Methods of health risk and impact assessment at industrially contaminated sites: a systematic review

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ABSTRACT
BACKGROUND: this paper is based upon work from COST Action ICSHNet. Industrially contaminated sites (ICSs) are a serious problem worldwide and there is growing concern about their impacts on the environment and public health. Health risk assessment methods are used to characterize and quantify the health impacts on nearby populations and to guide public health interventions. However, heterogeneous methods and inconsistent reporting practices compromise comparability risk and impact estimates.

OBJECTIVES: to review the literature on assessment of the adverse health effects of ICSs. Specifically, we:
• collect published, peer-reviewed literature addressing health assessment of ICSs;
• identified and evaluated the methods and tools for the assessment of health impacts related to ICSs;
• analysed the methods and tools used in different conditions;
• discussed the strengths and weaknesses of the identified approaches;
• presented an up-to-date understanding of the available health risk and impact assessment in ICSs. In addition, the terminologies were described and harmonization was proposed.

METHODS: we systematically searched PubMed and Web of Science to identify peer-reviewed reviews and original studies from January 1989 to December 2017. We used a qualitative approach for analysing the different elements (type of ICSs, Country of research, active years of working, distance from sources, pollutants, affected population, methods and tools, health outcomes, main founding, method stage, dose-response assessment, risk characterization) of included studies. We divided risk assessment methods used in the papers into four stages: semi-quantitative, quantitative, health impact, and health burden stage.

RESULTS: a total of 92 relevant original papers at ICSs were found and analysed. In current practice, the health risks have been characterized mainly as hazard quotients or hazard indexes (23 studies), and as cancer risk probabilities (60 studies). Only 8 studies estimated the number of cases and one study evaluated years of life lost.

CONCLUSION: hazard quotients and cancer probabilities are suitable for semi-quantitative and quantitative personal risk estimation, respectively. More comparable risk characterization on public health level requires specificity on the type of outcome and corresponding number of cases. Such data is needed for prioritization of action at low to medium risk sites. We found limited amount of studies that have quantified the health impact at industrially contaminated sites. Most of the studies have used semi-quantitative risk characterization approaches and the adopted methods are mostly of toxicological origin, while epidemiological analysis is almost lacking. There is a need to improve quantitative risk assessment and include health impact and environmental burden of disease assessments at ICSs.

Keywords: health risk assessment, health impact assessment, contaminated sites, impact assessment, industry, methods

KEYPOINTS
What is already known
■ Health risk assessment extrapolating from exposures is the fastest way to health risk characterization.
■ Since the health risk assessment paradigm formulation in the 1980’s, the methods have been applied also at contaminated sites.

What this paper adds
■ This paper presents a summary of methods applied at contaminated sites as they have been reported in the peer-reviewed literature and proposes a way forward.
■ Development of burden of disease methodologies proposes substantial benefits towards more comparable presentation of risks.
■ In the future, it would be necessary to follow-up the development of health risk assessment and health impact assessment, especially in conjunction with industrially contaminated sites; the researchers in this field should harmonize terminology.
INTRODUCTION

Population exposure due to industrially contaminated sites (ICSs) is a global environmental health problem. Contaminated sites result from past and present industrial activities, including the operation of factories, mines, smelters, electrical power plants, and other production facilities, municipal and medical waste incineration plants and harbours. The term ‘contaminated site’ may, however, have different meanings. The World Health Organisation (WHO) gives a general operational definition of contaminated sites, based on a public health perspective, as “areas hosting or having hosted human activities which have produced or might produce environmental contamination of soil, surface or groundwater, air, and food chain, resulting or being able to result in human health impacts”. Given this definition, an area affected by a single chemical contamination of a single environmental matrix (e.g., the soil contamination caused by a given pesticide) and a large area with soil, water, air, and food chain contamination by multiple chemicals (e.g., the contamination caused by long-term emissions of a petrochemical complex) can be both considered contaminated sites.

Industrial activity often results in soil contamination, which has been recognized as a serious problem requiring immediate actions. In Europe alone, the European Environment Information and Observation Network for Soil (EIONET-SOIL) has recorded 342,000 sites with contaminated soil and, in addition, over two million sites are suspected for potential contamination. The number of contaminated sites can globally be expected to be millions since limited data are yet available for Eastern Europe, Africa, South America, Asia, and for key countries such as China and India.

According to the European estimates, industrial production and commercial service are the main cause of soil contamination (41.4% of identified sites), followed by municipal waste treatment and disposal (15.2%). Main contaminants include mineral oil (33.7% of contaminated sites) and heavy metals (37.3%), followed by polycyclic aromatic hydrocarbons, toxic volatile organic compounds, and chlorinated hydrocarbons. It has to be acknowledged that the environmental performance of the European industry has improved in the last decades in terms of reducing emissions; however, the sector is still responsible for significant amounts of pollution to air, water, and soil, as well as generation of waste.

An estimated 40 million Americans live within 6.4 km (4 miles) of contaminated sites (superfund sites, formally called comprehensive environmental response, compensation and liability act) requiring a long-term response to clean up hazardous material contaminations in the USA. About 11 million people live within 1.6 km from these superfund sites, 3 to 4 million of them are children under 18 years of age. The amount of European population living close to contaminated sites is also large, as on average there are 5.7 contaminated sites (CSs) per 10,000 inhabitants, based on soil contamination data. In Italy, for instance, approximately 5.5 million people reside in 44 contaminated sites of national concern for environmental remediation, and about one million are younger than 20 years. A broad range of health effects have been associated with living near contaminated sites and/or exposure to pollutants, such as cancer, acute bronchitis, asthma, cardiovascular disease, increased allergies and congenital anomalies. The WHO estimated that 12.6 million deaths globally, representing 23% of all deaths in 2012, were attributable to the environmental risk factors. Industrial contamination causes complex multipollutant exposures, potentially with acute and long term adverse health effects. However, the assessment of possible health impacts related to ICSs entails considerable challenges. The challenges arise from the complex exposure patterns at ICSs, which are often situated close to urban and/or socially deprived areas. Additionally, exposure often refers to multiple pollution sources and a mixture of pollutants. The health conditions associated with ICSs have multifactorial aetiology, and the interactions with risk factors from the social environment (lifestyle) are largely unknown. For the assessment, the relevant exposures and associated endpoints must be known. Often available data are less than optimal and determine which methods can be used. The choice of pollutant and endpoint may also be influenced by the availability of regulatory benchmark concentrations (or doses) or dose response data. These data are essential to estimate the potential impact of exposure and magnitude of effect. A lot of studies about the health impact (HIA) or risk assessment (HRA) of the ICSs have been done, and a variety of methods and tools have been used. Many studies and assessments concern air pollutants, while investigations on the contribution from soil and water contamination, as well as those related to food chain, are less represented in the scientific literature. Moreover, there is scarce application of suitable approaches to face the complex exposure scenarios associated with mixtures of hazardous chemicals in different environmental media that typically characterise many industrial contaminated areas. Therefore, it is necessary to identify and evaluate the methods and tools adopted in these studies. In response to these environmental health challenges, the COST Action IS1408 on Industrially Contaminated Sites and Health Network (ICSHNet) has been launched. The Action, which involves researchers and experts from 33 Coun-
tries, is centred on developing a common European framework for research and response on environmental health issues in industrially contaminated sites, and establishing a European network of experts and institutions involved in assessing the health impacts and/or managing remediation and response. This scientific review has been inspired by the Action objectives, and contributes to the identification of suitable methodologies for characterising the potential risks and impacts on health in ICSs that can fit to data and resources available in different regions and ICS scenarios across Europe and beyond.

HRA is the process to estimate the nature and probability of adverse potential health effects (current or future) in humans who may be exposed to hazardous chemicals in contaminated environmental media, in the past, now or in the future. It includes 4 basic steps:

- **Hazard characterization**: the evaluation of scientific information on the hazardous properties of environmental agents;
- **Dose-response assessment**: examines the numerical relationship between exposure and effects;
- **Exposure assessment**: the extent of human exposure to those agents;
- **Risk characterization**: the product of the risk assessment is a statement regarding the probability that populations or exposed individuals will be harmed and to what degree.

Risk characterization is the final and very important step of the HRA. It is to summarize and integrate information from hazard assessment, dose-response assessment, and exposure assessment, to synthesize an overall conclusion about risk.

This step of HRA involves combining the exposure quantities, the toxicity benchmarks available, to calculate the excess lifetime cancer risks (risk) and non-cancer hazards (hazard) for each of the pathways and receptors identified. According to the definition from the WHO Gothenburg Consensus Paper from 1999 HIA is “a combination of procedures, methods, and tools by which a policy, program, or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population.” It aims to produce the information that will help decision-makers to make choices that promote health and minimize the negative health outcomes. HIA is usually consisting of six steps:

1. **Screening**: define if HIA is needed;
2. **Scoping**: identify the health impacts;
3. **Assessment**: identify the affected population and quantify the magnitude of positive and negative impacts;
4. **Recommendation**: strategies to manage health impacts;
5. **Reporting**: communication of findings and recommendations;
6. **Monitoring and Evaluating**.

None of the identified 12 previous review papers summarized the overall risk assessment methods (see section S1 in the on-line supplementary material).

The overall objective of our work was to create an up-to-date summary of HIA and HRA methods as applied to ICSs in Europe and globally. To do this, we conducted a systematic search of original studies on quantitative HRA and HIA in industrially contaminated sites. Specifically, we wanted to identify, describe, and evaluate methods used in quantification of health risks and impacts. We discuss the strengths and weaknesses of the identified approaches, classify the studies by contamination type, by pollutants, region/continent, and finally give recommendations on developing and applying the identified methods towards quantitative health impact.

## Methods

### Strategy Study Selection Criteria and Process

A systematic literature review was conducted in PubMed and Web of Science. English language articles published from January 1989 to December 2017 were included. Search terms were developed to identify studies by outcome and sources of pollution (contaminated sites) (table 1). To limit the number of occupational and worker’s health studies, these terms were used as exclusion criteria. As a result of the original searches conducted on December 6th, 2017, a total of 325 papers in PubMed and 180 in Web of Science were identified (figure 1). After title and abstract screening and full-text review, 92 original articles are included in the final analysis (see the list of references of the original papers and on-line supplement 3 on study characteristics).

<table>
<thead>
<tr>
<th>Selectors</th>
<th>Search Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Outcome</strong></td>
<td>#1 (assessment AND health)</td>
</tr>
<tr>
<td><strong>Sites</strong></td>
<td>#5 (polluted sit* OR contaminated sit* OR industrial sit*)</td>
</tr>
<tr>
<td><strong>Exclusions</strong></td>
<td>#7 (occupational OR worker OR worker OR miners)</td>
</tr>
</tbody>
</table>

### Table 1. Search terms used in definition of the search strategies in PubMed and Web of Science.
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In the screening, the original papers were sub-grouped by site types. Almost half of the studies were conducted at mining sites (42 studies), followed by heterogeneous group of different types of industries, including five cement plants, a chromate plant, a coking plant, an electronic appliances factory, a fertilizer plant, a glasswork, a harbour, three metal smelters, three refineries, a power plant, an organic chemical plant, and twelve industrial complexes.

SUMMARY OF THE MATHEMATICAL METHODS
Risk assessment methods applied in the papers were grouped into four stages (table 2, box 1). On the first level (stage 1, eq. 1a-b), the exposures or doses are compared with corresponding reference levels to produce a hazard quotient. Stage-2 methods estimate risk probabilities (eq. 2) using, e.g., cancer slope factor (CSF), cancer risk factor (CRF) or unit risk factor (UR, URF), typically per lifetime exposure of an individual. These approaches at stages 1-2, originating from the US Environmental Protection Agency (EPA),11-14 do not typically report the type of health impact (non-cancer endpoints) or type of cancer (i.e., results are expressed as any cancer or total cancer).

Accounting for the size of the exposed population in addition to the risk probability and potentially the background incidence of the endpoints, it is possible to es-

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**Table 2.** Grouping of methods used to characterize the health risk and impact.

<table>
<thead>
<tr>
<th>STAGE</th>
<th>INFORMATION NEEDED</th>
<th>OUTPUTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Semi-quantitative</td>
<td>Reference level</td>
<td>None</td>
</tr>
<tr>
<td>2. Quantitative</td>
<td>Cancer slope</td>
<td>None</td>
</tr>
<tr>
<td>3. Health impact</td>
<td>Relative risk</td>
<td>Incidence rate</td>
</tr>
<tr>
<td>4. Health burden</td>
<td>“-”</td>
<td>+ life expectancy</td>
</tr>
</tbody>
</table>

**BOX 1. MATHEMATICAL APPROACHES USED IN HEALTH RISK ASSESSMENT**

**Semi-quantitative methods generally used for non-cancer risks**

Hazard quotient; exposure, reference level

\[
HQ_i = \frac{E_i}{Rf_i}
\]

- HQ: hazard quotient
- E: exposure
- Rf: reference level

Hazard index (cumulative over hazard quotients)

\[
HI = \sum HQ_i
\]

- HI: hazard index
- HQ: hazard quotient

**Quantitative risk**
Especially cancer risks are typically estimated as cancer probability

\[
P = E \times UR
\]

- P: probability
- E: exposure
- UR: unit risk

**Number of cases (HIA)**
Unit risk model for attributable incidence (cases)

\[
AI = E \times UR \times N
\]

- AI: attributable incidence (No. of cases)
- E: exposure
- UR: unit risk
- N: population size (persons)

**Attributable incidence (cases)** (excess risk approach)

\[
AI = (RR_E - 1) \times BR
\]

- AI: attributable incidence
- RR: relative risk of exposed population
- BR: background rate

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1. Semi quantitative risk (HQ)
   - MINE: 18
   - FACTORIES*: 4
   - INCINERATOR**: 0
   - LANDFILL: 1
   - STUDIES: 23

2. Cancer risk probability (p)
   - MINE: 21
   - FACTORIES*: 26
   - INCINERATOR**: 6
   - LANDFILL: 7
   - STUDIES: 60

3. Health impact (n)
   - MINE: 0
   - FACTORIES*: 0
   - INCINERATOR**: 1
   - LANDFILL: 0
   - STUDIES: 1

4. Health impact (YLL)
   - MINE: 0
   - FACTORIES*: 0
   - INCINERATOR**: 1
   - LANDFILL: 0
   - STUDIES: 1

Original studies by site type
- MINE: 42
- FACTORIES*: 31
- INCINERATOR**: 11
- LANDFILL: 8
- STUDIES: 92

* Including ten types of industries and industrial complexes (see the "Methods" section for details).
** Several incinerator studies included also landfill sites.

Table 3. Original studies grouped by mathematical methods and by site types.

GROUP
- Criteria air pollutants and inorganic substances
- Metals
- Dioxins and furans (PCDD/Fs)
- Chlorinated monocyclic aromatics
- Polycyclic aromatic hydrocarbons (PAHs)
- Volatile organic compounds (VOCs)

POLLUTANT
- Nitrogen dioxide (NO₂), particulate matter 10 micrometers or less in diameter (PM₁₀), particulate matter 2.5 micrometers or less in diameter (PM₂.₅), sulfur dioxide (SO₂), total suspended particles (TSP), asbestos, cyanide, hydrogen chloride (HCl), hydrogen fluoride (HF)
- Aluminium (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), chromium (Cr), copper (Cu), cobalt (Co), gold (Au), lead (Pb), lithium (Li), iron (Fe), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), phosphorus (P), scandium (Sc), silver (Ag), selenium (Se), strontium (Sr), thallium (Tl), tin (Sn), titanium (Ti), uranium (U), vanadium (V), zinc (Zn)
- Acenaphthylene, acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)fluorine, benzo(b)fluorine, benzo(g,h,i)perylene, benzo(e)pyrene, chrysene, dibenz(a,h)anthracene, dibenz(e,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, perylene, phenanthrene, pyrene, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene
- Acetaldehyde, benzene, biphenyl, bromodichloromethane, bromomethane, dichlorodifluoromethane, dichloroethene, 1,1-ethylbenzene, ethylene dibromide (1,2 dibromoethane), formaldehyde, tetrachloroethylene, toluene, trichloroethylene, 1,1,2-vinyl chloride (chloroethene), xylenes, m-, p- and o-bromofluoromethane, carbon tetrachloride, chloroform, dichloromethane, o-terphenyl, trichloroethene, 1,1,1-trichlorofluoromethane

Table 4. Total of 95 pollutants divided into six groups considered in the original papers.

HEALTH ENDPOINTS
- NON-SPECIFIC CANCER:
  - Any cancer
  - Lung cancer
  - Mesothelioma
- SPECIFIC TYPE OF CANCER:
  - Lung cancer
  - Mesothelioma
- NON-SPECIFIC OUTCOMES:
  - Non-cancer
  - Morbidity
- SPECIFIC NON-CARCINOGENIC OUTCOMES:
  - acute bronchitis
  - asthma
  - cardiovascular effects
  - congenital anomalies
  - chronic obstructive pulmonary disease
  - developmental risks
  - haematological effects
  - irritation of the respiratory system
  - low birth weight
  - neuro-behavioural effects
  - renal effects
- MORTALITY OUTCOMES:
  - Mortality
  - YoLL

Note: see the separate list of references of the original papers; see S3 on line supplementary material to consult the characteristics of the original studies.

Table 5. Health endpoints covered in the 92 original studies with some examples of pollutant associations.
timate the number of cases (stage 3; eq. 3). Finally, for premature mortality outcomes, the fourth stage estimates the number of life years lost (eq. 4).

We used qualitative approach for analysing the different elements of included studies: type of ICSs, Country of research, active years of working, distance from sources, pollutants, affected population, methods and tools, health outcomes, main founding, method stage, dose-response assessment, risk characterization.

RESULTS AND DISCUSSION
In the articles, we identified the mathematical methods. The most often applied method was characterization of cancer risk as probability (60 studies; 65%) (table 3). Second largest number of studies characterized non-cancer risks using hazard quotient and hazard indexes (23 studies; 25%) (table 3). HIA has been reported only in a small fraction of articles (10%). Number of cases of identified disease or endpoint was estimated in eight studies (9%). Stage 4 assessment, which includes the application of WHO’s burden of disease methodology, has been reported only once. The study quantified the health impact of premature all-cause mortality as number of years of life lost.23

Almost all the studies followed US EPA for the characterization of the health risk at ICSs, and characterized toxicity with cancer slope factor and reference doses from Agency for Toxic Substances and Disease Registry (ATSDR) and International Agency for Research on Cancer (IARC), 2 study in Europe also compared WHO office for air quality.24, 25 Uddh-Soderberg et al. used the reference from Swedish EPA.26 For carcinogen pollutants, risk estimates represent the incremental probability that an individual will develop cancer over a lifetime as a result of a specific exposure to a carcinogenic chemical.9

DIFFERENT SITE TYPES
The original studies were divided into four groups by the type of industrial contamination. Largest group consists of mining sites (42 original studies), followed by different types of factories and industrial complexes (31 original studies), industrial and municipality waste incinerators (11 original studies), and landfill sites (8 original studies) (table 3). Various types of industries and industrial complexes were associated with industrial contamination in the identified studies: cement plants (4 studies), chromate plants (1 study), coking plants (1 study), electronic appliances factories (1 study), fertilizer plants (1 study), glassworks (1 study), metal smelters (2 studies), chemical plants (1 study), refineries (2 studies), power plants (1 study), other industrial areas (8 studies).

The identified studies originated from nearly all continents. Best represented was Europe, covering nearly all the different site types with 35 studies (38%), except some heterogeneous group of different types of factories. Over 90% of the incinerator studies were performed in Europe and about 74% of the mining studies come from Africa (21%) and Asia (55%). This geographical imbalance may be partly responsible for the corresponding site type specific differences in the mathematical methods applied: 78% of the mining site studies applied hazard quotient methods, while none of the incinerator studies did.

Pollutants at industrially contaminated sites
Given the similarity between contaminating industrial activities in the same site type, they have the most prevalent pollutants in common (table 4) (see table S3.1 and S3.2, on-line supplementary material). For mines, the main assessed contaminants are metals. Of the 42 studies about mines, 28 studies evaluated the health risk of lead; 27 studies evaluated arsenic and cadmium, followed by copper, zinc, chromium, nickel, mercury, cobalt, manganese, iron, vanadium, barium, and molybdenum. Asbestos, cyanide, and polycyclic aromatic hydrocarbons (PAHs) was evaluated by 1 study, respectively. For incinerators, the main contaminants assessed were dioxins and some heavy metals (such as cadmium, mercury, lead, nickel, and arsenic), together with particulate matter 10 micrometres or less in diameter (PM_{10}) and PAHs. Common pollutants assessed in landfills are volatile organic compounds (VOCs), dioxins, PAHs, and some heavy metals (such as lead and chromium). As two studies of cement plants belong to Spain, the contaminants assessed are similar as dioxins, PM_{10}, nitrogen dioxide (NO_{2}), sulphur dioxide (SO_{2}), and metals. Both one study for glassworks and one for fertilizer plants selected arsenic as a main contaminant to assess the health risk.

Most studies looked at pollutants in soil, 25 studies based only on soil, and 33 studies analysed mixture environmental media samples including soil. Nine of the latter studies included vegetables and fruits. Metals were the most evaluated pollutants at mines. 15 studies investigated only air and 10 studies only water. For waste and recycling sites, air pollutants were often evaluated. Three studies evaluated sediment samples, 1 study house dust, and 2 studies road dust. Only 2 studies collected biomonitoring (hair and urine) samples.

Health endpoints assessed in the original papers
Health effects related to the site contamination depend on the nature of the contaminant, the level of exposure, and the vulnerability of the individual affected.27 The

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health endpoints used in the studies usually expressed as cancer or non-cancer, while a few studies also specify as any cancer, lung cancer, and mesothelioma; acute bronchitis and asthma (table 5).

TERMINOLOGY
The terminology used in the identified studies may be at places ambiguous or using slightly different terms for similar meaning, as shown by these examples for exposure/dose, toxicity/carcinogenicity, and resulting risk. Chronic daily intake (CDI) is used to estimate the intake (via ingestion) of a chemical during a specific time period and lifetime average daily dose (LADD) for carcinogenic chemicals to take the lifelong effect into account. US EPA uses terms slope factor seemingly synonymously with cancer slope factor. Similar terms used in the studies include cancer slope factor (CSF), which is used to calculate ingestion cancer risk, and unit risk factor (URF) or inhalation cancer risk calculation, and the term was harmonized by WHO as slope factor (SF) for oral slope factor and slope factor in relation to a concentration of a chemical in air or in water. Cancer risks are expressed using terms such as incremental lifetime-risk, individual lifetime excess risk, excess lifetime cancer risks, total carcinogenic risks (TCR), individual cancer risk (ICR), lifetime cancer risk (LCR), incremental lifetime cancer risks (ILCR), individual risk (IR), annual incremental risk, and individual excess cancer risk (IECR). For a summary of terms used in the original papers see on-line supplementary material S2.

LIMITATIONS AND RECOMMENDATIONS
Current work collects, discusses, and reviews different methodological approaches to HRA and tries to build a basic methodological approach to conduct HRA. Nevertheless, it is conceivable that a number of scientific papers have been published in journals which are not indexed in PubMed or Web of Science or they used a different terminology than HRA and consequently were not included in this review. HIA method stages 1 and 2 are often required by the legal framework for ICSs and might not be reported in scientific articles, but in administrative reports. Peer-reviewed scientific publications are necessary for developing the field and should be encouraged. Overall, a positive trend emerged with increasing numbers of studies published in peer-reviewed journals in recent years. From the included studies, only 22% (21 out of 92) were published before 2010, while 53% (49 out of 92) were published between 2015 and 2017. Data availability may dictate which identified methods can be used for HRA since the data needs increase from stage 1 to 4. Stages 1 and 2 require only exposure (or concentration or dose) information and related reference values, which are routinely available from databases. Stages 3 and 4, however, also require incidence data, which may not be routinely available for the contaminated area. HIA would greatly benefit from routine collection of morbidity/mortality information in combination with spatial information. Cancer registers are well established in many high-income Countries and can serve as an example for routine collection of such required data. In the future, it would be necessary to follow up the development of the HRA and HIA, especially in conjunction with ICSs. The researchers in this field should prepare the set of some rules suggestions for the use of terminology.

Contaminated sites may also produce unpleasant odours which should also be considered as one of the pollutants at ICSs. The obnoxious odours generated from industries are a complex mixture of gases present at higher concentrations, dust, and vapours. Odour emissions may be difficult to quantify objectively. Odour nuisance may also have direct and indirect impacts on health. Among the symptoms caused by unpleasant odours, there are the symptoms of classical stress response, nausea, fatigue, irritations (eyes, nose, and throat), sleep disturbance, and inability to concentrate. Application of environmental burden of disease methods, including preclinical, or perceived, health endpoints, such as odour, headaches, cognitive performance, as well as effects in sensitive time windows and health consequences later in life should be promoted for better comparability and more complete understanding of the health implications.

CONCLUSIONS
The present report is, to our knowledge, the first systematic review on health risk and impact assessment methods related to industrially contaminated sites. Systematic search of HRA methods at ICSs produced a total of 92 original papers published between 1989 and 2017 covering waste, incinerator, mining, and a group of various types of industrial sites. The most commonly used type of risk characterization was lifetime risk probability of (any) cancer, followed by hazard quotients and indexes. Only eight studies estimated the number of cases, including preclinical, or perceived, health endpoints, such as odour, headaches, cognitive performance, as well as effects in sensitive time windows and health consequences later in life should be promoted for better comparability and more complete understanding of the health implications.
characterization. A parallel review is conducted on summarizing the epidemiological approaches used in the literature to be published in this same issue (De Sario et al.; pp. 59-68).

While the basic methods used were mathematically identical, the terminology used in different contexts was extremely heterogeneous and will benefit from harmonization. In this study, we did not analyse and compare the estimated magnitude of health risks by different pollutants, endpoints or site types. This would be a meaningful follow-up approach.

The results of this work contribute to address the main objective of ICSHNNet COST Action which is the identification of sound methodologies for health risk and impact assessment in the development of guidance documents on how to face the heterogeneous environmental health scenarios of ICS across participating Countries.

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