RASSEGNE E ARTICOLI

Industrial contaminated sites and health: results of a European survey

Siti industriali contaminati e salute: risultati di un'indagine europea

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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 characterising the impact on environment and health of ICS.

OBJECTIVES: evaluate the availability of information and studies concerning selected ICSs in participating Countries within the ICSHNet, with particular consideration on the accessibility to environmental, health and demographic data, and research and assessment tools.

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

RESULTS: information was gathered from 81 sites out of the initially selected 99, reported by 45 participants from 27 Countries (82% of Countries in the ICSHNet). The predominant polluting activities were waste disposal (46%) 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 BTEX (benzene, toluene, ethylbenzene, and xylene) and ambient air pollutants (e.g., particulate matter, SO_x). Human health risk assessment was the most prevalent methodological approach for characterising impacts on health (32%), followed by epidemiological studies (26%),

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 recognised as one of the 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 ICSs is a priority for defining best methodological approaches that allows characterising health impacts of ICSs.**

WHAT THIS ARTICLE ADDS

- **This paper identifies a set of issues that risk assessment programmes on ICSs should address.**
- **Improving the collection and access to specific environmental, health, and demographic data related to ICSs is crucial to meet methodological requirements to better analyse the health impact of ICSs.**
- **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 the impacts on health of ICSs.**

and health impact assessment (12%). The low reporting, both referring to data availability or methodologies, 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 the environmental information.
CONCLUSIONS: survey findings suggest that improving the collection and access to specific environmental, health and demographic data related to ICSs is crucial to meet the methodological requirement to better analyse the health impact of ICSs.

Keywords: industrially contaminated sites (ICSs), data availability, human health risk assessment, health impact assessment, environmental epidemiology

RIASSUNTO

INTRODUZIONE: i siti industriali contaminati (ICS) sono stati riconosciuti come un importante problema di salute, poiché implicano l'esposizione a numerosi fattori di stress ambientali, normalmente distribuiti in modo non uniforme all'interno della popolazione. La COST Action on Industrially Contaminated Sites and Health Network (ICSHNet) è una rete di esperti a livello europeo finalizzata a chiarire le lacune di conoscenza, le necessità e le priorità per meglio caratterizzare l'impatto che gli ICS hanno sull'ambiente e sulla salute.
OBIETTIVI: valutare la disponibilità di informazioni e studi riguardanti i siti industriali contaminati presenti nei Paesi appartenenti alla rete ICSHNet, prendendo in considerazione in particolare l'accessibilità ai dati ambientali, sanitari e demografici, e la disponibilità di strumenti di ricerca e valutazione.
METODI: per valutare la disponibilità di dati, è stato sviluppato un questionario chiamato Action questionnaire (AQ), basato su questionari precedenti utilizzati in altri progetti europei e sulla consultazione di esperti. L'AQ, contenente 84 item organizzati in 8 sezioni, è stato adattato creando una versione on-line tramite il software LimeSurvey. L'indagine è stata condotta inviando l'AQ a 47 partecipanti scelti all'interno della rete ICSHNet, che avevano precedentemente contribuito a costruire una lista di 99 ICS.
RISULTATI: sono state raccolte informazioni da 81 siti sui 99 inizialmente selezionati, segnalati da 45 partecipanti provenienti da 27 Paesi (l'82% dei Paesi presenti nella rete ICSHNet). Le attività inquinanti predominanti sono state lo smaltimento dei rifiuti (46%) e le industrie chimiche (37%), che interessano tutti i comparti ambientali, ma in modo più estensivo le acque superficiali e sotterranee (70%) e il suolo (68%). Le principali categorie di contaminanti che interessano comparti ambientali sono i metalli pesanti e gli idrocarburi clorurati, ma anche BTEX (benzene, toluene, etilbenzene e xilene) e inquinanti atmosferici (per esempio, particolato, SOx). La valutazione del rischio sulla salute umana è stato l'approccio metodologico prevalentemente utilizzato per caratterizzare gli impatti sulla salute (32%), seguito da studi epidemiologici (26%) e valutazione di impatto ambientale (12%). La bassa numerosità nella risposta, in riferimento sia alla disponibilità di dati sia alle metodologie, potrebbe essere dovuta all'assenza di dati o al fatto che la persona che li ha comunicati (i più erano provenienti dal settore della sanità pubblica) non era in grado di ottenere informazioni esaustive di tipo ambientale.
CONCLUSIONI: i risultati dell'indagine suggeriscono che è di cruciale importanza migliorare la raccolta e l'accesso ai dati specifici ambientali, sanitari e demografici legati agli ICS. In questo modo, sarà possibile soddisfare i requisiti metodologici per meglio analizzare l'impatto sulla salute degli ICS.

Parole chiave: siti industriali contaminate, disponibilità dei dati, valutazione del rischio per la salute, valutazione di impatto sanitario, epidemiologia ambientale

INTRODUCTION

The term "contaminated site" is included in Article 3 of Regulation (EC) No. 1272/2008,[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 (ICSs), has been associated with a broad range of different health outcomes: the body of literature is large and systematic reviews on the impact of ICSs 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 an ICS by socio-economic/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 ICSs need to adequately address issues such as contamination related health risks, the prioritisation of efforts for remediation, and cost-effective actions for 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 an 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 ICSs. 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 work conducted in the course of the ICSHNet was focused in the review and analysis of research tools, assessment procedures, and sound methodologies available in the scientific literature to deal with ICSs and health. This target has been mainly achieved through the publication on this Journal of a Monographic volume dedicated to environmental health challenges from industrial contamination.[13,15-18] The aim of the current paper, also included as a main goal of this COST Action, was to evaluate the availability of information and studies concerning selected ICSs in participating Countries within the network, with particular emphasis 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] It should be noticed that these sites include also small point sources like petrol stations, while the target of this study is a small proportion of the 650,000 sites, i.e., those with documented industrial contamination. Trying to quantify the issue, an approximate number of the ICSs across Europe would therefore be a fraction of the 14,009 industrial facilities recorded in all 28 EU member states by the European Pollutant Release and Transfer Register (E-PRTR) in 2017. E-PRTR is the Europe-wide register that provides accessible key data on emissions from industrial facilities in all European Union Member States (https://prtr.eea.europa.eu/#/industrialactivity).

The evaluation under study was anyway 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 ICSs intended to gather some relevant examples for evaluating the capacity to deal with ICS-related environmental health issues in Europe. With this purpose, all participating Countries within the COST Action were invited to list up to five sites based on the operational definition adopted by the ICSHNet, and certain selection criteria. This definition, based on a previous one established by WHO,[19] consider ICSs 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 ICSs 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 (see on-line 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[20] or the Guidelines for the collection of contaminated sites data through European Environment Information and Observation Network – EIONET[21]).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;
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 no personal information or site-specific information were going to be revealed or made public.

The AQ was adapted to an on-line version using the software LimeSurvey (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 ICSs, 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 participant's 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. The geographical distribution of Countries participating in the survey is shown in Figure S1 (on-line supplementary material)

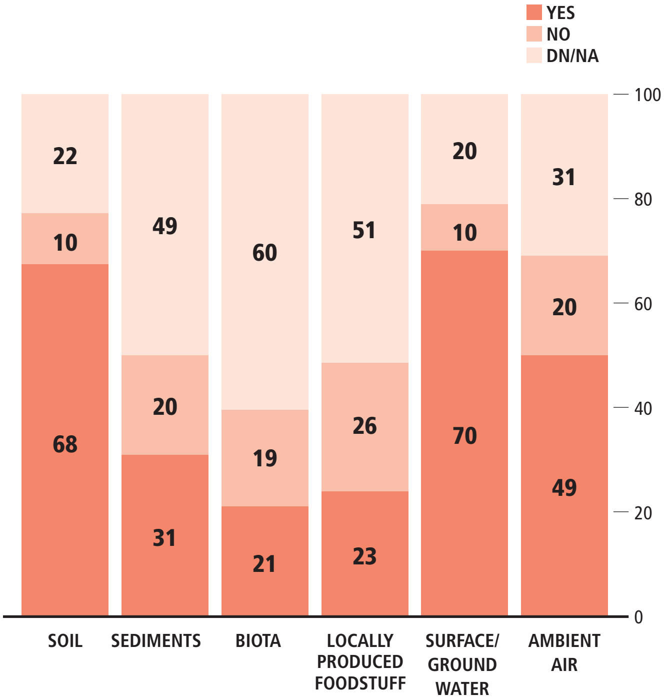
This survey concerns a very small proportion of sites from the estimated total number of ICSs that exist in the area covered within this network. However, sites were identified based on environmental health and policy criteria and therefore expected to provide an important insight about data and tools 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 organisations (9%), and regional/local health institutions (2%).

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 are accessible in Table S1 (online supplementary material). 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)[22] 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.

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 ICSs 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 when the survey was conducted. Data related to emissions and activity from each main category of reported industrial activity (Table S1) 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 1 shows the percentage of sites with different environmental media (soil, sediments, biota, locally-produced foodstuff, 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 locally-produced foodstuff. 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 the 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)[16] in their review on environmental and health data needed to develop national surveillance systems in ICSs.
Participants were asked to report on the main categories of contaminants affecting different environmental media in each ICS, as well as the monitoring frequency for each contaminant (for presentation purposes, such frequency have been summarised as routine or ad hoc). Results shown in Table 1 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, 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 BTEX (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.[23-25] 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 focused on ICSs 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. [16,26]
The percentage for the monitoring frequency of main contaminants (Table 1) indicate that only pollutants subjected to EU regulations either under ambient air quality (e.g. Directive 2008/50/EC;[27] Directive 2004/107/EC26[28]), water (e.g. Directives 98/83/EC27)[29] or food safety legislation (e.g. Regulation EU 1881/200628)[30] 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 in 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.[19,22,31] Li and Jennings (2017)[32] or Weber et al. (2019)[31] 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 pro-



DN/DA: sites where reporters did not know or did not answer / *siti per cui la risposta è stata «non so» oppure la risposta non era presente*

Figure 1. Percentage of environmental media reported to be polluted over total number of ICS (No. 81).
Figura 1. Percentuale di comparti ambientali che sono segnalati come inquinati sul totale degli ICS esaminati (n. 81).

	SOIL (No. 55)			SEDIMENTS (No. 25)			BIOTA/FOOD (No. 29)			WATER (No. 57)			AIR (No. 40)		
Contaminants	No.	Monitoring (%)		No.	Monitoring (%)		No.	Monitoring (%)		No.	Monitoring (%)		No.	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	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	14	14	29	5	0	20	1	100	1	20	30	10	14	18	0
PCDDs PCDFs	9	33	33	6	33	33	5	60	2	8	38	0	7	8	8
Organophosphorus Compounds	–	–	–	–	–	–	–	–	–	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	–	–	–	–	–	–	–	–	–	–	–	–	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

* Frequency calculated as a percentage over that declared number. / *Frequenza calcolata come percentuale sul numero dichiarato.*
PAH: polycyclic aromatic hydrocarbon / *idrocarburi policiclici aromatici*
BTEX: benzene, toluene, ethylbenzene, and xylene / *benzene, toluene, etilbenze, xylene*
PCDDs PCFs: polychlorinated dibenzodioxins and polychlorinated dibenzofurans / *dibenzodiossine policlorurate e dibenzofurani policlorurati*
VOCs: volatile organic compounds / *composti organici volatili*

Table 1. Reported number of sites and industrial contaminants by environmental media; frequency* of data reporting: regularly (R) or ad hoc (AH).
Tabella 1. Numeri riferiti di siti e di contaminanti industriali, per comparto ambientale; frequenza* dei dati riportati: regolare (R) o ad hoc (AH).

tection of human health, especially in soils with agronomic purposes.

Information on demographic characteristics of population living close to an ICS was available for 53 out of 81 sites included in our survey (65%), with around 42% of those being updated yearly. 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 available at all. 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%).

Exposure assessment of people living close to an 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 20-44 years, 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 2 shows the reported indicators applied for characterising the exposure in the ICSs included in this survey. Environmental sampling together with distance of residence to the industrial activity in each site were the two most frequent 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 was identified in two recent literature reviews. The first one focused on data availability in surveillance studies conducted by Martin-Olmedo et al. (2018),[16] and the other more specifically centred on methods for exposure assessments used in epidemiological studies conducted by Hoek et al. (2018),[17] both of them in the context of ICS. Table 2 also records different software used to model exposure in the context of our survey, with atmospheric dispersion modelling being the most frequently reported one. Hoek et al. (2018)[17] included in their article a critical analysis of most of these models, as they are often used in the context of ICSs in several European Countries, mostly in the framework of soil.

According to the respondents in our survey, the availability of health data for population close or near an ICS is usually low, being reported as available only for 30% of sites for mortality data and 21% for morbidity information (Table 3). 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

EXPOSURE ASSESSMENT INDICATOR	No.	%*
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 assessments (No. 39) / *Percentuale calcolata sul numero totale dichiarato di valutazioni dell'esposizione (n. 39).*

Table 2. Reported number of sites and environmental exposure assessment indicators, and type of dispersion models applied.
Tabella 2. Numero riportato di siti e di indicatori per la valutazione dell'esposizione ambientale e tipologia di modello di dispersione applicato.

	MORTALITY DATA		MORBIDITY DATA	
Data availability	**No.**	**% over 81**	**No.**	**% over 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	**No.**	**% over 24**	**No.**	**% over 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)	**No.**	**% over 24**	**No.**	**% over 17**
Yes	20	83.3	16	94.1
No	2	8.3	0	0.0
DN/DA	2	8.3	1	5.9
Population characteristics	**No.**	**% over 24**	**No.**	**% over 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: do not know / *non so*
DA: do not answer / *nessuna risposta*
SEP: socioconomic position / *livello socioeconomico*

Table 3. Reported number of sites and mortality and morbidity data availability
Tabella 3. Numero riportato di siti e disponibilità di dati di mortalità e morbilità.

	HHRA (No. 26)	EPIDEMIOLOGICAL STUDIES (No. 21)	HIA (No. 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. / *Domanda non inculsa nella survey.*
HHRA: human health risk assessment / *valutazione del rischio sulla salute umana* - **HIA:** health impact assessment / *valutazione di impatto sulla salute* - **POPs:** persistent organic pollutants / *inquinanti organici persistenti* - **PAH:** polycyclic aromatic hydrocarbons / *idrocarburi policiclici aromatici* - **HBM:** human biomonitoring / *biomonitoraggio umano* - **PM:** particulate matter (mainly PM_{10} and $PM_{2.5}$) / particolato (sopratuttto PM_{10} e $PM_{2.5}$) - **AC/AF:** attributable cases/attributable fraction / *casi attribuibili/frazione attribuibile* - **YPLL:** years of potential life lost / *anni di vita potenzialmente persi* - **DALYS:** disability adjusted life years / *anni di vita vissuti con disabilità*

Table 4. Characteristics about contaminants, exposure assessment, population under investigation, and health outcomes for the three main strategies adopted for characterising the health impact of ICS
Tabella 4. Caratteristiche dei contaminanti, della valutazione dell'esposizione, della popolazione considerata e degli outcome di salute per le tre strategie principali adottate per la caratterizzazione degli impatti sulla salute dei siti contaminati industriali.

outcomes (cause of death or disease) was reported for nearly all the sites (94% for mortality and 83% for morbidity data), with information stratified by age and gender, between 70% and 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 summarises 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 ICSs: 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.[33,34] **Environmental Epidemiological studies** aim at identifying and quantifying the associations between exposure to environmental factors and the risk of health effects.[35] 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 "analytical" studies, cohort or case-control studies, able to control for confounding factors at individual level. **Health Impact Assessment** is defined by WHO as "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".[36] One approach for the quantification of such impacts could be the HHRA approach based on toxicological dose-response functions. Another approach, many times called HIA itself, implies calculating the potential impact fraction defined as the proportion of burden of disease or injury that could be avoidable if current or future exposure levels to a risk factor or group of risk factors are reduced to hypothetical lower scenarios. This is a population-based approach, which aims at assessing changes in the specific studied population, using epidemiological methods and evidences.[34,37]
In the ICSHNet survey, the most extensively methodological approach used for characterising the potential impact on health of ICSs was HHRA (Table 4), 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).[18] 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 (No. 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 ICSs 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 4). De Sario et al. (2018)[13] from a literature search capturing 655 studies on the health impact of ICSs 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) – 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 4), 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 for epidemiological dose-response function related to those pollutants in air.[23,24] The exposure indicators most broadly used in the identified HHRA and HIA were ad hoc environmental monitoring (73%), followed by modelling (50%), and human biomonitoring (23%), while for epidemiological studies were residence (at individual or area level) (73%) and environmental monitoring (52%), followed by distance (43%) and human biomonitoring (38%).

The reported health outcomes differ according to the methodological approach adopted. Cause-specific mortality and morbidity, and cancer incidence were the more reported outcomes (Table 4) while congenital anomalies were evaluated only when an epidemiological study design was applied, and years of potential life lost (YPLLs) 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 reported ICSs. 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] *"What could inhabitants - inspired by authorities and risk managers - practically do to prevent or reduce further personal exposure and protect from adverse health effects?"* 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 an ICS, regular blood tests for anaemia in children.

FINAL REMARKS

This study has some limitations concerning aspects of representativeness of the surveyed areas within participating Countries and in terms of most relevant industrial sectors. In this respect, it is important to emphasise that this survey was not aimed at identifying neither national priority sites, nor priority settings across Europe. No comparison among Countries was either intended or feasible. The ICSs included in the survey are examples proposed by participating Countries within the ICSH-Net in order to get a first overview of the capacity to deal with ICS-related environmental public health issues in Europe. In fact, this is, to our knowledge, the first available international survey specifically addressing the availability of environment, health and demographic data, as well as research tools and methodologies applied for charactering the impact on health in ICSs. 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 in the future.

With the normal caution required by the reduce number of sites analysed in this survey, these findings suggest certain variability across 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 uncertainty.

On the bases of our results and those from the reviewed literature, it is possible to identify a preliminary list of actions and recommendations requested to improve the capabilities of dealing with environmental health issues in ICSs. 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 ICSs. 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 research 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 subpopulations 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 ICS 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 programmes 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 ICSs. 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 ICSs 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.

This Action Survey and the review of methods previously conducted within the ISCHNet are actually strongly interrelated allowing the identification of different approaches for characterising the impacts on health in ICSs that can fit to the data and resources available in ICS scenarios across Europe. This last goal is the aim of the Action Guidance Document that is going to be jointly published by WHO and COST Action.

Conflict of interest: none reported.

Funding disclosures: this publication is based upon work from COST Action ICSHNet, supported by COST (European Cooperation in Science and Technology). Dr. J.P. Arrebola is under contract within Ramon y Cajal Program (RYC-2016-20155, Ministerio de Economía, Industria y Competitividad, Spain).

Acknowledgments: this work was performed within the framework of the COST Action IS1408 on *Industrially Contaminated sites and Health Network* (ISHNet). Management Committee Members of the Cost Action IS1408: Ivano Iavarone (IT), Giovani Leonardi (UK), **Konstantinos Makris** (CY), **Anna Cidlinova** (CZ), **Bozena Sera** (CZ), Jörg Frauenstein (DE), **Jacob Dahl Rendtorff** (DK), **Piedad Martin-Olmedo** (ES), Juan Alguacil (ES), **Jelena Tomasova** (EE), **Hedi Harzia** (EE), Jean-François Viel (FR), Sébastien Denys (FR), Sari Kauppi (FI), Otto Hänninen (FI), Rupert Hough (UK), **Olga-Ioanna Kalantzi** (EL), **Dimosthenis Sarigiannis** (EL), Tamas Pandics (HU), **Gyula Dura** (HU), Martina Jakovcic (HR), Krunoslav Capak (HR), Roberta Pirastu (IT), **Roberto Pasetto** (IT), Shai Linn (IL), Hrönn Jörundsdóttir (IS), Saulius Vasarevicius (LT), **Dragan Gjorgjev** (MK), Gerard Hoek (NL), **Maria do Ceu Costa** (PT), Joao Paulo Teixeira (PT), Wojciech Hanke (PL), **Malgorzata Kowalska** (PL), **Elena Nechita** (RO), Laszlo Barna Iantovics (RO), Peter Otorepec (SI), Ivan Erzen (SI), Michal Jajcaj (SK), Katarína Halzlová (SK), Lokman Hakan Tecer (TR), Banu Çetin (TR), **Ilse Loots** (BE), **Greet Schoeters** (BE), Maja Colovic Daul (BA), **Kamen Petrov** (BG), Stela Todorova (BG), **Kees de Hoogh** (CH), Nevenka Pavlicic (ME), **Borko Bajć** (ME), **Branislava Matić Savićević** (RS), **Uroš Rakić** (RS).

Authors are very grateful to all participants who take part in the survey, who are those in bold here above, plus: Silvia Toro Cárdenas (ES), Michele Santoro (IT), Carla Ancona (IT), Lucia Fazzo (IT), Ann Colles (BE), Andrej Ursic (SI), Dijana Djurovic (ME), Elena-Roxana Ardeleanu (RO), Enver Roshi (AL), Harri Helminen (FI), Sari Myllyoja (FI), Timo Kinnunen (FI), Visa Niittyniemi (FI), Petri Siiro (FI), Adam Hofer (HU), Hrönn Jörundsdóttir (IS), Lokman Hakan Tecer (TR), Lorand Ferencz (RO), Maja Colovic Daul (BA), Milada Eštóková (SK), Nabil Seyidov (AZ), Nataša Janev Holcer (HR), Nikolay Panayotov (BG), Spyros Karakitsios (EL), Sarah Dack (UK).

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