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Risk of adverse birth outcomes in populations living near landfill sites

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Abstract

Objective To investigate the risk of adverse birth outcomes associated with residence near landfill sites in Great Britain.

Design Geographical study of risks of adverse birth outcomes in populations living within 2 km of 9565 landfill sites operational at some time between 1982 and 1997 (from a total of 19 196 sites) compared with those living further away.

Setting Great Britain.

Subjects Over 8.2 million live births, 43 471 stillbirths, and 124 597 congenital anomalies (including terminations).

Main outcome measures All congenital anomalies combined, some specific anomalies, and prevalence of low and very low birth weight (<2500 g and <1500 g).

Results For all anomalies combined, relative risk of residence near landfill sites (all waste types) was 0.92 (99% confidence interval 0.907 to 0.925) unadjusted, and 1.01 (1.005 to 1.023) adjusted for confounders. Adjusted risks were 1.05 (1.01 to 1.10) for neural tube defects, 0.96 (0.93 to 0.99) for cardiovascular defects, 1.07 (1.04 to 1.10) for hypospadias and epispadias (with no excess of surgical correction), 1.08 (1.01 to 1.15) for abdominal wall defects, 1.19 (1.05 to 1.34) for surgical correction of gastrochisis and exomphalos, and 1.05 (1.047 to 1.055) and 1.05 (1.03 to 1.05) for low and very low birth weight respectively. There was no excess risk of stillbirth. Findings for special (hazardous) waste sites did not differ systematically from those for non-special sites. For some specific anomalies, higher risks were found in the period before opening compared with after opening of a landfill site, especially hospital admissions for abdominal wall defects.

Conclusions We found small excess risks of congenital anomalies and low and very low birth weight in populations living near landfill sites. No causal mechanisms are available to explain these findings, and alternative explanations include data artefacts and residual confounding. Further studies are needed to help differentiate between the various possibilities.

Introduction

Waste disposal by landfill accounts for over 80% of municipal waste in Britain.1 Human exposure to toxic chemicals in landfill (which include volatile organic compounds, pesticides, solvents, and heavy metals) may occur by dispersion of contaminated air or soil,2 leaching or runoff,3 or by animals and birds, although evidence for any substantial exposures is largely lacking.4 Excess risks of congenital anomalies and low birth weight near landfill have been reported,5 including from recent European and UK studies,6 11 although some have reported less significant12 or negative findings.7 The aim of our present study was to examine risk of adverse birth outcomes associated with residence near landfill using data on all known sites in Great Britain.

Methods

Classification of populations near landfill sites

Data provided by the national regulatory agencies were merged in a geographical information system to give a database containing 19 196 sites. Data on boundaries were unavailable for most sites, so point locations had to be used. These comprised the site centroids for 70% of sites and, for the remainder, the location of the site gateway at the time of reporting. Data for site locations were of low accuracy (often rounded to 1000 metres), and data on area were inadequate to allow estimation of the extent of most sites. Landfill sites also change considerably over time as old areas are closed and new areas develop, while postcodes (used to define the location of cases and births) give only an approximation of place of residence, accurate to 10-100 metres in urban areas but >1 km in some rural areas; also, landfill sites are highly clustered, so that individual postcodes may lie close to 30 or more sites. Therefore, distance from nearest landfill site was not regarded as a meaningful proxy for exposure. As a compromise between the need for spatial precision and the limited accuracy of the data, we constructed a 2 km zone around each site (figure), giving resolution similar to or higher than that of previous studies,10 11 and at the likely limit of dispersion for landfill emissions.12 Postcodes within the 2 km buffer zone were classified hierarchically by operational status, year on year, such that sites still operating took precedence over those closed earlier in the study period, which took precedence over sites opening later in the study period.13 People living more than 2 km from all known landfill sites during the study period comprised the reference population.

Because of concerns about the quality of landfill data for earlier years, and because health data were available only to 1998, we excluded 9631 sites (25% of the population) that closed before 1982 or opened after 1997 (to allow a one year lag period for the birth outcomes) or for which there were inadequate data. The remaining 9565 sites comprised 774 sites for special (hazardous) waste, 7803 for non-special waste, and 988 handling unknown wastes. The 2 km surrounding these sites included 55% of the national population; 20% were included in the reference area.

Health and denominator data

We used national postcoded registers held by the Small Area Health Statistics Unit. These comprised the National Congenital Anomaly System in England and...
Wales, 1983-98, and data on terminations, 1992-8, performed for “grounds E” of the 1967 Abortions Act (“where there is a substantial risk that if the child were born it would suffer from such physical or mental abnormality as to be seriously handicapped”); congenital anomaly and terminations data for Scotland, 1988-94; hospital admissions data for England and Scotland, 1993-8 (Welsh data were considered unreliable); and national births and stillbirths data, 1983-98.

Cases were coded to ICD-9 (international classification of diseases, ninth revision) from 1983 to 1994, and to ICD-10 thereafter. Outcomes were all congenital anomalies combined (ICD-9 740-59; ICD-10 Q00-Q99); neural tube defects (ICD-9 740.0-740.2, 741.0-741.9, 742.0; ICD-10 Q00-Q00.2, Q05.0-Q05.9, Q01.0-Q01.9); cardiovascular defects (ICD-9 745.0-747.9; ICD-10 Q20.0-Q28.9); abdominal wall defects (ICD-9 756.7; ICD-10 Q79.2-Q79.4); hypospadias and epispadias (ICD-9 752.6; ICD-10 Q54.0-Q54.9, Q64.0); surgical correction of hypospadias and epispadias (M731, M732); and surgical correction of gastrochisis and exomphalos (T281). Multiple anomalies were counted under each outcome (once only for all anomalies combined).

Surgical corrections (England and Scotland only) were analysed by date of birth, not date of surgical procedure. For hypospadias and epispadias, we included only procedures carried out before the age of 3 years, and, for gastrochisis and exomphalos, in the first year of life only. Low and very low birth weights were defined as <2500 g and <1500 g respectively. The relevant denominators and years of analysis are shown in table 1.

### Statistical methods

We calculated risks for the population within 2 km of landfill relative to the reference population by indirect standardisation, assuming a common relative risk for all landfill sites. We used model predictions from Poisson regression of data from the reference area to provide standard rates. The regression function included year of birth, administrative region (n = 10), sex (for birth weight and stillbirths), and deprivation. We obtained deprivation by assigning postcodes to tertiles of the national distribution of the Carstairs’ deprivation index based on 1991 census statistics at enumeration district level (we used tertiles rather than quintiles of the Carstairs index because of the small number of events for the rarer outcomes in the most deprived part of the reference area). We used a descending stepwise selection procedure starting from the fullest model including all possible interactions. This was repeated without deprivation, and then the two models were constrained (where necessary) to differ only in terms of deprivation (table 2). For the hospital admissions data (where there were fewer years), unadjusted and deprivation-adjusted results only were obtained, and no modelling was done.

Some degree of overdispersion and a widening of the confidence intervals is to be expected if our model assumptions fail to hold (for example, because of data anomalies, unmeasured confounding, or sampling variability of the rates). We therefore calculated Poisson 99% (rather than 95%) confidence intervals, but this does not necessarily ensure that all additional variability has been captured—we emphasise estimation of relative risks and their stability (or otherwise) to choice of model confounders rather than significance testing.

We assessed the sensitivity of our results to model choice by using an alternative model for each birth outcome (table 2). We also included urban or rural status and examined risks for rural areas only, and for birth weight (where data were sufficient) we examined sensitivity to the use of quintiles (rather than tertiles) of the Carstairs index. For abdominal wall defects, we also examined maternal age (<20 and ≥20 years, available 1986-98 for England and Wales only).

The main analysis identified at outset was for all landfill sites for the combined period during their
operation and after closure. Subsidiary analyses examined risks separately for special and non-special waste sites, and in the period before and after opening for the 5260 landfill sites with available data.27

Results

Urban or rural status and Carstairs index were strongly correlated. Within the reference area, 49% of the most affluent tertile of areas was classified as rural (7% for the most deprived tertile), while for all outcomes rates were higher in the most deprived areas compared with the most affluent areas: the ratio ranged from 1.02 (surgical correction of hypospadias and epispadias) to 1.52 (very low birth weight).31 The area within 2 km of the 9565 landfill sites tended to be more deprived than the reference area: 34% (vs 23%) of the population were in the most deprived tertile of Carstairs score (36% for special waste sites). The area near landfill also had a higher proportion of births to mothers under 20 years of age (7.7% vs 6.1%) and, among women aged 15-44, included (1991 census) a higher proportion of women of Indian, Pakistani, or Bangladeshi origin (4.8% vs 3.2%) and a lower proportion of black women (2.0% vs 3.4%).

Table 3 shows the numbers of cases for each birth outcome and relative risks for the area near landfill compared with the reference area. The relative risk for all congenital anomalies combined was 0.92 (99% confidence interval 0.907 to 0.923) unadjusted, and 1.01 (1.005 to 1.023) adjusted for deprivation and other confounders. After adjustment for deprivation (which reduced excess risks) relative risk was 1.05 (1.01 to 1.10) for neural tube defects, 1.08 (1.01 to 1.15) for abdominal wall defects (and 1.07 (1.03 to 1.18) for hospital admissions), 1.10 (1.05 to 1.15) for surgery correction of gastroschisis and exomphalos, and 1.05 (1.047 to 1.055) and 1.04 (1.03 to 1.05) for low and very low birth weight respectively. The risk was 0.96 (0.93 to 0.99) for cardiovascular defects and 1.07 (1.04 to 1.10)

Table 2  Models chosen by the stepwise selection procedure in the reference area for each outcome*

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Model</th>
<th>No of parameters in chosen model</th>
<th>Terms added in alternative model†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deprivation unadjusted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All anomalies</td>
<td>Year × region × region × year</td>
<td>151</td>
<td></td>
</tr>
<tr>
<td>Neural tube defects</td>
<td>Year × region</td>
<td>25</td>
<td>Region × year</td>
</tr>
<tr>
<td>Cardiovascular defects</td>
<td>Year × region</td>
<td>25</td>
<td>Region × year</td>
</tr>
<tr>
<td>Hypospadias and epispadias</td>
<td>Year × region</td>
<td>25</td>
<td>Region × year</td>
</tr>
<tr>
<td>Abdominal wall defects</td>
<td>Year × region</td>
<td>25</td>
<td>Region × year</td>
</tr>
<tr>
<td>Stillbirth</td>
<td>Year × sex × region × sex</td>
<td>35</td>
<td>Region × year</td>
</tr>
<tr>
<td>Low birth weight</td>
<td>Year × region × sex</td>
<td>28</td>
<td>Region × year</td>
</tr>
<tr>
<td>Very low birth weight</td>
<td>Year × region</td>
<td>25</td>
<td>Region × year</td>
</tr>
<tr>
<td>Deprivation adjusted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All anomalies</td>
<td>Deprivation + year × region × region × deprivation</td>
<td>171</td>
<td>Year × deprivation</td>
</tr>
<tr>
<td>Neural tube defects</td>
<td>Deprivation + year × region</td>
<td>27</td>
<td>Region × year</td>
</tr>
<tr>
<td>Cardiovascular defects</td>
<td>Deprivation + year × region × region × deprivation</td>
<td>45</td>
<td>Region × year</td>
</tr>
<tr>
<td>Hypospadias and epispadias</td>
<td>Deprivation + year × region × region × deprivation</td>
<td>45</td>
<td>Region × year</td>
</tr>
<tr>
<td>Abdominal wall defects</td>
<td>Deprivation + year × region × region × deprivation</td>
<td>27</td>
<td>Region × year</td>
</tr>
<tr>
<td>Stillbirth</td>
<td>Deprivation + year × region × region × sex</td>
<td>37</td>
<td>Deprivation × year</td>
</tr>
<tr>
<td>Low birth weight</td>
<td>Deprivation + year × region × sex × deprivation + deprivation × sex</td>
<td>48</td>
<td>Region × year</td>
</tr>
<tr>
<td>Very low birth weight</td>
<td>Deprivation + year × region × region × deprivation</td>
<td>45</td>
<td>Deprivation × year</td>
</tr>
</tbody>
</table>

Interactions are denoted by “×.”

*No modelling was done for the hospital admissions data.
†Terms added in alternative model used in sensitivity analysis, defined as the most important term excluded at the last step (no alternative is shown for all anomalies combined, deprivation unadjusted, because the model is already saturated).
‡Deprivation not selected by stepwise selection process but was added as a main effect.
Table 3 Risks of congenital anomalies, stillbirths, and low and very low birth weight in populations living within 2 km of a landfill site (all waste types) during operation or after closure compared with those in the reference area (>2 km from any site)

<table>
<thead>
<tr>
<th>Birth outcome</th>
<th>Near landfill (&lt;2 km)</th>
<th>Reference area</th>
<th>Relative risk (99% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of cases</td>
<td>Rate (per 100 000 births)</td>
<td>No of cases</td>
</tr>
<tr>
<td>Congenital anomalies (register and terminations data)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All congenital anomalies</td>
<td>90 272</td>
<td>1550</td>
<td>34 325</td>
</tr>
<tr>
<td>Neural tube defects</td>
<td>3 508</td>
<td>60</td>
<td>1 140</td>
</tr>
<tr>
<td>Cardiovascular defects</td>
<td>6 723</td>
<td>115</td>
<td>2 716</td>
</tr>
<tr>
<td>Hypospadias and epispadias‡</td>
<td>7 363</td>
<td>247</td>
<td>2 485</td>
</tr>
<tr>
<td>Abdominal wall defects</td>
<td>1 488</td>
<td>26</td>
<td>448</td>
</tr>
<tr>
<td>CONGENITAL ANOMALIES (HOSPITAL ADMISSIONS)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypospadias and epispadias‡</td>
<td>1 503</td>
<td>257</td>
<td>536</td>
</tr>
<tr>
<td>Abdominal wall defects</td>
<td>755</td>
<td>40</td>
<td>227</td>
</tr>
<tr>
<td>Gastroscisis and exomphalos¶</td>
<td>467</td>
<td>25</td>
<td>126</td>
</tr>
</tbody>
</table>

Stillbirths and birth weight

<table>
<thead>
<tr>
<th>Birth outcome</th>
<th>Near landfill (&lt;2 km)</th>
<th>Reference area</th>
<th>Relative risk (99% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of cases</td>
<td>Rate (per 100 000 births)</td>
<td>No of cases</td>
</tr>
<tr>
<td>Stillbirths</td>
<td>32 271</td>
<td>532</td>
<td>11 200</td>
</tr>
<tr>
<td>Low birth weight</td>
<td>422 149</td>
<td>7000</td>
<td>137 958</td>
</tr>
<tr>
<td>Very low birth weight</td>
<td>62 191</td>
<td>1031</td>
<td>20 858</td>
</tr>
</tbody>
</table>

See table 1 for denominators and years of analysis and table 2 for adjustments.
†Excludes terminations (3 cases).
§Excludes terminations (3 cases).
¶Surgical corrections.

and 0.96 (0.90 to 1.02), respectively, for hypospadias and epispadias and their surgical correction (for which deprivation adjustment had little or no effect).

Table 4 summarises findings (adjusted for deprivation) for the special and non-special waste sites, and for the sites that opened during the study period. For special waste sites, risks above one were found for all but two outcomes, ranging up to 1.21 (1.13 to 1.29) for congenital anomalies (register and terminations data), 1.12 (1.10 to 1.14) for congenital anomalies (hospital admissions), 1.11 (1.10 to 1.13) for stillbirths, and 1.11 (1.10 to 1.13) for low birth weight. For very low birth weight, risks were higher in the period before opening of a landfill site compared with after opening, especially for hospital admissions for abdominal wall defects. For birth weight and stillbirth, risks were higher after opening.

Sensitivity analysis showed that the risk estimates were robust to the different models used. Urban or rural status did not materially alter results with deprivation included, though modelling of data for rural areas only (where numbers of cases were much lower than in the main analysis) did reduce risk estimates for neural tube defects and hypospadias and epispadias—relative risks (for all waste types, deprivation adjusted) were 0.99 (0.89 to 1.10) and 1.01 (0.94 to 1.09) respectively. Inclusion of maternal age as a confounder had only a small effect on risk of abdominal wall defects.

**Discussion**

This is by far the largest study of associations between residence near landfill and adverse birth outcomes. We found a small excess risk of neural tube defects, abdominal wall defects, surgical correction of gastro-
schisis and exomphalos, low and very low birth weight. Findings for cardiovascular defects and hypospadias and epispadias were inconsistent, and there was no association with stillbirth. By including all landfill sites in Great Britain and using routine data sources, we avoided the possibility of bias from selective reporting, and maximised statistical power, but problems with data quality and confounding could have led to spurious associations. These merit further discussion.

**Exposure classification and data quality issues**

In the absence of information on site or geological factors affecting emissions from landfill, we examined data for special waste sites as a proxy for potential hazard. The UK practice of co-disposal of special and non-special wastes (in contrast, for example, with US “superfund” sites) means that most special waste sites handle small volumes of hazardous wastes. They are subject to stricter management and design standards than other UK sites, while hazardous wastes may have been disposed of, unreported, in non-special sites. Thus exposure risks from special waste sites may be no greater than from other sites. Exposures to environmental contamination from sources other than landfill may also be relevant because sites tend to be located in old mineral or other excavations, often on old industrial or contaminated land or close to current industrial activities.

A key issue was the possibility of misclassification from use of a 2 km zone to define proximity to landfill sites. However, in view of the low spatial resolution of the landfill data (hundreds of metres) and complex nature of landfill sites, using finer subdivisions of the 2 km zone or distance as a continuous measure to examine proxy dose-response relationships would not yield meaningful results. Misclassification of potential exposure to landfill may also have occurred if mothers moved home during the relevant period after conception.

While the data for births and stillbirths are well recorded, the national congenital anomaly system in England and Wales is known to be incomplete (though we found relative over-reporting in Scotland), and there were marked fluctuations in rates of anomalies over the study period, partly because of coding changes and the dates that the terminations data became available. We adjusted for calendar year to deal with fluctuating rates, but ascertainment artefacts could have biased our results (in either direction) if they were differential with respect to landfill locations. Though we had no reason to suspect that this had occurred, such inconsistencies could explain differences of the order detected in this study. On the other hand, we included data on terminations to improve ascertainment, especially for neural tube defects, and included data on hospital admissions and surgical corrections to give an independent source of data for those specific anomalies.

**Confounding**

We addressed confounding in two ways. Firstly, analysis included potential confounders, and with and without adjustment for deprivation. Residual confounding may persist if the adjustment did not account completely for relevant individual characteristics such as smoking, drug use, and infections during pregnancy. As in the Eurohazcon study, maternal age (for risk of abdominal wall defects) did not seem to be a strong confounder, and, unlike in the United States, location of waste sites near ethnic minority communities was not a key feature. Increased risks (about 1.5 to 2) of low and very low birth weight, and (more weakly) of certain congenital anomalies (especially neural tube defects) have been reported among offspring of women of South Asian origin, but the higher proportions of women of Indian, Pakistani, or Bangladeshi origin living near landfill sites compared with the reference area would explain only around 1% excess in our study.

Secondly, we examined rates both before and after the opening of landfill sites that opened during the study period. Because this analysis is restricted to one set of areas, it is less subject to confounding by socio-demographic factors than comparisons between different areas—although confounding by temporal trends (which are strong for some of the health outcomes studied here) is possible. Consequently, we did not compare the risks before and after opening directly but estimated each with respect to the reference region. We found excess risks for some specific anomalies in the period before opening (and which were higher than in the period during operation or after closure, especially for hospital admission for abdominal wall defects). This implies that factors other than landfill might be responsible. The Nant-y-Gwryddon study also noted an excess risk of all congenital anomalies combined before the site was opened.

A possible causal association with landfill should also be considered. Given the large heterogeneity between landfill sites and the likelihood that the effect of any emissions would be greatest close to the sites, causal effects related to particular landfill sites might have been greatly diluted. None the less, we know of no causal mechanism that might explain our findings, and there is considerable uncertainty as to the extent of any possible exposure to chemicals found in landfills. Further understanding of the potential toxicity of landfill emissions and possible exposure pathways is needed in order to help interpret the epidemiological findings.

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**What is already known on this topic**

- Various studies have found excess risks of certain congenital anomalies and low birth weight near landfill sites.
- Risks up to two to three times higher have been reported.
- These studies have been difficult to interpret because of problems of exposure classification, small sample size, confounding, and reporting bias.

**What this study adds**

- Some 80% of the British population lives within 2 km of known landfill sites in Great Britain.
- By including all landfill sites in the country, we avoided the problem of selective reporting, and maximised statistical power.
- Although we found excess risks of congenital anomalies and low birth weight near landfill sites in Great Britain, they were smaller than in some other studies.
- Further work is needed to differentiate potential data artefacts and confounding effects from possible causal associations with landfill.
We thank the Office for National Statistics, the Department of Health, and the Information and Statistics Division of the Scottish Health Service for providing data on congenital anomalies, births, stillbirths, and hospital admissions. We thank the Environment Agency in England and Wales and the Scottish Environment Protection Agency for providing data on landfill and for their help in resolving discrepancies. The views expressed in this publication are those of the authors and not necessarily those of the funding departments, data providers, or of the Office for National Statistics. We thank Sean Reed and Richard Arnold for their help in preliminary analyses and Alex Lewin for help in the statistical analysis.

Contributors: PE and LJ initiated the project and, with DB and SM, drafted the paper. DB, CéH, CH, and IM performed the analysis of landfill sites, SM, CH, and IM performed the statistical analysis, overseen by JW and SR. TJK contributed to the epidemiological analysis and interpretation. All authors contributed to and approved the final paper. PE is guarantor for the paper.

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Competing interests: None declared.

References

18 Office for National Statistics. We thank Sean Reed and Richard Arnold for help in the statistical analysis.

My only sermon

After speaking at the medical school in Mangalore, India, in 1992 I stopped at the mission hospital in Miraj to visit a former student. I was horrified. “What about?” I whispered. “About polio immunisation of course,” he replied. So, in as simple language as I could muster, I gave a sermon about polio immunisation, which was translated sentence by sentence.

In India I have grown used to giving lectures on polio and immunisation of course,” he replied. So, in as simple language as I said. I was horrified. “What about?” I whispered. “About polio immunisation of course,” he replied. So, in as simple language as I could muster, I gave a sermon about polio immunisation, which was translated sentence by sentence.

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