Industrial contaminated sites and health: results of a European survey

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Abstract

BACKGROUND. Industrially contaminated sites (ICSs) have been recognised as a major public health concern since they involve exposure to multiple environmental stressors, normally distributed unevenly within population. The COST Action on *Industrially Contaminated Sites and Health Network* (ICSHNet) comprises a European network of experts and institutions to clarify needs and priorities for better characterizing the impact on environment and health of ICS.

OBJECTIVE. Collecting and evaluating available data and experiences regarding ICS in participating countries within the network, with particular consideration to availability of environmental, health and demographic data.

METHODS. To evaluate the availability of data an Action Questionnaire (AQ) was developed based on previous questionnaires used in different European projects, and an expert consultation. The AQ, with 84 items organised in eight sections, was adapted to an online version using the software ñlime surveyò. The survey was sent to 47 participants within the ICSHNet, over a list of 99 ICS previously identified.

RESULTS. Information was gathered from 81 ICS from the initial 99, corresponding to 82% of participating countries in the ICSHNet. The predominant polluting activities were waste disposal (45.7%) and chemical industries (37%), affecting all environmental media but more extensively surface and groundwater (70%) and soil (68%). Main categories of contaminants affecting different media were heavy metals and chlorinated hydrocarbons, but also BETX and ambient air pollutants (e.g. particulate matter, SOx). Human health risk assessment was the most prevalent methodological approach for characterising impacts on health (32%), followed by epidemiological studies (26%), and health impact assessment (12.3%). For many aspects, both related to data availability or methodologies, respondents did not answer or were not sure how to reach that information.

CONCLUSIONS. Survey findings suggest that additional data collection and reporting efforts are required to meet the methodological requirement to better analyse the health impact of ICS.

Key words

Industrially contaminated sites (ICS), data availability, human health risk assessment, health impact assessment, environmental epidemiology

Key points

What is already known:

- Industrially contaminated sites (ICSs) remains a significant source of environmental pollution, and a lasting cause of preventable non-communicable diseases, with important inequalities in exposure within the population.
- The theme of waste and contaminated sites has been recently recognized as one of seven priority areas for the European policy agenda in environmental health (Ostrava Declaration), with emphasis in preventing and eliminating associated health risk and health inequalities
- Evaluating data availability within ICS is a priority for defining best methodological approaches that allow characterising health impacts of ICS.

What this paper adds:

- This paper identifies a set of issues that risk assessment programs on ICSs should address.

- Improving the collection and access to specific environmental, health and demographic data related to ICS is crucial to meet the methodological requirement to better analyse the health impact of ICS.
- Promoting a strong interdisciplinary approach would be required, with greater collaboration and sharing of data and expertise between environmental and public health experts.
- Accurate measurement of health outcomes, including breakdown of outcomes for different sub-population groups, is an important methodological consideration for responding to ICS

Introduction

The term "contaminated site" is included in Article 3 of Regulation (EC) No1272/2008[1], and refers to sites where hazardous substances are present in a level that pose a significant risk to the environment and human health. The concept of polluting activities, as recorded in the Proposal of a Soil framework Directive[2], refers to certain installations and industrial activities that are damaging the capacity of soil to perform in full its broad variety of crucial functions[3]. These concepts, though extremely important, address the soil dimension of the problem, while air, water and food-chain contaminations are also relevant aspects of the multifaceted nature of many industrial polluted areas that deserve to be dealt with an integrated approach.

Environmental regulation and improved pollutant abatement technology, among other factors, have led to decreasing environmental pollution in Europe, especially referring to air and water quality, but industrial activity still remains a significant source of contamination (mainly from hazardous substances)[4] that can seriously affect human health[5]. Industrial related air pollution include greenhouse gases (e.g. carbon dioxide, nitrogen oxide pollutants), but also sulphur oxides (SO_x), particulate matter, non-methane volatile organic compounds and heavy metals. Surface and ground water can be affected by chemicals that contain nutrients such as nitrogen and phosphorous causing eutrophication, and also by trace elements (including heavy metals) and chlorinated hydrocarbons. Soil contamination as a result of industrial activity is less documented but encompasses heavy metals, mineral oils and a host of different types of hydrocarbons with potential relevance to human health, including known or suspected carcinogenic, teratogenic and/or endocrine disrupting capacity[4, 6]. In fact, exposure to mixtures of chemicals of toxicological interest, typically found on Industrial Contaminated Sites (ICS), has been associated with a broad range of different health outcomes: the body of literature is large and systematic reviews on the impact of ICS are available[7-13]. On the other hand, a recent review on scientific evidence conducted in the WHO European Region highlighted that the analysis of exposure and health risk from ICS by socioeconomic/demographic characteristics, and according to mechanisms of their generation and maintenance, is in its early stages with the exemption of the UK[14].

In recent years, networking, research initiatives, and scientific literature on industrial contamination and health has increased, following the need to acquire evidence for risk management and policy actions[15]. In this respect many ICS need to adequately address issues such as contamination related health risks, the prioritization of efforts for remediation, cost-effectiveness of actions promoting public health. This information could be relevant for prioritising actions and research agendas in the future allowing progress in improving the characterisation of the health impact of populations living close to ICS.

The COST Action on *Industrially Contaminated Sites and Health Network* (ICSHNet) (https://www.icshnet.eu/) was launched in 2015 with the general aim to establish a European network of experts and institutions involved in assessing the health impacts and/or managing remediation and response in ICS. Additionally, it aims to clarify needs and priorities, by collecting and evaluating available data and experiences throughout Europe. The ICSHNet involves in overall about 150 researchers and experts from public health institutions, universities, and environmental agencies from 33 countries plus official support from the World Health Organisation (WHO) and European Commission with DG Joint Research Centre and DG Environment.

The aim of this paper, as part of the main goals of the ICSHNet, was to evaluate the availability of information and studies concerning selected ICSs in participating countries within the network, with particular consideration on the accessibility to environmental, health and demographic data, and research and assessment tools.

Materials and Methods

A recent report on the *Status of local soil contamination in Europe* reveals the possible existence in all 28-EU Member States of around 2.8 million sites where polluting activities took or are taking place, with more than 650.000 sites identified and registered in national and/or regional inventories[3]. The evaluation under study was not feasible for all known ICSs among the 33 countries participating in the ICSHNet, and a shortlist of sites at country level was obtained. This list did not aim to identify national priority sites, nor priority settings across Europe. Rather, the proposed list of ICS intended to gather a wide variety of examples for evaluating the capacity across countries to deal with ICS-related environmental health issues. With this purpose, all participating countries within the COST ACTION were invited to list up to five sites per country based on the operational definition adopted by the ICSHNet, and certain selection criteria. This definition, based in a previous one established by WHO[15], consider ICS as "areas hosting or having hosted industrial human activities which have produced or might produce, directly or indirectly (waste disposals), chemical contamination of soil, surface or ground-water, air, food-chain, resulting or being able to result in human health impacts".

The ICS proposed by partners within the ICSHNet were also requested to fulfil one or more of the following criteria:

- POLICY RELEVANCE. Sites for which citizens, politicians, environment and health experts, scientists, media and other interested parties, raised concern.
- AVAILABLE EVIDENCE. Sites for which local environmental contamination by industrial activities has been documented as dangerous or potentially dangerous for the possible health effects
- EXTENT OF EXPOSURE. Sites involving large or in any case non-negligible size of the population directly affected by the contaminations – exposed or potentially exposed in the neighbourhood of the contaminated sites.

A list of 99 ICSs from 30 countries was generated at the end of 2017.

To evaluate the availability of data and studies concerning the 99 ICSs an Action Questionnaire (AQ) has been implemented (Supplementary material). The design of AQ was first drafted on the base of previous questionnaires for data availability conducted in different European projects (e.g. APHKEKOM research project for the characterization of the impact on health of ambient air[16] or the Guidelines for the collection of contaminated sites data through European Environment Information and Observation Network (EIONET)[17]). The proposed draft of the questionnaire was then submitted for a consultation with environmental and health experts participating in the ICSHNet. The AQ consisted of 84 items organised in the following eight sections: 1) industrial activities operating at the ICS, 2) data regarding environmental pollution of different media and main categories of contaminants monitored by type of media, 3) population data, 4) exposure assessment conducted at each site, 5) health data, 6) health studies, 7) communication strategies, and 8) available references.

A cover letter explaining the purpose and structure of the survey was sent to ICSHNet delegates, together with a privacy policy statement to clarify that that no personal information or site-specific information were going to be revealed or made public individually.

The AQ was adapted to an online version using the software ĩlime surveyò (http://www.limesurvey.org), an open source tool that allows branching and recovery of partially or completed questionnaires. The survey was hosted at the Andalusian School of Public Health servers, and managed by two professionals from this institution who were available for answering any enquiry participants might have. The survey was piloted before its launch and tested for language, workflow, and accurate interpretation of questions by six experts of the ICSHNet who had not participated in the development of the questionnaire itself.

In the process of identifying the short list of ICS, participants were invited to propose a reporting person for each single site; even do this person could contact other experts in their institutions, regions or country for gathering information about certain specific sections they did not feel so expert about. The survey with 99 sites was addressed to a list of 47 participants within the ICSHNet.

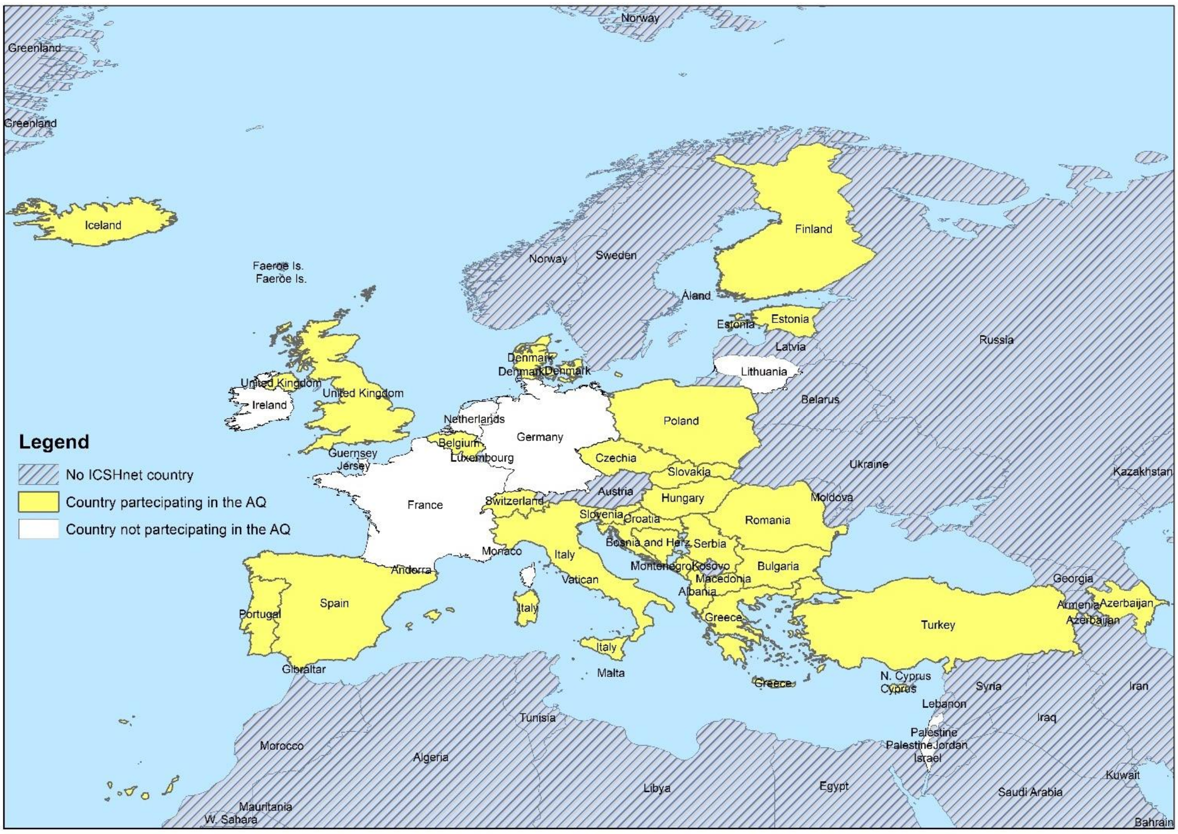
The survey was launched on 22nd February 2018, being accessible until 15th July 2018. Each site was assigned to one single reporter with a code/password for entry that was used together with their email address to identify potential duplicate entries from the same sites. No further personal information from participants was recorded, and the brief analysis of participantðs profile (institution they work for) was extracted from the reported information in the COST Website. Participants were able to review and change their answers before submitting the final version of the questionnaire.

Data analysis was conducted using R.5.3.1 software.

Results and Discussion

Information was gathered from 81 sites out of the initial 99, reported by 45 participants from 27 countries, which corresponded to 82% of all countries integrated in the ICSHNet. Figure 1 shows the geographical distribution of countries participating in the survey.

Figure 1: Geographical distribution of countries participating in the ICSHNet survey



This survey concerns a very small proportion of sites from the estimated total number of ICSs that exist in the area covered within this network. However, sites were identified based on environmental health and policy criteria and therefore expected to provide an important insight about data and tools availability across Europe for assessing the impact on health of the pollution caused by industrial contamination.

Respondents of this survey worked mainly in the public health sector (22) followed by environmental science (11), medicine (3), agronomy (2), economy (2), occupational health (1) and ethics (1). The majority of them worked in research institutions (56%) followed by national health agencies (36%), national environmental organizations (9%), and regional/local health institutions (2%).

Table 1 shows results referring to the number of main industrial sectors leading to contamination in the ICSs included in the survey, and the percentage that were still operating in the moment of answering. The predominant reported polluting activities were waste disposal (45.7%), followed by chemical industries (37%), metallurgic plants (29.6%), mining industry (23.5%), and electric power plants (16%). Other types of industrial activities listed by respondents included oil refinery, steel plan, petrochemical plants, pharmaceutical industry and oil extraction. Panagos et al. (2013)[18] reported similar findings in the data collection for the indicator CSI015 on "Progress in the Management of Contaminated sites" conducted by the European Soil Data Centre (ESDAC) for the period 2011-2012 with participation of counties involved in EIONET. In that survey, responses from 22 countries also pointed out to waste disposal and industrial activities as the two main sectors leading to pollution (37.2% and 33.3%, respectively). A similar description was also reported in the literature search published by De Sario et al. (2018)[13] over a selection of 655 epidemiological studies from all over the world.

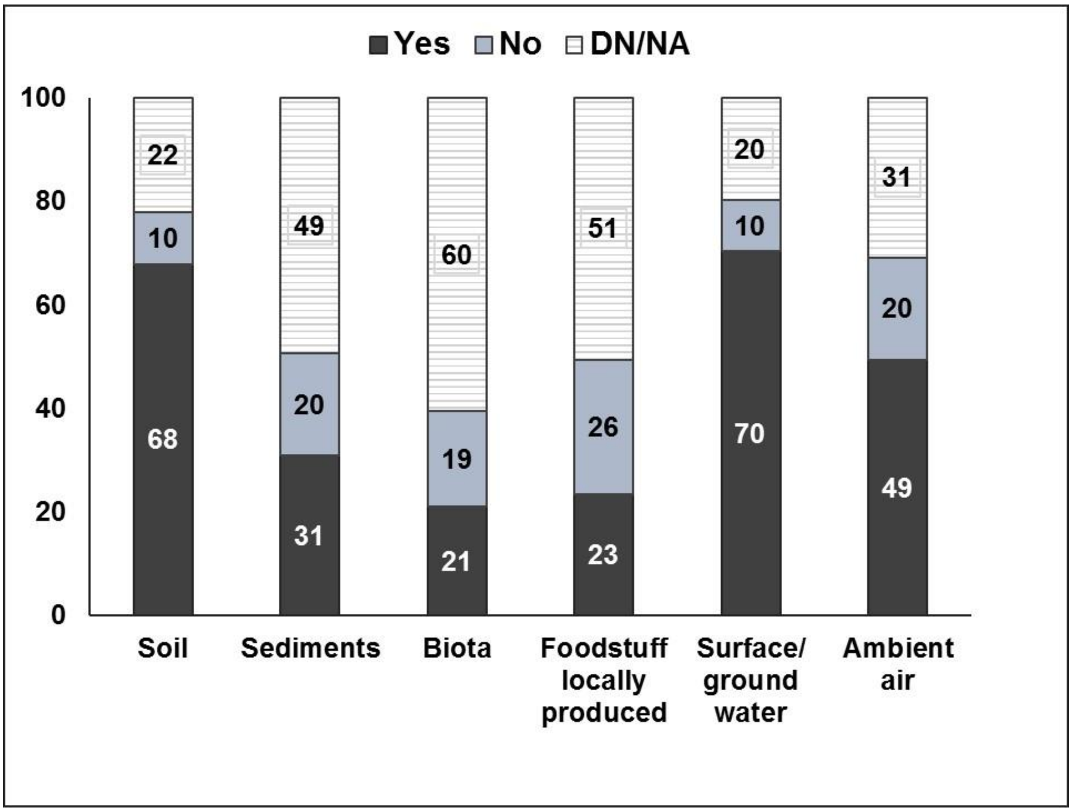
Table 1: Number of main industrial categories reported in the survey and percentage of sites declared to be still operating, and for which there is data available.

Main industrial categories	N	Still operating (%)	Data availability (%)
Chemical industry	30	67	33
Pharmaceutical industry	6	100	33
Petrochemical plant	9	78	44
Oil refinery	11	91	36
Oil extraction	5	40	20
Electric power plant	13	92	54
Steel plant	10	100	60
Metallurgic plant	24	92	33
Waste Disposal	37	65	32
Waste treatment plant	20	70	25
Mining industry	19	63	37
Other	27	40	44

A large proportion of sites in our survey (33/81) were reported to have at least two industrial activities established in the same area, illustrating the complexity and challenges that ICS represent for characterizing the health impacts of the associated environmental contamination[15,19]. All of the reported pharmaceutical industries and steel plants and the majority of the electric power plants, metallurgic plants, and oil refinery sites were still operating at the moment of conducting the survey. Data related to emissions and activity from each main category of reported industrial activity (Table 1) was available only for 60% of the informed steel plants and 54% of the sites with electric power plants, while for the rest such availability was even lower, ranging from 20% for oil extraction and 44% for petrochemical plants.

Figure 2 shows the percentage of sites with different environmental media (soil, sediments, biota, foodstuff locally produced, surface and ground water, and ambient air) reported being polluted due to the presence of any kind of industrial activity. According to this data, polluting activities affected most extensively surface and ground water (70%), followed by soil (68%), and ambient air (49%), with some limited information for sediments, biota and foodstuff locally produced. An important finding in this section was the large percentage of "don't know" reported in many cases (60% regarding data for contamination of biota; 20% related to surface and ground water). This could be due to absence of data, or to the fact that the reporting person (many of them from the public health sector) did not know how to reach that information. A better collaboration between environmental and public health experts is needed as well as a better integration and accessibility to environmental data as reported by Martin-Olmedo et al. (2018)[20] in their review on environmental and health data needed to develop national surveillance systems in ICS.

Figure 2: Percentage of environmental media reported to be polluted over total (N= 81)



DN/DA= sites where reporters didn't know or didn't answer

Participants were asked to report on the main categories of contaminants affecting different environmental media in each ICS, as well as the monitoring frequency of those contaminants (for presentation purposes, such frequency have been summarised as routine or *ad hoc*). Results shown in Table 2 reflect that heavy metals and chlorinated hydrocarbons were the contaminants identified with greater impact in all environmental media, being more relevant in soils and surface and ground waters (76% and 74% for heavy metals, and 40% and 46% for chlorinated hydrocarbons, respectively). Other relevant reported pollutants were arsenic and its compounds, especially in water and air (40% and 45%, respectively) and BTEXT (benzene, toluene, ethylbenzene and xylene). A special mention deserves all main pollutants included in the EU regulation for ambient air quality (e.g. particulate matter, SO_x, etc.) for which there is ample scientific evidence linking human exposure to health effects[21-23]. The legal requirement for establishing local monitoring networks for routine data collection on ambient air quality increases availability of those data, as reported in our survey, with data available for particulate matter (PM_{10} and $PM_{2.5}$) in 83% of all sites, in a 70% for SO_2 and SO_x or in a 65% for NO_x. However, the utility of the data generated by this type of air quality networks in epidemiological studies focussed on ICS is often hampered by the location of the monitoring sites restricted mainly to urban areas, and thereby potentially not covering the population at risk from pollution generated by industrial activity[20, 24]

The percentage for the monitoring frequency of main contaminants (Table 2) indicate that only pollutants subjected to EU regulations either under ambient air quality (e.g. Directive 2008/50/EC[25]; Directive 2004/107/EC[26]), water (e.g. Directives 98/83/EC[27]) or food safety legislation (e.g. Regulation EU 1881/2006[28]), were most frequently monitored on a regular basis. For the rest of contaminants, data collection was conducted by *ad hoc* campaigns, at the best. It seems paradoxical that despite soil being one of the most extensively media affected by almost all reported industrial activities, pollutants detected in this environmental media were only routinely monitored at 33% of the sites. The lack of consensus for the establishment of a soil framework directive at EU, forces that legal quality control standards for the general protection of soil only exist at national levels, with different criteria among countries[15, 18, 29]. Li and Jennings (2017)[30] or Weber et al. (2019)[29] provided information on the very important disparities worldwide in soil regulatory guidance values for many pollutants, showing that the limit value for many of them might vary to above six order of magnitude, compromising the protection of human health, especially in soils with agronomic purposes.

Information on demographic characteristics of population living close to ICS was available for 53 out of 81 sites included in our survey (65%), with around 42% of those having yearly updates. Among the 28% for which frequency of population data was reported as “others”, the majority referred to CENSUS surveys, renewed every 10 years on average. For another 17 sites, respondents informed that no data was accessible, and for 11 that they were not sure how to get that information, if at all available. As expected, age and gender were the most easily accessible information (76% of reported sites with demographic data), followed by ethnicity and socioeconomic position (57% and 45% of cases, respectively), with the following disaggregated type of data: educational level (40%), income (34%), occupation (32%), and household characteristics (32%).

Table 2: Reported number of sites and industrial contaminants by environmental media; frequency* of data reporting (regularly (R) or *ad hoc* (AH))

	SOIL (N= 55)			SEDIMENTS (N= 25)			BIOTA/FOOD (N= 29)			WATER (N= 57)			AIR (N= 40)		
CONTAMINANTS	N	Monitoring (%)		N	Monitoring (%)		N	Monitoring (%)		N	Monitoring (%)		N	Monitoring (%)	
		R	AH		R	AH		R	AH		R	AH		R	AH
Chlorinated Hydrocarbons	22	32	27	10	30	50	7	43	2	26	46	11	8	50	50
Mineral Oil	8	25	25	3	33	0	1	0	0	--	--	--	--	--	--
PAH[1]	18	33	22	8	25	38	5	40	5	--	--	--	--	--	--
Heavy metals	42	33	36	17	18	41	17	35	9	42	36	28	23	48	17
Phenols	11	27	18	6	0	17	1	100	1	--	--	--	--	--	--
Cyanides	4	25	25	1	0	0	1	0	0	--	--	--	1	100	0
BTEX[2]	14	14	29	5	0	20	1	100	1	20	30	10	14	18	0
PCDDs PCDFs[3]	9	33	33	6	33	33	5	60	2	8	38	0	7	8	8
Organophosphorus Comp.	--	--	--	--	--	--	--	--	--	8	50	2	--	--	--
Organotin Compounds	--	--	--	--	--	--	--	--	--	6	67	2	--	--	--
Arsenic and derivate	--	--	--	--	--	--	--	--	--	23	43	9	18	50	28
Biocides and Pesticides	--	--	--	--	--	--	--	--	--	8	50	2	--	--	--
SO_2 and SO_x	--	--	--	--	--	--	--	--	--	--	--	--	28	75	0
NO_x	--	--	--	--	--	--	--	--	--	--	--	--	26	69	4
CO	--	--	--	--	--	--	--	--	--	--	--	--	20	70	0
VOCs[4]	--	--	--	--	--	--	--	--	--	--	--	--	13	62	15
Black carbon	--	--	--	--	--	--	--	--	--	--	--	--	9	33	11
PM_{10}, $PM_{2.5}$	--	--	--	--	--	--	--	--	--	--	--	--	33	61	3
Asbestos	--	--	--	--	--	--	--	--	--	--	--	--	2	50	50
Chlorine	--	--	--	--	--	--	--	--	--	--	--	--	3	100	0
Fluorine	--	--	--	--	--	--	--	--	--	--	--	--	5	80	0
others	13	15	31	0	0	0	4	25	0	5	40	3	9	33	33

* *calculated as a percentage over that declared number*

[1]*PAH*= Polycyclic aromatic hydrocarbon; [2]*BTEX: benzene, toluene, ethylbenzene and xylene;* [3]*PCDDs PCFs= polychlorinated dibenzodioxins and Polychlorinated dibenzofurans;* [4]*VOCs= volatile organic compounds*

Exposure assessment of people living close to the ICS was conducted only in 39 sites, less than half of those surveyed (42%), and when available focused mainly on general population (82.1%) followed by children (53.8%) and workers (38.5%). Two other cases focused on homeless people and on the age group between 20-44 years old respectively. The main categories of contaminants monitored in the informed exposure assessments were heavy metals (71.8%), those encountered in ambient air, mainly particulate matter (56.4%), sulphur (41%) and nitrogen oxide (35.9%), chlorinated hydrocarbons (35.9%) and BTEX (35.9%).

Table 3: Reported number of sites and environmental exposure assessment indicator, and type of dispersion models applied

EXPOSURE ASSESSMENT INDICATOR	N	Percentage*
Distance of residence to ICS	21	54
Environmental sampling	28	72
Dispersion models plus environmental sampling	19	49
Personal exposure measurements (e.g. dosimeters)	7	18
Human biomonitoring	18	46
SOFTWARE USED IN MODELLING	Nº times mentioned	
Atmospheric dispersion modelling	5	
RISC5	3	
Visual MODFLOW	1	
INTEGRA platform	1	
Box model	1	
CLEA	1	
Stata	1	
AIVIRO	1	
IEUBK model	1	

**Percentage were calculated over the total number of declared exposure assessment (N=39)*

Table 3 shows the reported indicators applied for characterising the exposure in the ICS included in this survey. Environmental sampling together with distance of residence to the industrial activity in each site was the most frequently utilised approaches. More precise methods, such as the use of dispersion modelling, biomonitoring or personal exposure measurements were also applied, but in a lower number of sites. A very similar proportion among existing methods for exposure assessment were identified in two recent literature reviews. The first one focused on data availability in surveillance studies conducted by Martin-Olmedo et al. (2018)[20], and the other more specifically centred on methods for exposure assessments used in epidemiological studies conducted by Hoek et al. (2018)[31], both of them in the context of ICSs. Table 3 also records different software used to model exposure in the context of our survey, with atmospheric dispersion modelling being the most frequently reported. Hoek et al. (2018)[31] included in their article a critical analysis of most of these models, as they are frequently used in the context of ICSs in several European countries, although most of them in the framework of soil.

According to the respondents in our survey, the availability of health data for population close or near ICS is frequently low, being reported as available only for 30% of sites for mortality data and 21% for morbidity information (Table 4). For an important proportion of sites, such data sets were reported either as not existing or participants did not know how to reach that information. For both health indicators, information was available mostly at municipal level, although for some sites, data was also accessible at individual level. When available, the diagnosis of relevant health outcomes (cause of death or disease) was reported for most of sites (94% for mortality and 83% for morbidity data), with information stratified by age and gender, between a 70-52% by places of birth, death or residence, and for one third of sites by socioeconomic position or individual address. When asked about the presence of specific disease registries, respondents reported that 36% of all sites were served by a cancer registry, and 20% by any registry of congenital anomalies.

Table 4: Reported number of sites and mortality and morbidity data availability

	MORTALITY DATA		MORBIDITY DATA	
Data availability	**N**	**% (over N=81)**	**N**	**% (over N=81)**
Yes	24	29.6	17	21.0
No	30	37.0	35	43.2
DN/DA	27	33.0	29	35.8
Smallest level for data availability		**% (over N=24)**		**% (over N=17)**
Municipality	14	58.3	7	41.2
District	1	4.2	0	0.0
Individual level	6	25.0	6	35.3
DA	1	4.2	1	5.9
Other	2	8.3	3	17.7
Diagnosis (death or illness)				
Yes	20	83,3	16	94.1
No	2	8,3	0	0.0
DN/DA	2	8.3	1	5.9
Population characteristics		**% (over N=24)**		**% (over N=17)**
Gender	23	95.8	16	94.1
Age	22	91.7	16	94.1
Place of birth	14	58.3	12	70.6
Place of residence	17	70.8	13	76.5
Place of death	13	54.2	9	52.9
SEP	8	33.3	8	47.1
Individual address	9	37.5	8	47.1

**DN= Don� Know; DA= Don� answer; SEP= Socio Economic Position*

Table 5 summarize characteristics about contaminants, exposure assessment, population under investigation, and health outcomes for the three main types of strategies adopted for characterising the health impact on health of ICS: Human Health Risk Assessments (HHRA); Environmental Epidemiology (EE) studies and Health Impact Assessments (HIA).

Human Health Risk Assessment is a procedure that allows to estimate the nature and probability of occurrence of an adverse health effects in humans who may be exposed to certain hazards (e.g. chemicals) in contaminated environmental media, in the past, now or in the future. HHRA involves combining a level of exposure dose to a given agent based on environmental monitoring data and biometric parameters, with toxicity benchmarks available, to calculate the excess lifetime cancer risks and non-cancer hazards (hazard quotient) for each of the exposure pathways and receptors identified[32, 33]. Environmental Epidemiological studies aim at identifying and quantifying the associations between exposure to environmental factors and the risk of health effects[34]. EE studies are carried out by analysing the exposure and health events directly in the affected human populations. The most informative EE studies are those referred to as ñanalyticalò studies, cohort or case-control studies, able to control for confounding factors at individual level. Health Impact Assessment is defined by WHO as ña 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 populationò[35]. One approach for the quantification of such impacts implies calculating the population attributable impact fraction, defined as the proportion of burden of disease or injury related to the exposure to a risk factor or group of risk factors[33, 36]

Table 5: Characteristics about contaminants, exposure assessment, population under investigation, and health outcomes for the three main strategies adopted for characterising the health impact of ICS

	HHRA (N= 26)	**Epidemiological studies (N=21)**	**HIA (N=10)**
Main contaminants	- Metals (81%) - PAH (59%) - POPS (46%)	Not applicable*	- Metals (50%) - PM (50 %) - BTEX & As (40%)
Exposure indicators	- Environmental monitoring (73%) - Modelling (50%) - HBM (23%)	- Residence (71%) - Environmental monitoring (52%) - Distance from the ICS (43%) - HBM (38%)	- Environmental monitoring (70%) - Modelling (60%) - HBM (50 %)
Health outcomes	- Cancer incidence (39%) - Others (31%) - Morbidity (23%) - Mortality (19%)	- Morbidity (71%) - Mortality (62%) - Cancer incidence (57%) - Congenital anomalies (24%)	- AC/AF (50%) - YPLL (30%) - DALYs (20%)
Population	- General population (73%) - Children (42%) - Workers (23%) - None (4%)	- General population (86%) - Children (52%) - Workers (24%) - None (5 %)	- General population (80%) - Children (50%) - Workers (10%) - Others (10%)

**this question was not included in the survey*

Acronyms: HHRA: human health risk assessment; HIA: health impact assessment; POPs: persistent organic pollutants; PAH: polyromantic hydrocarbons; HBM: human biomonitoring; PM: particulate matter (mainly PM_{10}, and $PM_{2,5}$); AC/AF: attributable cases/attributable fraction; YPLL: Years of potential life lost: DALYS: Disability adjusted life years

In the ICSHNet survey, the most extensively methodological approach used for characterising the potential impact on health of ICS was HHRA (Table 5), applied in one third of the sites (26 out of 81), epidemiological studies were conducted in 21, and HIA performed in 10. The higher prevalence of HHRA is well correlated with findings reported by Xiong et al. (2018)[37]. In their literature search, these authors revealed that 90% of the total identified published studies focused on the quantification of health impacts in ICSs conducted worldwide (N= 92) used HHRA, either by calculating the hazard quotient for non-cancer endpoints (25%) or by estimating the probability excess risk of cancer (65%). However, once again, an important percentage of participants in our survey were not sure about possible HHRA/epi studies or HIA conducted around the ICSs they were reporting for, showing the difficulties in accessibility to the information in this field. It is important to highlight that in many ICS worldwide, environmental departments (national or regional level) are normally responsible for conducting HHRA, particularly for categorising soils contamination level, but those reports are not easily accessible as they are often published in restricted databases.

According to the epidemiologic design to assess the extent of the exposure and associated risks, we observed a predominance of cross-sectional/descriptive studies, followed by ecological studies, case-control, and geographical studies (Table 5). De Sario et al. (2018)[13] from a literature search capturing 655 studies on the health impact of ICS on resident populations similarly found that most of the studies were descriptive (32.5%), cross-sectional (16.3%), or narrative review (14.8%) while analytical studies - case-control and cohort studies (9.6% and 8.4%, respectively) ï were rarer and HBM were only 6.9%.

The main contaminants monitored, both in the reported HHRA and HIA studies, were heavy metals, polycyclic aromatic hydrocarbons, and persistent organic pollutants (Table 5), but other contaminants especially considered under the HIA approach were arsenic, BTEX, and particulate matter measured in air. This finding is well correlated to the most extensive scientific evidence available from epidemiological dose-response relationships according to changes in the environmental exposure to those pollutants in air[21,22]. These studies allow calculating the increase number of specific health outcomes within a population (attributable cases or attributable fraction for specific causes of morbidity or mortality or other indicators). The exposure indicator most broadly used in the identified HHRA and HIA was *ad hoc* environmental monitoring (73%), followed by modelling (50%) and human biomonitoring (23%), while for epidemiological studies residence (at individual or area level) (73%), environmental monitoring (52%), followed by distance (43%) and human biomonitoring (38%) were the most frequently reported exposure indicators.

The health outcomes reported differ according to the methodological approach adopted. Cause-specific mortality and morbidity, and cancer incidence were the more reported outcomes (Table 5) while congenital anomalies were evaluated only when an epidemiological study design was applied, and years of potential life lost (YPLL) and disability adjusted life years (DALYs) were specific of the HIA approach.

In the AQ a specific section was dedicated to communication strategies. Survey respondents were asked about communication campaigns on risk issues in the ICS reported. Survey findings show that almost half (47%) of respondents were either not aware or did not know whether a risk communication campaign was ever undertaken on the industrial contaminated site of interest or whether stakeholders were involved in the development of the communications strategy. About two thirds of reported communication strategies focused on either environmental pollution only or environment pollution combined with health risk data. There were very few campaigns focusing solely on health risk data. Brochures, websites and research

reports have been the main tools adopted. The main stakeholders involved in the community strategy were the public sector, voluntary organisations, populations living close to industrially contaminated sites, the public and the private sector.
At least 40% of survey respondents thought that there is underreporting of uncertainty in health risk estimates, independently of the stakeholder categories involved in the risk communication strategies.

Addressing messages referring to control groups at risk is considered an important principle in risk communication, going beyond the mere provision of information (institutional trust and personal efficacy)[38]. ñ*What could inhabitants - inspired by authorities and risk managers - practically do to prevent or reduce further personal exposure and protect from adverse health effects?*ò In our survey, 29 cases (out of 81) included recommendations for action into the communication strategy, which could by classified into 4 types:

1. Regulation and management (governance); e.g. optimizing and tightening the legislation on open fires, development of waste-water treatment plants
2. Exposure reduction recommendation (households); e.g. children not to eat eggs, washing hands after gardening
3. Technological recommendations (industry); e.g. implement new cleaner technologies, water-service companies had installed activated carbon filters in the water-treatment plants
4. Monitoring and surveillance (science); e.g. epidemiological surveillance of population living in the ICS, regular blood tests for anaemia in children

Final remarks

This is, to our knowledge, the first available international survey specifically addressing the availability of environment, health and demographic data, as well research tools and sound methodologies in ICS.

There are some limitations of the study that mainly concerns aspects of representativeness of the surveyed areas within participating countries and in terms of most relevant industrial sectors. In this respect, it has to be emphasised that this survey was not aimed at identifying national priority sites, nor priority settings across Europe. The ICSs included in the survey were identified with the purpose to have a variety of examples for evaluating the capacity across countries to deal with ICS-related environmental public health issues. The selection of ICS was, in fact, based on *ad hoc* criteria: the compliance with the operational definition adopted by the ICSHNet, and with specific environmental health and health policy aspects previously described. This paper enables to evaluate the availability of key information, as well as needs and priorities among the surveyed ICSs in participating countries in terms of which issues and fields should be mainly addressed.

With the normal caution required by the reduce number of sites analysed in this survey, these findings suggest certain variability among countries in getting access to different type of data (environmental, health or population data) that could be partially explained by the way each country interpret the definition of ICS. The already mentioned lack of a common regulation for soil, and therefore in a common methodology for gathering data and assessing contamination levels of sites affected by industrial pollution, can contribute to such variability and to the lack of information. Moreover, the reported data are usually based on expert judgement, which includes a high degree of uncertainly.

Based on the main findings of the survey it is possible to identify a preliminary list of actions and recommendations requested to improve the capabilities of dealing with environmental health issues in ICS. Desirable improvements should concern a systematic collection and access to industrial emissions, environmental, health and demographic data in order to be able to characterize the multiple impacts on health from ICS. This survey also shows that experts in specific fields are not sufficiently aware of the activities carried out by other sectors, suggesting that national government should support the implementation of a strong interdisciplinary and intersectoral approach, with greater cooperation and sharing of data and expertise between environmental and public health experts.

Environmental and exposure assessments should involve measuring key pollutants related to industrial emissions and of toxicological concern in all affected environmental media. In addition, further researches should include methods for exploring exposure to mixtures of pollutants and their potential synergisms/antagonisms[39]. On the other hand, accurate measurement of health outcomes should include breakdown of information for different groups, as these data will help to assess the impact, and implement preventive actions, on the behalf of vulnerable sub-populations like children, workers, and socio-economic deprived communities. If the data are already available, then greater sharing and promotion of this data with environment and health researchers and public health experts and policy makers involved in industrially contaminated sites is required.

This survey highlights the priority need to build up and implement national health and environmental information systems in contaminated areas so that they could feed programs to monitor changes in exposure and health profiles of affected resident populations. Stronger efforts should be also addressed to integrate risk communication strategies as essential elements of any approach for characterizing the impacts on health of ICS. These strategies should be implemented at all stages of the process and involve all potential affected stakeholders, putting emphasis on a better understanding of the results and its uncertainties. The relationship between scientific research, information and political decisions is very complex and a greater sharing and promotion of information among interested stakeholders in ICS is required. The most tangible output of this survey is the AQ that can be updated and used in contexts in which there is no information on environmental media and the health of the exposed population.

Conflict of interest

The authors declare they have no conflict of interest.

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