Health hazards and waste management

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Different methods of waste management emit a large number of substances, most in small quantities and at extremely low levels. Raised incidence of low birth weight births has been related to residence near landfill sites, as has the occurrence of various congenital malformations. There is little evidence for an association with reproductive or developmental effects with proximity to incinerators. Studies of cancer incidence and mortality in populations around landfill sites or incinerators have been equivocal, with varying results for different cancer sites. Many of these studies lack good individual exposure information and data on potential confounders, such as socio-economic status. The inherent latency of diseases and migration of populations are often ignored. Waste management workers have been shown to have increased incidence of accidents and musculoskeletal problems. The health impacts of new waste management technologies and the increasing use of recycling and composting will require assessment and monitoring.

Introduction

The generation of waste and the collection, processing, transport and disposal of waste—the process of ‘waste management’—is important for both the health of the public and aesthetic and environmental reasons. Waste is anything discarded by an individual, household or organization. As a result waste is a complex mixture of different substances, only some of which are intrinsically hazardous to health. The potential health effects of both waste itself and the consequences of managing it have been the subject of a vast body of research. This chapter gives an overview of waste, waste management processes, and the research into health hazards associated with these, discusses the limitations of studies to date and outlines some future developments and challenges.

What is meant by waste?

The UK Environment Agency classifies waste as either controlled waste or non-controlled waste. Controlled waste includes waste generated
from households (municipal solid waste), commercial and industrial organizations and from construction and demolition. Non-controlled waste includes waste generated from agriculture, mines and quarries and from dredging operations. In 1998–99 over 470 million tonnes of waste were generated in the UK (Fig. 1). The mean production\(^2\) of daily household and commercial waste in EU Member States in 1993–96 was approximately 370 kg/capita/annum, ranging from 350 to 430 kg. Municipal solid waste (MSW) consists of many different things including food and garden waste, paper and cardboard, glass, metals, plastics and textiles. These are also generated by commercial and industrial organizations although large volumes of chemical and mineral waste are produced in addition, depending on the sector. Agricultural waste comprises mainly slurry and farmyard manure with significant quantities of straw, silage effluent, and vegetable and cereal residues. Most of this is spread on land. Certain types of waste are defined as hazardous because of the inherent characteristics (e.g. toxic, explosive). The three largest waste streams in this category are oils and oily wastes, construction and demolition waste and asbestos, and wastes from organic chemical processes.

**Methods of waste management**

Waste management is now tightly regulated in most developed countries and includes the generation, collection, processing, transport and disposal of waste. In addition the remediation of waste sites is an important issue, both to reduce hazards whilst operational and to prepare the site for a change of use (e.g. for building).

The major methods of waste management are:

- **Recycling**—the recovery of materials from products after they have been used by consumers.
- **Composting**—an aerobic, biological process of degradation of biodegradable organic matter.
- **Sewage treatment**—a process of treating raw sewage to produce a non-toxic liquid effluent which is discharged to rivers or sea and a semi-solid sludge, which is used as a soil amendment on land, incinerated or disposed of in land fill.
- **Incineration**—a process of combustion designed to recover energy and reduce the volume of waste going to disposal.
- **Landfill**—the deposition of waste in a specially designated area, which in modern sites consists of a pre-constructed ‘cell’ lined with an impermeable layer (man-made or natural) and with controls to minimize emissions.
Table 1 (adapted from Pheby et al\textsuperscript{3}) outlines some of the advantages and disadvantages of different methods of waste disposal.

**Hazardous substances associated with waste management**

Environmental monitoring of all potential sources of pollution from different waste management options has been, and is being continuously, carried out and thus a great deal is known about the types and amount of substances emanating from them. Whatever the waste management option, it is generally the case that: (a) there are usually a large number of different substances; and (b) only a few of these are produced in any quantity with many being at extremely low levels\textsuperscript{4}. Gases emitted from landfill sites, for example, consist principally of methane and carbon dioxide, with other gases, such as hydrogen sulphide and mercury vapour being emitted at low concentrations, and a mixture of volatile organic compounds...
(VOCs) comprising approximately 0.5%\(^5\). A WHO exposure assessment expert group suggested that priority pollutants should be defined on the basis of toxicity, environmental persistence and mobility, bioaccumulation and other hazards such as explosivity\(^6\). In addition to the substances above, they suggested that landfill site investigations should consider metals, polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB), chlorinated hydrocarbons, pesticides, dioxins, asbestos, pharmaceuticals and pathogens. Waste incineration also produces a large number of pollutants from the combustion of sewage sludge, chemical, clinical and municipal waste, which can be grouped as particles and gases, metals, and organic compounds\(^7\). Ten pollutants considered\(^8\) to have the greatest potential impact on human health based on environmental persistence, bioaccumulation and amount emitted and/or on inherent toxicity were cadmium, mercury, arsenic, chromium, nickel, dioxins, PCBs, PAHs,

**Table 1** Waste management options—key advantages and disadvantages

<table>
<thead>
<tr>
<th>Option</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Recycling</td>
<td>Conservation of resources, supply of raw materials to industry, reduction of waste disposed to landfill and incineration</td>
<td>Diverse range of processes, emissions from recycling process, may be more energy used for processes than original manufacture, currently low demand for products, requires co-operation from individuals</td>
</tr>
<tr>
<td>Composting</td>
<td>Reduction of waste to dispose to landfill and incineration, recovery of useful organic matter for use as soil amendment, employment opportunities</td>
<td>Bio-aerosols—organic dust containing bacteria or fungal spores, emits volatile organic compounds, potential pathway from use on land for contaminants to enter food chain, odours, noise, vermin nuisance</td>
</tr>
<tr>
<td>Sewage treatment</td>
<td>Safe disposal of human waste</td>
<td>Discharges may contain organic compounds, endocrine disrupting compounds, heavy metals, pathogenic microorganisms</td>
</tr>
<tr>
<td>Incineration</td>
<td>Protects sources of potable water supply, reduces weight and volume of waste, about 30% is left as ash which can be used for materials recovery, reduces potential infectivity of clinical waste, produces energy for electricity generation</td>
<td>Discharges contaminated waste water, emits toxic pollutants, heavy metals, and combustion products</td>
</tr>
<tr>
<td>Landfill</td>
<td>Cheap disposal method, waste used to back fill quarries before reclamation, landfill gas contributes to renewable energy supply</td>
<td>Water pollution from leachate and run off, air pollution from anaerobic decomposition of organic matter to produce methane, carbon dioxide, nitrogen, sulphur and volatile organic compounds, emission of known or suspected carcinogens or teratogens (e.g. arsenic, nickel, chromium, benzene, vinyl chloride, dioxins, polycyclic aromatic hydrocarbons), animal vectors (seagulls, flies, rats) for some diseases, odour, dust, road traffic problems</td>
</tr>
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PM$_{10}$ and SO$_2$. Microbial pathogens are a potential source of hazard, particularly in composting and sewage treatment but also in landfill. Dust and the production of particulate matter are produced in landfill, incineration and composting processes and by road traffic involved in all waste management options.

Less easily quantifiable hazards, which might nevertheless impact on the population near a waste disposal site include odours, litter, noise, heavy traffic, flies and birds.

**Impact of waste management practices on health**

**Introduction**

There is a large body of literature on the potential adverse health effects of different waste management options, particularly from landfill and incineration. There is little on potential problems resulting from environmental exposures from composting and very little on recycling. Although much research has focused on the health of the general population, particularly those living near a waste disposal site, occupational health problems of the workforce involved in waste management are also important to consider.

Much of the health literature on the toxicity of the individual substances highlighted above relates to occupational or accidental exposure and thus generally to higher levels of exposure than those expected from waste disposal methods. Many of the substances, such as cadmium, arsenic, chromium, nickel, dioxins and PAHs are considered to be carcinogenic, based on animal studies or studies of people exposed to high levels. Evidence that these substances cause cancer at environmental levels, however, is often absent or equivocal. In addition to carcinogenicity, many of these substances can produce other toxic effects (depending on exposure level and duration) on the central nervous system, liver, kidneys, heart, lungs, skin, reproduction, etc. For other pollutants such as SO$_2$ and PM$_{10}$, air pollution studies have indicated that there may be effects on morbidity and mortality at background levels of exposure, particularly in susceptible groups such as the elderly. Chemicals such as dioxins and organochlorines may be lipophilic and accumulate in fat-rich tissues and have been associated with reproductive or endocrine-disrupting endpoints.

**Landfill sites**

One of the mostly widely known and publicized landfill sites is that of Love Canal in New York State. Large quantities of toxic materials, including residues from pesticides production, were deposited in the 1930s and...
1940s, followed by the building of houses and a school on and around the landfill in the 1950s. By the mid 1970s, chemicals leaking from the site were detected in local streams, sewers, soil and indoor air of houses. This site and the subsequent studies of the health of the population in the vicinity fuelled public opinion on the problems of waste disposal practices and raised public concern more generally.

Since then there have been many studies of populations living near landfill sites, frequently carried out near one specific site in response to public concern. These studies have varied in design and include cross-sectional, case-control, retrospective follow-up and ecological (geographical comparison) studies (see Chapter 2). The last of these have often been initiated after apparent clusters of specific diseases have been reported near a site. In addition, several large studies have been carried out investigating health outcomes near hundreds of sites.

There have been several comprehensive reviews of epidemiological studies9–12.

Birth defects and reproductive disorders

Reproductive effects associated with landfill sites have been extensively researched and include low birth weight (less than 2500 g), fetal and infant mortality, spontaneous abortion, and the occurrence of birth defects. Vianna and Polan13 and Goldman et al14 both found increased incidence of low birth weight in the populations around the Love Canal site, the former during the period of active dumping (1940–1953) and the latter among house owners (although not among those renting) from 1965 to 1978. A similar increase in the proportion of low birth weight babies was found in those living within a radius of 1 km of the Lipari Landfill in New Jersey, particularly in 1971–75 following a period of heavy pollution of streams and a nearby lake from leachate from the site15. Trends in low birth weight and neonatal deaths were found to correspond closely with time and quantities of dumping at a large hazardous waste disposal site in California, with significantly lower birth weights in exposed areas than control areas during the periods of heaviest dumping16. It should be noted that exposed areas were defined according to the number of odour complaints rather than any more objective measure.

The results from these single site studies for low birth weight contrast with results from two large multiple site case-control studies in the USA17,18. These used residence as an exposure measure and found no association with low birth weight. However, a geographical study of adverse birth outcomes associated with living within 2 km of a landfill site between 1982 and 1997 in Great Britain found a significantly excess risk, which increased during operation or after closure compared with the risk before opening19.
An interesting finding from this study was that 80% of the population in Great Britain live within 2 km of an operating or closed landfill site.

The results of studies of congenital malformations are less convincing than those of low birth weight. In the two US multiple site studies, one found a small increase (1.5-fold) in heart and circulatory malformations but no increased risk for other malformations. The other found no association, although the response to the questionnaire used to collect data was relatively poor (63%) and it is unclear how congenital malformations were defined. The UK study found significantly elevated risks for several defects, including neural tube defects, hypospadias and epispadias, abdominal wall defects and surgical correction of gastrochisis and exomphalos, although there was a tendency for there to be a higher risk in the period before opening compared with after opening of a landfill site, for several anomalies. A similar finding was also reported in the analysis of congenital malformation rates among the population living near the Welsh landfill of Nant-y-Gwyddon where nearly double the risk was found in exposed areas both before and after the site opened. However four cases, a nine-fold excess, of gastrochisis, were observed after the site opened. A study of 21 European hazardous waste sites found that residence within 3 km of a site was associated with a significantly raised risk of congenital anomaly, with a fairly consistent decrease in risk with distance away from the sites. Risk was raised for neural-tube defects, malformations of the cardiac septa and anomalies of great arteries and veins. A study by the same group showed similar increases in chromosomal anomalies, even after adjustment for maternal age.

The studies of congenital malformations described above have generally used residential proximity as a measure of exposure. A similar study was carried out in New York State but also attempted to investigate associations with off-site migration of chemicals and certain categories of chemicals present at the sites. A small (12%) statistically significant risk of congenital malformations was associated with maternal proximity to a site which increased with off-site chemical leaks. Significant associations were found for pesticides with musculoskeletal system defects, metals and solvents with nervous system defects, and plastics with chromosomal anomalies. However, a case-control study to follow-up these findings which established the probability of low, medium or high exposure for four potential pathways of exposure (groundwater ingestion and inhalation, air, vapour, particulates) found no increased risk for mothers assigned a medium or high exposure.

Cancer

Several geographical comparison studies have investigated cancer mortality and incidence around waste sites. Increased frequency of cancers in counties

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containing hazardous waste sites was found in two US studies\textsuperscript{25,26}, particularly for gastrointestinal, oesophageal, stomach, colon and rectal cancer. These studies are, however, limited by a lack of chemical release data. No increase in cancer rates or the frequency of chromosome changes was found in relation to the Love Canal site\textsuperscript{27,28}. Two reports\textsuperscript{29,30} of cancer incidence among persons living near the Miron Quarry site, the third largest in North America found increased incidence of cancers of the liver, kidney, pancreas and non-Hodgkin’s lymphomas. Once again no measurements of exposure were available, and there was a relatively short period from first exposure (1968) to cancer onset (1979–1985).

Studies of self-reported health symptoms

Many of the studies investigating health outcomes other than birth defects and reproductive orders and cancers have been community health surveys and have relied on the self-reporting of symptoms through interviews or questionnaires. These are comprehensively reviewed by Vrijheid\textsuperscript{10}. The health problems investigated include respiratory symptoms, irritation of the skin, nose and eyes, gastrointestinal problems, fatigue, headaches, psychological problems and allergies. It has been suggested that evaluation of a relationship between these symptoms is complicated by confounding by stress, public perception of risk, odours and nuisance related to the site, and recall bias. For example, a survey\textsuperscript{31} found that residents who indicated they were worried about pollution reported more symptoms than those who were not worried, both in the exposed and control areas.

Incineration

Evaluation of the potential health effects of the large number of pollutants which can be produced by waste incineration can be approached by assessing the effects of individual pollutants\textsuperscript{8,32} or through more general studies of community residents\textsuperscript{33} and incinerator workers (see below).

Individual pollutants

From the health aspect, the most important pollutants associated with incineration are particles, acidic gases and aerosols, metals and organic compounds. There is an extensive research literature on both the acute and chronic effects of particles (see Chapters 10 and 11). Despite methodological limitations, epidemiological studies worldwide have demonstrated considerable consistency of findings with regard to the association of
particle exposure and acute health effects such as increased overall mortality and emergency hospital admissions, particularly cardiovascular and respiratory mortality and morbidity. Effects appear to be more severe in susceptible groups such as children, the elderly, or those with chronic conditions such as asthma or pre-existing cardiovascular disease.

Although less well established, results from large US cohort studies suggest that long-term exposure to low concentrations is associated with chronic health effects such as increased rates of bronchitis and reduced lung function, shortened life span, elevated rates of respiratory symptoms and lung cancer.

Studies of outdoor levels of NO₂ and health effects may be hampered by difficulties in separating the effects of the various components of ambient pollution. Results for mortality and morbidity have been inconsistent between cities and studies. Less equivocal are results relating to acidic gases, in particular sulphur dioxide (SO₂), for which there is also an extensive literature. Asthmatics appear to be particularly sensitive to the effects of SO₂ on lung function, although the concentrations at which these occur vary between studies. Environmental exposure has been shown, like particulates, to be associated with increased cardiovascular and respiratory mortality and morbidity.

Metals associated with incinerator emissions include lead, cadmium, mercury, chromium, arsenic and beryllium. Different forms of these at various levels and via various media and exposure pathways have all been shown to cause a range of carcinogenic and non-carcinogenic health effects. In general, however, epidemiological evidence for increased risk at environment levels of exposure is scarce or equivocal and it is therefore extremely difficult to assess what impact, if any, a relatively small additional exposure from incinerators would have.

The organic compounds which have received the most attention relating to incineration are dioxins and PCBs, partly because of their ability to accumulate in the body. High levels of dioxin exposure found in workplaces and after accidents such as that at Seveso have caused chloracne and an increase in cardiovascular disease. Some studies have also found increased risk from some cancers, although the results vary depending on the specific substance. Extrapolation of these results to the low levels of exposure generally experienced environmentally remains problematical.

**Health effects in communities**

Most of the studies of communities living near incinerators have assessed exposure using some measure of distance from the site or an estimate of areas at most risk from emissions. Little evidence has been found for an association between modern waste incinerators and reproductive
or developmental effects. In addition, there is little evidence of increased prevalence of respiratory illness near incinerators, using either self-reported symptoms or physiological measures.

Studies focusing on a single waste incinerator suggested some relationship between distance from the site and mortality or incidence from some cancers, for example laryngeal and lung cancers, childhood cancers and leukaemias and soft-tissue sarcoma and non-Hodgkin’s lymphoma. A series of studies in the UK\textsuperscript{39–41} of multiple sites compared observed cancer incidence rates in bands of increasing distance from each incinerator with rates based on national data. Adjustment was made for age, sex and deprivation and lagged analyses were also carried out. No evidence of an increasing risk of lung or laryngeal cancer was found with proximity to incinerators used for the disposal of solvents and oils. However, a study of residence near MSW incinerators found statistically increasing risk with increasing proximity for all cancers and for colorectal, lung, liver and stomach cancers, although there was evidence of residual confounding for all cancers, stomach and lung. Because of the substantial level of misdiagnosis which can occur among registrations and death certificates for liver cancer, the authors carried out a histological review of the cases and reanalysis for this disease. Reduced estimates of excess incidence of primary liver cancer were reported\textsuperscript{41}.

**Worker populations**

There is a large workforce employed in waste collection, sorting and disposal. Workers may be exposed to the same potential hazards as the general population, although the amount of exposure and risk may differ. The type of work varies between waste management options with some, such as landfill and incineration, being more automated than others, such as waste collection, sorting and recycling. The incidence of occupational accidents in waste collection workers has been found to be higher than the general workforce\textsuperscript{42}. The work of waste collectors involves considerable heavy lifting as well as other manual handling of containers, increasing the risk of musculoskeletal problems. It has been suggested that increased exposure to bio-aerosols and volatile compounds may lead to elevated incidence of work-related respiratory gastrointestinal and skin problems in waste collections compared to the general workforce. Cross-sectional studies of workers in the waste sorting and recycling industries and in landfill sites, have observed similar work-related problems to those of waste collectors\textsuperscript{43}.

In addition to VOCs and bioaerosols, dust levels have been found to be high at refuse transfer stations and incinerators. An excess of deaths [Standardized Mortality Ratio (SMR) = 355, 95% confidence interval (CI) 162–165] due to lung cancer was observed in the workforce of a large
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Swedish incinerator\textsuperscript{44}. However, reduced mortality from lung cancer was found for Italian incinerator workers\textsuperscript{45}. In the Italian study, a non-significant increased risk was found for gastric cancer (SMR 2.79, 90\% CI 0.94–6.35).

There is little published information on the health risks of compost workers. A small cross-sectional study of 58 compost workers\textsuperscript{46} found significantly increased antibody concentrations against fungi and actinomycetes compared to a control group of 40 newly employed compost workers and biowaste collectors. This was associated with significantly more symptoms and diseases of the airways ($P = 0.003$) and skin ($P = 0.02$) diagnosed by occupational health physicians.

Remediation of waste and waste sites is an expanding activity, particularly the mediation of hazardous or toxic waste. The health of the workforce involved in this is an important issue. Although no data to date indicate any adverse health effects in remediation workers, countries like the USA have introduced a surveillance programme\textsuperscript{47}. An assessment of the risk of occupational fatalities associated with hazardous waste site remediation estimated that the fatality risks to remediation workers were orders of magnitude greater than human cancer risk, and that truck drivers and labourers were particularly at risk\textsuperscript{48}.

**Discussion**

There is no doubt that, given the diversity of material coming under the heading of waste, there is considerable potential for hazardous exposure to occur through waste management. High levels of contamination of air, soil and water in a few well publicized situations have led to widespread unease about the potential health effects of waste management processes, particularly within communities living in the proximity to relevant sites. Overall, however, the vast body of literature does not generally support these concerns, particularly for the two most common methods, incineration and landfill disposal. There is also a lack of evidence as to the precise substance(s) implicated. Any emissions from waste management processes are likely to be a mixture of many substances for which a toxicological profile is unknown.

Many of the studies are hampered by a lack of good exposure information and use surrogate indirect measures perhaps leading to exposure misclassification. The levels of most of the potential substances would also be expected to be extremely low, even if all sources of exposure were taken into account. Lack of specificity can also occur in defining health outcomes, particularly if these are self-reported. Many outcomes, such as cancers, would not be expected to occur until several years after exposure, requiring analysis for latency which is lacking in many studies. Migration into and out of relevant areas is also often ignored.
The greatest challenge, however, is to eliminate the effects of factors which might relate to both health outcome and environmental exposure, such as age, ethnicity, gender, socio-economic or deprivation status, smoking, access to health care and occupational history. Lack of complete adjustment for such confounders probably exists in many of the studies relating to waste management particularly those using geographical designs. Studies have shown that socio-economically disadvantaged populations and minority groups may be disproportionately located in areas around waste disposal sites.47

Studies based on individuals rather than communities are thus perhaps the way forward for future evaluations of potential health effects relating to waste management. However, all of the limitations described above would need to be addressed. Epidemiology is increasingly making use of developing biomarker technology both for estimating internal dose (exposure) and the biological response (effect). This would be particularly relevant in situations where one or two specific substances are of concern (either because of high levels of exposure or because of the health effects the substance may cause), but may be less appropriate for investigating the more general exposures emitted from waste management processes, which tend to be heterogeneous in nature. In addition to a potential reduction in misclassification, biomarkers offer the possibility of identification of lower level exposures and the total burden of exposure, the identification of health events earlier in the natural history of clinical disease and insight into the mechanisms relating exposure and disease. However care is also needed to ensure that the chosen biomarkers are appropriate for the epidemiological design. For example, the use of urinary cotinine levels can confirm whether someone is currently smoking or exposed to environmental tobacco smoke but would not aid the assessment of long-term exposure. In contrast, biomarkers of genetic susceptibility can be valuable for use in studies of chronic disease. The field of molecular epidemiology offers the opportunity to combine epidemiology with molecular toxicology to investigate interactions between genetic factors and environmental factors in the cause of disease and identify susceptible groups.

The need to keep the emission of pollutants and exposure to other nuisances arising from waste management operations is widely acknowledged and increasingly stringent regulations have resulted in the development of waste management technologies to achieve this. It is also likely that the proportion of waste managed by different processes will change and that these proportions will vary between communities depending on the characteristics of the waste generated, the facilities already available, economic considerations, and public opinion. The general trend at the moment is towards an increasing proportion of waste being recycled. However, this may generate new challenges, not
only a likely considerable financial investment, but a need for a larger workforce for waste sorting and recycling, increasing the need for the issues previously highlighted relating to worker health to be addressed. Wider use of alternative technologies is likely, including advanced thermal treatment, such as gasification and pyrolysis, and bio-mechanical waste treatment which refers to a number of mechanical and biological processes to treat waste before disposal. The health impacts of these technologies will need to be assessed and monitored.

Although the possible physical health effects arising from waste management processes have been addressed, there has been little research into socio-economic impacts of waste-management options. Public perceptions of the relative health risks reflect not only differences in understanding but underlying social values. The development of effective participatory programmes is essential to ensure the public right and responsibility to be involved in the assessment and management of hazards in their communities is addressed, leading hopefully to improved assessments and management strategies.

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