Does living near a constellation of petrochemical, steel, and other industries impair health?

R S Bhopal, S Moffatt, T Pless-Mulloli, P R Phillimore, C Foy, C E Dunn, J A Tate

Abstract

Objectives—To investigate concern that local industrial air pollution in Teesside, England, was causing poor health, several areas there were compared with parts of the City of Sunderland.

Methods—Populations in similar social and economic circumstances but varying in their proximity to major industries were compared. Study populations lived in 27 housing estates in Teesside and Sunderland, north east England, with some data from subsets of estates. The estates were aggregated into zones (designated as A, B, and C in Teesside where A is closest to and C furthest from industry, and S in Sunderland). Zone S provided a reference area. The hypothesis was that a health gradient both within Teesside (A>B>C) and between Teesside and Sunderland (ABC>S) would indicate a possible health effect of local industrial air pollution. Data presented were: mortality (1981–91) from 27 housing estates; population self completion questionnaire survey data (1993, 9115 subjects) from 15 housing estates; and general practitioner (GP) consultation data (1989–94) from 2201 subjects in 12 Teesside estates.

Results—The populations in the four zones were comparable for indicators including smoking habits, residential histories, and unemployment. All cause and cause specific mortalities were high compared with England and Wales. Mortality in all Teesside zones (ABC) combined was mostly higher than in zone S. In people aged 0–64, lung cancer and respiratory disease showed gradients with highest mortality in areas closest to industry (A>B>C and ABC>S). The association was clearest for lung cancer in women (0–64 years old, trend across zones ABC, p=0.07, directly standardised rate ratio relative to zone S was 169 (95% confidence interval [95% CI] 116–122)). There were no important, consistent gradients in the hypothesised direction between zones in consultation rates in general practice, and self reported respiratory and non-respiratory health including asthma.

Conclusions—There was no clear evidence that living close to industry was associated with morbidity, including asthma, or for most measures of mortality. For lung cancer in women the gradients indicated a health effect of local industrial air pollution. In the age group 0–64 observed gradients in lung cancer in men and mortality from respiratory disease in men and women were consistent with the study hypothesis, although not significant. The reasons for the different patterns at different ages, and between men and women, remain a puzzle.

Keywords: industry and health; air pollution; epidemiology

Teesside in north east England is the location of one of western Europe's largest steel and petrochemical complexes. Among the many industries there are ICI and British Steel. There has been longstanding debate about the relative contribution of industrial pollution and poverty to the high levels of ill health in Teesside.1–5 Two earlier studies into the effects of smoking and industrial pollution on lung cancer and mortality from bronchitis implicated industrial air pollution as a contributor to the high rates of these diseases in Teesside.2,3

Local debate about poverty, industrial air pollution, and ill health was fuelled by research showing that populations living in some of the poorest areas in Teesside had unexpectedly high death rates compared with similar areas in Sunderland, a city 25 km to the north.4 Between 1975 and 1986 the standardised mortality ratio (SMR) in the Teesside area was 158, compared with 133 in Sunderland areas.4 One explanation was that air pollution from industry on Teesside was exacerbating health problems. The public in Teesside perceive air pollution to be the top ranking environmental problem and identified industry as a major contributor.7 The public, health professionals, the media, and local statutory agencies have been embroiled in the health controversy, and when this study began litigation by residents against local industries was threatened.

This study tried to answer three questions:

- What is the health status of populations living in the poorest areas of Teesside?
- How does the health status of people in Teesside compare with those in Sunderland, and specifically, do morbidity patterns show the same disparity as those of mortality?
- Has air pollution from local industry impaired the health of people living close by?

Papers focusing on otitis media and lung cancer have been published.8 9 This paper gives an overview of the key findings of this complex report,4 develops some of the earlier analysis, and focuses on the third question above, presenting data from a community question-
naire survey, an analysis of general practice records, and mortality statistics. Information on perinatal deaths, stillbirths, birthweights, otitis media based on a screening survey, cancer registration, and a detailed review of environmental information including a land use survey are in our report. Before describing the epidemiological studies we briefly summarise knowledge on air quality in Teesside, and introduce the study design and the terminology used for the areas under investigation.

STUDY DESIGN, AREAS STUDIED, AND OVERVIEW OF AIR POLLUTION IN THE TEESSIDE ENVIRONMENT

We used proximity to industry as a surrogate for long term exposure to air pollution from local industries. Twenty seven housing estates in Teesside and Sunderland, north east England, were the focus of the study, with more detailed information from subsets of these estates. The estates were aggregated into zones (designated as A, B, and C in Teesside where A is closest to industry and C the furthest, and S in Sunderland). Areas in zone A have been the centre of concern for many decades about the potential effect of air pollution on health. Our strategy was to study the geographical areas where concern has been greatest and not restrict ourselves to those areas for which environmental data were already available. The areas are shown on the map.

Existing data on monitoring air pollution together with computer dispersion modelling and a historic land use survey helped (a) to characterise the spatial and temporal trends in health related air pollutants, (b) to inform us of the likely validity of the selection of study areas based on residential proximity to industry as a proxy for exposure, and (c) to examine associations between general practitioner (GP) consultation rates and daily measures of air quality. This section summarises a complex set of data, much of which is discussed in detail elsewhere.

A review of routinely available air quality monitoring data from the mid-1950s to the present showed abundant data for Teesside (reflecting long standing concerns about air pollution there) presented in annual reports of medical officers of health, local government reports on air quality, specifically commissioned studies, and the national air quality archive. Data on air quality in the 1960s and 1970s in the study zones are either not available, or are incomplete. Information about air quality in zone A areas is, surprisingly, less comprehensive than other areas despite the long standing concerns there. The best continuous data are for smoke and SO2, available from the Internet since 1997 (http://www.aeat.co.uk/netcen/aqarchive/nonauto/smjkjava1.html). When systematic local authority monitoring started in the early 1960s, it concentrated on smoke (as an indicator for fine suspended particles), SO2, insoluble deposits, and ferric oxide identified as a marker for industrial activity (especially steel). We identified spatial variations in air quality in Teesside; but this was not feasible in Sunderland, where less monitoring has taken place. We could not follow spatial patterns in air quality over time.
because monitoring sites were regularly relo-
cated. Many sites to monitor spatial variations in
smoke and SO₂ came into operation in the early
1970s, by which time the levels of these pollutants
were greatly reduced.

The overall trend towards falling pollution
levels from 1960 onwards is shown in table 1
for four sites (three in Teesside, one in Sunder-
land) for which continuous smoke monitoring
data are available. One site falls within our zone
B. No such data are available for our zones A
and C or our Sunderland zone. This table shows
higher smoke levels in Sunderland, reflecting the later introduction there of
domestic smoke control measures.

Local government used insoluble solids and
ferric oxide as key indicators of industrial
pollution. Insoluble solids are particulates of
all sizes excluding secondary salts. Monitoring
in Teesside showed persistently higher pollution
in areas close to industry. Indicative data are
presented in table 2, which covers 6 years in
the 1960s, and shows a sharp gradient between
industrial, semi-industrial, and residential
areas (based on groupings of monitoring sites
made by local government). Little decline in
pollution over time is evident in these years.

Table 3 summarises variations in smoke and
SO₂ at particular monitoring sites for winter
and summer in 1968. The site which falls
within our zone A (marked a on the map) has
the highest levels of smoke and SO₂. Two
further sites (marked b and c on the map) lie
close to industry but outside our study zones;
levels are generally higher at these two sites

than at the site in zone B (marked d on the
map), whereas levels are lowest at site e, which
lies outside our study zones and well away from
industry.

The high readings recorded for the zone A
site, in the area known as South Bank, situated
close to steel, coking, and chemical operations,
are repeatedly mentioned in local documenta-
tion including local government reports from
the late 1960s to the early 1980s. Within the
first months of this monitoring site being intro-
duced in late 1967, daily winter smoke peaks of
over 700 µg/m³ were reported there. The local
government report on pollution between 1964
and 1973 summarised the position thus: “In
contrast to the general improvements in all four
pollutants there remain particular sites where
the pollution is becoming worse or where high
levels of pollution are still being registered.
South Bank is the area most severely
affected”. Even in 1981 this site still had the
highest levels of SO₂ in Teesside. These
findings support our general strategy of basing
choice of areas on priority to industry.

In the 1990s local air quality monitoring has
focused on pollutants—such as nitrogen diox-
ide (NOₓ), ozone (O₃), small particles (PM₁₀),
volatile organic compounds (VOCs), and poly-
cyclic aromatic hydrocarbons (PAHs)—few of
which were monitored before 1989. The
concentrations have mostly been below long
term guideline values. Problems with short
term and localised peaks were a continuing
concern. Results of monitoring benzene
from Middlesbrough, the largest town within
Teesside, showed sporadic peaks of benzene
superimposed on a steady baseline not found at
other United Kingdom centres with automatic
monitoring sites. Such peaks have been associ-
ated with industrial sources.

Dispersion modelling of various pollutants
in Teesside, which distinguished industrial
from other kinds of emissions, suggested that
spatial variations remain, although annual
mean concentrations were low. Table 4
presents modelled NOₓ and benzene concen-
trations for 1993 and 1994. The NOₓ is used in
this context to illustrate uneven overall pollution
loads coupled with differentials in the
relative contribution from industrial sources.

Highest predicted concentrations were along
busy roads and around housing areas closest to
major industries. In some areas closest to
industry the industrial contribution to both
NOₓ (59% in 1994) and benzene (78% in
1994) was well above the national average of
38% and 32% respectively, whereas modelled

<table>
<thead>
<tr>
<th>Study zone, if applicable</th>
<th>A</th>
<th>A</th>
<th>A</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>284</td>
<td>84</td>
<td>211</td>
<td>72</td>
</tr>
<tr>
<td>Summer</td>
<td>219</td>
<td>73</td>
<td>151</td>
<td>58</td>
</tr>
</tbody>
</table>

Table 2

<table>
<thead>
<tr>
<th>Year</th>
<th>Industrial areas</th>
<th>Semi-industrial areas</th>
<th>Residential areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>22</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>1963</td>
<td>20</td>
<td>11</td>
<td>6</td>
</tr>
<tr>
<td>1964</td>
<td>18</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>1965</td>
<td>20</td>
<td>12</td>
<td>6</td>
</tr>
<tr>
<td>1966</td>
<td>25</td>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>1967</td>
<td>21</td>
<td>10</td>
<td>7</td>
</tr>
</tbody>
</table>

Table 3

<table>
<thead>
<tr>
<th>Site code</th>
<th>Study zone, if applicable</th>
<th>Winter</th>
<th>Summer</th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>A</td>
<td>284</td>
<td>84</td>
<td>211</td>
<td>72</td>
</tr>
<tr>
<td>b</td>
<td>98</td>
<td>37</td>
<td>151</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>c</td>
<td>140</td>
<td>33</td>
<td>109</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>d</td>
<td>56</td>
<td>57</td>
<td>94</td>
<td>57</td>
<td></td>
</tr>
<tr>
<td>e</td>
<td>56</td>
<td>32</td>
<td>64</td>
<td>45</td>
<td></td>
</tr>
</tbody>
</table>

Table 1

**Table 1** Annual mean of smoke* concentrations in Teesside and Sunderland 1963–75 (µg/m³) (data source: internet site given in text)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Teesside</td>
<td>B</td>
<td></td>
<td>107</td>
<td>60</td>
<td>51</td>
<td>32</td>
<td>25</td>
<td>22</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>B</td>
<td></td>
<td>57</td>
<td>49</td>
<td>51</td>
<td>43</td>
<td>32</td>
<td>23</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>B</td>
<td></td>
<td>95</td>
<td>79</td>
<td>60</td>
<td>53</td>
<td>35</td>
<td>23</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>B</td>
<td></td>
<td>95</td>
<td>79</td>
<td>60</td>
<td>53</td>
<td>35</td>
<td>23</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>B</td>
<td></td>
<td>144</td>
<td>126</td>
<td>116</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>59</td>
</tr>
</tbody>
</table>

*Smoke was used as a measurement of fine suspended particulate matter <15 µm by examining blackness of filters.
†See map for monitoring positions of sites and study zone B.
Does living near many industries impair health?

Having exceptionally high mortalities, and on the poorest parts of localities close to ICI United Kingdom. The focus of this study was among the poorest neighbourhoods in the century. Specifically, industry has been close to zone A throughout the century.

Overall, these data supported our assumption that residential proximity of a population to industry was a reasonable surrogate for long term exposure to local industrial emissions.

Methods

CHOICE OF AREAS

Areas close to Teesside’s major industries are among the poorest neighbourhoods in the United Kingdom. The focus of this study was on the poorest parts of localities close to ICI and British Steel, previously identified as having exceptionally high mortalities, and socioeconomically comparable areas in Sunderland which served as a reference zone for this analysis. The poorest enumeration districts (EDs) in Teesside were identified with the Townsend deprivation index. Clusters of adjacent EDs with similar characteristics were aggregated and checked by fieldwork and local consultation as socially homogenous and locally recognisable neighbourhoods.

We sought populations at varying distances from industry, yet comparable on factors posing a risk to health such as smoking, occupation, and socioeconomic status. This study started before publication of the 1991 census, so 1981 census data were assembled for enumeration districts (EDs), the smallest unit area for which census data are available, consisting of a mean of about 150 households. When published, 1991 census data were examined to verify that study areas remained similar to one another in social characteristics. Twenty seven areas, 19 in Teesside (1991 population 77 330) and eight in Sunderland (population 43 485) were included.

Table 4 Relative modelled contributions from industry to NOx and benzene emissions 1993–4 in selected areas

<table>
<thead>
<tr>
<th>Zone, pollutant</th>
<th>Year</th>
<th>Total concentration (ppb)</th>
<th>Industrial contribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone A: NOx</td>
<td>1993</td>
<td>18.6</td>
<td>53.6</td>
</tr>
<tr>
<td>NOx</td>
<td>1994</td>
<td>15.6</td>
<td>59.0</td>
</tr>
<tr>
<td>Benzene</td>
<td>1993</td>
<td>0.77</td>
<td>74.7</td>
</tr>
<tr>
<td>Benzene</td>
<td>1994</td>
<td>0.59</td>
<td>78.2</td>
</tr>
<tr>
<td>Zone B: NOx</td>
<td>1993</td>
<td>20.6</td>
<td>22.2</td>
</tr>
<tr>
<td>NOx</td>
<td>1994</td>
<td>14.4</td>
<td>20.8</td>
</tr>
<tr>
<td>Benzene</td>
<td>1993</td>
<td>0.41</td>
<td>7.4</td>
</tr>
<tr>
<td>Benzene</td>
<td>1994</td>
<td>0.29</td>
<td>5.1</td>
</tr>
<tr>
<td>Zone C: NOx</td>
<td>1993</td>
<td>12.9</td>
<td>13.5</td>
</tr>
<tr>
<td>NOx</td>
<td>1994</td>
<td>9.4</td>
<td>14.2</td>
</tr>
<tr>
<td>Benzene</td>
<td>1993</td>
<td>0.27</td>
<td>8.0</td>
</tr>
<tr>
<td>Benzene</td>
<td>1994</td>
<td>0.21</td>
<td>6.6</td>
</tr>
</tbody>
</table>

A postal questionnaire, based mainly on previously tested questions, was sent to residents in 12 estates in Teesside (as shown on the map as zones As, Bs, and Cs) and the three estates in Sunderland (not shown on map). Questions covered socioeconomic circumstances, personal behaviour, illnesses, symptoms (focusing particularly on respiratory ill health), health status, and factors influencing health. The questionnaire is available from us and is reported in full elsewhere.

Questionnaires were sent to 7524 Teesside adults; 2269 Sunderland adults; 3366 Teesside parents to complete on behalf of their children; and 1687 Sunderland parents. An overall response rate of 59.7% (9097 completed questionnaires) was achieved after two reminders. The response varied little among the Teesside zones, but was slightly lower in Sunderland— for example, for adults it was 59.8% compared with 62.3% in Teesside. Odds ratios and their 95% confidence intervals (95% CIs) for self reported illnesses and symptoms were calculated with multiple logistic regression, with zone S as the reference population. Logistic regression was also used to test the hypothesis that a trend in odds ratios would be found (zone A>zone B>zone C).

Community survey

For pragmatic reasons of time and cost this part of the study was carried out in Teesside only, in nine GPs’ practices, three in each of zones A, B, and C. A sub-sample of people from the community survey was selected with a systematic sampling technique. From each practice 240 adults and children were selected giving a sample size of 720 in each of the three zones.

Customised encoding software developed to our specification by the company Computer Aided Medical Systems (Loughborough, UK) was used to extract date of consultation, diagnosis or symptoms, repeat prescriptions, chronic illnesses, and hospital in-patient
episodes from patient records for the period December 1989 to September 1994.

Environmental data corresponding with some of the period of GP data were available for two sites. Hourly readings of NO₂ and SO₂ were available from a site close to zone A, from January 1992 until September 1994, albeit with some gaps. These were used in conjunction with the general practice data from zone A. Hourly readings of particulates (PM₁₀), NO₂, SO₂, and O₃ were available from a site in zone B for June 1993 to September 1994; these were used with the data from general practices in zone B. For analysis we used the mean over each period 0900 to 0800 the next day, and the maximum reading in the period.

To assess whether the consultation rate varied significantly with air quality, a Poisson log linear model of the number of daily consultations was used, taking into account day of the week, daily temperature (average of the minimum and maximum temperatures in the previous 24 hours) and mean and peak daily pollutant values up to 0800 that day. This model was implemented with the statistical package GLIM. Consultations were also analysed for air quality during the 24 hours up to 0800 on the previous day.

### Table 5 Socioeconomic circumstances, housing conditions, smoking, and occupational experience by area

<table>
<thead>
<tr>
<th>Adults (16–79 y)</th>
<th>Zone A (n=1539)</th>
<th>Zone B (n=1464)</th>
<th>Zone C (n=1486)</th>
<th>Zone S (n=1910)</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
</tbody>
</table>

Indicators of socioeconomic circumstances:
- No access to car or van: 45, 53, 51, 57
- Rented housing: 52, 59, 63, 72
- Male unemployment: 30, 32, 33, 35
- Female unemployment: 12, 15, 14, 16
- Overcrowded households*: 6, 5, 5, 4
- Left school 16 years or under: 93, 94, 94, 94

Residential history:
- Mean years at current address (n): 21, 17, 17, 22
- Same address for most of life: 57, 58, 59, 51

Housing conditions:
- Damp in house: 21, 17, 17, 22
- Heating and cooking:
  - Coal fires: 1, 1, 1, 6
  - Gas fires: 41, 39, 47, 50
  - Gas cooker: 72, 69, 74, 72
- Smoking habits:
  - Men:
    - Never smoked: 26, 26, 27, 24
    - Ex-smokers: 37, 35, 39, 40
    - Current smokers: 37, 39, 35, 36
  - Women:
    - Never smoked: 35, 33, 31, 36
    - Ex-smokers: 24, 24, 24, 26
    - Current smokers: 40, 43, 45, 38

### Table 6 Adjusted* odds ratios (95% CIs) of self reported illness and symptoms with Sunderland as the reference population

<table>
<thead>
<tr>
<th>Adults</th>
<th>Zone A (n=1539)</th>
<th>Zone B (n=1464)</th>
<th>Zone C (n=1486)</th>
<th>Zone S (n=1910)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td>OR (95% CI)</td>
<td></td>
</tr>
</tbody>
</table>

- Long term limiting illness: 0.95 (0.80 to 1.12) 0.86 (0.73 to 1.02) 0.83 (0.70 to 0.98) 0.32
- Chronic bronchitis: 1.23 (0.93 to 1.63) 1.46 (1.11 to 1.93) 1.19 (0.89 to 1.59) 0.18
- Hay fever: 1.12 (0.84 to 1.49) 1.25 (0.94 to 1.66) 1.15 (0.86 to 1.54) 0.84
- Sinus trouble: 1.26 (0.84 to 1.33) 1.20 (0.96 to 1.51) 1.07 (0.84 to 1.35) 0.46
- Tuberculosis: 0.57 (0.33 to 0.99) 0.91 (0.56 to 1.48) 0.72 (0.43 to 1.21) 0.23
- Symptomatic in previous month:
  - Colds or flu: 0.91 (0.78 to 1.06) 0.86 (0.74 to 1.00) 0.90 (0.78 to 1.05) 0.68
  - Sinus or catarrh: 0.87 (0.70 to 1.09) 0.97 (0.78 to 1.21) 0.98 (0.79 to 1.22) 0.60
  - Skin rash or trouble: 0.97 (0.79 to 1.20) 0.97 (0.80 to 1.20) 1.04 (0.84 to 1.29) 0.85
- Ever had asthma: 0.79 (0.61 to 1.02) 0.98 (0.77 to 1.26) 1.07 (0.84 to 1.36) 0.28
- Those with asthma only (n): 203 213 215

*Odds ratio adjusted for: age, sex, smoking, alcohol consumption, exercise level, occupation in heavy industry, damp housing, coal fires, and gas appliances.
†Zone CS (n=1910).
‡Responses to survey question to “Have you ever had, or been told you have any of the following illnesses”.
§Zone CS (n=278).
*4 df.
Table 7 Adjusted* odds ratios of self reported illness and symptoms with Sunderland as the reference population

<table>
<thead>
<tr>
<th>Illness‡</th>
<th>Zone A (n=641) OR (95% CI)</th>
<th>Zone B (n=614) OR (95% CI)</th>
<th>Zone C (n=633) OR (95% CI)</th>
<th>Zone A, B, C trend ( \chi^2 ) (df) ( P ) value</th>
<th>ABC c Sp OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long term limiting illness</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Illness‡‡</td>
<td>1.07 (0.76 to 1.52)</td>
<td>1.03 (0.73 to 1.46)</td>
<td>1.05 (0.74 to 1.48)</td>
<td>0.70</td>
<td>1.05 (0.80 to 1.39)</td>
</tr>
<tr>
<td>Asthma</td>
<td>1.20 (0.75 to 1.92)</td>
<td>1.92 (1.26 to 2.95)</td>
<td>1.88 (1.23 to 2.87)</td>
<td>0.14</td>
<td>1.66 (1.16 to 2.40)</td>
</tr>
<tr>
<td>Hay fever</td>
<td>1.42 (0.96 to 2.10)</td>
<td>1.41 (0.95 to 2.09)</td>
<td>1.50 (1.02 to 2.20)</td>
<td>0.96</td>
<td>1.44 (1.05 to 1.99)</td>
</tr>
<tr>
<td>Sinus trouble</td>
<td>1.07 (0.66 to 1.74)</td>
<td>1.21 (0.76 to 1.95)</td>
<td>0.97 (0.59 to 1.59)</td>
<td>0.88</td>
<td>1.08 (0.74 to 1.59)</td>
</tr>
<tr>
<td>Itchy rash or eczema</td>
<td>1.31 (0.59 to 2.20)</td>
<td>0.97 (0.56 to 1.67)</td>
<td>0.83 (0.47 to 1.47)</td>
<td>0.16</td>
<td>1.03 (0.68 to 1.59)</td>
</tr>
</tbody>
</table>

Symptoms in previous month:

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Zone A (n=641) OR (95% CI)</th>
<th>Zone B (n=614) OR (95% CI)</th>
<th>Zone C (n=633) OR (95% CI)</th>
<th>Zone A, B, C trend ( \chi^2 ) (df) ( P ) value</th>
<th>ABC c Sp OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In previous year:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colds or flu</td>
<td>1.22 (0.97 to 1.55)</td>
<td>0.85 (0.68 to 1.08)</td>
<td>1.12 (0.89 to 1.41)</td>
<td>0.02</td>
<td>1.05 (0.88 to 1.26)</td>
</tr>
<tr>
<td>Sinus or catarrh</td>
<td>1.23 (0.78 to 1.95)</td>
<td>1.05 (0.65 to 1.68)</td>
<td>1.05 (0.66 to 1.66)</td>
<td>0.59</td>
<td>1.03 (0.72 to 1.48)</td>
</tr>
<tr>
<td>Skin rash or trouble</td>
<td>1.26 (0.90 to 1.76)</td>
<td>0.99 (0.70 to 1.40)</td>
<td>1.40 (1.02 to 1.93)</td>
<td>0.05</td>
<td>1.21 (0.93 to 1.59)</td>
</tr>
<tr>
<td>Ever had asthma</td>
<td>0.84 (0.61 to 1.15)</td>
<td>0.76 (0.55 to 1.04)</td>
<td>1.02 (0.76 to 1.36)</td>
<td>0.13</td>
<td>0.87 (0.69 to 1.11)</td>
</tr>
<tr>
<td>Those with asthma only (n)</td>
<td>108</td>
<td>92</td>
<td>107</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In previous year:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4–12 Asthma attacks</td>
<td>0.73 (0.43 to 1.26)</td>
<td>0.65 (0.37 to 1.13)</td>
<td>1.15 (0.70 to 1.89)</td>
<td>0.85</td>
<td>0.56 to 1.28</td>
</tr>
<tr>
<td>&gt;12 Asthma attacks</td>
<td>2.01 (0.90 to 4.30)</td>
<td>1.83 (0.80 to 4.16)</td>
<td>0.55 (0.20 to 1.53)</td>
<td>0.05</td>
<td>1.38 (0.68 to 2.78)</td>
</tr>
</tbody>
</table>

*Odds ratios adjusted for: damp housing to overcrowding to parental smoking to family history of asthma to gas appliances and coal fires
†Zone CS to N=828
‡Responses to survey question, “Has your child had to or have you been told they have any of the following illnesses”.
§Zone CS (n=189).
¶df.

Mortality data

Postcoded data on mortality were obtained from the former Northern Regional Health Authority. Individual postcodes were allocated to 1981 Census enumeration district codes with Newcastle University’s POSTCODEX programme. Comparison of the former Northern Regional Health Authority data with the Office for National Statistics published data showed inconsequential discrepancies.8

Deaths of permanent residents of institutions were excluded.19 A mid-decade denominator was constructed with census data for the populations resident in private households (1981) and resident in households (1991) to match the numerator of non-institutional deaths. Underenumeration of the population in the 1991 census in our 27 areas of study was minimal—for example, zone A 1.4%, zone B 0.7%, zone C 1.4%, and zone S 0.8%.17

Results

INDICATORS OF SOCIOECONOMIC AND LIFESTYLE COMPARABILITY OF POPULATIONS

Table 5 contains socioeconomic and lifestyle indicators for adults from the community survey and shows that the populations were broadly comparable. This was not a surprise as census data on socioeconomic factors formed the basis for choosing study areas.8

The DSRRs (95% CIs) were calculated for each of zones A, B, and C separately, and for Teesside as a whole, in each case with Sunderland as the reference population. The hypothesis of a trend in mortality within Teesside (A>B>C) was tested with logistic regression for a trend in the probability of dying from 1981 to 1991 in zones A, B, C, taking into account sex and 5 year age group.
Table 8  Reasons for consultation by area

<table>
<thead>
<tr>
<th>Consultations/patient-year</th>
<th>Zone A</th>
<th>Zone B</th>
<th>Zone C</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patents (n)</td>
<td>734</td>
<td>724</td>
<td>743</td>
<td>2201</td>
</tr>
<tr>
<td>Total consultations</td>
<td>3.97</td>
<td>4.45</td>
<td>3.86</td>
<td>4.09</td>
</tr>
<tr>
<td>Respiratory diagnosis</td>
<td>0.71</td>
<td>0.68</td>
<td>0.68</td>
<td>0.69</td>
</tr>
<tr>
<td>Coughs reported</td>
<td>0.52</td>
<td>0.58</td>
<td>0.25</td>
<td>0.38</td>
</tr>
<tr>
<td>Asthma diagnosis</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Bronchitis diagnosis</td>
<td>0.05</td>
<td>0.12</td>
<td>0.18</td>
<td>0.12</td>
</tr>
<tr>
<td>Upper respiratory tract infection diagnosed</td>
<td>0.58</td>
<td>0.51</td>
<td>0.48</td>
<td>0.53</td>
</tr>
</tbody>
</table>

SO2 category:
- Total 497 4.22 0.80
- 39 ppb or more 48 4.58 0.73
- 9 to 38 ppb 190 4.06 0.77
- Up to 8 ppb 259 4.26 0.84

NO2 category:
- Total 814 4.15 0.75
- 39 ppb or more 75 4.27 0.68
- 9 to 38 ppb 321 4.26 0.82
- Up to 8 ppb 418 4.05 0.71

χ² for effect of NO2 (to 0800 previous day) 0.01, p=0.74 1.45, p=0.23
χ² for effect of NO2 (to 0800 same day) 0.04, p=0.84 0.39, p=0.53

χ² for effect of SO2 (to 0800 previous day) 0.04, p=0.84 0.39, p=0.53
χ² for effect of SO2 (to 0800 same day) 0.37, p=0.54 3.09, p=0.08
χ² for effect of SO2 (to 0800 previous day) 5.00, p<0.03 3.45, p=0.06

General Practice Data

Table 8 shows that consultation rates were higher in zone B than in zone A and lowest in zone C. Respiratory diagnoses disaggregated into different categories showed marginal differences and no pattern across the areas. Furthermore, the three zone A practices combined had lower hospital admission rates, chronic conditions, and repeat prescription items dispensed than did practices in the other two areas (data not shown here).³

Table 9 shows the association between consultation rates and daily peak NO2 and SO2 concentrations in zone A. Slight increases in consultation rates on days when pollutants were higher were found, but the associations were not significant with one exception: overall consultations were raised on days when the SO2 concentration up to 0800 the previous day was relatively high.

Mortality

Table 10 shows that at all ages, all cause mortality showed a slight Teesside gradient (A>B>C; NS) among men but not among women. Mortality ratios for all Teesside zones (ABC) combined were marginally higher than zone S (ABC>S) for men but not for women. All cause mortality for the 0–64 age group exhibited a gradient among men (p=0.11) and women (p=0.16) and was higher for all Teesside zones, compared with zone S, in both men and women.

Mortality for all cancers excluding lung cancer, showed no gradients in the hypothesised direction across the Teesside zones but mortality ratios were generally higher for all Teesside zones combined than for zone S. For some analyses specific to cancer site, the number of cases were too small for meaningful comparisons, and for some others which are presented (digestive system, lymphatic or haematopoietic, bladder, genitourinary, lip or oral cavity) only all age analyses were possible. For most of the analyses specific to cancer site there were no gradients in the hypothesised direction across the Teesside zones. With the exception of breast cancer in women of all ages, however, the three Teesside zones combined had higher (or equal) cancer rates than zone S. Across the Teesside zones a gradient in the hypothesised direction for lung cancer was not present in men of all ages, and unclear for women at all ages (but the gradient is significant, in fact, zone C has a higher ratio than zone B). The hypothesised gradient was present for men and women aged 0–64 (p=0.69 for men, 0.07 for women). For women aged 0–64 in zone A, the DSRR was 229, this being standardised to zone S, an area which itself has a high SMR for lung cancer (SMR 170).³ The SMR for lung cancer in women aged 0–64 in zone A, standardised to England and Wales mortality data, was 387 (95% CIs 277–525).³ The mortality ratio for lung cancer in the three Teesside zones was substantially higher than zone S in women of all ages, and particularly, 0–64 years. For a fuller analysis based on SMRs see reference 8.

There was no clear gradient in respiratory mortality in men of all ages across Teesside zones. Such gradients were there for women of all ages (p=0.29) and for men (p=0.33) and women aged 0–64 (p=0.07). For all the age groups, respiratory mortality ratios were higher for Teesside zones combined than for zone S (95% CIs included 100). For chronic obstructive airways disease there were no gradients in the hypothesised direction across the Teesside.
Table 10  
Directly standardised rate ratios (DSRRs), 95% CIs, and number of deaths 1981–91, standardised to Sunderland population (DSRR=100)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Men, all ages</th>
<th>Women, all ages</th>
<th>Men, 0 to 64</th>
<th>Women, 0 to 64</th>
<th>All cancers excluding lung</th>
<th>Men, all ages</th>
<th>Women, all ages</th>
<th>Men, 0 to 64</th>
<th>Women, 0 to 64</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone A</td>
<td>107 (100 to 114)</td>
<td>86 (55 to 104)</td>
<td>115 (103 to 127)</td>
<td>112 (100 to 137)</td>
<td>110 (120 to 136)</td>
<td>103 (86 to 120)</td>
<td>94 (71 to 118)</td>
<td>114 (97 to 134)</td>
<td>109 (86 to 137)</td>
</tr>
<tr>
<td>Zone B</td>
<td>105 (95 to 115)</td>
<td>89 (59 to 119)</td>
<td>112 (100 to 128)</td>
<td>111 (99 to 131)</td>
<td>110 (120 to 136)</td>
<td>103 (86 to 120)</td>
<td>95 (71 to 118)</td>
<td>114 (97 to 134)</td>
<td>109 (86 to 137)</td>
</tr>
<tr>
<td>Zone C</td>
<td>103 (91 to 116)</td>
<td>88 (57 to 118)</td>
<td>110 (100 to 128)</td>
<td>109 (99 to 131)</td>
<td>108 (119 to 130)</td>
<td>101 (85 to 127)</td>
<td>98 (72 to 123)</td>
<td>113 (96 to 133)</td>
<td>108 (85 to 127)</td>
</tr>
<tr>
<td>Tests trend*</td>
<td>1.10 (0.99 to 1.21)</td>
<td>1.02 (0.99 to 1.04)</td>
<td>1.05 (1.00 to 1.10)</td>
<td>1.01 (0.99 to 1.03)</td>
<td>1.03 (1.02 to 1.04)</td>
<td>1.02 (0.99 to 1.04)</td>
<td>1.01 (0.99 to 1.03)</td>
<td>1.03 (1.02 to 1.04)</td>
<td>1.02 (0.99 to 1.04)</td>
</tr>
<tr>
<td>P Value</td>
<td>0.29 (0.19 to 0.41)</td>
<td>0.47 (0.40 to 0.55)</td>
<td>0.50 (0.45 to 0.55)</td>
<td>0.51 (0.46 to 0.55)</td>
<td>0.53 (0.50 to 0.56)</td>
<td>0.47 (0.40 to 0.55)</td>
<td>0.49 (0.46 to 0.53)</td>
<td>0.50 (0.45 to 0.55)</td>
<td>0.51 (0.46 to 0.55)</td>
</tr>
</tbody>
</table>

Discussion

Investigation of concern about the health effects of local industrial pollution is one of the more difficult applications of epidemiology to public health. The technical problems are formidable, particularly estimating exposures and reaching judgements on cause and effect, but the need to undertake and interpret a study in the public eye poses additional challenges. The study of populations concerned about the health effects of local industrial pollution makes interpretation of self reported data difficult, especially when the health effects are subtle. Failure to unearth causal associations may harm the public health and weaken the case for environmental improvement and compensation. Interpreting mere association as causation may undermine the standing of industry, and damage the economic and health status of the community. In a Canadian city with petrochemical industry a pseudoepidemic of cancer arose from an error in the denominator, and led to a drop in property prices, public anxiety, and a lasting reputation as a cancer city.

The present study was done amidst simmering controversy and adversarial dynamism, common underlying factors in studies of this kind which hinder resolution of conflict. The populations involved were at the extremes of deprivation in the United Kingdom, bringing the additional issues of inequalities of health to the fore. Our data collection was purposely comprehensive in scope, with a strong emphasis on both health data and social and economic information. The analysis of data in several ways was deliberate, to avoid missing any important health effects. This follows our strategy developed in examining the impact of pollution from a coking works and a wallpaper factory. The strategy of analysing data in several ways may be criticised on statistical grounds, but the recent reanalysis and reinterpretation of the data pertaining to the Three Mile Island nuclear reactor accident, which has given new conclusions, and controversy, is
a reminder that there is scientific merit in comprehensive analysis, and an open and diverse approach to interpretation, which includes the perception of the affected community. Our statement of initial hypotheses, with a prediction of health gradients across the Teesside zones and between Teesside and Sunderland areas, was our principal guide to interpreting the many associations which are inevitably detected when large data sets are subjected to comprehensive analysis.

Severe air pollution undoubtedly affects health, which may be shown even years after the exposure as in the case of the gas leak in the City of Bhopal, but there is controversy on the health impact of low or variable levels of air pollution. Studies on the local health impact of air pollution from industry do not yet provide generalisable principles, possibly because the effects, if any, are dependent on local context. Morbidity has been studied among several communities including those living close to coal fuelled power plants, gas refineries, pulp mills, iron foundries, power stations, a coking works, a wallpaper factory, chemical dumping sites, and a cement works. Some studies have shown a health impact, others have not.

Studies of mortality have also been done. For example, a study of communities living close to steel foundries in central Scotland concluded that the high risk of lung cancer was causally linked to industrial air pollution. Fear of a raised incidence of laryngeal cancer in people living near oil and solvent incinerators was not verified. Studies of mortality relating to radiation hazards have been a source of controversy and methodological difficulty. Relatively few studies have simultaneously studied morbidity and mortality.

Of the methodological questions that determined the value of this study (and others like it) two are outstanding: was the population chosen as the focus of the study (in zone A) the right one, and were the populations in the zones sufficiently alike to sustain comparisons of the kind made?

**CHOICE AND CHARACTERISTICS OF AREAS AND ZONES**

Proximity of residence to industry as a proxy for exposure is the basis of many studies of industrial impact on local health. The populations of zone A were the focus of the study because of their proximity to major industry, their economic hardship, their previously demonstrated high mortality and the hypothesis that at least part of their poor health was attributable to industrial pollution.

Teesside and Sunderland have been similar economically for many decades. Comparison between the 1981 and 1991 censuses showed social and economic similarity of the areas studied. The 1993 community survey confirmed that the zones were well matched economically and in lifestyle indicators including smoking. Similar proportions of men had at least 1 year’s experience of working in heavy industries. Variations in specific male occupational histories, however, reflect the different industries of the two conurbations with steel and chemicals dominant in Teesside and deep coal mining in Sunderland. Differences in the socioeconomic indicators of access to a car or van and living in rented accommodation are a reflection of different historical traditions of public housing and public transport provision between Teesside and Sunderland. Within Teesside the three study zones were highly comparable on social and economic factors, both historically and currently, but were different in their proximity to petrochemical and steel industries.

Modelled data confirmed indications from monitored data that there is spatial variation in exposure to industrial air pollutants across Teesside. We have no detailed retrospective exposure information but evidence from the historical land use survey shows that our zone A has been close to industry throughout this century, and monitoring data on insoluble solids, ferric oxide, smoke, and SO confirm that pollution in the Teesside areas closest to industry has been higher than in areas further away. Studies by Wicken and Buck and Dean et al showed relatively high levels of SO and smoke in the Eston area, which overlaps with our zone A. The evidence supports our assumption that exposure to industrial pollution has varied with proximity to industry.

**WERE THERE DIFFERENCES IN HEALTH BETWEEN THE POPULATIONS STUDIED?**

Patterns of illness or disability, as measured in the community survey and general practice records study showed some differences across the zones. Particularly for children, respiratory symptoms were higher in the Teesside zones combined than in zone S. For no measure of morbidity was there a convincing gradient across the three Teesside zones (A>B>C) and between Teesside and Sunderland (A>B>C) as hypothesised. The view that the high prevalence of asthma in Teesside might be linked to local industrial emissions was not supported. Our data are mainly on the prevalence of diseases with extremely limited detail about the possible exacerbation of diseases by industrial pollution (an area for future research). Holtby et al showed that those living within 1 km of the major industries had a higher prevalence of otitis media with effusion but in a logistic regression analysis incorporating distance from industry and an economic disadvantage score, no association was apparent, leading the authors to an equivocal conclusion. The analyses of daily air pollution and general practice consultation rates indicated that local variations in air quality were not sufficient to create clinically important and measurable effects on consultation behaviour.

The above findings seem surprising. On the basis of previous research, and testimony from medical personnel and local residents, the expectation was that living close to industry would augment the health problems of people living in neighbourhoods where material hardship is widespread and longstanding. Some gradients in ill health might have been anticipated on the basis of artefact alone, for
example, awareness bias.\textsuperscript{21,22} These were not found. Some studies have linked particulate air pollution with respiratory diseases\textsuperscript{23} and acute asthma episodes.\textsuperscript{24} Others, however, failed to find a relation between increased prevalence of asthma and higher concentrations of pollution as recently summarised by the Committee on the Medical Effects of Air Pollution.\textsuperscript{21}

The mortality findings were complex. Some differences between Teesside zones combined and the Sunderland zone were found for all cause mortality (0–64 year age group), all cancers excluding lung, and particularly relative to lung cancer and respiratory mortality in women. Mortality ratios for lung cancer in women were extremely high in the Teesside zones, and highest in the zone closest to industry. In several analyses, carried out at various levels of spatial and temporal aggregation,\textsuperscript{3,7} only lung cancer deaths among women were consistently highest in the zone closest to industry and in the combined Teesside zones when compared with Sunderland. The findings for lung cancer in women, and to a lesser extent, respiratory mortality, particularly in women 0–64 years old, agreed with the study hypothesis. There were no important differences between women in the study zones in smoking, occupation, and poverty levels. The questions raised by our findings on the different lung cancer patterns found in women and men and the possibility of subtle differences in smoking patterns not apparent in our and others' cross-sectional data,\textsuperscript{3,7} are discussed in detail elsewhere.\textsuperscript{7} We judged that the evidence pointed to a role for industrial air pollution in the higher levels of lung cancer in women living close to industry in Teesside.\textsuperscript{7}

In conclusion, living close to the constellation of petrochemical and steel industries does not have clear effects on morbidity or on most causes of death. For lung cancer, and to a lesser extent respiratory mortality, particularly in women, the evidence points to an effect. The reasons for the different patterns in men and women, in those <65 years and at all ages, and the precise causes and future course of lung cancer mortality in women in Teesside, warrant further research.

Grants to enable this research to take place were received from the Middlesbrough Borough Council (City Challenge), South Tees Health Authority and Tees Health, Cleveland Family Health Services Authority, Cleveland County Council, Northern and Yorkshire Regional Health Authority. For help, support, expertise and advice we thank: Dr H R Grifith, Dr G Guy, Dr R Harrison, Mr J R Hindmarsh, Mr P Larter, Dr D Ruffett, John Mann, David Thompson, Les Milne, Colin Mills, Paul Reynolds, Bill Carruthers, John Stevenson, Jim Waldron, Angus McNeave, Marjorie Renwick, Jill Rollings, Paul Baldwin, Colin Waine, Susan Mills, Alastair Beattie, Dick Derwent, Simon Raybould, Martin Charlton, David Nevrick, Martin Strange, Hazel Keeble, Jane Halpin, Fred Nimmo, Alison Watson, Drs Joshi and Acquilla, Ann Rookke, Patricia McCauley, Jane Nash, Simon Kingfisher Island, Alastair Hay, Raymond Agus, Finton Hurley, members of the Industry/Researcher Group, AEA Technology (formerly Warren Spring Laboratory), Carolyn McGregor, Dawn Winpenny, Louise Walker, Lorina Hutchinson, and Carole Frazer. Finally, we thank an anonymous referee for detailed comments which greatly influenced the presentation of this paper. The following were members of the Teesside Environmental Epidemiology Group: Professor RA Bhopal (chairman), Professor Peter Blain, Mo Jo Denn, Mr Jeff Duffield, Dr Christine Dunn, Dr John Edwards, Mr Christopher Foy, Mrs Catherine Hall, Dr Erasmus Hatzlhal, Dr Ian Heiby, Dr Jim Longstaff, Dr Suzanne Moffatt, Dr Peter Phillimore, Dr Tanja Piess-Mulloli, Ms Jacqui Tate, Dr Anthony Luke, Ms Lesley Charpe, Mr David Sutherland.

1 Medical Officer of Health. Annual report. Teeside: Eston Urban District, 1921.
11 Teeside County Borough Council Health Department. The Health of Teesside During 1968. Teeside, UK: Teeside County Borough Council Health Department, 1968.
21 Mayon-White RT. Commentary: assessing the effects of environmental pollution when people know that they have been exposed. BMJ 1997;314:342–3.
23 Mayon-White RT, Commentary: assessing the e-
24 Mayon-White RT, Commentary: assessing the e-
25 Mayon-White RT, Commentary: assessing the e-
26 Mayon-White RT, Commentary: assessing the e-
50 Walters S, Griffiths RK, Ayres JG. Temporal association between hospital admissions for asthma in Birmingham and ambient levels of sulphur dioxide and smoke. Thorax 1994;49:133–44.

**Vancouver style**

All manuscripts submitted to *Occup Environ Med* should conform to the uniform requirements for manuscripts submitted to biomedical journals (known as the Vancouver style.) *Occup Environ Med*, together with many other international biomedical journals, has agreed to accept articles prepared in accordance with the Vancouver style. The style (described in full in the JAMA[1]) is intended to standardise requirements for authors, and is the same as in this issue.

References should be numbered consecutively in the order in which they are first mentioned in the text by Arabic numerals on the line in square brackets on each occasion the reference is cited (Manson[1] confirmed other reports[2][3][4][5]). In future references to papers submitted to *Occup Environ Med* should include: the names of all authors if there are three or less or, if there are more, the first three followed by *et al*; the title of journal articles or book chapters; the titles of journals abbreviated according to the style of Index Medicus; and the first and final page numbers of the article or chapter. Titles not in Index Medicus should be given in full.

Examples of common forms of references are:

Does living near a constellation of petrochemical, steel, and other industries impair health?

R S Bhopal, S Moffatt, T Pless-Mulloli, P R Phillimore, C Foy, C E Dunn and J A Tate

doi: 10.1136/oem.55.12.812

Updated information and services can be found at:
[http://oem.bmj.com/content/55/12/812](http://oem.bmj.com/content/55/12/812)

**Email alerting service**

Receive free email alerts when new articles cite this article. Sign up in the box at the top right corner of the online article.

**Notes**

To request permissions go to:
[http://group.bmj.com/group/rights-licensing/permissions](http://group.bmj.com/group/rights-licensing/permissions)

To order reprints go to:
[http://journals.bmj.com/cgi/reprintform](http://journals.bmj.com/cgi/reprintform)

To subscribe to BMJ go to:
[http://group.bmj.com/subscribe/](http://group.bmj.com/subscribe/)