The human health impact of waste management practices

A review of the literature and an evaluation of the evidence

Lisa Saffron, Lorenzo Giusti and Derek Pheby

Centre for Research in Environmental Systems, Pollution and Remediation, CRESPAR, University of the West of England, Bristol, UK

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Abstract *A literature review was carried out of the health impacts of incineration, landfill, composting, landspreading sewage sludge and sewage discharges. A protocol for making judgements about the strength and reliability of the evidence was applied using an algorithm with defined criteria. Possible judgements were "convincing", "probable", "possible" or "insufficient". The review found that the evidence linking any adverse health outcomes with incineration, landfill or landspreading sewage sludge was "insufficient" to claim a causal association. The evidence is "insufficient" to link residence near a centralised composting facility with adverse health outcomes but it is "possible" that working at a centralised composting facility causes health problems. Working in sewage treatment plants "probably" causes gastrointestinal tract problems, headache, fatigue and airways symptoms. The only "convincing" evidence is that gastrointestinal symptoms result from bathing in sewage contaminated recreational waters.*

Introduction

This paper is an attempt to present a balanced appraisal of the epidemiological evidence concerning the public health implications of five key waste management processes – incineration, landfill, composting, sewage discharges and landspreading sewage sludge.

The public health impacts are determined by the overall waste management strategy adopted locally, regionally and nationally. The waste management options chosen by decision makers could have an impact on health:

- directly, by leading to potential adverse and/or beneficial health impacts such as increased risk of cancer or decreased quality of life;

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- indirectly, by the broader environmental impact on the global ecology, such as the contribution to global warming, loss of bio-diversity and the depletion of non-renewable resources.

Health impacts

The type of health problems experienced by people around waste facilities and those experienced by people nowhere near a waste facility are basically the same. Health effects are non-specific. The human body has only a limited number of responses to a wide range of internal and external assaults. Contaminant levels and individual susceptibility determine which responses occur. Unlike laboratory animals, which are bred for homogeneity, human populations are made up of sensitive types, i.e. children, foetuses, women of child-bearing age and the elderly as well as more robust types. From individual to individual, there are great variations in resistance or sensitivity to a range of chemical and physical insults. Some families living near a waste site may be affected while others are not, and within these families some individuals may be affected while others are not. Even where increased incidence of an adverse health outcome can be demonstrated in proximity to a hazard, it is impossible to say which of the cases are directly attributable to the hazard in question.

Exposure

The real challenge to the scientific method is in linking the hazard to the health impact. It is all very well to demonstrate that hazardous compounds leave the waste facility and that people living or working nearby experience health problems. The crucial question is whether there is any uptake by people, whether in fact anybody is exposed to these hazards and by how much. If no one is exposed or if there is an insignificant amount of the hazard, it is difficult to make a case linking the waste facility to the health impact. There are various ways people can come in contact with pollutants from waste facilities – by inhalation, by ingestion of food or of water, by skin contact and by fire or explosion.

A hierarchy of exposure data have been proposed which ranks the exposure assessment from best (i.e. yields the most convincing evidence) to worst in terms of its relation to actual exposure (National Research Council, 1991):

(1) *Best*:

- quantified personal measurements;
- quantified area or ambient measurements in the vicinity of the residence or other sites of activity;
- quantified surrogates of exposure such as estimates of drinking water use;
- distance from site and duration of residence (add direction from site for more refined data);

- distance or duration of residence;
- residence or employment in reasonable proximity to site where exposure can be assumed;

(2) *Worst*. Residence or employment in defined geographical area of the site.

The majority of the epidemiological studies investigating links between waste management practices and health outcomes rely on the worst type of evidence, i.e. residence or employment near the site. A tiny minority of studies are based on quantified ambient measurements or personal measurements taken at the time of potential exposure. In most studies, the waste management facility is like a black box, assumed to be emitting toxic compounds but with no actual measurements that could be used in exposure assessment.

A summary of health hazards, exposure routes and health impacts is shown in Figure 1.

Proving causation

It is difficult to establish a cause-and-effect relationship in epidemiological studies because:

- The data are often incomplete due to lack of exposure data, unreliable health data, or low statistical power.
- Variability is inherent in the data, in both the human populations studied and the waste procedures.
- Other unrelated factors may explain the results as well as the factor under investigation.

Confounding takes place when the exposure is associated with some other factor which also increases the risk of the health outcome studied. This includes other sources of pollutants and other factors which affect health status.Whilst it is technically possible to detect the presence of health hazards in waste sites and health impacts among people working or living nearby, there are many problems demonstrating the relationship between exposure and the health impacts observed. An association cannot be considered convincing unless it is confirmed in many hypothesis-testing studies based on the best kind of exposure data.

Methods

Literature search

To find studies on the health impacts of waste management processes, searches were made of online databases, relevant organisations and references in journal articles:

- *Online databases*. Those used were Biosis, CAB Abstracts, Cochrane Controlled Trials Register, Compendex*Plus, Index to Theses, Ingenta,

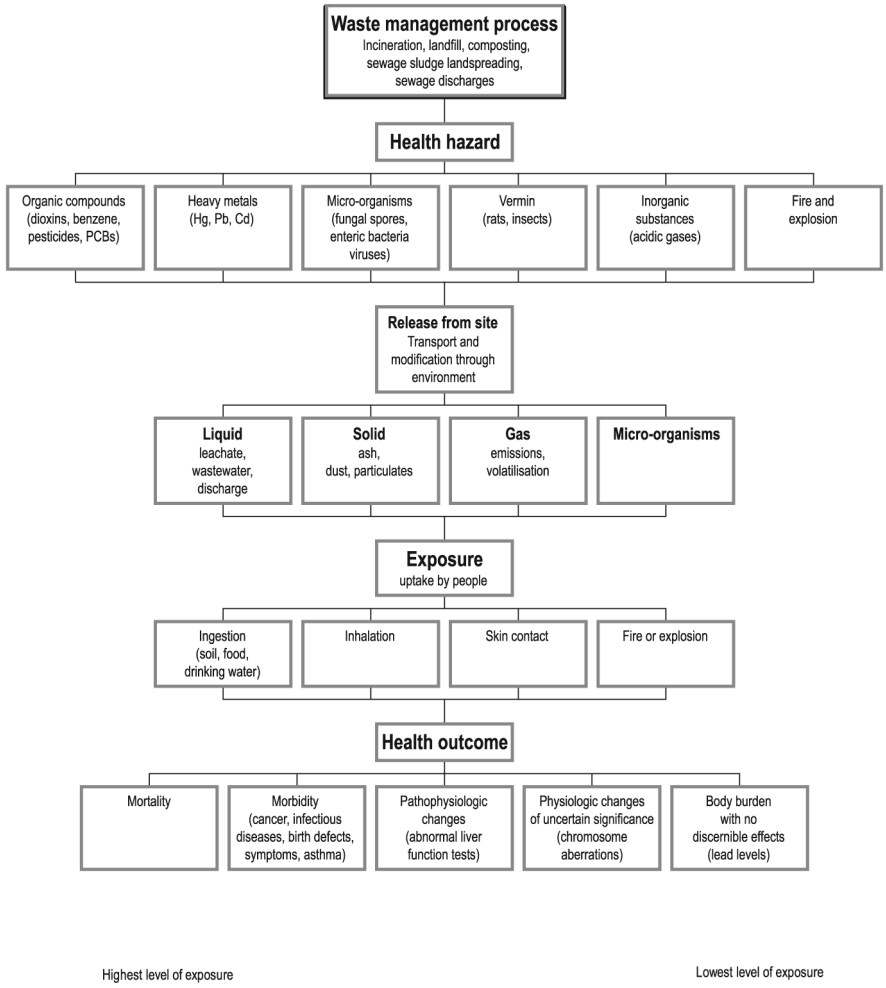

Figure 1.
Pathways from health hazards to health impacts

Medline, Mental Health Collection, PsycINFO, ScienceDirect, The Science Citation Index Expanded.

- *Organisations*. These were Composting Association, County Councils and Unitary Authorities in the South West of England, Department for Environment, Food and Rural Affairs, Dyfed Powys Health Authorities, Entrust, Environment Agency, Friends of the Earth, Greenpeace Research Laboratories, University of Exeter, London Hazards Centre, WARMER Bulletin Library, Wastewatch.

The following search strategy was adopted:

- Inclusion of epidemiological studies only, i.e. studies about health impacts (changes in health risk that can be attributable to a project) rather than studies about health hazards i.e. anything that can potentially cause harm (British Medical Association, 1998).
- Inclusion of studies about landfill, incineration, sewage discharges, soil amendments and composting. Disposal of radioactive waste was not included.
- Use of the WHO definition of health: "state of complete physical, mental and social well-being and not merely the absence of disease and infirmity".
- Use of myriad permutations of keywords: air pollutants, bathing beaches, birth defects, cancer, community health, composting, congenital, dental waste, disposal, gastroenteritis, hazardous waste, health, human, incineration, incinerator, infection, land fill, landfill, medical waste, occupational, occupational health, public health, recreation, recycling, refuse disposal, sanitary engineering, sea, sea bathing, seawater, sewage, waste, waste disposal, fluid, waste management, waste treatment, water pollution.
- Priority was given to reviews over primary studies.
- Inclusion of studies published since 1982 and reviews published since 1992.
- Inclusion of studies done in developed countries: UK, continental Europe, the USA, Canada, Australia and New Zealand.

Reviewing the evidence

To avoid duplicating effort, we checked whether adequate reviews already existed. The reviews found during the literature search were appraised according to the approach developed by the Health Evidence Bulletins Wales steering group (Welsh Office, 1999).

None of the reviews were systematic literature reviews as defined in the guidelines. Systematic literature reviews make use of meta-analyses where possible. A meta-analysis involves the aggregation of results from a number of published studies in order to provide a quantitative assessment of the extent to which bias might account for observed results and of the patterns and sources of heterogeneity. A meta-analysis can only be done if the biases and confounding factors are adequately addressed in the studies and if the studies measured the same exposures in the same way and compared risk between or among similar levels of exposure. For most epidemiological studies of the health impacts of waste management systems, exposure data are missing and there is no confounding control. With the exception of the work of Pruss (1998),

none of the reviews attempted to aggregate results and none carried out meta-analyses.

It became apparent that following a protocol for a systematic literature review would not result in different conclusions than those reached by published unsystematic reviews. Therefore, the decision was taken not to embark on a systematic literature review of primary studies.

Making judgements

In this paper, the model used to appraise the evidence is the one used by the World Cancer Research Fund to evaluate the role of food and nutrition in the prevention of cancer (World Cancer Research Fund and American Institute for Cancer Research, 1997). The model consists of guidelines for making judgements about the reliability and strength of the evidence and was chosen because the judgements are straightforward and easy to comprehend with relatively clear criteria for inclusion.

Assessment of the strength of the evidence depends on two factors:

(1) the scale of the association demonstrated between exposures and presumed health effects; and

(2) its statistical significance (i.e. the likelihood that such an association could have arisen by chance.)

To determine the strength of an association, the concept of relative risk (RR) is generally used. RR is the ratio of the risk or incidence of a health outcome among people with a particular characteristic (e.g. people living near an incinerator) to that among people without that characteristic (e.g. people living far from the incinerator). An RR of less than 1 implies a protective effect; more than 1 indicates an increased risk; equal to 1 implies no effect.. For example, an RR of 2 indicates a doubling of the risk. An RR of 1.1 indicates a 10 per cent increase:

- *Strong.* An association is strong when the RR is greater than 2 or less than 0.5 and is statistically significant. An example is the association between smoking more than 25 cigarettes a day and lung cancer, where the RR is 30 (Tomatis, 1990).
- *Moderately strong.* An association is moderately strong when the RR is greater than 2 or less than 0.5 but is not statistically significant or the RR is between 1.5-2.0 or 0.5-0.75 and is statistically significant. An example is the association between exposure to a landfill site and the incidence of skin problems where the RR is 1.76, $p < 0.001$ (Hertzman *et al.*, 1987). Another example is maternal exposure to a landfill site in Canada and congenital malformations where the RR is 1.63 (95 per cent confidence intervals 1.34-1.99) (Geschwind *et al.*, 1992).
- *Weak.* An association is weak when the RR is between 1.5-2.0 or 0.5-0.75 but is not statistically significant.

- *No association.* There is no association when the RR is between 0.75 and 1.5 whether or not it is statistically significant. An example is maternal residence within 2km of landfill sites and congenital abnormalities where the RR = 1.01 ($p < 0.001$) (Elliott *et al.*, 2001, Table 27). Maternal residence in a census tract containing a landfill site in California and neural tube defects where the RR is 0.9 (95 per cent confidence interval 0.7-1.3) (Croen *et al.*, 1997).

However, an association, even if strong and statistically significant, is not proof of causation. To determine causation, we took the following criteria from the approach used to evaluate the diet and cancer evidence (Table I).

From these categories, we developed an algorithm to help us make the judgements about the evidence on the associations with health outcomes from the different waste practices (Figure 2). Based on the review articles, abstracts and the primary papers found in the literature search, we used this algorithm to assign judgements to the evidence about the health impacts of landfill, incineration, sewage treatment, sewage sludge landspreading and composting.

Results

Landfill

(1) *Have studies been done on human populations?* Yes. The literature search revealed more than 220 papers published about the hazards to health from landfill sites. Of these, 101 are primary studies about the health impacts of landfill sites and 23 about the health impacts of contaminated drinking water. Six review papers were found which covered the epidemiological evidence linking health effects with landfill sites (Cantor, 1997; Johnson, 1997; 1999; Miller, 1996; Sever, 1997; Vrijheid, 2000). The drinking water studies were included in this section because an important source of exposure from landfill sites is leachate into groundwater. However, in many studies, the source of the contamination was not known. In some studies the source was leaking chemical storage tanks, in others, chemical accidents. Studies were not included if the water was contaminated by sewage (see section on sewage below). Only seven of the total are occupational health studies, the rest being studies about the health impacts on nearby communities.

The studies looked for links between the landfill sites and the following health outcomes: reproductive outcomes/developmental effects on children (31 studies), cancer (29), symptoms (28), psychosocial impacts (19), biomarkers (13), health problems not specified in abstract (14), mortality (five) and injuries/poisoning (two).

(2) *Have hazards been identified? Does the appearance of the hazard precede the health outcome? Is the association biologically plausible? Are there data on exposure?* No. The main weakness of the studies about landfill health

Judgement	Interpretation	Criteria
Convincing	There is conclusive evidence of a cause-and-effect association	The studies are on human populations, not just laboratory studies on animals or chemicals
		There are a considerable number of hypothesis-testing studies, with strong relative risks, preferably more than 20
		The association is consistent and observed in most of the studies, with few studies showing the opposite Possible confounding factors have been controlled for
		There are a range of hypothesis-testing study designs, preferably including prospective studies
		Studies have been carried out in different population groups
		The appearance of the hazard must precede the health effect. Data should refer to the time preceding the occurrence of the health outcome
		If dose-response relationships are observed, they should confirm the relationship
		The associations should be biologically plausible
		Coherence – the cause-and-effect, interpretation of the data do not conflict with other knowledge of the health outcome. Laboratory evidence is usually supportive or strongly supportive
Probable	A causal association is likely	There is less consistency among the studies with some not supporting the association. There are fewer studies. Laboratory evidence is usually supportive or strongly supportive
Possible	There may be a causal relationship but the evidence is not strong enough to be sure	Studies show an association. However, there may not be very many studies; or existing studies are of poor quality or results are inconsistent. There may or may not be supportive evidence from laboratory studies but there is strongly supportive evidence from other disciplines
Insufficient	The evidence merely suggests a causal association. No judgement can be made	There are a limited number of studies which may be consistent but the poor quality of the studies limit the reliability of the conclusions drawn from them

Table I.
Criteria used to make judgements

effects is the complete lack of exposure data. All use residence near the site as a proxy measure of exposure, i.e. data based on census tract, post code, or residence within 2 or 3km of the site. A few studies provided more detailed exposure data. For example, in a French study (Zmirou *et al.*, 1994) individual exposure was estimated for one point in time, using a dispersion model of volatile air pollutants and the daily activity

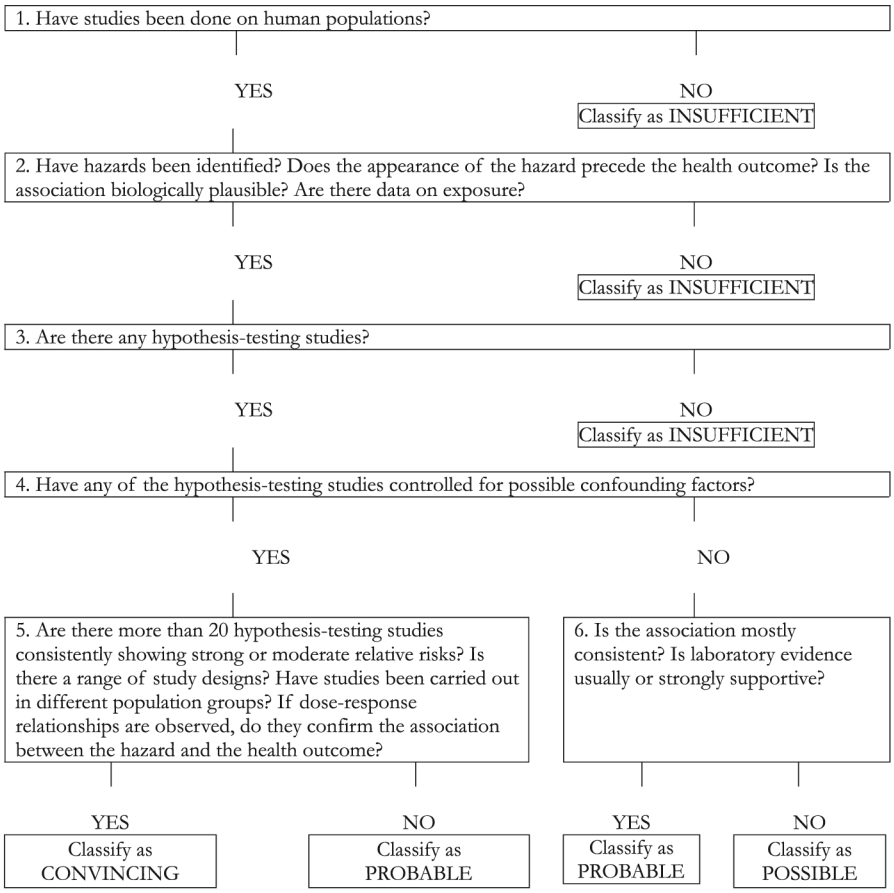

Figure 2.
Algorithm for making judgements

patterns of each individual within the area under investigation. The landfill site had been in operation for the previous nine years. In this study, there were no statistically significant differences in consumption of prescription drugs.

Where the hazards from landfill sites have been identified, as is the case in the National Priorities List sites in the USA, it is possible to estimate exposure using the EPA Human Exposure Model (Wolfinger, 1989). The model is based on assumptions about the rate and toxicity of site emissions and can be used to estimate cancer risks from inhalation for each site in terms of risk to the maximally exposed individual (MEI risk), to the average individual (AEI risk), and to the population. The results of this type of analysis are uncertain and are based on risky assumptions. These remain estimates, not data.

(3) *Are there any hypothesis-testing studies?* No. Because of the lack of exposure data, the studies are hypothesis-generating studies rather than hypothesis-testing studies.

(4) *Have any of the hypothesis-testing studies controlled for possible confounding factors?* No. With ecological studies of this type, it is impossible to control for other sources of pollutants. For example, the conclusion that the landfill site in Nant-y-Gwyddon may have been responsible for an increased rate of congenital abnormalities in residents near the site (Fielder *et al.*, 2000) has been challenged by researchers who pointed out that a municipal incinerator operated in the same area just before the landfill site opened (Roberts *et al.*, 2000). There was no direct evidence that the landfill, rather than the poorly performing and heavily polluting incinerator, was the cause of the adverse health outcomes. As well as other environmental pollutants from industrial and traffic pollution, there is usually concurrent exposure to occupational hazards, indoor air pollutants, tobacco smoke, alcohol, prescription drugs and recreational drugs.

(5) *Are there more than 20 hypothesis-testing studies consistently showing strong or moderate relative risks?* No. There are more than 20 hypothesis-generating studies but the results were inconsistent, with some showing associations between landfill and various health impacts while other studies found no associations. Relative risks ranged from no association to strong.

In reviews, discussion papers, conferences and consensus meetings, many attempts have been made to determine whether the findings indicate real risks associated with exposure to landfill sites. There is general agreement with the cautious position taken at a meeting convened by the WHO Regional Office for Europe in 1998 which concluded:

> Many of the studies detected an increased risk of the studied diseases and symptoms in populations living close to the landfills. However, the evidence supporting the causality of the association is inconsistent and inconclusive. Probably the strongest suggestion for causality was generated by studies on reproductive outcomes, such as reduced birth weight or some birth defects. However, all studies lacked direct exposure assessment, and the limited sample size of most studies makes a more specific analysis impossible … Considering all the uncertainties, the meeting concluded that the present data do add to a suspicion that population exposure to emissions from hazardous wastes may pose a risk to population health. The present studies are not powerful enough to indicate which of the characteristics of the very inhomogeneous group of landfills that are included in the studies might be responsible for the observed small increase in the risk (WHO, 1998).

Judgement: insufficient.

Incineration

(1) *Have studies been done on human populations?* Yes. The literature search yielded 50 primary studies and three reviews ((Allsopp *et al.*, 2001; Hu and Shy, 2001; National Research Council, 2000). The majority were studies on communities but there were 14 occupational health studies.

All types of health outcomes were investigated, including: cancer (15 studies); health problems/diseases/unspecified health effects (12 studies); biomarkers (ten studies); reproductive outcomes/developmental effects on children (nine studies); symptoms (eight studies); mortality (five studies); injuries/poisoning (three studies); psychosocial impacts (two studies); economic impacts (one study).

(2) *Have hazards been identified? Does the appearance of the hazard precede the health outcome? Is the association biologically plausible? Are there data on exposure?* Yes. Among the occupational health studies, there were three studies where exposure was presumed from occupation in the incinerator, two studies with quantified ambient measurements of PM10 (particulates) or metals, and seven studies providing quantified personal measurements (of blood levels of lead or of urinary mutagens). There was not enough information about the remaining two studies to categorise the exposure data.

Among the studies of communities living near to incinerators, four used quantified ambient measurements, two used quantified estimates and 27 studies used residence as a proxy measure of exposure.

(3) *Are there any hypothesis-testing studies?* Yes. There were four hypothesis-testing studies (Bresnitz *et al.*, 1992; Shy *et al.*, 1995; Lee and Shy, 1999; Gray *et al.*, 1994).

(4) *Have any of the hypothesis-testing studies controlled for possible confounding factors?* Yes. For example, the study by Lee and Shy (1999) analysed how health outcomes varied according to the degree of exposure to ambient pollutants as well as to other cofactors including, sex, age, respiratory hypersensitivity, hours spent outdoors within the area of the selected community, and surrogate measures for indoor air pollution exposure (vacuum use and experience of air irritants at work).

(5) *Are there more than 20 hypothesis-testing studies consistently showing strong or moderate relative risks?* No. The four hypothesis-testing studies consistently showed no association between the hazards from incineration and any health outcomes. Even among the hypothesis-generating studies, the results were inconsistent. Roughly half the primary studies found an increase in the incidence of a health problem and half did not.

Judgement: insufficient.

Composting

(1) *Have studies been done on human populations?* Yes. Two review papers were found (Maritato *et al.*, 1992; Environment Agency, 2001) and 11 primary studies.

(2) *Have hazards been identified? Does the appearance of the hazard precede the health outcome? Is the association biologically plausible? Are there data on exposure?* Yes. The main hazards identified from composting are bioaerosols containing bacteria such as *Clostridium botulinum* and endotoxin-producing gram negative bacteria and/or fungal spores such as *Aspergillus fumigatus*. The main health impacts from composting (Bunger *et al.*, 2000) are inflammatory responses of the upper airways, i.e. congested nose, sore throat and dry cough, toxicoses, i.e. toxic pneumonitis due to endotoxins, respiratory tract and skin infections, and allergies, i.e. bronchial asthma, allergic rhinitis, extrinsic allergic alveolitis (hypersensitivity pneumonitis).

The association between bioaerosols and these health outcomes is biologically plausible. The route of exposure is inhalation. The data on exposure are measurements of specific immunoglobulins (IgG) antibodies to fungi and bacteria as immunological markers of exposure to bioaerosols.

(3) *Are there any hypothesis-testing studies?* Yes. There is a case control study (Bunger *et al.*, 2000) which found that the compost workers had significantly more symptoms and diseases of the airways ($p = 0.003$) and the skin ($p = 0.02$) than the control subjects. They had significantly increased antibody concentrations against fungi and actinomycetes. No studies were found about the health impacts to residents living by composting facilities.

(4) *Have any of the hypothesis-testing studies controlled for possible confounding factors?* Yes. The participants were interviewed for work-related symptoms, conditions of exposure to bioaerosols at their workplaces, exposure to bioaerosols from other sources, atopic diseases and smoking habits.

(5) *Are there more than 20 hypothesis-testing studies consistently showing strong or moderate relative risks?* No. Only one case-control study was found. The rest were case reports or hypothesis-generating studies.

Judgement regarding occupational exposure and composting: possible.

Judgement regarding residence near composting facilities: insufficient.

Sewage: bathing in sewage contaminated recreational waters

Because only a few studies investigated skin, eye, ear and respiratory illnesses associated with recreational use of contaminated water, this judgement is limited to the association with gastrointestinal symptoms.

The judgement is based on a review paper by Pruss (1998) evaluating the health risks caused by poor microbiological quality of recreational natural water. Water quality was measured by indicator-bacteria of faecal origin assumed to be resulting from sewage discharge. It is possible but unlikely that the contamination could be due to other bathers:

(1) *Have studies been done on human populations?* Yes. Six review papers (Ashbolt, 1996; Barrell *et al.*, 2000; Mugglestone *et al.*, 2000; Kindzierski and Gabos, 1996; Pruss, 1998) and 37 primary studies were found about the health effects of recreational bathing in sewage contaminated waters.

(2) *Have hazards been identified? Does the appearance of the hazard precede the health outcome? Is the association biologically plausible? Are there data on exposure?* Yes. The hazards are microbial pathogens known to cause gastrointestinal symptoms. The exposure data consist of measurements of viral, bacterial and fungal pathogens and faecal indicator organisms typically found in sewage discharges.

(3) *Are there any hypothesis-testing studies?* Yes. In the review by Pruss (1998), there were 22 hypothesis-testing studies, which met strict criteria for inclusion.

(4) *Have any of the hypothesis-testing studies controlled for possible confounding factors?* Yes. The confounding factors controlled for included food and drink intake, age, sex, history of certain diseases, drug use, personal contact, additional bathing, sun and socio-economic factors. Out of 22 studies, 12 controlled for less than three of the previous factors, four studies took into account three to four factors and six studies accounted for seven or more factors. Given the number of potential confounding factors, the pathogen threshold level for increased risk is still controversial. For example, it is possible that increased immunity in adult populations and in populations of countries with higher endemicity may result in higher threshold levels. Different countries detect different ranges of pathogens in water and use different detection methods.

(5) *Are there more than 20 hypothesis-testing studies consistently showing strong or moderate relative risks?* Yes. Of the 22 studies in the Pruss (1998) review, 19 showed significant relationship of gastrointestinal symptoms to faecal indicator bacteria or bacterial pathogens. In three studies, there were no significant relationships. The relative risks included strong and moderately strong associations: 17 correlations where RR $>$ 2 (strong); 13 correlations where RR 1.5-2 (moderate); and 18 corrrelations where RR $<$1.5 (weak):

- *Is there a range of study designs?* Yes. There were two randomised controlled trials, 18 prospective cohort, and two retrospective cohort studies.

- *Have studies been carried out in different population groups?* Yes. Studies were carried out in the UK, USA, New Zealand, Hong Kong, Australia, Egypt, South Africa, Israel, Spain, France, and Canada.
- *If dose-response relationships are observed, do they confirm the association between the hazard and the health outcome?* Yes. Most of the studies showed significant dose-response relationship. The best dose-illness correlation was found with enterococci or faecal streptococci.

Judgement: convincing.

Sewage: occupational diseases of sewage treatment workers

(1) *Have studies been done on human populations?* Yes. There was one review (Thorn and Kerekes, 2001) and 38 primary studies. The health effects investigated were symptoms (17 studies), infections, i.e. hepatitis, legionella, leptospirosis, gastroenteritis (16 studies), mortality (three studies), reproductive outcomes (one study), biomarkers (three studies) and cancer (five studies).

(2) *Have hazards been identified?* Yes. From studies on symptoms and infections, the following hazards were identified: bacteria, bacterial endotoxins, hydrogen sulphide, and organic solvents. No hazards were identified in mortality and cancer studies:

- *Does the appearance of the hazard precede the health outcome? Is the association biologically plausible?*
  - Yes. For symptoms, it is plausible that pathogenic microorganisms, bacterial endotoxins, organic solvents and hydrogen sulfide could be related to the symptoms observed.
  - No. For cancer, none of the agents commonly found in sewage treatment plants have been related to an increased risk of stomach cancer. The spread of the other cancers over a multitude of organs does not support a hypothesis of causality with agents commonly found in sewage treatment plants.
- *Are there data on exposure?* Yes. Detailed exposure measurements were included in some of the studies on symptoms and infections but in most of the studies, the exposure was inferred by the subjects' occupation as a sewage treatment worker. The exposure route was inhalation. Measurements were given of airborne viable bacteria (Lundholm and Rylander, 1983; Melbostad *et al.*, 1994), airborne endotoxin levels (Rylander, 1999; Melbostad *et al.*, 1994), hydrogen sulphide (Richardson, 1995), airborne organic solvents (Kuo *et al.*, 1996), and amount of specific antibodies in the blood. For the mortality and cancer studies, no exposure data were provided.

(3) *Are there any hypothesis-testing studies?* Yes. There were 29 hypothesis-testing studies. An example is a retrospective cohort study from the USA in which 28 sewage treatment workers were compared with data from a pooled non-exposed population (Kuo *et al.*, 1996). The health outcome was central nervous system effects, determined by postural stability assessment. Exposure assessment was by measurement of organic solvents in the sewage treatment plant. In this, there was a statistically significant correlation between postural sway and organic solvent exposure and sewage workers had an increased postural sway compared with controls.

(4) *Have any of the hypothesis-testing studies controlled for possible confounding factors?* Yes. Of the 29 studies, there were 16 which adjusted for personal factors such as smoking, alcohol use, age, educational level and gender.

(5) *Are there more than 20 hypothesis-testing studies consistently showing strong or moderate relative risks?* No. There were ten studies showing strong or moderately strong odds ratios (although there were no relative risks in four of the studies):

- *Is there a range of study designs?* Yes. Uncontrolled cohort, cross-sectional, case-control, case reports, and retrospective cohort studies.
- *Have studies been carried out in different population groups?* Yes. Studies on sewage treatment workers in Germany, the USA, Sweden, Denmark, Norway, the UK, Canada, Greece, France, Israel and Italy.
- *If dose-response relationships are observed, do they confirm the association between the hazard and the health outcome?* Not observed.

Judgement: probable.

Sewage discharges and reproductive outcomes

Have studies been done on human populations? No. Field and laboratory studies on a range of wild animals have demonstrated adverse reproductive outcomes from xeno-oestrogens, natural and synthetic substances with oestrogenic or anti-oestrogenic properties (IEH, 1995). These compounds occur in sewage discharges and have been associated with endocrine disruption in wildlife, including "thyroid dysfunction in birds and fish, decreased fertility in birds, fish, shellfish and mammals, gross birth deformities in birds, fish and turtles, metabolic abnormalities in birds, fish and mammals, behavioural abnormalities in birds, demasculinisation and feminisation of female fish and birds, and compromised immune systems in birds and mammals" (IEH, 1995). The relevance of these studies to human health is not clear but there is concern about the fall in quantity and/or quality of sperm in recent decades (IEH, 1995; Colborn *et al.*, 1997).

Judgement: insufficient.

Landspreading of sewage sludge

(1) *Have studies been done on human populations?* No. There were no studies about the health impacts of landspreading sewage sludge although there were two studies about the health impacts of working in facilities which prepare sewage sludge for landspreading (Clark *et al.*, 1984; Baker *et al.*, 1980). These were included in the section on occupational hazards of sewage treatment workers.

(2) *Have hazards been identified? Does the appearance of the hazard precede the health outcome? Is the association biologically plausible? Are there data on exposure?* No. Hazardous substances have been identified in sewage sludge (e.g. Dumontet *et al.*, 2001; Rogers, 1996; Ross *et al.*, 1992; Straub *et al.*, 1993) but there are no studies linking those hazards to human health effects. *The Canadian Handbook on Health Impact Assessment* (Office of Environmental Health Assessment, Health Canada, 2000) evaluated the risks to human health as minimal because:

- pathogens have a short lifespan and their persistent forms remain in the soil;
- metals are not usually metabolised by soil micro-organisms and will persist in the soil;
- most pollutants bind to soil components;
- most organic compounds, i.e. dioxins, are broken down by soil micro-organisms;
- Most organic compounds do not migrate into surface or ground waters because they adhere to soil components;
- volatile organic compounds evaporate within 48 hours of landspreading.

However, there is a lack of understanding of the potential for transfer of toxic compounds to food and about the degradability and persistence of some toxic contaminants (Rogers, 1996).

(3) *Are there any hypothesis-testing studies?* No.

Judgement: insufficient.

Summary of the judgements

This examination of the literature came to the judgements shown in Table II about the health impacts of the main waste management procedures.

Discussion

In an attempt to make sense of the abundant epidemiological evidence about the health impacts of waste disposal methods, we developed an algorithm based on a set of relatively impartial and transparent criteria. The algorithm turned out to be a useful tool for generating simple and unambiguous

Table II. Summary of the judgements

Judgement	Waste management activity	Exposure route	Hazard	Health outcome
Convincing	Sewage discharges	Ingestion through bathing in recreational waters	Pathogens, primarily enterococci and faecal streptococci	Gastrointestinal symptoms
Probable	Sewage treatment plants	Occupational exposure	Pathogens such as enteric bacteria, faecal streptococci, campylobacter, and viruses	Gastrointestinal tract problems, headache, fatigue and airways symptoms
	Composting	Occupational exposure at a centralised composting facility	Bioaerosols with bacteria (e.g. Clostridium botulinum, endotoxin-producing gram negative bacteria) and/or fungal spores (Aspergillus fumigatus)	Airways symptoms
Insufficient	Landfill	Residence near site, occupational exposure	Any hazards – organic compounds, heavy metals, etc.	Any health outcomes
	Incineration	Residence near site, occupational exposure	Any hazards - heavy metals, organic compounds such as dioxins, etc.	Any health outcomes
	Composting	Residence near centralised composting facility	Any hazards – pathogenic bioaerosols	Any health outcomes
	Sewage treatment	Occupational exposure	Any hazards – pathogens, hydrogen sulfide, mercury, radionuclides	Cancer
	Landspreading sewage sludge	Occupational exposure, Ingestion of food grown on land fertilised with sewage sludge	Any hazards – heavy metals, organic compounds, pathogens	Any health outcomes

judgements about the strength of the associations and their causality. Despite the objectivity of the criteria and the rigour with which they were applied, these judgements are inherently subjective. Other reviewers may legitimately come to different conclusions.

A glance at the judgements reveals two distinct groups based on the type of hazard. Where the hazards arising from the waste disposal facility are pathogenic microorganisms, the judgements given are "convincing" or "probable". For example, there is convincing evidence that ingestion of faecal bacteria through bathing in sewage-contaminated recreational waters causes gastrointestinal symptoms. However, where the hazards are toxic chemicals, heavy metals or are undefined (as is the case in many such studies), the judgements given are "insufficient". For example, the evidence is insufficient to say that exposure to an incinerator or to a landfill site causes any health outcomes.

There are implications of this approach to the evidence for both policymaking and research.

Research

A judgement of "insufficient" does not necessarily mean that more studies are needed, although this is sometimes the case. It may mean that more hypothesis-testing studies are needed. Many epidemiological studies are designed to generate hypotheses, to point out what the problems might be, rather than to confirm causation. For example, a trawl of the cancer registry would give an indication of whether there is an increased incidence of specific cancers among people living near landfill sites compared with those who live further away. Different kinds of studies would then need to be done to test the hypothesis that living near a landfill site causes cancer.

To provide convincing evidence of an association between exposure and a health impact, detailed data are needed. However, the data collected about waste are rarely, if ever, detailed enough to make meaningful assessments of potential health impacts that might result from waste management practices. The data do not include detailed information about the composition of the waste collected nor of off-site emissions from waste management operations. Accurate exposure assessments are not possible without such data.

Recommendations and research programmes to increase the epidemiological knowledge base are made by many agencies, including the Department of Health (Environmental Chemical Unit, DoH, 1999), the Department of the Environment (1994), the Environment Agency's Waste Regulation and Management Research Programme and the World Health Organisation (WHO European Centre for Environment and Health, 2000; WHO, 1998). Recommendations focus on:

- refining exposure assessment and modelling;
- improving health outcome datasets, and using geographical information systems (GIS);

- determining the teratogenicity of substances emanating from waste disposal sites.

The judgements which are generated by this approach are useful for planning future research in this area, as they provide pointers to the kind of research needed.

Policy and decision making

Increasing and strengthening the epidemiological evidence base is crucial but it is unlikely that uncertainty can be reduced entirely. Policy decisions still have to be made even though the evidence is inconclusive. The use of judgements provides a quick guide to policy makers, enabling them to factor in the health impact evidence along with the social, economic and political aspects involved in the decision. Judgements based on an overview of the evidence are more reliable than those based on single studies. Debate about the interpretation of individual studies and whether a particular waste disposal method is or is not "safe" diverts attention from the key issues in decision making, i.e. balancing the different priorities and values of the people involved in the decision.

Health impact assessment (HIA) is being developed as a democratic, health-protective decision-making technique, which incorporates the epidemiological evidence base as well as public values and concerns. An HIA is an iterative and an interactive process, based on principles of participation, equity, democracy and a broad definition of health. The aim is to incorporate a public health perspective into the waste planning process.

Although there is no standard methodology for carrying out an HIA, there is considerable experience with the process in other countries and within the UK. The following procedures are from the Merseyside Guidelines:

1. *Screening* – procedure whereby policies are selected for assessment. The idea is to see if the project or policy is likely to have significant impacts on health and if it is worth subjecting it to a HIA.
2. *Scoping* – a multidisciplinary steering group is established to agree the Terms of Reference. Steering group should include commissioners of HIA, assessors, policy proponents, affected communities and other stakeholders.
3. Conducting the risk assessment – characterising the nature and magnitude of the harmful and beneficial factors, how many and which people will be affected by them and how they will be affected.
   A. Policy analysis
   B. Profiling of affected communities
   C. Interview stakeholders and key informants
   D. Identify health determinants
   E. Collect evidence from other reports and assess evidence
   F. Establish priority impacts
   G. Recommend and justify options for action
4. *Appraise the assessment*
5. *Decision-making*
6. *Monitoring and evaluation.*

For this process to work effectively, the evidence base (Step 3E) should be as solid as possible. It is not enough to present a descriptive summary of the evidence with no evaluation. The approach used in this paper would go a long way towards aiding the decision-making process in an HIA.

Conclusions

Most epidemiological studies linking waste management practices and health outcomes are based on weak or non-existent exposure data. These studies are very rarely based on quantitative environmental measurements and on direct measurements on people at the time of exposure. Also, they usually do not include an evaluation of statistical significance and show no control of confounding factors.

The algorithm we used to appraise the epidemiological evidence leads to the conclusion that the evidence reported in the literature is not usually of the standard required to consider an association as convincing or probable. The exception is studies on microbiological hazards.

The interpretation of the evidence, although based on rigorous and objective criteria, may still lead to subjective judgements. To reduce the degree of uncertainty, new methods of exposure assessments are required, together with a better understanding of the adverse effects of a wide range of substances for which toxicological and teratogenic data are still not available. Also, modern databanks with GIS applications are needed, and improved modelling tools.

The use of these summary judgements in HIAs and waste management decision-making processes would facilitate decision-making by focusing the debate away from different interpretations of the scientific evidence and towards different values and beliefs about risk.

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