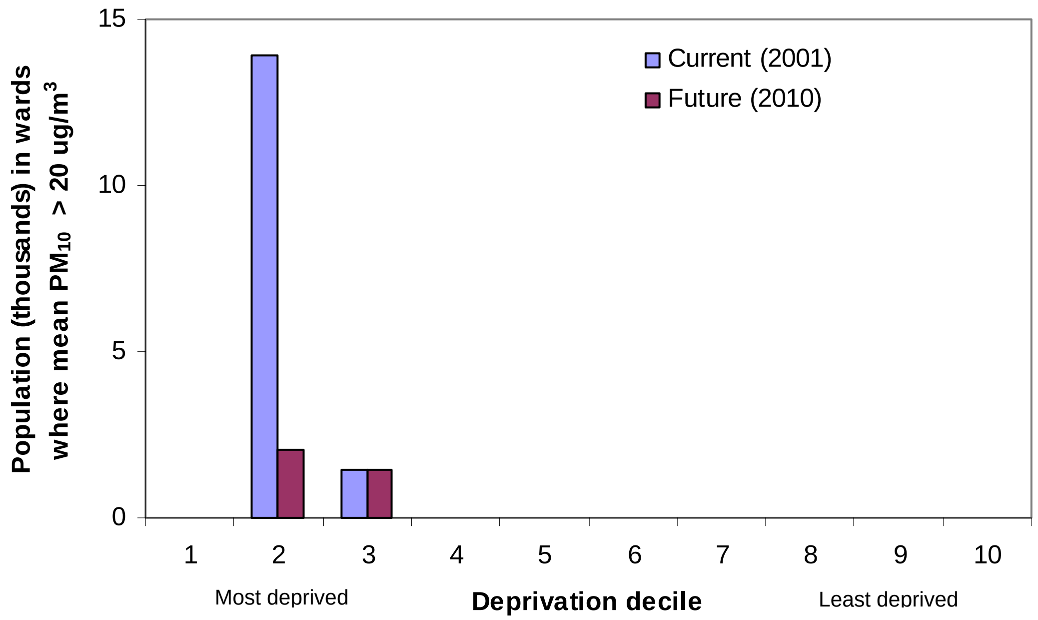


Figure 4.19:Change in social distribution of ward mean PM_{10}, 2001-2010



Notes:

1. Annual mean standard is 40 ug/m^3 (in 2001), of which there are no exceedences, and 20 ug/m^3 (in 2010), for which there are 3,500 person exceedences;
2. Decile 1 is most deprived (see section 1.2). All deciles have 0.3 million people;
3. In 2001, 15,000 people are in a ward where mean PM_{10} > 20 ug/m^3, all of which are the most deprived 30% of the population. Note however, that this covers only 3 wards altogether;
4. In 2010 just 4,000 people are in a ward where mean PM_{10} > 20 ug/m^3, again, all of which are in the most deprived 30% of the population. Note however, that this now covers only 2 wards altogether;

Figure 4.20: Change in population in wards where mean PM_{10} exceeds 20 ug/m^3, 2001-2010

4.6 'Pollution-Poverty' Hot Spots

Using our database of atmospheric concentrations and deprivation, we are able to identify those wards in which particular combination of air quality and deprivation occur. Our concern is with social exclusion, hence we are particularly interested in those areas in which air quality is well below average, and where deprivation is well above average. Whilst we have seen that below average air quality does occur in wards characterised as well off (particularly in Wales and London), we are most concerned with the most deprived wards, as residents here are much more constrained (economically), in their choice of residential location, and hence unlike their more affluent counterparts, are not able to flee the poor air quality, or trade it off against other benefits of that location.

By way of illustration, consider the Queen. Whilst at Buckingham Palace, she is resident in the ward with the third worst air quality in England (excluding unpopulated City of London wards). However, she trades off this cost against the benefits of living at the palace, and is also economically able to relocate to areas with much better air quality (which she does do for some of the year - e.g. to Balmoral in the Scottish highlands). Thus in developing environmental equity policy and strategies, the focus should be on excluded groups (e.g. the poor), even though others may experience equally poor air quality.

Our 'pollution-poverty' hot spots can be mapped using any combination of air quality and deprivation thresholds. In this example, we use the air quality index to summarise air quality for four of the NAQS pollutants. Using the England database, we selected wards with an AQI >1.5 and which were in the most deprived (population weighted) decile. This selection identifies several major and minor pollution-poverty clusters throughout the country (Table 4.8, Figure 4.21).

Table 4.8: Pollution-poverty clusters ('hotspots')[1] in England, 2001

Large clusters [2]	**Wards**
Liverpool	10 wards in Centre and West of city (133 k people)
London	102 wards ranging from Edmonton (N) to Southwark (S) and Barking (E) to the City of London (W) (914 k people)
Manchester	30 wards in the North East of the city (344 k people)
Nottingham	11 wards in Centre and West of city (103 k people)
Sheffield	8 wards in Central Sheffield (103 k people)
Small clusters	
Bristol	Lawrence Hill
Derby	Litchurch (Derby); Holmewood and Heath (N.E. Derbyshire); Bolsover Central (Bolsover)
Essex	Tilbury Riverside (Thurrock)
Leicester	Wycliffe, Spinney Hill, Belgrave, North Braunstone.
Luton	Biscot, Dallow
Tyneside	Grangetown (Laugbaugh-on-Tees)
W. Midlands	Aston (Birmingham); Chelmsley Wood (Solihull); Folsehill (Coventry)
W. Yorkshire	Deighton (Kirklees); City and Holbeck (Leeds)

1. Wards selected using criteria of AQI > 1.5 and deprivation decile 1.
2. The five large clusters account for 161 of the 178 wards that are selected using the above criteria.

1. Wards selected using criteria of AQI > 1.5 and deprivation decile 1.
2. The five large clusters account for 161 of the 178 wards that are selected using the above criteria.

Figure 4.21: Air quality Pollution-poverty hotspots in England, 2001.

The use of pollution-poverty maps provides a potentially useful tool for identifying those areas where remedial action to reduce pollution inequality could focus. However, the application has a strong subjective element in the selection of appropriate threshold values for both air quality and deprivation, and focuses attention on the development of policy and practice aimed at reducing inequality. For example, should remedial action simply be focussed on eliminating air quality exceedences (the purpose of the NAQS air quality management area designation), or should policy be seeking to reduce inequity in the burden of air quality that complies with standards, but which nevertheless still has implications for health?

4.7 Discussion

4.7.1 The social distribution of air quality

The purpose of the analysis reported above was to examine the relationship between air quality and deprivation through a ward level national analysis. The study sought to examine the social distribution of several key air pollutants, both individually and collectively, with respect to the Index of Multiple Deprivation 2000. The study has extended the prior Agency analysis to include Wales, and for the first time has attempted a preliminary investigation of possible future social distributions of air quality at the national scale.

The results of our analysis of England are largely consistent with the only small area national analyses of air quality (Environment Agency 2002; Mitchell and Dorling, 2003). However, the analysis reveals that the social distribution of air quality in Wales is very different to that of England.

(a) The social distribution of air quality in England

We studied five pollutants which are addressed by the National Air Quality Strategy (NAQS) (NO_2, PM_{10}, CO, SO_2, benzene). For each of these pollutants, there is a clear and consistent pattern in their social distribution (the relationship between deprivation, and mean ward concentration). Whilst there is considerable variability of pollutant concentration within each decile, it is apparent that, overall, those wards which are most deprived are also those with highest pollutant concentrations.

We note however, that the least deprived do not enjoy the best air quality. The relationship between pollutant concentration and deprivation is curvilinear, with residents of both the most and least deprived wards bearing a greater burden of pollution than wards characterised by people of average deprivation (see also Table 4.9). However, for all pollutants, it is the poor who carry the greatest burden of atmospheric pollution. Typically, the least deprived experience ward mean pollutant concentrations that are up to 12 % above the average. In contrast, the poor experience concentrations that are above the average by, typically, 11 % (PM_{10}), 30-40 % (NO_2, SO_2, CO) and 76 % (Benzene).

When we examine those wards with the highest pollutant concentrations, those which might be considered to be most problematic, we also find a clear and consistent social distribution. Here, the distribution is no longer curvilinear. Instead, we see that the number of people resident in wards above a particular threshold increases progressively with increasing deprivation (Table 4.10).

Table 4.9: Social distribution of air quality (all wards by Gini Concentration Index)

Air quality parameter	Year	Gini Index of Concentration [1,2]	
		England	**Wales**
Nitrogen dioxide	2001	0.05	-0.01
	2010	0.06	-0.01
Particulates (PM_{10})	2001	0.02	0.02
	2010	0.02	0.00
Sulphur dioxide	2001	0.06	0.02
Carbon monoxide	2001	0.06	0.00
Benzene	2001	0.11	0.02
Air Quality Index	2001	0.04	0.00

Notes:
1. Gini Index of Concentration values range from -1 to +1. A value of 1 indicates perfect inequality where the poorest person in the study group bears all the costs. A value of -1 also indicates perfect inequality, but the least poor person bears all the costs. A value of zero indicates perfect equality.
2. There are no significance tests for the GCI, but note that Gini coefficients of income in the UK vary from 0.25 to 0.35 from 1979-2001.

Table 4.10: Social distribution of most adverse air quality in England (Gini Concentration Index) [1]

Definition of most adverse air quality	NO_2	PM_{10}	SO_2	CO	Benzene	AQI
Exceedences of NAQS annual mean standard	0.47	None	None	None	None	N/A
Highest 5 % of ward mean concentrations [2]	0.47	0.51	0.24	0.47	0.46	0.52
Highest 10 % of ward mean concentrations	0.43	0.45	0.25	0.42	0.40	0.43
Highest 20 % of ward mean concentrations	0.34	0.33	0.22	0.32	0.31	0.34

Notes:
1. See Table 4.9 for explanation of Gini coefficient
2. I.e. wards are ranked by ward mean annual mean concentration, and the most polluted wards selected from analysis until 5% of the national population are included in the ward selection. The deprivation characteristic (IMD decile) is then used to determine the social distribution of these most polluted wards.

The case that gives most concern, is that of nitrogen dioxide, where there are 2.5 million people in England who are resident in wards where the ward mean concentration is above the NAQS annual mean standard of 40 ug/m^3. Of these people, one third are resident in the most deprived 10 % of wards, and over half in the most deprived 20 % of wards. Of the 2.5 million 'person exceedences', only 1 % occur in the least deprived decile.

Our ward mean concentrations do not exceed NAQS annual mean standards for any other pollutants. This is not to say that exceedences do not occur for these pollutants, simply that peak values are lost when working with ward averages. We did not feel it appropriate to work with ward maximum concentration values, as within ward heterogeneity in both deprivation and pollutant concentration could lead to misleading results of analysis that attempted to relate the two (e.g. maximum concentration occurs away from a population centre). Instead, we chose to examine the social distribution of people who are resident in wards that have the highest (10 %, 20 %) ward mean concentrations in England.

This analysis reveals a similar pattern to that observed for the NO_2 exceedences, with a progressive increase in the number of most highly exposed people, with increasing deprivation. If we consider the 10 % of the national population that are resident in wards with the poorest air quality, we find that, typically, half of them are also resident in wards characterised as amongst the 20 % most deprived. In contrast, typically only 5% of this 'most exposed' group are in the least deprived 20 % of the population. Thus whilst the poorest air quality can be found in all communities, from the most to the least deprived, it is the poor that bear the greatest burden (by an order of magnitude).

The Air Quality Index (AQI) was applied to four of the NAQS pollutants (not CO, for which annual mean standard or guide values are not determined). The index closely reflects the consistent concentration - deprivation patterns observed for the constituent pollutants, for both average and peak values.

The Air Quality Index has also been used, to identify deprivation-concentration 'hot-spots'. That is, wards and clusters of wards in which air quality is amongst the poorest, and deprivation the highest. In our example (section 4.6 above), we identified around a dozen areas that have both poor air quality *and* high deprivation. The AQI provides a useful tool in this respect, but the selection of threshold values remains a subjective process, to be agreed more widely.

(b) The social distribution of air quality in Wales

At first sight, the results for Wales suggest a similar relationship between pollutant concentration and deprivation as observed for England. There is a curvilinear relationship, with both the most and least deprived wards experiencing pollutant concentrations above those found in wards of average deprivation. However, this is the only parallel with England, as in Wales, pollutant concentrations are highest in the *least* deprived wards.

The differential between least and most deprived in Wales, is however, much less than that observed for England. The greatest differential occurs with respect to NO_2 (least deprived decile has a ward mean concentration 58 % above that for average deprivation decile, compared to only 38 % for the most deprived decile), with little difference for other pollutants (Table 4.6).

When we examine those wards with the highest pollutant concentrations, we do not find the clear pattern observed for England, where the poorest air quality is mostly found in deprived wards. All pollutants share a broadly similar social distribution of highest concentrations, but the pattern is much less clear than that of England. In part, this is a product of population size. The England analysis has roughly 5 million people in the most polluted wards (population weighted decile), in contrast to just 300,000 people in the most polluted Welsh wards.

Table 4.11: Social distribution of most adverse air quality in Wales (Gini Concentration Index)

Definition of most adverse air quality	NO_2	PM_{10}	SO_2	CO	Benzene	AQI
Exceedences of NAQS annual mean standard	None	None	None	None	None	N/A
Highest 5 % of ward mean concentrations [2]	-0.19	-0.07	0.13	-0.43	-0.31	-0.03
Highest 10 % of ward mean concentrations	-0.29	-0.16	0.01	-0.31	-0.30	-0.21
Highest 20 % of ward mean concentrations	-0.13	-0.14	0.02	-0.10	-0.07	-0.12

See Table 4.10 for explanatory notes.

If we examine the social distribution of the most polluted wards by (population weighted) deprivation quantile (Tables 4.7 and 4.11), a clearer pattern emerges. Here we see that the most polluted wards tend also to be the least deprived. For example, the least deprived 20 % of the Welsh population have over 40 % of the highest (top 10 %) ward mean concentrations of CO and NO_2. This is twice what would occur if high pollution was equally distributed by deprivation. Note also that the differential between least and most affluent is also substantial, with 3 to 4 times as many 'affluent' people resident in wards with highest concentrations, as there are poor. The exception is SO_2, where highest ward mean concentrations are equally distributed by deprivation.

It is then, appropriate to ask why should the pollution-deprivation relationship be so different between England and Wales. The smaller population of Wales means that much greater variability is evident in the analyses of high pollutant wards. This however, is not adequate to explain the observed differences, as analysis of the mean pollutant concentration by decile is based on the entire population, but exhibits a different pattern to England, where the most deprived clearly bear the greatest burden of poor air quality.

From their NO_2 analysis of Great Britain, Mitchell and Dorling (2003) speculated that the above average pollution observed amongst the least deprived was attributed to well off households locating in urban centres, and particularly London where there is a high occurrence of urban affluent wards. If we map the distribution of deprivation and pollution in Wales, we see that this is a probable explanation for the high pollution amongst the more affluent in Wales. Figure 4.22 shows the distribution of air quality (as NO_2) in Wales, whilst Figure 4.23 shows the distribution of deprivation, with the least deprived wards (population weighted decile) highlighted. Note the very strong co-incidence between the distribution of poorest air quality, and the least deprived wards.

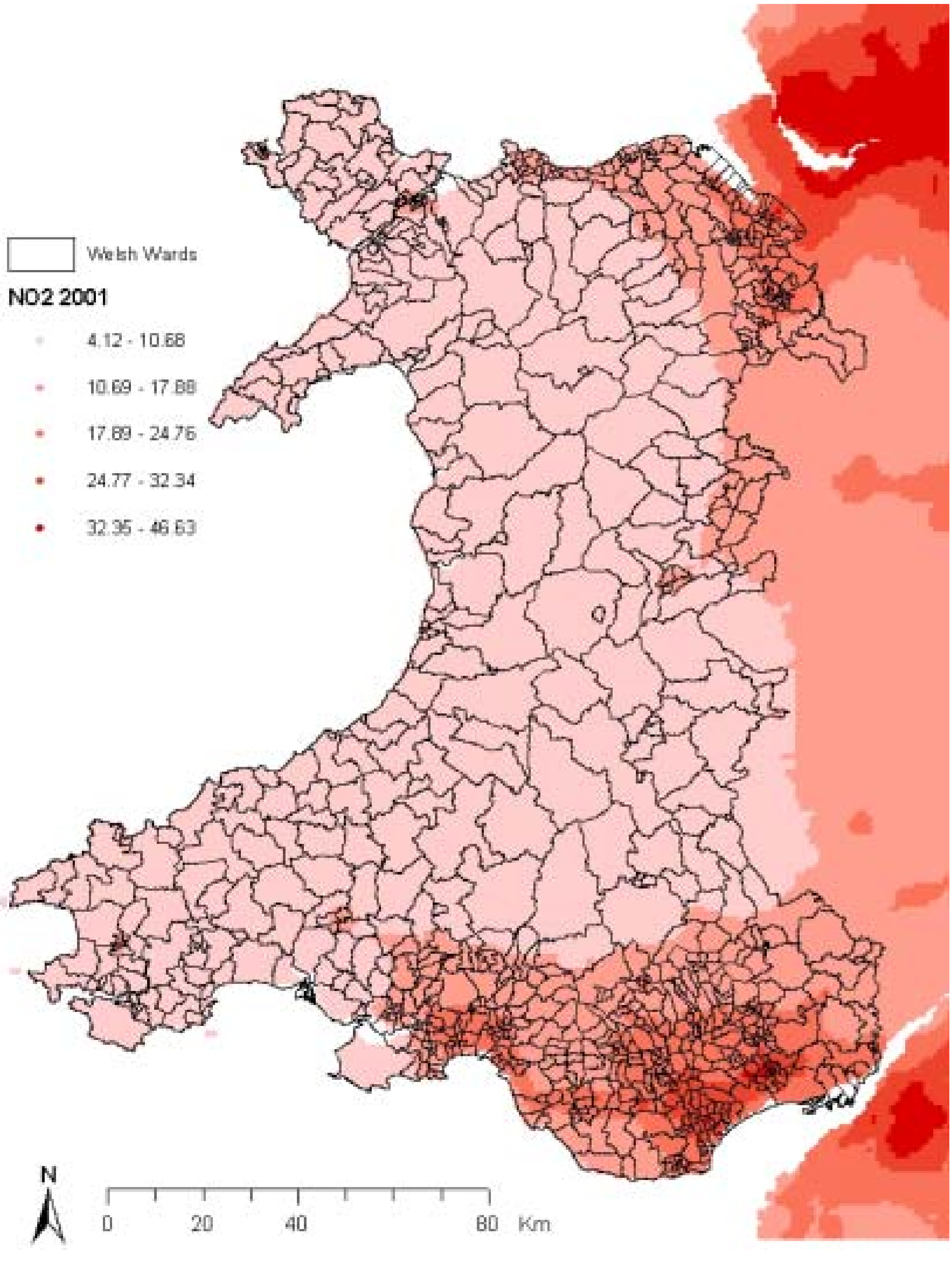


Figure 4.22: Distribution of annual mean nitrogen dioxide in Wales.

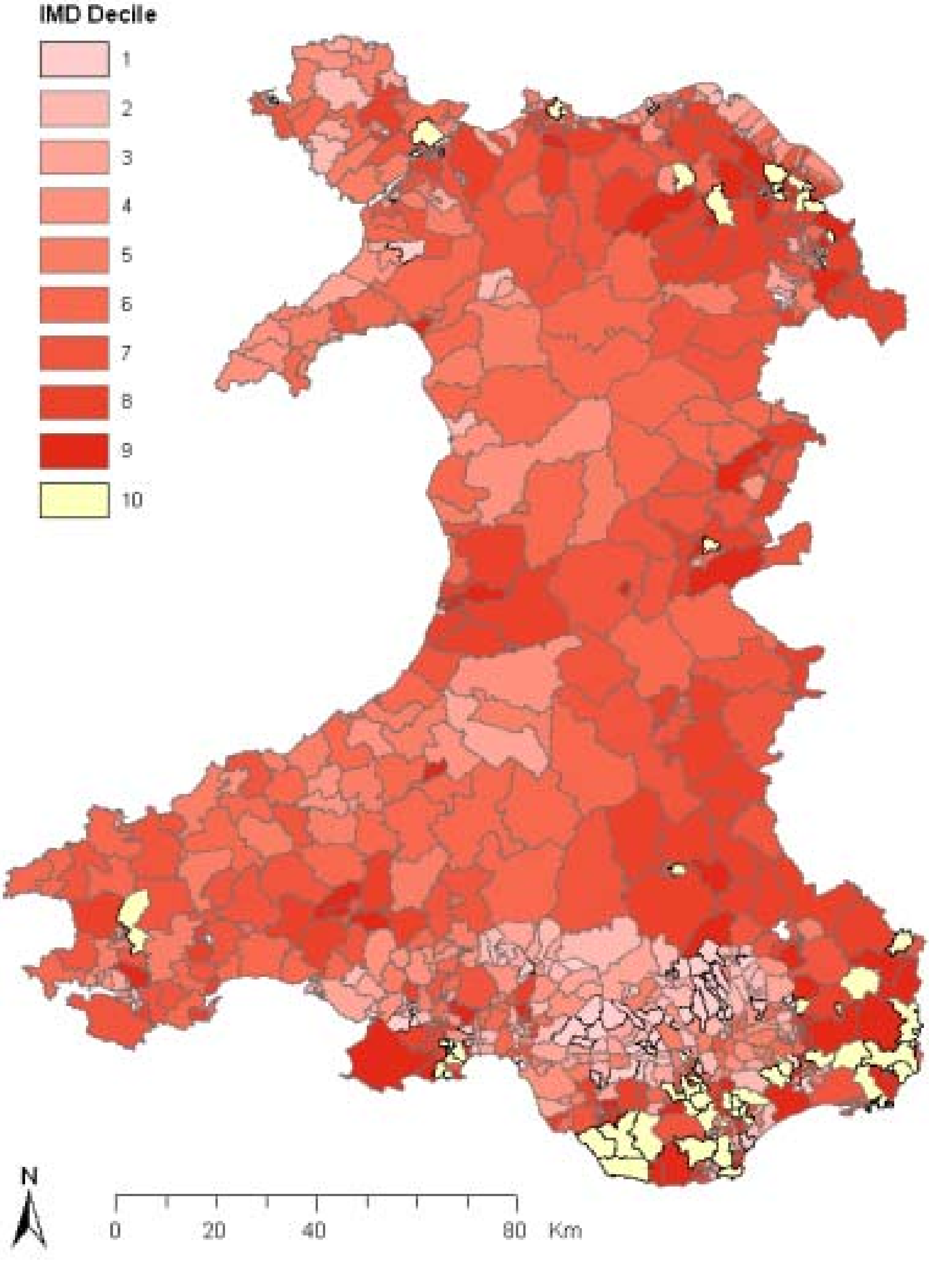


Figure 4.23: Distribution of deprivation in Wales, highlighting the least deprived wards.

These maps indicate that the least deprived wards in Wales tend to be urban (they are mostly in Cardiff) and tend to be more urban than the similarly least deprived wards in England. Our assumption is that the more affluent wards are not found in a distant rural peripheral commuter belt, as we might find with large English metropolitan areas, due to the geography of south Wales. Essentially, the affluent in Cardiff are constrained in their residential location by the sea to the south, and the deprived valleys to the North, and so the affluent Welsh tend to be more urban than their English counterparts, and consequently located in areas of poorest air quality. Note however, that air quality in Wales is much better than England (e.g. no ward mean exceedences of the NO_2 annual mean standard), and hence poor air quality (and associated factors such as traffic noise and congestion) is a weaker deterrent to locating in the city. Cardiff may not be unique in the UK, but Cardiff dominates the Welsh situation, and hence exerts a major influence on the national pattern.

4.1.1 Future air quality - deprivation patterns

In recent decades, air quality in Britain has improved dramatically, and this trend is forecast to continue, although at a more modest rate. Our analysis of changing air quality-deprivation patterns (from 2001 to 2010), is to some extent constrained by the availability of good data for 2010, particularly with respect to the representation of spatially dependent emission processes. Nevertheless, our analysis is sufficient to suggest that whilst the total burden of air pollution will continue to fall, there will be relatively little change in the social distribution of that pollution, although the distribution of the poorest air quality should become more equitable.

Our analysis is relatively unsophisticated, as we have no data on the likely spatial distribution of deprivation in 2010, which we represent using the 2001 deprivation data. This assumption is necessary, but is not so gross as to negate the analysis. Patterns of deprivation are known to change very slowly, and we are confident that the broad spatial pattern of deprivation seen in 2010 is likely to be comparable to that of 2001 (although absolute levels may change significantly). The air quality data for 2010 (NO_2, PM_{10}) is modelled using the same tools and techniques as used to model 2001 air quality. This ensures that changes in air quality over the forecast period are a product of model inputs and not the model.

However, we note that model inputs are unlikely to display significant spatial variation between 2001 and 2010. For example, air quality improvements will occur due to technological development (e.g. emission control, alternative fuels), a factor represented in the model by aspatial emission factors. Some spatially dependent processes are represented in the model, but display little change in the relative spatial pattern. The National Trip End Model is used to forecast traffic volumes on major highways, for example, but results show that, overall, the busiest roads in 2001 remain the busiest roads in 2010. Other spatial processes, such as land use - transport interaction, are more poorly represented.

It is perhaps not surprising then, that whilst air quality forecasts show an improvement in air quality overall, there is relatively little change in the spatial distribution of NO_2 and PM_{10}, and hence little change in the social distribution of pollution, as judged by ward average air quality (Figure 4.7, Figure 4.19). In absolute terms (ug/m^3), the poor enjoy the greatest benefits of air quality improvement. Figure 4.24, for example, shows that the most deprived decile experiences a reduction in ward mean annual NO_2 of 7.1 ug/m^3 from 2001-10, compared to 5.5 ug/m^3 for people of average deprivation and 6.5 ug/m^3 for the least deprived decile. In relative (% change) terms however, the poor do not enjoy the same improvement in NO_2 as others, although the differences are small (Figure 4.24).

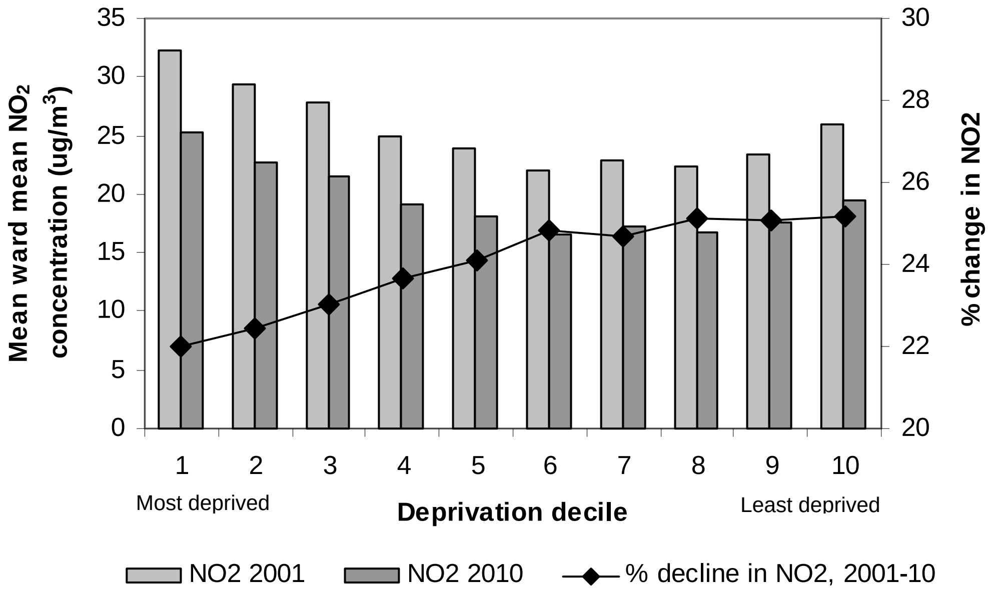


Figure 4.24: Change in social distribution of ward mean NO_2, 2001-2010 (England)

If we examine the social distribution of the poorest air quality, we see that the poor enjoy greater benefits than others. Figure 4.8 shows that, of the two million people 'removed' from an NO_2 exceedence ward by air quality improvement, most will be poor. Note however, that there are a great many more of them in the exceedence band to begin with, and that the poorest quintile continues to bear over half the NO_2 exceedences that remain in 2010. Plotting the data from Figure 4.8 using Lorenz curves (cumulative distributions), we see that the social inequality in distribution of NO_2 exceedence (wards where annual ward mean NO_2 > 40 ug/m^3) declines. Thus air quality improvement leads to a more equitable distribution in peak concentrations.

The introduction of tighter air quality standards may lead to an increase in exceedences, and the burden of these new exceedences is likely to be borne disproportionately by the poor (note that changing the standard does not affect actual exposure). This is the case with the 20 ug/m^3 PM_{10} standard to be introduced in 2010 (DEFRA 2003). Figure 4.25 illustrates Lorenz curves for 2001 and 2010, addressing people in wards where annual mean PM_{10} is forecast to exceed 20 ug/m^3. Note that, unlike NO_2, the distribution of peak values becomes more inequitable. This pattern arises as by 2010, all people resident in wards where PM_{10} > 20 ug/m^3 are in the poorest three deciles, with none in any other decile. Note however, that overall the total number of people in a PM_{10} 'exceedence' ward falls from 650,000 in 2001 to just 25,000 in 2010.

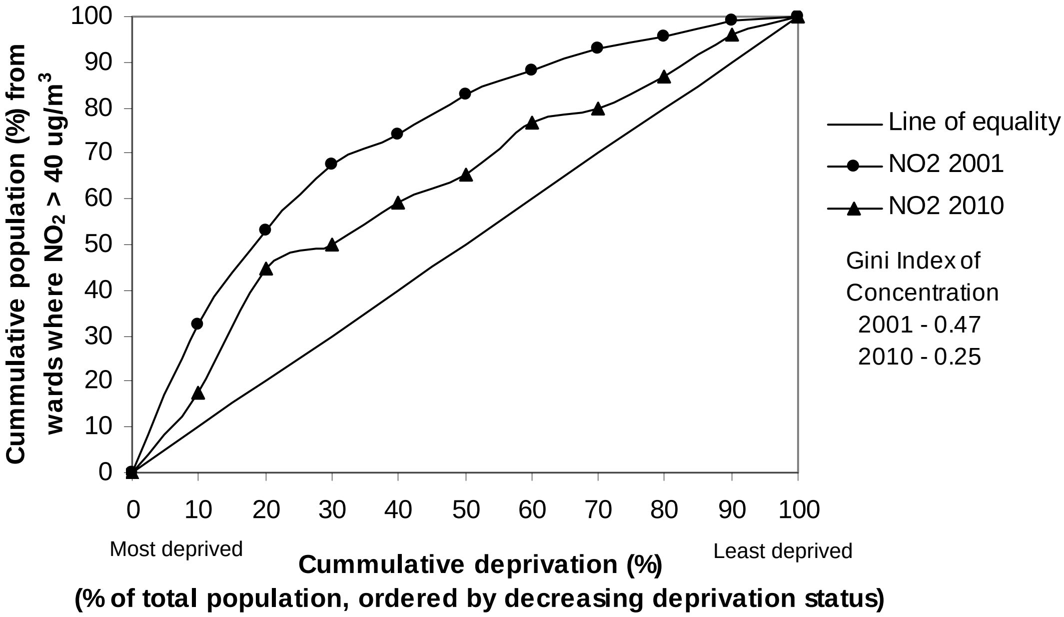


Figure 4.25: Social distribution of high annual ward mean NO_2 (England)

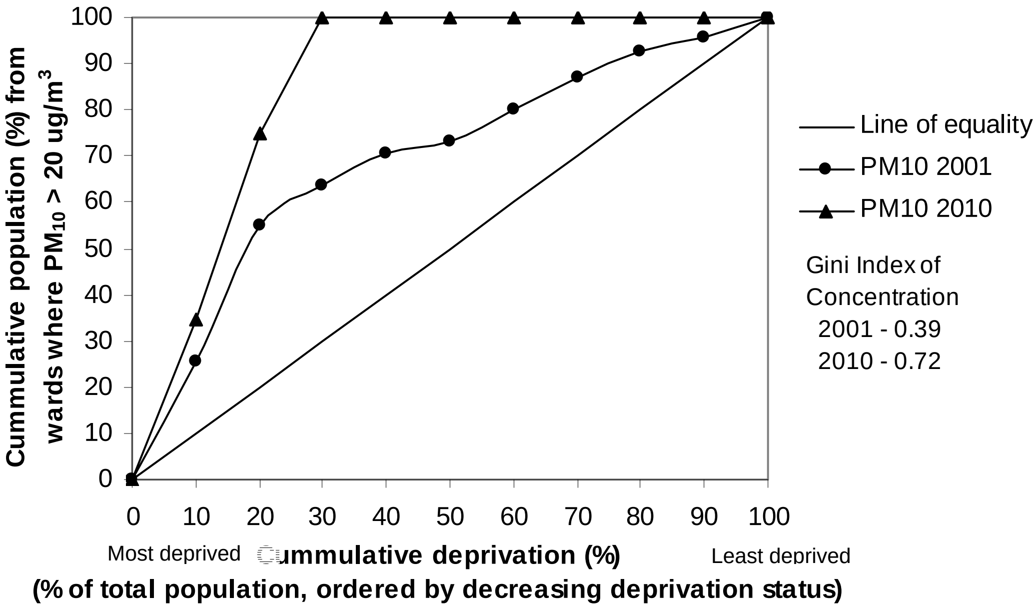


Figure 4.26: Social distribution of high annual ward mean PM_{10} (England)

The temporal analyses illustrates that equity analyses are sensitive to characteristics of the data (e.g. whether thresholds are applied to environmental data) and that results should be interpreted carefully. On balance, our temporal analysis shows that the social distribution of pollution is likely to change little when considering all wards, but that when examining only those wards where air quality is poorest, we find that the social distribution of pollution becomes more equitable. As air quality continues to improve, its social distribution could appear increasingly inequitable. This is because the poorest air quality is largely confined to urban areas which tend to be more deprived. However, these areas will enjoy very much better air quality than at present.

Finally we note that the designation of NAQS air quality management areas (AQMA's) is not addressed in the NETCEN data upon which this analysis is based. AQMA's are deliberately zoned so as to address current/forecast exceedences of air quality standards, most of which are in urban centres, which are disproportionately populated by the poor. Thus AQMA designation should act to make a more equitable social distribution of pollution. The caveat is that AQMA management measures could have locally undesirable consequences, such as traffic management measures that cause traffic to re-route away from an AQMA and through a high deprivation neighbourhood.

4.7.2 Air quality and social justice

Through the above analysis, we have established that there is an unequal social distribution of air quality in both England and Wales, with the most deprived bearing a greater air quality burden than people of average means. However, in both countries we also see that the least deprived also bear an above average air pollution burden. In England, this burden is significantly less than that borne by the deprived, whilst in Wales, it is roughly equal. This brings into focus the issue of equality and justice. That is, are the observed social distributions unfair? In part, this is a subjective and political decision, which we have discussed in our earlier Phase I report (Mitchell and Walker, 2003), particularly with reference to welfare theory and the application of different welfare perspectives that lead to radically different views on whether the same outcome is just or not. Here, we discuss some additional, more practically rooted issues, exemplified by our air quality analysis, but which are pertinent to the wider debate on environmental equality and justice. These issues are those of metrics, polluter pays, and freedom of choice.

(a) Metrics of adverse effect and disadvantage

Currently, we have no agreed means of identifying a social distribution of pollution that most would consider unfair. Whilst we can identify extreme differences in the burden of pollution borne by different groups, we face difficulties when attempting to assess whether this unequal distribution is unfair. Different interpretations will result from the application of different welfare theories, but even before we get to that stage, there is a need for more standard measures of inequality.

In our air quality analysis we have used two principal metrics: pollutant concentration and a deprivation index. In the case of the pollutant concentration we analysed ward mean values, with special attention paid to the highest ward mean values. Of these high values, we examined the social distribution of those that exceeded prevailing standards, as well as the distribution of the highest values (highest 10 % of population weighted wards), whether they breached a standard or not.

Air quality standards are publicly agreed, and hence it is tempting to conduct equality analysis that just examines their social distribution (noting that our exceedence analyses are necessarily based on ward means, and hence will miss more local, within-ward extremes). However, air quality standards are designed to protect health at a cost acceptable to society [note, for example, that recent revisions to air quality standards for the UK have resulted in different standards between UK countries, and even within England (DEFRA, 2003)], and current epidemiological evidence suggests that a health burden exists at all concentrations below the prevailing standards (DoH 1998). Thus an argument can also be made for conducting equity assessments of air quality that complies with standards. When conducting equity analysis there is then clearly a need to have a better understanding of what constitutes an unacceptable environmental burden.

Air quality is perhaps one of the simpler domains to address here, as at least there are scientifically well founded standards to provide a for debate. In other areas, (e.g. environmental risk from proximity to a hazardous installation), this is more subjective and problematic.

We also note that the selection of the disadvantaged group requires agreement. Equity analyses often address ethnicity, simplifying analysis as the data is categorical - an individual either does or does not belong to a particular group (although a decision must be made on which groups to address). In contrast, deprivation allows no such distinction, and the analyst must decide which deprivation groups to address. We chose to base much of our analysis on the 10 and 20 % of the population resident in the most deprived wards, but this is a relatively arbitrary choice, and others may choose differently. Clearly our pollution-poverty maps would highlight different areas, had we used different air quality and deprivation metrics.

Finally, we note that, even with agreed environmental and demographic metrics, there remains a need for wider agreement on what constitutes and acceptable degree of difference in the distribution of unacceptable environmental burden between social groups. How much additional environmental burden is it acceptable for a target group to bear before it is considered unacceptable: 10 % above the average, 100 %, 1000 % ?

(b) The Polluter Pays

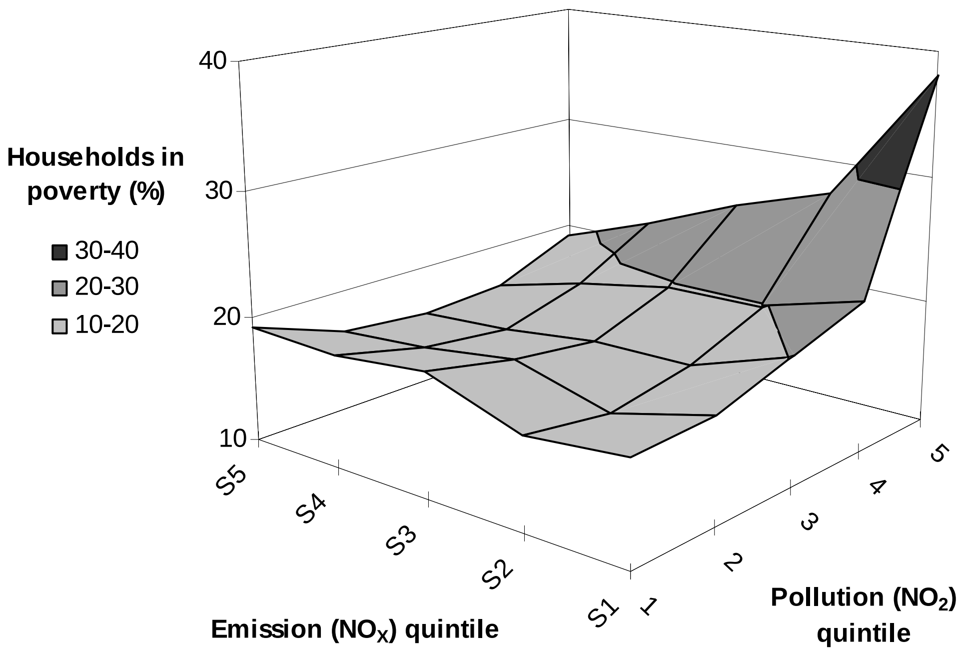
In addressing the issue of acceptable degree of difference in environmental burden, it is appropriate to consider the issue of polluter pays. From their study of air quality in London, Stevenson *et al.* (1999) concluded that air quality is poorest in areas of low car ownership, a finding used by Friends of the Earth to claim that "traffic pollution is mainly caused by the better off, but the poor feel its effects", and that "traffic pollution is largely caused by richer people living in comparatively clean environments" (Higman 1999).

In their ward level analysis of the social distribution of NO_2 in Britain, Mitchell and Dorling (2003) attempted to test such assertions by including emission of NO_X from vehicles in their analysis. Using DVLA data on car ownership and type by ward, and an emissions model, they estimated total NO_X emissions from cars owned by people resident in particular wards. This then allowed an assessment of the social distribution of NO_X emissions from private cars (emissions are allocated to the ward in which they owner of the vehicle lives, not where the vehicle is driven).

The analysis revealed no relationship of NO_X emission from cars with deprivation. Households in affluent wards own more cars and drive them further than average. Households in deprived wards own fewer cars, and drive them less than average, but these cars tend to be older and much more polluting *per se*, hence we find no relationship between deprivation and emission. This finding is significant from the polluter pays perspective, and suggests that statements like those of Friends of the Earth presented above require careful scrutiny.

This does not, however, suggest that inequality does not occur. Mitchell and Dorling (2003) did find evidence of environmental inequality when deprivation, air quality and emission were considered collectively. A series of wards were identified that were amongst the poorest in Britain, and where NO_X emissions were very low, but where levels of NO_2 were amongst the highest observed (Figure 4.27). This is interpreted as inequitable as the residents contribute little to the pollution problem, but can do little about it (i.e. move home).

Figure 4.27. Poverty rate by NO_X emission and ambient air quality for 10,444 British wards in 1999.



Inequality may also occur due to the ecological fallacy. That is, in a ward based analysis we assume homogenous deprivation and emission characteristics. In reality, some households within a ward will be more deprived than the ward average. If these households emit less than the ward average (e.g. they do not own a car), they may be in a position where the pollution burden they bear is not offset by their emissions. Thus the distribution of costs and benefits of a polluting activity may display significant inequality at the household level, but not at the ward level.

(c) Freedom of choice

A further consideration in assessing inequality is that of freedom of choice. People make choices in which environmental quality is one factor traded off against others. Thus an urban location with poor air quality (and associated factors of traffic congestion and noise) may be acceptable given the compensatory benefits of living there (e.g. housing quality, access to jobs and services). However, households that are strongly constrained economically have less choice in residential location, and may be unable to make satisfactory compensatory trade-offs (e.g. resident in a polluted urban location through economic necessity, but with poor access to compensatory services).

Similarly, we have argued above, that the inequality observed between deprivation and NO_2 is less than that claimed by Friends of the Earth, as poor wards make a contribution to NO_2 pollution that is roughly equivalent to that made by less deprived groups. However, this ignores the fact that the deprived face greater economic constraints than many, and may have no option but to run and older and hence more polluting vehicle.

4.8 Recommendations

4.8.1 Recommendations for policy and practice

1. Our analysis indicates that there is a strong relationship between poor air quality, and social deprivation. The relationship is particularly strong when considering peak pollutant values, including exceedences of air quality standards, and the upper (population weighted) decile of pollutant concentration. Improving air quality where it is worst, should act to reduce this inequality. We therefore recommend that the Agency <u>extend any necessary support to local authorities seeking to meet NAQS objectives through the designation of air quality management areas (AQMA's).</u>

2. There are numerous mitigation measures that can be adopted in AQMA's to reach NAQS objectives. These may include measures that redistribute emissions (e.g. traffic management). We also note that local transport plans (LTP's) include measures which will impact upon air quality. The distributional impacts of these measures, in air quality-deprivation terms are not widely understood [although see Mitchell (*in press*) on road user charging and other transport measures for Leeds]. There is a need to ensure that these measures do not produce an undesirable redistribution of pollution to deprived communities. <u>We therefore recommend that the Agency, in partnership with local authorities and transport planners, seek to understand the equity implications of AQMA's and LTP's.</u>

3. AQMA's are designated on the basis of observed or forecast exceedence of NAQS air quality standards. However, compliance with a standard does not imply freedom from a health impact. Health impacts can occur at all concentrations (and may fall have different impacts on different demographic groups), and standards do not yet adequately address effects from chronic exposure. As there is an inequitable burden of air pollution that complies with current standards, there is therefore a need to agree on appropriate adverse effect thresholds for use in equity assessment. More generically, there is a need to develop agreed methods for air quality equity appraisal, addressing, for example, issues discussed in 4.7 above. <u>We therefore</u>

recommend that the Agency develop technical guidance on air quality equity appraisal.

4. The Agency should identify critical "poverty-pollution" areas, and support efforts to improve air quality in these areas. There are alternative means of identifying these areas (e.g. using deprivation and exceedence data; using deprivation, concentration and emission data) hence there is a need here for technical guidance on evaluating inequality in air quality (see 3 above). It is likely that critical areas identified using deprivation and exceedence data will be addressed by AQMA's. However, this should be verified.

5. In the future, the greatest influence on the changing spatial pattern of air quality, and hence its changing social distribution, is likely to be development, not specific air quality management measures. Therefore, the Agency should promote the inclusion of equity assessment in the appraisal of developments which are likely to impact on air quality. Key partners in this process would include the Highways Agency and planning authorities.

4.8.2 Recommendations for additional research

Areas for further research include:

- Further equity appraisal employing code point data to permit more precise geographical association of air quality and demographic data;

- Development of robust (scientifically sound, widely supported) technical guidance on air quality-equity appraisal;

- Assessing the impact, in air quality-equity terms, of AQMA designation and local transport plan implementation. The analysis could selectively focus on those cities currently displaying greatest inequality (based on critical area analysis in 4.6 above);

- Further small area analysis of air quality and equity. This would address within ward heterogeneity using NAQS modelled air quality data for selected cities. The analysis could address target groups based on demographic parameters other than deprivation (e.g. age - children are a particularly relevant group), and consider individual domains within the deprivation index (e.g. relationship of pollution to access).

5 RECOMMENDATIONS

5.1 Recommendations for Policy and Practice

1. There is an unequal social distribution of pollution and risk, but a very limited knowledge base upon which to develop appropriate responses. As a matter of general policy, the Agency should therefore continue to support efforts to further understand the nature and significance of such distributions, and aim to identify appropriate measures to reduce unacceptable inequalities. The reduction of inequalities should be achieved through an overall reduction in environmental burden, and not through the redistribution of existing burdens.

2. There are currently no standard methods for assessing environmental equality. The lack of agreed methods hampers the identification of inequality, and therefore the development of sound environmental equity policy and practice. Problems facing robust environmental equity assessment are varied, and include issues such as:

   - Which are the environmental burdens of most concern to stakeholders?
   - What is an adverse impact?
   - Which environmental thresholds are appropriate?
   - How should multiple and cumulative environmental burdens be assessed?
   - When is unequal unfair, and what degree of inequity is acceptable?
   - Which target / minority groups should be addressed?
   - What is the appropriate spatial scale (national to local) for appraisal?
   - How should issues of polluter pays and consumer choice be addressed?
   - How can welfare theory and the distribution of benefits arising from activities that produce environmental risk be incorporated into equity assessment?
   - How should results of assessments be used, and who are they intended for?
   - How can results of assessments be communicated effectively to stakeholders, and how should the evaluation procedure be incorporated into mitigation strategies and into wider sustainability appraisal?

   The Agency should therefore appoint a Technical Working Group on environmental equity appraisal. The purpose of the group would be to develop, in consultation with appropriate stakeholders, strategic guidelines on the appraisal of environmental equity in England and Wales. The guidelines would be used to: (a) support the appraisal of policy and practice within the Agency; and (b) provide a basis from which the Agency can comment on the equity implications of the policies and plans of external bodies.

   In developing technical guidance on equity appraisal, the Agency will be better able to comment on the environmental equity implications of development proposals. This could be a key dimension of the Agency's response to environmental inequality, as, over the long term, future development is likely to be a stronger influence on changing social distributions of environmental burdens than mitigation measures.

3. There is a need for more widespread use of environmental equality assessment. Therefore, the Agency should work with government, local authorities, and other appropriate stakeholders to ensure that environmental equity assessment becomes more widely adopted in the environmental impact appraisal process. Wider recognition of equity issues in environmental appraisal may range from developing environmental equity indicators in government sustainability indicators sets, to specific treatment of equity issues in development appraisal (e.g. in Environmental Impact Statements).

4. Environmental inequality can be tackled by specifically addressing those target communities which bear the greatest proportion of environmental burden, and develop appropriate remediation strategies for those areas. Such strategies may tackle existing inequality (e.g. traffic management to improve air quality), or may minimise the imposition of further environmental burdens (e.g. tighter discharge consents; presumption against planning permission for further hazardous facilities).

   In this report we have made a preliminary identification of 'pollution-poverty hotspots' with respect to air quality and IPC sites. However, our analyses are based on our own subjective assessment of appropriate thresholds. We therefore recommend that the Agency identify critical 'pollution-poverty' areas, based on criteria agreeable to the Agency and its stakeholders (see 2 above), so as to identify those communities most in need of remedial action. Critical areas can be identified with respect to individual and/or multiple risks, and at the national and/or regional level. Possible remediation strategies are best developed following a more detailed investigation of these critical areas.

5. Questions of environmental equity and deprivation are clearly of particular relevance to communities that experience a high burden of environmental 'bads' of various forms. The Agency therefore needs to develop ways of engaging and working with communities in deprived areas to ensure that their local knowledge and viewpoints are included in policy decisions and management measures. This raises questions of procedural equity which sit alongside and interrelate with those of distributional equity on which we have focused in this project.

5.2 Recommendations for Further Research

We have made specific recommendations for further research for each of the three environmental issues covered in this project. In addition there are a number of more generic research needs:

- further equity analysis for other environmental variables identified as relevant and important by the stakeholder workshop (Mitchell and Walker 2003, Chalmers 2003).

- further equity analysis examining variables other than deprivation making use of small scale output area data of the 2001 census. As the census output areas are now postcode base this would also enable the linking of other data sets such as lifestyle data and house price data

- case study equity analysis focusing more intensively on particular local communities and examining the combination of environmental goods/bads experienced there.

REFERENCES

Bowen W, 2002 *An analytical review of environmental justice research: what do we really know?* Environmental Management, **29**, 1, 3-15.

Brainard J S, Jones A P, Bateman I J, Lovett A A, Fallon P J, 2002, *Modelling environmental equity: access to air quality in Birmingham, UK.* Environment and Planning A, **34**, 695-716.

Chalmers H, 2003 *Environmental Equality Research, Policy and Action*. Report on the first meeting of the Environment Agency environmental equality steering group, *CREATE Centre*, 3 April 2003, 25pp, Environment Agency, Bristol.

DoH 1998, *Quantification of the Health Effects of Air Pollution in the United Kingdom*. Department of Health Committee on the Medical Effects of Air Pollution. The Stationary Office, London

DETR 2000a *Indices of deprivation 2000*. Regeneration Research Summary 31, Department of the Environment, Transport and the Regions.

DETR, 2000b *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland: Working Together for Clean Air*. Department of the Environment, Transport and the Regions. The Stationary Office, London

DEFRA, 2003 *The air quality strategy for England, Scotland, Wales and Northern Ireland: Addendum*. Department of the Environment, Food and Rural Affairs, London.

Environment Agency, 1997 *Operator Pollution Risk Appraisal (OPRA). Version 2*. Environment Agency, 38pp

Environment Agency, 2002 *The Urban and Environment in England and Wales: A Detailed Assessment*, The Environment Agency.

Friends of the Earth, 2000 *Pollution Injustice,* www.foe.co.uk/pollution-injustice/ Friends of the Earth

Friends of the Earth, 2001 *Pollution and Poverty - Breaking the Link*, Friends of the Earth, London

Goodwin J W L, Salway A G, Murrells T P, Dore C J, Passant N R, Eggleston H S, 2000 *UK emissions of air pollutants 1970-1998*. National Atmospheric Emissions Inventory. AEA Technology Report AEAT/R/EN/0270. National Environmental Technology Centre

Higman R, 1999 *Poor hit hardest by transport pollution*. Press release from Friends of the Earth, 16th June 1999.

Jerrett M, Burnett R T, Kanaroglou P, Eyles J, Finkelstein N, Giovis C and Brook J R, 2001, *A GIS-environmental justice analysis of particulate air pollution in Hamilton, Canada*. Environment and Planning A, **33**, 955-973.

Kriesel W, Centner T J, Keeler A G, 1996, *Neighbourhood exposure to toxic releases: Are there racial inequalities?* Growth and Change **27** (Fall), 479-499

King K, Stedman J, 2000 *Analysis of Air pollution and social deprivation*. Report AEAT/R/ENV/0241. AEA Technology Environment

Lejano R P, Piazza B and Houston D, 2002 Rationality as social justice and the spatial-distributional analysis of risk, *Environment and Planning C,* **20**, pp 871-888

Liu F, 2001 *Environmental Justice Analysis: Theories, Methods and Practice*, CRC Press

Lyons R A, Matthews I P, Fone D, Morgan H, Govier P, 2002 *Does exposure to pollution vary by social class? Results of a preliminary analysis*, Epidemiology **13**, 4, 673. Abstract of a presentation to the 14th Conference of the International Society for Environmental Epidemiology, Vancouver.

McLeod H, Langford I H, Jones A P, Stedman J R, Day J R, Lorenzoni I and Bateman I J, 2000, *The relationship between socio-economic indicators and air pollution in England and Wales: implications for environmental justice*, Regional Environmental Change **1** (2), 78-85

Mitchell G, *In press The Response of Urban Air Quality to Strategic Road Transport Initiatives: An Environmental Justice Analysis of Leeds, UK.* Transportation Research.

Mitchell G and Dorling D, 2003 *An Environmental Justice Analysis of British Air Quality,* Environment and Planning A, **35**, p909-929.

Mitchell G and Walker G, 2003 *Environmental Quality and Social Deprivation. Phase I: A Review of Research and Analytical Methods*. Research and Development Project Record 12615, Environment Agency, 108pp.

Pennycook F, Barrington-Craggs R, Smith D, Bullock S, 2001, *Environmental justice. Mapping transport and social exclusion in Bradford.* Friends of the Earth, London

Pye S, Stedman J, Adams M, King K, 2001 *Further analysis of NO_2 and PM_{10} air pollution and social deprivation* A report produced for DEFRA, The National Assembly for Wales and The Northern Ireland Department of the Environment. Report AEAT/ENV/R/0865. AEA Technology Environment

Shephard, A, 2003, *Inequality under the Labour Government*, Briefing Note No 33, Institute for Fiscal Studies, London.

Sol V M, Lammers P E M, Aiking H, De Boer J, and Feenstra J F, 1995 *Integrated environmental index for use in land use zoning*. Environmental management, **19**, 457-467

Stedman J R and Handley C, 2001 *A comparison of national maps of NO_2 and PM_{10} concentrations with data from the NETCEN 'Calibration Club'*, AEA Technology Report AEAT/ENV/R/0725 (AEA Technology Environment, National Environmental Technology Centre)

Stedman J R, Vincent K J, Campbell G W, Goodwin J W, Downing C E H, 1997 *New high resolution maps of estimated background ambient NO_X and NO_2 concentrations in the UK* Atmospheric Environment , **31**, 3591-3602

Stedman J R, Bush T J, Murrells T P, King K, 2001a *Baseline PM_{10} and NO_x projections for PM_{10} objective analysis*, Report AEAT/ENV/R/0726, AEA Technology Environment, National Environmental Technology Centre

Stedman J R, Bush T J, Murrells T P, King K, 2001b *Projections of PM_{10} and NO_x for concentrations in 2010 for additional measures*, Report AEAT/ENV/R/0727, AEA Technology Environment, National Environmental Technology Centre

Stevenson S, Stephens C, Landon M, Fletcher T, Wilkinson P, Grundy C, 1999 *Examining the inequality and inequity of car ownership and the effects of pollution and health outcomes.* Environmental Epidemiology Unit, London School of Hygiene and Tropical Medicine. Presentation to the Healthy Planet Forum, June 1999, Unpublished

Stevenson S, Stephens C, Landon M, Pattendon, S, Wilkinson P, Fletcher T, 1998 *Examining the inequality and inequity of car ownership and the effects of pollution and health outcomes such as respiratory disease*. Epidemiology **9**, 4, S29. Abstract of an oral presentation to the 10th Conference of the International Society for Environmental Epidemiology, Boston

Tapsell S M, Penning-Roswell E C, Tunstall S M and Wilson T L, 2002 *Vulnerability to flooding: health and social dimensions*. Philosophical Transcations of the Royal Society, **360**, 1511-1525

Wagstaff A, Paci P and Van Doorslaer E, 1991, On the Measurement of Inequalities in Health, *Social Science in Medicine*, **33**, 5, 545-577

Wheeler B, *in press Health related environmental indices and environmental equity in England and Wales*, Environment and Planning A

WHO, 2000 *WHO air quality guidelines*. 2nd edition. World Health Organisation, European Regional Office, Copenhagen (www.who.dk/air/Activities/20020620_1)