

Systematic Review of Epidemiological Studies on Health Effects Associated with Management of Municipal Solid Waste

Simona Milani, Daniela Porta, Antonio I. Lazzarino, Carlo A. Perucci, and Francesco Forastiere

Department of Epidemiology, Rome E Health Authority, Rome Italy

E-mail addresses:

Simona Milani: milani@asplazio.it

Daniela Porta: porta@asplazio.it

Antonio Ivan Lazzarino: a.lazzarino@imperial.ac.uk

Francesco Forastiere: forastiere@asplazio.it

Carlo Alberto Perucci: perucci@asplazio.it

Corresponding author:

Francesco Forastiere

Dipartimento di Epidemiologia ASL RME

Via di S. Costanza, 53

00198 ROMA, Italy

Tel: +39 0683060484

Fax: +39 0683060374

e-mail: forastiere@asplazio.it

Abstract

Background: Management of municipal solid waste (mainly landfills and incineration) releases a number of toxic substances, most in small quantities and at extremely low level. Because of the wide range of pollutants, different pathways of exposure, long-term low-level exposure, and a potential for synergism among the pollutants concerns remain about potential health effects but there are many uncertainties involved in the health assessment. Our aim was to systematically review the available epidemiological literature on health effects in the vicinity of landfills and incinerators and among workers of waste processing plants in order to derive usable excess risk estimates for health impact assessment.

Methods: We examined the published, peer-reviewed, literature addressing health effects of waste management between 1983 and 2008. For each paper, we examined the study design and assessed potential biases in the effect estimates. We evaluated the overall evidence and scored the associated uncertainties.

Results: In most cases the overall evidence was inadequate to establish a relationship between a specific waste process and health effects. In particular, the evidence from occupational studies was not sufficient to make an overall assessment. For community studies, at least for some processes/conditions, a limited evidence of a causal relationship has been found and few studies were selected for a quantitative evaluation. In particular, for populations living within 2 km from landfills a limited evidence was found for congenital anomalies and low birth weight with excess risk of 2% and 6%, respectively (moderate confidence). For populations living within 3 km from old incinerators, a limited evidence was found for an increased risk of cancer with an estimated excess risk of 3.5% (moderate confidence). The confidence in the evaluation and in the estimated excess risk tended to be higher for specific cancer forms such as non-Hodgkin lymphoma and soft tissue sarcoma.

Conclusions: The values of the excess risks that we have found could be used for health impact assessment of old landfill and incineration plants. The uncertainties around these numbers should be considered with care. It is clear that future research into the health risks of waste management needs to solve the limitations currently available.

Introduction

The “waste management”, that is the generation, collection, processing, transport, and disposal of municipal solid waste (MSW) is important for both environmental reasons and public health. There are a number of different options available for the management and treatment of waste including minimisation, recycling, composting, energy recovery and disposal. At present, an increasing amount of the resources contained in waste is recovered as materials but a large part is incinerated or permanently lost in landfills. The various methods of waste management release a number of substances, most in small quantities and at extremely low levels. However, concerns remain about potential health effects associated with the main waste management technologies. Because of the wide range of pollutants that may be released by the various management options, the different pathways of exposure, usually long-term low-level character of exposure, and a potential for synergistic and cumulative effects, there are many uncertainties involved in the assessment of health effects.

Several studies on the possible health effects for populations living in proximity of landfills and incinerators have been published and well-conducted reviews are available [1-4]. Associations with some reproductive and cancer outcomes have been suggested for both landfills and incineration. However, the reviews indicate the weakness of the results of the available studies due to design issues, mainly related to lack exposure information, use of surrogate indirect measures such distance from the source, lack of control for potential confounders. As results, the controversy over the possible health effects of waste management in the public is large for many reasons that include risk communication, risk perception and conflicting interests of various stakeholders. Therefore, there is a need of an appropriate risk assessment that informs both policy makers and the public with the currently available level of information on the health risks associated with the different waste management technologies. Of course, the current level of uncertainties should be taken into account.

Within the EU funded INTARESE project [5], we aimed to assess potential exposures and health effects arising from municipal solid wastes, from generation to disposal or treatment. A key part in the health impact assessment was the selection or the development of a suitable set of relative risks that link individual exposures with specific health endpoints. We have then conducted a systematic review of epidemiologic literature on health effects associated with collecting, recycling, composting, incinerating, and landfilling of municipal solid waste with the specific aim to derive appropriate relative risk estimates associated to various waste management technologies. The levels of scientific uncertainties associated to these estimates have been considered.

Methods

We have considered epidemiological studies conducted on the general population with potential exposures from collecting, recycling, composting incinerating, and landfilling municipal solid waste. We considered also studies of workers employed in waste management plants as they may be exposed to the same potential hazards as the community residents, even if the intensity and duration of the exposure may differ. Studies on populations with potential exposures from toxic and hazardous wastes were excluded as the exposures are different and not completely comparable to those arising from municipal wastes [6] Furthermore, we did not consider studies on biomarkers of exposure and health effects.

Relevant papers were found through computerized literature searches on the MEDLINE and PubMed Databases from 1/1/1983 through 31/12/2008, using the MeSH terms “waste management”

and “waste products” and the subheading “adverse effects”. We obtained 144 papers with this method. We also conducted a free search with several combinations of relevant key words ((waste incinerator or landfill or composting or recycling) and (cancer or birth outcome or health effects) and NOT hazardous), and 285 papers were obtained.. In addition, articles were traced through references listed in previous reviews [1-3, 7-10], and in publications of the UK Department for Environment, Food and Rural Affairs [11].

All papers were independently evaluated by three observers about eligibility, and disagreements were resolved by discussion. As indicated, studies on industrial, toxic or hazardous waste, on sewage treatment or on biological monitoring were not included. We also excluded articles in languages other than English, not journal articles, and six studies [12-17] conducted at municipality level (usually small towns) where it was not possible to evaluate the extent of the population potentially involved and the possibility of exposure misclassification was high.

Papers have been grouped according to the following criteria:

- waste management technologies: recycling, composting, incinerating, landfill (the term landfill is used here only for controlled disposal of waste land);
- health outcomes: cancers (stomach, colorectal, liver, larynx and lung cancer, soft tissue sarcoma, kidney and bladder cancer, non Hodgkin’s lymphoma, childhood cancer), birth outcomes (congenital malformations, low birth weight, multiple births, abnormal sex ratio of newborns), respiratory, skin and gastrointestinal symptoms or diseases.

For each paper, we have reported in appropriate tables (in the appendixes) study design (e.g. geographical, cohort, cross-sectional, case-control study, etc.), population characteristics (subjects, country, age, sex), exposure measures (e.g. occupational exposure to municipal waste incinerator by-products, residence near a MSW landfill, etc.), and the main results (incl. control for major confounders) with respect to the quantification of the health effects studied. For each study we have evaluated the potential sources of uncertainty in the results due to design issues. In particular, the possibility that selection bias, information bias, or confounding could artificially increase or decrease the relative risk estimate has been noted in the tables using the plus/minus scale to indicate that effect estimates are likely to be overestimated (or underestimated) up to 20% (+/-), from 20 to 50% (++) and more than 50% (+++/-). Scoring of the uncertainties was done by two observers (SM and FF) with a discussion over the inconsistencies.

After the description of the available studies, the overall evaluation of the epidemiological evidence regarding the process/disease association was done on the basis of the IARC (1999) criteria, and two categories were chosen, namely: “*Inadequate*” when the available studies are of insufficient quality, consistency, or statistical power to decide the presence or absence of a causal association; “*Limited*” when a positive association has been observed between exposure and disease for which a causal interpretation is considered to be credible, but chance, bias, or confounding could not be ruled out with reasonable confidence. There were no instances where the category “sufficient” evidence could be used. Only when the specific process/disease association was judged as limited (suggestive evidence but not sufficient to infer causality) we decided to evaluate the strength of the association and to derive appropriate relative risks. For this purpose, we considered the set of studies providing the best evidence and assigned an overall level of scientific confidence of the specific effect estimate based on an arbitrary scale: very high, high, moderate, low, very low. This process was done by three assessors (SM, DP, and FF) with a discussion over the inconsistencies.

Results

A total of 47 papers were reviewed: 32 concerning health effects in communities living in proximity to waste sites, 15 on employees working at waste management sites. The majority of community studies evaluated possible adverse health effects in relation to incinerators and landfills. We did find little evidence on potential health problems resulting from environmental or occupational exposures from composting or recycling, and very little on storage/collection of solid waste. A description of the main findings follows. The appendixes contain several details of the studies reviewed.

Studies of communities living near landfills

Eleven epidemiological studies conducted on residents of communities near a landfill for municipal solid waste are reviewed and their main characteristics are listed in Appendix 1.

Cancer

Four studies analysed the cancer risk of populations living near landfills.

Michelozzi et al [18] investigated the mortality risk in a small area of Italy (Malagrotta, Rome) with multiple sources of air contamination (a very large waste disposal site serving the entire city of Rome, a waste incinerator plant, and an oil refinery plant). Standardised Mortality Ratios (SMRs) were computed in bands of increasing distance from the plants, up to a radius of 10 km. No association between proximity to the sites and cancer of various organs, in particular liver, lung, and lymph haematopoietic cancer, was found; however, mortality from laryngeal cancer declined with distance from the pollution sources, and a statistically significant trend remained after adjusting for a four level index of socio-economic status. The main uncertainty of the study is related to the exposure assessment (--) since only distance was considered decreasing the possibility to detect an effect. There are also uncertainties in using mortality to estimate cancer incidence in proximity to a suspected source (+). On the other hand, even though the authors did adjust for an area-based index of deprivation, a residual confounding (+) from socioeconomic status was likely.

In a case-control study, Goldberg et al [19] investigated cancer incidence among persons who had been living near a municipal solid waste landfill site in Montreal (Quebec, Canada). The exact street address at the time of diagnosis was used to classify subjects by geographic zones and distance from the site. The results of the analyses suggested a possible association for liver, kidney, pancreatic cancer, and non-Hodgkin's lymphomas with a borderline statistical significance. In this study, participation rate was greater for cases than for controls with a slight possibility of a selection bias (+) whereas there are some possibilities that misclassification in the exposure assessment would have diluted the effect estimates (-).

In Finland, Pukkala et al. [20] studied whether the exposure to landfill caused cancer or other chronic diseases in inhabitants of houses built on a former dump area containing industrial and household wastes. After adjustment for age and sex, an excess number of male cancer cases was seen, especially for cancers of the pancreas and of the skin. The relative risk slightly increased with the number of years lived in the area. Some uncertainties were likely to affect the results of the study with regards to the exposure assessment (-), outcome assessment (+) and presence of residual confounding (-).

Jarup et al. [21] examined cancer risks in populations living within 2 km of 9,565 (from a total of 19,196) landfill sites that were operational at some time from 1982 to 1997 in Great Britain. No excess risks of cancers of the bladder and brain, hepatobiliary cancer or leukaemia were found, after adjustment for age, sex, calendar year and deprivation. The study is very large and with a high power, however misclassification of exposure could have decreased the possibility to detect an effect (--).

In summary, there is inadequate evidence of an increased risk of cancer for communities living in proximity of a landfill. The two slightly positive studies from Goldberg et al [19] and Pukkala et al [20] are not consistent, although pancreatic cancer was elevated in both investigations.

Birth defects and reproductive disorders

Six studies examined reproductive effects of landfill emissions. We did not include in the present review two relevant publications (the EUROHAZCON study [22], the most comprehensive multi-site study of congenital anomalies in the vicinity of hazardous waste landfill sites in Europe, and the study by Gilbreath et al. [23] on 197 Alaska Native villages containing open dumpsites with hazardous waste) since we were dealing with municipal solid waste disposal.

The most important research in this field is that by Elliott et al. [24]. This study investigated the risk of adverse birth outcomes in populations living within 2 km of 9,565 landfill sites in Great Britain, operational at some time between 1982 and 1997, compared with those living further away (reference population). The sites comprised 774 sites for special (hazardous) waste, 7803 for non-special waste and 988 handling unknown waste, and the 2 km zone was constructed around each site to give resolution at the likely limit of dispersion for landfill emissions, including 55% of the national population. Among 8.2 million live births and 43,471 stillbirths, 124,597 congenital anomalies (including terminations) were examined: neural tube defects, cardiovascular defects, abdominal wall defects, hypospadias and epispadias, surgical correction of gastroschisis and exomphalos; low and very low birth weights were also analysed, defined as less than 2500 g and less than 1500 g, respectively. The main analysis was for all landfill sites for the combined period during their operation and after closure, and additional analysis was carried out separately for sites handling special waste and non-special waste, and in the period before and after opening for the 5,260 landfills with available data. After adjustment for deprivation and other potential confounding variables (sex, year of birth, administrative region), there was a small increase in the relative risks for low and very low birth weight and for all congenital anomalies, except for cardiovascular defects. There was no excess risk of stillbirth.

The study has been recently updated by the authors [25] to evaluate whether geographical density of landfill sites was related to congenital anomalies. The analysis was restricted to 8804 sites operational at some time between 1982 and 1997. There were 607 sites handling special (hazardous) waste and 8197 handling non-special or unknown waste type. The assessment of exposure took into account the overlap of the 2 km buffers around each site, to construct an index of exposure with four levels of increasing landfill density. Several anomalies (hypospadias and epispadias, cardiovascular defects, neural tube defects and abdominal wall defects) were evaluated. The analysis was carried out separately for special and non-special waste sites and was adjusted for deprivation, presence or absence of a local congenital anomalies register and maternal age. The study found a weak association between intensity of hazardous sites and some congenital anomalies (all, cardiovascular, hypospadias and epispadias). No association was found for the other type of sites

In a study published in 2000, Fielder et al. [26] found that residents living near the Welsh landfill of Nant-y-Gwiddon in Wales had an increased risk of having a baby with a congenital malformation, not only after the site became operational but also before. Palmer et al. [27], however, examined rates of congenital anomalies in births to mothers living within 2 km of 24 landfill sites in Wales, and found a significant increase in birth defects after the sites were opened.

The studies conducted in United Kingdom suffer from the same limitations, namely the possibility that misclassification of exposure could have decreased the relative risk estimates to some extent (--); on the other hand, there are several uncertainties related to the quality of registration of congenital malformations. In the latter case, a positive bias is more likely (++). For the recent report by Elliott et al [25], locational uncertainties and differential data reliability regarding the sites, together with the use of distance as a basis for exposure classification, limit the interpretation of the findings (--).

In Denmark, Kloppenborg et al. [28] marked the geographical location of 48 landfills (Geographical Information System) and used maternal residence as the exposure indicator in a study of congenital malformations. The authors found no association between landfill location and congenital anomalies combined or of the nervous system, and a small excess risk for congenital anomalies of the cardiovascular system. Potential confounding from socioeconomic status is the major limitation of this study (+++).

Jarup et al. [29] studied the risk of Down Syndrome in the population living near 6829 landfills in England and Wales. People were considered exposed if they lived in a 2-km zone around each site, people beyond this zone were the reference group. A 2-year lag period between potential exposure of the mother and her giving birth to a Down syndrome child was allowed. The analysis was adjusted for maternal age, county urban-rural status and deprivation index. No statistically significant excess risk was found in population potentially exposed, regardless of waste type

In summary, an increased risk of congenital malformations and of low birth weight has been reported from studies conducted in UK. The main uncertainty from these studies is completeness of the registration of birth defects and use of distance from the sites for exposure classification.

Respiratory diseases

A study conducted by Pukkala et al. [20] in Finland evaluated prevalence of asthma in relation to the residence in houses built on a former dump area containing industrial and household wastes. Prevalence of asthma was significantly higher in the dump cohort than in reference cohort (living nearby but clearly outside the landfill site), and the increased relative risk of asthma did not vary by time after residents moved into dump site houses, nor with years lived in those houses. Unfortunately, there are no replications of this observation and the overall evidence may be considered inadequate.

Studies of landfills workers

Only one study on landfill workers was reviewed. Gelberg et al. [30] conducted a cross-sectional study to examine acute health effects among employees working at the New York City Department of Sanitation, focusing on Fresh Kills landfill employees. Telephone interviews conducted with 238 landfill and 262 off-site male employees asked about potential exposures both at home and work,

health symptoms for the previous six months, and other information (social and recreational habits, socio-economic status). Landfill workers reported a significantly higher prevalence of work-related respiratory, dermatological, neurologic and hearing symptoms than controls; respiratory and dermatologic symptoms were not associated with any specific occupational title or work task, other than working at the landfill, and the association remained, even when controlling for smoking status.

Studies of communities living near incinerators

Twenty-one epidemiologic studies conducted on residents of communities with municipal solid waste incinerators have been reviewed and their characteristics are listed in Appendix 2.

Cancer

Eleven studies have been reviewed on cancer risk in relation with incinerators, usually of old generation with high polluting characteristics. The studies are reported below by country.

In United Kingdom, Elliott et al. [31] investigated cancer incidence between 1974 and 1987 among over 14 million people living near 72 solid waste incinerator plants. Data on cancer incidence among the residents, obtained from the national cancer registration scheme, were compared with national cancer rates, and numbers of observed and expected cases were calculated after stratification by a deprivation index, based on 1981 census. Observed-expected ratios were tested for decline in risk with distance up to 7.5 km. The study was conducted in two stages: the first involved a stratified random sample of 20 incinerators and, based on the findings, a number of cancers were then further studied around the remaining 52 incinerators (second stage). Over the two stages of the study there was a statistically significant ($p < 0.05$) decline in risk with distance from incinerators for all cancers, stomach, colorectal, liver and lung cancer. The use of distance as the exposure variable in this study could have led to some degree of misclassification (--). On the other hand, the same authors observed that residual confounding (+) as well as misdiagnosis (+) might have contributed to increase the risk estimates. When further analysis were undertaken, including histological review of liver cancer cases [32], the risk estimates were somehow reduced (0.53- 0.78 excess cases per 10^5 per year within 1 km, instead of 0.95 excess cases per 10^5 as previously estimated).

Using data on municipal solid waste incinerators from the initial study by Elliott et al. [31], Knox [33] examined a possible association between childhood cancers and industrial emissions, including those from incinerators. From a file of 22,458 cancer deaths occurring in children before their 16th birthday between 1953 and 1980, he extracted 9,224 cases known to have moved at least 0.1 km between birth and death, and using a newly developed technique of analysis, distances from the suspected sources to the birth addresses and to the death addresses, respectively, were compared. The childhood-cancer/leukaemia data showed highly significant excesses of migrations away from birthplaces close to municipal incinerators, but the specific effects of the municipal incinerators could not be separated clearly from those of nearby industrial sources of combustion. Misclassification of exposure is the main limit of this paper (--).

In France, Viel et al. [34] detected a cluster of patients with non-Hodgkin's lymphoma (NHL) and soft tissue sarcoma around a French municipal solid waste incinerator with high dioxin emissions. To better explore the environmental origin of the cluster suggested by these findings, Floret et al. [35] carried out a population-based case-control study in the same area, comparing 222 incident

cases of NHL diagnosed between 1980 and 1995 and controls randomly selected from the 1990 population census. The risk of developing lymphomas was 2.3 times higher among individuals living in the area with the highest dioxin concentration than among those in the area with the lowest concentration. Given that a model was used to attribute exposure to cases and controls, a random misclassification could have reduced the effect estimates (--). On the bases of these results, a nationwide study on NHL has been conducted [36]. A total of 13 incinerators in France were investigated and dispersion modelling was used to estimate ground-level dioxin concentration. Information about the exposure levels and potential confounders were available at census block level. A positive association between dioxin level and NHL was found with a stronger effect among females. Although the study represents an improvement regarding exposure assessment when compared to investigations based on distance from the source, it should be noted that the analysis was conducted at census block level and the possibility of misclassification of the exposure (-) as well as of residual confounding from socioeconomic status (+) remains.

Viel et al [37] has recently reported the findings from a case-control study on breast cancer. There was no association or even a negative association between exposure to dioxin and breast cancer in women younger or older than 60 years, respectively, living near a French municipal solid waste incinerator with high exposure to dioxin. Design issues and residual confounding from age and other factors (---) limit the interpretation of the study.

In Italy, Biggeri et al. [38] conducted a case-control study in Trieste to investigate the relationship between multiple sources of environmental pollution and lung cancer. Based on distance from the sources, spatial models were used to evaluate the risk gradients and the directional effects separately for each source, after adjustment for age, smoking habits, likelihood of exposure to occupational carcinogens, and levels of air particulate. The results showed that the risk of lung cancer was inversely related to the distance from the incinerator, with a high excess relative risk very near the source and a very steep decrease moving away from it. The main problem of the study is the difficulty to separate the effects of other sources of pollution based on distance and the possibility of a potential confounding from other sources remains (++).

An excess risk of lung cancer was also found in females living in two areas of the Province of La Spezia (Italy) exposed to environmental pollution emitted by multiple sources, including a waste incinerator [39]. Again in this study, a limited exposure assessment could have decreased the risk estimates (--) but positive confounding from other sources is very likely.

A case-control study by Comba et al. [40] showed a significant increase in risk of soft tissue sarcomas associated with residence within 2 km of an industrial waste incinerator in the city of Mantua, with a rapid decrease of risk at greater distances. There is a slight likelihood that an increased attention to the diagnosis for this form of cancer in the vicinity of the plant could have introduced a small bias (+) in the risk estimate. Another case-control study, carried out in the province of Venice by Zambon et al. [41] analyzed the association between soft-tissue sarcoma and exposure to dioxin in a large area with 10 incinerators of MSW. The authors found a statistically significant increase in the risk of sarcoma in relation with both with the level and the length of environmental modelled exposure to dioxin-like substances. The results were more significant for women than for men. The accuracy of case ascertainment from the cancer registry

In summary, although several uncertainties limit the overall interpretation of the findings, there is limited evidence that people living in proximity of an incinerator have increased risk of all cancer, stomach, colon, liver, lung cancers based on the studies of Elliott et al [31]. Specific studies on

incinerators in France and in Italy suggest an increased risk for non-Hodgkin lymphoma, and soft-tissue sarcoma.

Birth defects and reproductive disorders

Six studies examined reproductive effects of incinerator emissions (see Appendix 2).

Jansson et al. [42] analysed whether the incidence of cleft lip and palate in Sweden did increase since the start of operation of a refuse incineration plant. The results of this register study, based on information from the central register of malformations and the medical birth register, did not demonstrate an increased risk.

A study by Lloyd et al. [43] examined the incidence of twin births between 1975 and 1983 in two areas near a chemical and a municipal waste incinerator in Scotland: after adjustment for maternal age, an increased frequency of twinning in areas exposed to air pollution from incinerators was seen. In the same study areas, Williams et al. [44] investigated sex ratios, at various levels of geographical detail and using 3-dimensional mapping techniques: analyses in the residential areas at risk from airborne pollution from incinerators showed locations with statistically significant excesses of female births.

To investigate the risk of stillbirth, neonatal death, and lethal congenital anomaly among babies of mothers living close to incinerators (and crematoriums), Dummer et al. [45] conducted a geographical study in Cumbria (Great Britain). After adjustment for social class, year of birth, birth order, and multiple births, there was an increased risk of lethal congenital anomaly, in particular spina bifida and heart defects.

Subsequently, Cordier et al. [46] studied communities with fewer than 50,000 inhabitants surrounding the 70 incinerators that operated at least one year from 1988 to 1997 in France. Each exposed community was assigned an exposure index based on a Gaussian plume model, estimating inhalation per number of year the plant had operated. The results were adjusted for year of birth, maternal age, department of birth, population density, average family income, and when available, local road traffic. The rate of congenital anomalies was not significantly higher in exposed compared with unexposed communities; only some subgroups of congenital anomalies, specifically facial cleft and renal dysplasia, were more frequent in the exposed communities.

Tango et al. [47] investigated the association of adverse reproductive outcomes with mothers living within 10 km from 63 municipal solid waste incinerators with high dioxin emission levels (above 80 ng international toxic equivalents TEQ/m³) in Japan. To calculate the expected number of cases, national rates based on all live births, foetal deaths and infant deaths occurred in the study area during 1997-1998 were used and stratified by potential confounding factors available from the corresponding vital statistics records: maternal age, gestational age, birth weight, total previous deliveries, past experience of foetal deaths, and type of paternal occupation. None of the reproductive outcomes studied showed statistically significant excess within 2 km from the incinerators, but a statistically significant peak-decline in risk with distance from the incinerators was found for infant deaths and for infant deaths with congenital anomalies, probably due to dioxin emissions from the plants.

In sum, there are multiple reports of increased risk of congenital malformations among people living close to incinerators but there are no consistencies over the investigated outcomes. The

overall evidence may be considered as limited. The study by Cordier et al [46] provides the basis for risk quantifications at least for facial cleft and renal dysplasia. Quantification for other reproductive disorders is more difficult.

Respiratory and skin diseases or symptoms

Four studies examined respiratory and/or dermatologic effects of incinerator emissions (see Appendix 2).

Hsiue et al. [48] evaluated the effect of long-term air pollution resulting from wire reclamation incineration on respiratory health in children. 382 primary school children who resided in one control and three polluted areas in Taiwan were chosen for this study. The results revealed a decrement in pulmonary function (including forced vital capacity and forced expiratory volume in one second) of those residents in the vicinity of incineration sites.

Shy et al. [49] studied the residents of three communities having, respectively, a biomedical and a municipal incinerator, and a liquid hazardous waste-burning industrial furnace, and then compared results with three matched-comparison communities. After adjustment for several confounding (age, sex, race, education, respiratory disease risk factors), no consistent differences in the prevalence of chronic or acute respiratory symptoms resulted between incinerator and comparison communities. Additionally, no changes in pulmonary function between subjects of an incinerator community and those of its comparison community resulted from the study by Lee et al. [50], based on a longitudinal component from the Health and Clean Air study by Shy et al. [49].

Miyake et al. [51] examined the relationship between the prevalence of allergic disorders and general symptoms in Japanese children and the distance of schools from incineration plants, measured using geographical information systems. After adjustment for grade, socio-economic status and access to health care per municipality, decreases in the distance of schools from the nearest municipal waste incineration plant was associated with an increased prevalence of wheeze and headache; there was no evident relationship between the distance of schools from such a plant and the prevalence of atopic dermatitis. The main factors that may affect the relative risk estimates in this study may be considered both reporting bias (++) and residual confounding from socioeconomic status (++).

In sum, although the intensive study conducted by Shy et al [49] did not show respiratory effect, there are some indications of an increased risk of respiratory diseases, especially in children. However, the uncertainty related to outcome assessment and residual confounding is very high and the overall evidence may be considered as inadequate.

Occupational studies on incineration workers

Four studies conducted on incinerator workers were reviewed (see Appendix 3).

In 1997, Rapiti et al. [52] conducted a retrospective mortality study on 532 male workers employed at two municipal waste incinerators in Rome (Italy) between 1962 and 1992. Standardized mortality ratios (SMRs) were computed using regional population mortality rates. Mortality from all causes resulted significantly lower than expected, and all cancer mortality was comparable with that of the general population. Mortality from lung cancer was reduced, but increased risk was found for gastric cancer: analysis by latency indicated that this excess risk was confined in the category with more than 10 years since first exposure.

Bresnitz et al. [53] studied 89 of 105 Philadelphia incinerator male workers, employed at the time of the study in late June 1988. Based on a work site analysis, workers were divided into potential high and low exposure groups, and no statistically significant differences in pulmonary function were found between the two groups, after adjustment for smoking status.

A similar study was conducted by Hours et al. [54]: they analysed 102 male workers employed in 3 French urban incinerators during 1996, matching for age with 94 male workers from other industrial activities. The exposed workers were distributed into 3 categories of exposure based on air sampling at the workplace: crane and equipment operators, furnace workers, and maintenance and effluent-treatment workers. An excess of respiratory problems, mainly daily cough, was more often found in the exposed groups, and a significant relationship between exposure and decreases of several pulmonary parameters was also observed, after adjustment for tobacco consumption and centre. For the maintenance and effluent group, as well as for the furnace group, elevated relative risks were estimated for skin symptoms.

In the same year, Takata et al. [55] conducted a cross-sectional study in Japan on 92 workers of a municipal solid waste incinerator to investigate the health effects of chronic exposure to dioxins. The concentrations of these chemicals among the blood of the workers who had engaged in maintenance of the furnace, the electric dust collector, and the wet scrubber of the incinerator were higher compared with those of residents in surrounding areas, but there were no clinical signs or findings correlated to blood levels of dioxins.

In sum, some suggestions of increased gastric cancer and respiratory problems among incinerators workers are available. There is a very high level of uncertainties to derive conclusions.

Epidemiological studies of health effects of other waste management processes

Twelve epidemiologic studies on the potential adverse health effects of other waste management practices are reviewed and listed in Appendix 4.

Waste collection

Ivens et al. [56] investigated the adverse health effects among waste collectors in Denmark. In a questionnaire based survey among 2303 waste collectors and a comparison group of 1430 male municipality workers, information on self-reported health status and working conditions was collected and related to estimated level of bioaerosol exposure. After adjustment for several confounders (average alcohol consumption per day, smoking status, and the psychosocial exposure measures demand and support), a dose-response relationship between level of exposure to fungal spores and self-reported diarrhoea was indicated, meaning that the higher weekly dose, the more reports of gastrointestinal symptoms.

In contrast to these results, a study on 853 workers employed by 27 municipal household waste collection departments in Taiwan did not find an excess of gastrointestinal symptoms [57]. The workers answered a survey questionnaire and were classified into two occupational groups by specific exposures on the basis of the recorded designation of their specific task. The exposed group included those working in the collection of mixed domestic waste, front runner or loader, collection

of separated waste and special kinds of domestic waste (paper, glass, etc.), garden waste, bulky waste for incineration, and the vehicle driver; the control group included accountants, timekeepers, canteen staff, personnel, and other office workers. No significant differences were found in the prevalence of gastrointestinal symptoms, but results indicated that all respiratory symptom prevalence, except dyspnoea, were significantly higher in the exposed group, after adjustment for age, sex, education, smoking status, and duration of employment.

Composting facilities

In a German cross sectional study by Bünger et al. [58], work related health complaints and diseases of 58 compost workers and 53 biowaste collectors were investigated and compared with 40 control subjects. Compost workers had significantly more symptoms and diseases of the skin and the airways than the control subjects. No correction was performed for the confounding effect of smoking as there was no significant difference in smoking habits between the three groups.

A subsequent study in Germany by Herr et al. [59] examined the health effects of bioaerosol emitted by a composting plant on community residents. A total of 356 questionnaires from residents living at different distances from a composting site, and from unexposed controls were collected: self reported prevalence of health complaints during the past years, doctors' diagnoses, as well as residential odour annoyance were assessed, and microbiological pollution was measured simultaneously in residential outdoor air. Reports of irritative airway complaints were associated with residency in the highest bioaerosol exposure category, 150-200 m (versus residency >400-500 m) from the site, and period of residency more than five years. No residential odour annoyance was detected.

Bünger et al. [60] conducted a prospective cohort study to investigate, in 41 plants in Germany, the health risks of compost workers due to long term exposure to organic dust with special focus on respiratory disorders. Employees, exposed and non exposed to organic dust, were interviewed about respiratory symptoms and diseases in the last 12 months and spirometry was performed after a 5 year follow-up. Exposure assessment was conducted at 6 out of 41 composting plants and at individual level. Eyes, airways and skin symptoms were higher in compost workers than in control group. There was also a steeper decline of Forced Vital Capacity among compost workers compared to control subjects also considering smoking.

Materials recycling facilities

There are no epidemiological studies of populations living near materials recycling facilities, only studies on workers are available.

In the already quoted study of Rapiti et al. [52] on workers at two municipal plants for incinerating and garbage recycling, increased risk was found for gastric cancer in the category with more than 10 years since first exposure, in contrast with reduced mortality from lung cancer.

In the study by Rix et al. [61], 5377 employees in five paper recycling plants in Denmark between 1965 and 1990 were included in a historical cohort, and the expected number of cancer cases was calculated from national rates. The incidence of lung cancer was slightly increased among men in production and moderately increased in short term workers with less than 1 year of employment; there was significantly more pharyngeal cancer among male, but this increase may be influenced by confounders such as smoking and alcohol intake.

Sigsgaard et al. [62] conducted a cross-sectional study to examine the workshift changes in lung function among 99 recycling workers (resource recovery and paper mill workers), correlating these findings with measurements of total dust and endotoxins. Exposure to organic dust caused a fall in FEV₁ over the workshift, and this was significantly associated with the exposure to organic dust; no significant association was found between endotoxin exposure and lung function decrements.

The same authors [63] also analysed skin and gastrointestinal symptoms among 40 garbage handling, 8 composting and 20 paper sorting workers from all over Denmark, and an increased risk of itching of the skin and vomiting or diarrhoea in the garbage handling was found.

In a nationwide study, Ivens et al. [64] reported findings of self-reported gastrointestinal symptoms by self-reported type of plant. A questionnaire based survey among Danish waste recycling workers at all composting, biogas-producing, and sorting plants collected data on occupational exposures (including questions on type of plant, type of waste), present and past work environment the psychosocial work environment, and health status. Prevalence rate ratios adjusted for other possible types of job and relevant confounders were estimated with a comparison group of non-exposed workers, and an association was found between sorting paper and diarrhoea, between nausea and work at plastic sorting plants, and non significantly between diarrhoea and work at composting plants.

The health status of workers employed in the paper recycling industry was also studied by Zuskin et al. [65]. A group of 101 male paper-recycling workers employed in one paper processing plant in Croatia, and a group of 87 non exposed workers employed in packing food products in the food industry was studied for the prevalence of chronic respiratory symptoms, and results indicated significantly higher prevalences of all chronic respiratory symptoms were found in paper compared with control workers.

Gladding et al. [66] studied 159 workers from nine materials recovery facilities (MRFs) in United Kingdom. Measurements of airborne total dust, endotoxin, (1-3)-beta-D-glucan, and a questionnaire survey were carried out. The results suggest that materials recovery facilities workers exposed to higher levels of endotoxin and (1-3)-beta-D-glucan at their work sites experience various work-related symptoms, and that the longer a worker is in the MRF environment, the more likely he is to become affected by various respiratory and gastrointestinal symptoms.

Choosing relative risk estimates for health impact assessment of residence near landfills and incinerators

The reviewed studies have been used to summarize the evidence available, as it is indicated in table 1. Only when the overall degree of evidence was considered at least “limited”, relative risk estimates were extracted so that they can be used in the health impact assessment process. Table 2 summarizes the relevant figures for health effects related to landfills and incinerators that are most reliable. For each relative risk the distance from the source has been reported as well as the overall level of scientific uncertainty of the effect estimates based on an arbitrary scale: very high, high, moderate, low, very low.

Landfills

From the review presented above, it is clear that the studies on cancer are not sufficient to draw conclusions regarding a health effect near landfills. The two studies from Goldberg et al [19] and Pukkala et al [20] are not consistent with regards to the cancers sites, with the only exception of pancreatic cancer. The largest study conducted in England by Jarup et al [21] is not suggesting an increase for the cancer sites that were investigated. For other chronic diseases, especially respiratory diseases, investigations are lacking with only one suggestive indication of an increased risk of asthma in adults [20] but with no replication of the findings. Overall, the evidence that living near landfills may be associated with health effects in adults is inadequate.

A different picture appears for congenital malformations and low birth weight where a limited evidence exists of an increased risk for babies born to mothers living near landfill sites. The relevant results come from Elliott et al. [24]. Statistically significant increased risk were found for all congenital malformations, neural tube defects, abdominal wall defects, surgical correction of gastroschisis and exomphalos, and low and very low birth weight for births occurring in people living within 2 km from the sites. Although several alternative explanations, including ascertainment bias, and residual confounding cannot be excluded in the study, Elliott et al [[24] provides quantitative effect estimates whose level of confidence can be considered as moderate.

Incinerators

Quantitative estimates of excess risk of specific cancers in populations living near solid waste incinerator plants were provided by Elliott et al. [31]. We have reported in table 2 the effect estimates for all cancers, stomach, colon, liver, and lung cancer based on their “second stage” analysis. There was an indication of residual confounding from socioeconomic status near the incinerators and a concern of misdiagnosis among registrations and death certificates for liver cancer. The histological review of the liver cancer cases was done, giving a re-estimation of the previously calculated excess risk (from 0.95 excess cases 10^{-5} /year to between 0.53 and 0.78 excess cases 10^{-5} /year). We then score the confidence of the assessment for these tumours as “moderate” with the exception of liver cancer (high) since the reassessment of misdiagnosis was done and the extent of residual confounding was lower. In the Elliott et al [31] study no significant decline in risk with distance for non-Hodgkin lymphoma and soft tissue sarcoma was found. However, the studies of Viel et al [34] and Floret [35] conducted in France and the studies from Comba et al [40] and Zambon et al. [41] in Italy provide some indications that an excess of these form of cancers may be related to emissions of dioxin from incinerators. As a result, we provided effect estimates in table 2 also for non-Hodgkin lymphoma and soft tissue sarcoma as derived from the conservative “first stage” analysis conducted by Elliott et al [31]. We scored the level of confidence of this relative risk estimates as “high”.

With regards to congenital malformations near incinerators, Cordier et al [46] provided effect estimates for facial cleft and renal dysplasia as they were more frequent in the “exposed” communities living within 10 km from the sites. Other reproductive effects, such as an effect on twinning or sex determination, have been described; however the results are inadequate.

Conclusions

We have conducted a systematic review of the literature regarding health effects of waste management. After the extensive review, in many cases the overall evidence was inadequate to establish a relationship between a specific waste process and health effects. However, at least for some associations a limited evidence has been found and few studies were selected for a

quantitative evaluation of the health effects. These relative risks could be used for health impact assessment but it should be considered that the level of confidence in these effect estimates is at least moderate for most of them.

It is clear that future research into the health risks of waste management needs a more accurate characterization of individual exposure, an improved knowledge of chemical and toxicological data on specific compounds, multi-site studies on large populations to increase statistical power, approaches based on individuals rather than communities and a better control of confounding factors.

Table 1. Summary of the overall epidemiologic evidence on municipal solid waste disposal: landfills and incinerators.

HEALTH EFFECT	LEVEL OF EVIDENCE	
	LANDFILLS	INCINERATORS
All cancer	Inadequate	Limited
Stomach cancer	Inadequate	Limited
Colorectal cancer	Inadequate	Limited
Liver cancer	Inadequate	Limited
Larynx cancer	Inadequate	Inadequate
Lung cancer	Inadequate	Limited
Soft tissue sarcoma	Inadequate	Limited
Kidney cancer	Inadequate	Inadequate
Bladder cancer	Inadequate	Inadequate
Non Hodgkin’s lymphoma	Inadequate	Limited
Childhood cancer	Inadequate	Inadequate
Total birth defects	Limited	Inadequate
Neural tube defects	Limited	Inadequate
Orofacial birth defects	Inadequate	Limited
Genitourinary birth defects	Limited ¹	Limited ²
Abdominal wall defects	Inadequate	Inadequate
Gastrointestinal birth defects ³	Inadequate	Inadequate
Low birth weight	Limited	Inadequate
Respiratory diseases or symptoms	Inadequate	Inadequate

“*Inadequate*”: available studies are of insufficient quality, consistency, or statistical power to decide the presence or absence of a causal association. “*Limited*”: a positive association has been observed between exposure and disease for which a causal interpretation is considered to be credible, but chance, bias, or confounding could not be ruled out with reasonable confidence.

¹ Hypospadias and epispadias

² Renal dysplasia

³ The original estimates were given for “surgical corrections of gastroschisis and exomphalos”

Table 2. Relative risk estimates for community exposure to landfills and incinerators

2.1.1. Outcome	Distance from the source	Relative Risk (Confidence Interval)	Level of confidence ²
Landfills			
<i>Congenital malformations [24]</i>			
All congenital malformations	Within 2 km	1.02 (99% CI=1.01-1.03)	Moderate
Neural tube defects	Within 2 km	1.06 (99% CI=1.01-1.12)	Moderate
Hypospadias and epispadias	Within 2 km	1.07 (99% CI=1.04-1.11)	Moderate
Abdominal wall defects	Within 2 km	1.05 (99% CI=0.94-1.16)	Moderate
Gastroschisis and exomphalos ¹	Within 2 km	1.18 (99% CI=1.03-1.34)	Moderate
<i>Low birth weight [24]</i>			
Very low birth weight	Within 2 km	1.04 (99% CI=1.03-1.06)	High
Incinerators			
<i>Congenital malformations [46]</i>			
Facial cleft	Within 10 km	1.30 (95% CI=1.06-1.59)	Moderate
Renal dysplasia	Within 10 km	1.55 (95% CI=1.10-2.20)	Moderate
<i>Cancer [31]</i>			
All cancer	Within 3 km	1.035 (95% CI=1.03-1.04)	Moderate
Stomach cancer	Within 3 km	1.07 (95% CI=1.02-1.13)	Moderate
Colorectal cancer	Within 3 km	1.11 (95% CI=1.07-1.15)	Moderate
Liver cancer	Within 3 km	1.29 (95% CI=1.10-1.51)	High
Lung cancer	Within 3 km	1.14 (95% CI=1.11-1.17)	Moderate
Soft-tissue sarcoma	Within 3 km	1.16 (95% CI=0.96-1.41)	High
Non-Hodgkin's Lymphoma	Within 3 km	1.11 (95% CI=1.04-1.19)	High

¹ The original estimates were given for “surgical corrections of of gastroschisis and exomphalos”.

² The following scale for the level of confidence has been adopted: very high, high, moderate, low, very low.

List of abbreviations used

MSW: Municipal Solid Wastes

INTARESE: Integrated Assessment of Health Risks of Environmental Stressors in Europe

NHL: non-Hodgkin's Lymphoma

TEQ: Toxic Equivalent

Competing interests

The authors declare that they have no competing interests.

Authors' contribution

SM carried out the systematic review and draft the manuscript.

DP participated in the design of the study, in carrying out the systematic review and helped to draft the manuscript

AIL participated in carrying out the systematic review and helped to draft the manuscript

CAP participated in the conceiving of the study, and in writing and revising the manuscript

FF conceived and coordinated the study, and participated in writing and revising the manuscript

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