ARTICLE 6

Towards an assessment of the health impact of industrially contaminated sites: waste landfills in Europe

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ABSTRACT

OBJECTIVES: this paper is based upon work from COST Action ICSHNet. To develop and apply recently proposed methods for assessing the health impact of pollution from contaminated sites and apply them to the case of landfills using available large European datasets.

METHODS: standard methods for health impact assessment and burden of disease were applied using the available evidence on the health effects of living near a landfill. Geo-referenced data on landfills from the European Pollutant and Transfer Register (E-PRTR) were combined with population density data (European Environment Agency dataset) and disease frequency data from European health for all database (HfA); uncertainty was assessed via simulation methods.

Countries covered by the European Environment Agency's E-PRTR registry on contaminated sites were considered (European Union Member States plus four additional European countries) for the period 2007-2014.

Four outcomes, for which suggestive evidence is available, were included: • low birth weight; • congenital anomalies; • respiratory disease; • annoyance from odour. Firstly, they were analysed separately, in terms of excess number of cases, and then combined into disability-adjusted life years (DALYs).

RESULTS: 1,544 landfill sites were considered. 29.3 million people (6% of the total population) live within 4 km from one or more of these sites. The number of yearly attributable cases associated with low birth weight, congenital anomalies, respiratory diseases, and annoyance from odour were estimated, respectively, at 1,239, 70, 33,039, and 1,582,624. Associated DALYs were 10,192, 958, 2,688, and 47,505, respectively; 61,325 in total.

CONCLUSIONS: estimates indicate a sizable health impact, largest for annoyance from odour, given the high frequency of the outcome and in spite of its lesser severity compared to the other ones. Application of the methodology is relatively straightforward, once the main assumption of causality is made. The present work offers a first approximation of the impact on health of waste landfills in Europe and can be further applied to other contaminated sites.

Keywords: health impact analysis, industrially contaminated sites, landfill, disability adjusted life years.

KEYPOINTS

What is already known

- **In spite of increasingly ambitious goals on re-using and recycling, landfills and incinerators remain widely used to manage the final phase of waste disposal.**
- **A number of studies investigated the possible health effects on populations living in proximity of landfills and incinerators, finding associations with a variety of health outcomes.**
- **The importance of this issue is reflected by the inclusion of waste and contaminated sites among the priorities of the Declaration of the 6th Ministerial Conference on Environment and Health (Ostrava, Czech Republic, 2017).**

What this paper adds

- **An estimate of the population residing in close proximity to landfills in the EU is proposed: almost 30 million people (approximately 6% of the total population) reside within 4 km of a waste landfill facility.**
- **The burden of disease associated with living close to a landfill, measured through DALYs per year, was estimated, ranging from 47,505 for annoyance from odour to 958 for congenital anomalies.**
- **A methodology for health impact assessment of environmental stressors due to the presence of landfills, allowing for sources of uncertainty, that could be used more broadly in the field of environmental health impact analyses and contaminated sites, is proposed.**

INTRODUCTION

The environmental and health effects of industrial contamination and, in particular, the waste management of municipal solid waste have been studied by the international scientific community for many decades.[1] However, the nature in which different phases of the full process (waste production, collection, transport, recycling, treatment, disposal) may affect human health is not fully understood. Waste-related exposures are ubiquitous and a number of studies of the possible health effects on populations living in proximity of landfills and incinerators have been published,[2-7] with both landfills and incinerators having been associated with a variety of health outcomes. A series of reviews[1,8-13] did not reach definitive conclusions, with some difficulties in interpreting data from primary studies due to non-homogeneous designs, lack of accurate exposure information, and control of potential confounders.

In spite of increasingly ambitious goals on re-using and recycling,[14] landfills and incinerators remain widely used to manage the final phase of waste disposal. Consequently, despite the non-exhaustive knowledge on health effects of different waste management solutions, health impact assessment tools of different options for waste management are required by policy-makers, in order to provide them health-oriented information useful to identify priorities, goals, and policy action on waste management that can reduce detrimental health effects and their unequal distribution. The growing policy relevance of the issue is also reflected by the inclusion of waste and contaminated sites among the priorities of the Declaration of the 6th Ministerial Conference on Environment and Health, held in Ostrava (Czech Republic) in 2017.[15]

The increasing availability of large, complex, and potentially linkable data from diverse sources has led to exciting opportunities in environmental health in general, and provides the scope for studies on health and waste and local contamination. Over the past few decades, thanks to the rapid expansion in computing ability and data storage, there has been a growing appreciation for the potential of utilising big data in environmental health impacts analyses.[16] At the same time, routinely reported environmental data by national authorities are increasingly becoming publicly available. Here, we show how routinely collected, open access data from different sources can be used to assess the health impacts of waste management facilities in residential areas.

More in general, this approach can also apply to health impact assessment of different types of industrially contaminated sites (ICSs), like those considered in the COST Action on Industrially contaminated sites and health Network (ICSHNet, https://www.icshnet.eu/). The network aims at clarifying knowledge gaps and research priorities; supporting collection of relevant data and information, stimulate development of harmonised methodology, and develop guidance and resources on risk and health impact assessment in ICSs. In the light of these objectives, a broader application of the methodology proposed in this paper is envisaged.

DESIGN AND METHODS

Quantitative health impact analysis requires data on:

- nature and magnitude of risks for all health outcomes associated with exposures;
- frequency of these diseases/health outcomes;
- the population at risk.

NATURE AND MAGNITUDE OF RISKS

The risks associated with exposures were derived from the scientific literature.[5,6] Disability weights and durations of disease were taken from the Victorian burden of disease study[17] that contained the required information on the set of outcomes being considered here. Table 1 shows risks, disability weights, and duration of disease for four health outcomes: congenital anomalies, respiratory diseases, low birth weight, and annoyance from odour. These outcomes were selected on the basis of the relevant literature on the health effects of waste-related exposures as referenced in Ranzi et al.[6] The annoyance from odour is given as a percentage as it arises from surveys, while the remaining health outcomes are expressed as relative risk (RR) and related confidence interval (95%CI), as reported in the literature.

HEALTH OUTCOME	RISK MEASURE	DISABILITY WEIGHT	DURATION (YEARS)
Low birth weight	RR: 1.06 (99% CI: 1.052-1.062)*	0.106	79.6
Congenital anomalies	RR: 1.02 (99% CI: 1.01-1.03)*	0.170	79.6
Respiratory diseases	RR: 1.05 (95% CI: 1.01-1.08)**	0.080	1.00
Annoyance from odour	Prop: 5.4%^	0.030	1.00

RR: relative risk; **Prop:** proportion of affected * Exposure represented by 0-2 km ** Exposure represented by 0-5 km ^ Proportion based on data from questionnaires, confidence interval not available

Table 1. Risks, disability weights, and duration of disease for four health outcomes used in calculations of the health impacts associated with landfill sites (see Ranzi et al. for details).[6]

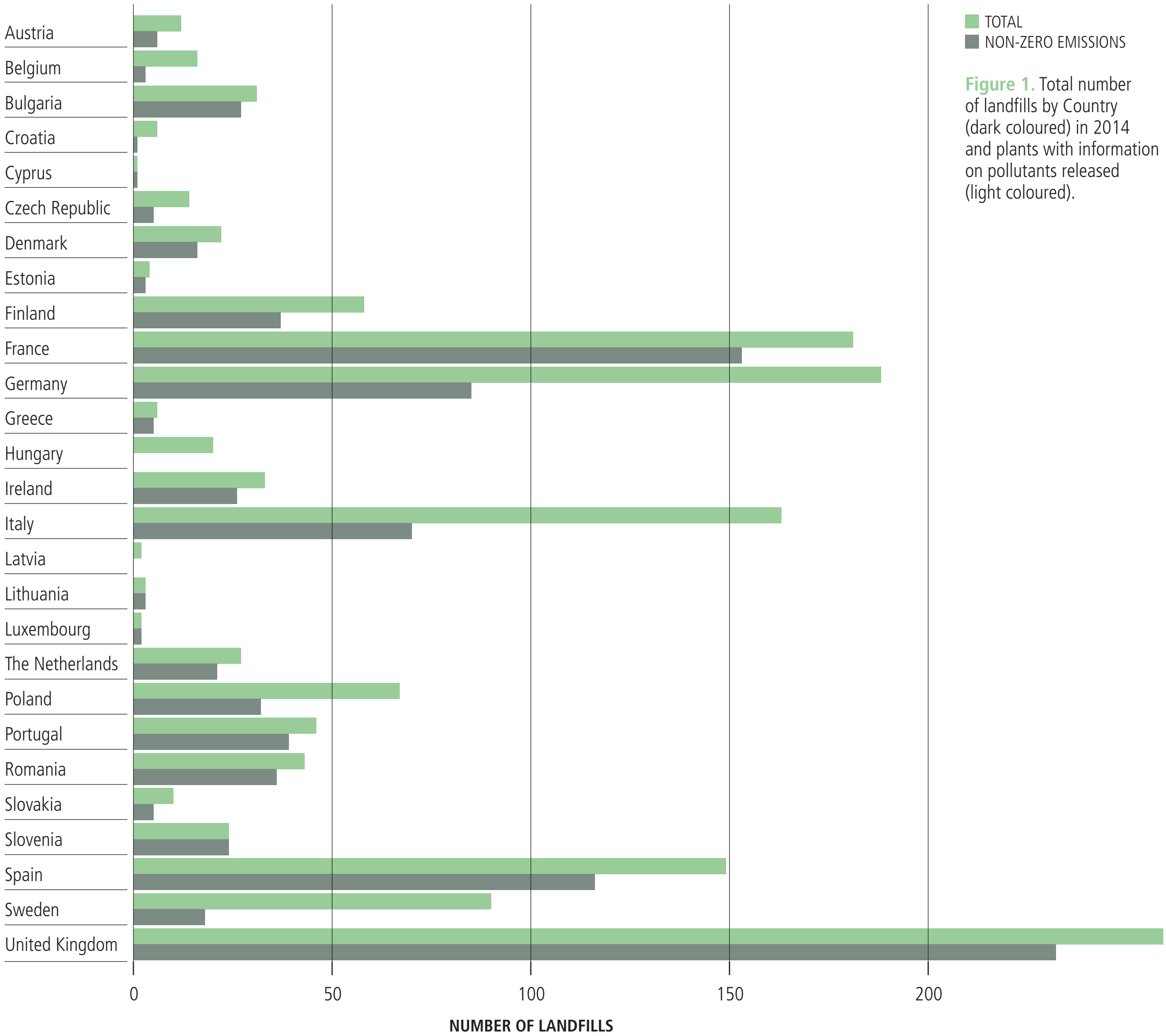

Figure 1. Total number of landfills by Country (dark coloured) in 2014 and plants with information on pollutants released (light coloured).

FREQUENCY OF HEALTH OUTCOMES

Background incidence rates for the health outcomes were obtained, at state level, from the European Health for all database.[18] As rates were not available for 2014 for all Countries, rates were used for the most recent year available for each Country (from 2014 onwards).

POPULATION AT RISK

The population exposed to landfill emissions is defined as all people living within a buffer of 4 km centred on each plant. This population was estimated by obtaining the locations of waste sites in the study region and then identifying the populations that live in proximity to each site. Population data were obtained from the European Environment Agency (EEA) at a resolution of 100×100 m, based on downscaling of Corine Land Cover 2000 information (CLC).[19,20] Estimates of population density is available on a grid in the form of inhabitants/km^2.

Details of contaminants and pollutants for a range of sources in the 28 Member States of the European Union (EU) and Iceland, Liechtenstein, Norway, and Switzerland are registered in the European Pollutant and Transfer Register (E-PRTR), hosted and run by the EEA.[21] The E-PRTR contains data reported annually for more than 30,000 industrial facilities covering 65 economic activities across Europe. For each facility, information concerns the amounts of pollutant releases to air, water, and soil as well as off-site transfers of waste and of pollutants in waste water from a list of 91 key pollutants including heavy metals, pesticides, greenhouse gases, and

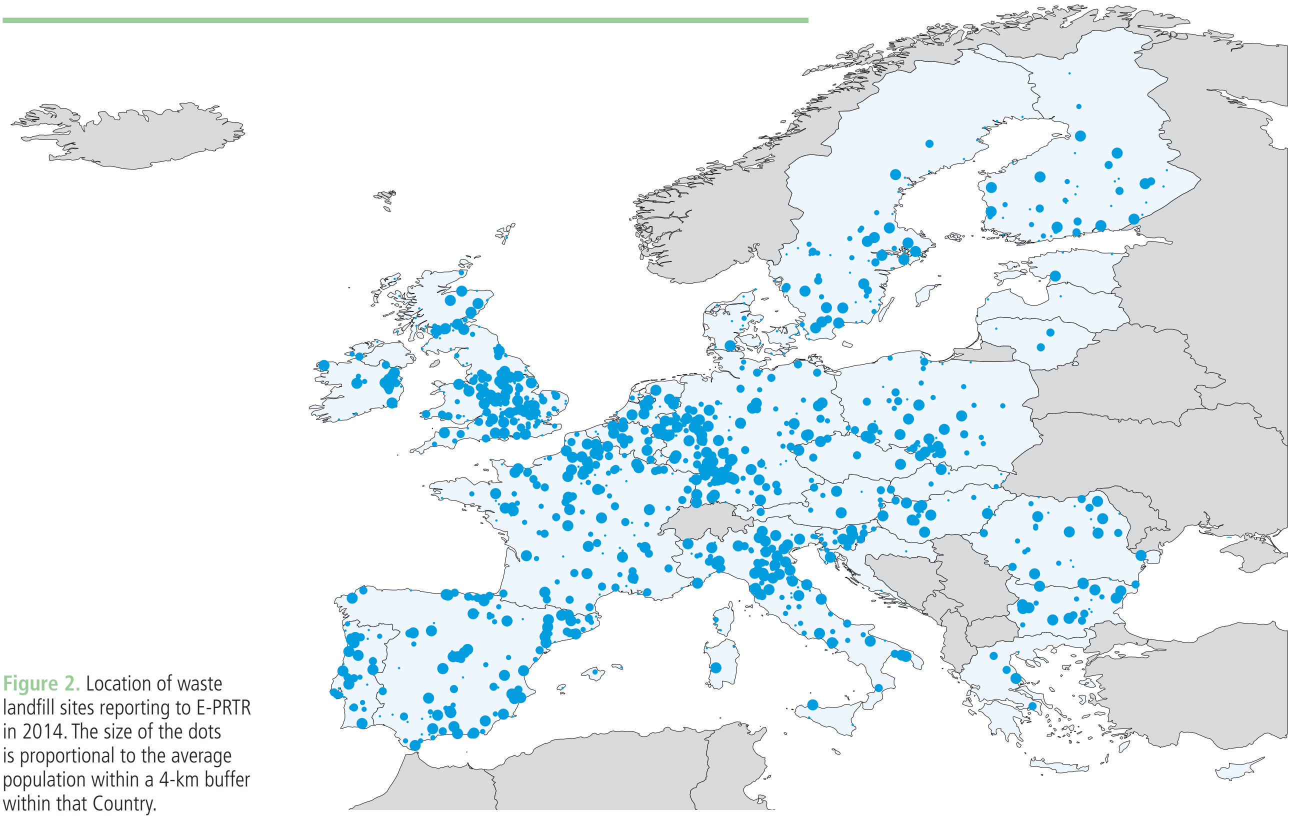

Figure 2. Location of waste landfill sites reporting to E-PRTR in 2014. The size of the dots is proportional to the average population within a 4-km buffer within that Country.

dioxins for years 2007 onwards.[22] Information on landfills can be found in section 5.d of the Register. This excludes: • landfills of inert waste; • landfills which were closed before July, 16th 2001; • landfills receiving less than 10 tonnes per day or with a total capacity less than 25,000 tonnes.[23]

Figure 1 shows the number of landfill sites that are present in the E-PRTR in 2014 and the number that have reported emissions. The total number of landfills remain fairly constant between 2007 and 2014. The United Kingdom accounts for the largest number of landfills (259 in 2014). The Countries with the largest populations (United Kingdom, France, Germany, Italy, and Spain) are the ones with largest number of landfills (more than 100 for each year of reporting). There are also Countries with no reports in some (or even all) years.

E-PRTR provide the geo-coded location of each plant based on most recent year of reporting (2014 for version 8 of the database); the locations of the 1,544 landfill sites present in the repository can be seen in figure 2. Large heterogeneity both in the number of plants in each Country and in the spatial distribution can be observed. Allowing for the different number of inhabitants in each Country, this reflects the different waste management policies within the EU.

The raster file of the EEA population was overlapped to the shape file of landfill locations from the E-PRTR. The aggregate of all populations within the considered buffers constituted the total exposed population of our study. When a 100×100 cell partially fell within the areas of interest (circular buffer), the portion of the exposed population was calculated according to the part of the cell overlapping the buffer. In order to align with the structure of the EEA population data, in the calculation of exposed population the final sum of the cell values within each buffer was divided by 100.[20]

The number of sites for which populations at risk could be estimated was 1,484 out of the total 1,544 due to the data not covering the entire area of E-PRTR (for example, Norway, with his 56 plants, was not included). All geographical analyses were carried out using the ArcMap 10.1 software.[24] The reference system used for the cartographic projection of all information was UTMWGS84-33N.

HEALTH IMPACT ANALYSES

Having collated information on risks, exposures, and population at risk, quantitative health impact analysis was performed using the method from Ranzi et al.[6] in which the number of attributable cases (ACs) for a specific cause-exposure pair is calculated as:

$$AC = AF_{exp} \cdot Rate_{pop} \cdot Pop_{exp}$$

where:

Pop_{exp} is the exposed population;

$Rate_{pop}$ is the background population incidence rate;

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$$AF_{exp} = \frac{(RR - 1)}{RR}$$

(where denotes the relative risk) is the attributable fraction in exposed population.

In order to compare the relative public health importance of different health outcomes, common metrics of the burden of disease are frequently used. In this application, disability adjusted life years (DALYs) are used, calculated as:

$$DALY = AC \cdot DW \cdot L$$

where:
DW is a disability weight associated with the disease which is established by expert judgment;
L is the average disease duration.

In the estimation of DALYs here performed, only the disability component of DALYs (years of living with disabilities, YLD) is considered; i.e., they do not consider the possible contribution of premature mortality (years of life lost, YLL).

The process of assessing health impacts involves several assumptions and sources of uncertainty. Uncertainties associated with the relative risk of the health outcomes were incorporated into the calculations using Monte Carlo simulation. In total, 10,000 samples of relative risks were drawn from the distribution of (log-)relative risks, that are assumed to be normally distributed on the log scale. The mean and standard deviation of the distributions were determined from the RR and associated CI from table 1. Repeated calculation of the DALYs for each health outcome was performed, once for each sample, taking advantage of the computational efficiency that can be achieved by performing the calculations in parallel. All calculations and sampling were performed using the R language,[25] with simulations run in parallel using the doParallel package.[26]

SETTING AND POPULATION

The study area comprises of the 28 Member States of the EU and Iceland, Liechtenstein, Norway, and Switzerland that are registered in the E-PRTR and for which CLC 2000 information was available to estimate populations at risk.
Exposed populations were defined as people living within 4 km from landfill sites within the study area. The 4-km radius was chosen a priori, consistently with published epidemiological literature on the health effects observed around waste facilities.[6,7] It is estimated that 29,308,192 people in the EU (approximately the 6% of the total population) live within 4 km of the 1,476 waste landfill sites here considered.

RESULTS

The number of attributable cases associated with low birth weight, congenital anomalies, respiratory diseases, and annoyance from odour were estimated, respectively, to be 1,239, 70, 33,039, and 1,582,624. Table 2 shows the estimates of DALYs associated with each health outcome, together with estimates of uncertainty.

DISCUSSION

To our knowledge, the present work represents the first quantitative assessment of the possible health impacts of landfills at the EU level. Almost 30 million people (approximately 6% of the total population) reside within 4 km of a waste landfill facility (with 0.7 million living within 2 km and 65 million within 6 km). The burden of disease, measured through DALYs per year, ranges from 47,505 for annoyance from odour to 958 for congenital anomalies; despite the low severity of annoyance compared to all other outcomes, the large number of cases of annoyance translates into a larger burden.
The findings confirm previous observations at local or national level that landfills are densely distributed in several Countries or regions, and a substantial proportion of the population lives within distances that have been associated to adverse health effects in epidemiological stud-

HEALTH OUTCOME	ACs (95%CI)	DALYs (95%CI)
Low birth weight	1,239 (1,110-1,307)	10,192 (9,371-11,030)
Congenital anomalies	70 (36-106)	958 (496-1,437)
Respiratory diseases	33,039 (0-63,829)	2,688 (0-5,106)
Annoyance from odour	1,582,624 (1,455,545-1,720,710)	47,505 (43,666-51,621)
Total	1,616,972 (1,487,370-1,759,540)	61,325 (56,618-66,265)

ACs: attributable cases; **DALYs:** disability adjusted life years

Table 2. Estimated health impacts (excess cases and DALYs) for the four health outcomes: medians and 95% confidence intervals from Monte Carlo simulations.

ies.[8] A rationale of the choice of these outcomes is reported in the original study by Ranzi et al.[6] Some evidence refers to old generation plants, and it is likely that recent developments in waste treatment technology have changed exposure patterns, at least in some Countries.

While this evidence allows the estimation of the possible health impacts, our findings must be interpreted with caution: the key assumption of this study is the causal nature of the associations between residence in the vicinity of a landfill and the health outcomes considered. For annoyance, the most important contributor to the total DALYs, the assumption seems to be safe; for the other outcomes, the underlying evidence is not fully conclusive; however, some consistency and replication, especially for old generation facilities, suggests causality.[27]

Conversely, additional adverse health impacts of waste landfills may arguably exist, but they will not be captured by these estimates. These include relatively certain ones, such as those of emissions of air pollutants, causing premature mortality and morbidity and contributing to climate change, as well as more uncertain ones, connected, for example, to contamination by specific compounds (e.g., dioxins and other endocrine disrupting chemicals) entering soil, water, and the food chain.

Although the methodology here presented allows the incorporation of certain sources of uncertainty (due, for example, to the estimates of relative risks), several other sources of uncertainty are present, including the selection of sites, the completeness of databases (e.g., lack of data from discontinued sites), a variable degree of possible emissions (e.g., quantity of waste managed, dimension of landfills, the shape of the facilities' perimeters), and the population estimates. Most importantly, perhaps, the use of a fixed circle with a 4-km radius around the centroid of the landfills introduces an error whose implications are difficult to judge. However, the choice is consistent with the nature of the underlying epidemiological evidence, so that better metrics, for example involving dispersion modelling, would not easily translate into better impact estimates.

An important dimension, beyond the magnitude of the impact, is its distribution among the population. The overall total of approximately 61,000 DALYs are likely to be unevenly distributed across population subgroups, notably in relation to socioeconomic status. Evidence from the literature suggests that people living near contaminated or industrial sites are more deprived than the general population.[28,29] In this analysis, the baseline population rate is applied to the exposed population. However, if rates in the exposed population were higher, as might be expected in more deprived areas, then the health impact may be underestimated. A disproportionate share of the burden of disease, therefore, is likely borne by people who are also exposed to additional risk factors, for example, relating to lifestyle. In addition, possible interactions may exist and enhance the power of environmental agents to damage health, for example, through higher vulnerability due to low-quality housing. Further investigations in this direction, of great value in the policy debate, would benefit from the development of standardised international metrics and indicators of social disadvantage or deprivation.

The potential for more and better assessments of this kind is large. The approach here presented is based on a standardized methodology, already used in other areas of environment and health, systematically applied to all Countries. It also extends previous work done for selected European Countries[5,6] to consider as much of the World Health Organization European Region as data allows.

All information used in the analysis is freely available, centrally collected with homogeneous protocols; this kind of assessment can be extended to other types of contaminated sites where evidence on health effects due to exposure to that kind of pollution are available. E-PRTR data represents a rich source of information about industrial facilities, their location, and activity over time, that can be exploited for health assessments in ICSs. In parallel, European data on population density allows the estimation of the total number of population in a 100x100-metre square.

However, no information about age and sex structure was found to be available, which is a limitation when considering health outcomes and related risk functions that are age- or gender-dependent (which is not the case in the present assessment).

Future methodological developments should consider:

- simple ranking criteria to differentiate sites based on the likely intensity of their environmental pressure;
- the use of more realistic buffers reflecting the fact that landfill sites are not points sources, but may cover extended areas;
- the integration of more complex risk surfaces than the step-changes considered here;
- integration of these information with others, potentially related to exposure and health (i.e., information on socioeconomic status of exposed population, as argued above);
- a more realistic approach in the assessment of the uncertainty associated with estimated populations, including the integration of the downscaling procedure within a formal modelling framework to allow uncertainty to be propagated through to the final estimates of uncertainty associated with total DALYs.

CONCLUSIONS

In conclusion, the present paper provides a methodology for health impact assessment of environmental stressors due to the presence of landfills. Acknowledging the underlying assumptions and uncertainties, the main value of this assessment is to provide an indication of the magnitude of the possible health impacts from the four most strongly associated health outcomes, for an approximate comparison between them and with the impact of other environmental determinants. In addition, the methodology is suitable for a first order approach to assess the order of magnitude of health impacts under alternative scenarios in waste management and could be used more broadly in the field of environmental health impact analyses and industrially contaminated sites.

Conflict of interest disclosure: the Authors declare they have no conflict of interest.

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