Environmental and health data needed to develop national surveillance systems in industrially contaminated sites

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ABSTRACT

BACKGROUND: this paper is based upon work from COST Action ICSHNet. Public health surveillance (PHS) of industrially contaminated sites (ICSs) is likely to play a role in supporting the monitoring of harmful aspects of ICSs and related interventions. Environmental public health tracking (EPHT) has been proposed and developed as an approach to PHS when environmental factors affecting health are involved.

OBJECTIVES: to identify existing arrangements for continuous collection and analysis of environmental and health data to guide the development of an optimal EPHT approach which would support the characterization of the impact on health of ICS.

METHODS: a literature search was conducted in PubMed following a structured approach to identify methodological aspects relevant to surveillance of ICSs. In addition, eight further studies on this topic, mainly from three European Countries (Spain, Italy, and France), were included by the research team.

RESULTS: the identified 17 examples of surveillance studies include a heterogeneous variety of industrial activities, covering from cross-national to local scenarios. Continuous monitoring systems for gathering environmental data related to ICSs were used only in two cases; a qualitative approach and/or punctual sampling for soil, air, and water of local foodstuff took place in the rest. Exposure assessment was conducted according to four main methods: qualitative definition for the presence/absence of a source, distance to a source, dispersion modelling, and biomonitoring. Health data relied on routinely vital statistics, hospital admission records, specific morbidity registers, and cancer and congenital abnormalities registries.

DISCUSSION: our revision identified an overall lack of national surveillance programmes of ICSs, rather than gaps in individual dimensions of surveillance. The epidemiological approaches reviewed provided methods, some of which could be adopted for an EPHT in ICSs. However, a large proportion of examples suffers from poor exposure characterization, relying on a qualitative definition approach, which cannot account for the multiple pathways that take place in ICSs. Use of more individual data from health registries combined with improved environmental data collection and exposure assessment would improve future surveillance.

Keywords: public health surveillance (PHS), environmental public health tracking (EPHT), routine health data, industrially contaminated sites (ICS)

KEYPOINTS

What is already known

- **Industrially contaminated sites (ICSs) represent a long-term legacy of past and current development, and a probable lasting cause of preventable non-communicable disease.**
- **Environmental public health tracking (EPHT) could be a valuable approach to monitor the evolution of the health profile of populations residing close to industrially contaminated sites (ICSs) and to assess the efficacy of remediation and preventive actions.**

What this paper adds

- **Further improvements for gathering and/or getting access to specific environmental data and exposure assessment models in ICSs seem crucial for improving the validity of environmental epidemiology and surveillance programmes.**
- **Great governmental stewardship would be required for allowing disparate public agencies to make progress in collecting routine exposure and health data sets with their linkage for future epidemiology research and EPHT in the context of ICSs.**

INTRODUCTION

Development of industry and its products has brought many benefits to modern societies, including a reduction in average deprivation, although it has also generated a huge dispersion of hazardous materials, in many cases dumped in places where some of the most disadvantaged people live. Such pattern could engender potential harm to health and wellbeing attributable to chemical exposure and to socioeconomic deprivation.[1-3] Industrially contaminated sites (ICSs) represent a long-term legacy of past and current development,[4] a probable lasting cause of preventable non-communicable disease (NCDs), and a living reminder of the inherent lack of sustainability of the linear economy.[5,6] Public health agencies have recognised a responsibility for addressing health issues attributable to ICSs, by characterising the hazards released to the environment and mitigating any potential impact on human health attributable to those sites. There is an urgent need to identify the most suitable interventions aimed at prevention in affected communities, to facilitate a better social and economic development, while minimising population exposure to harmful compounds associated with ICSs.[7]

Public health surveillance of ICSs is likely to play a role in supporting the capacity of society to monitor the harmful aspects of an ICS as well as providing a tool for documenting any benefit attributable to actions aimed at remediation or more widely regeneration of ICSs alongside their urban or rural context.[7,8] Environmental public health tracking (EPHT) has been proposed and developed as an approach to public health surveillance when environmental factors affecting health are involved.[9] EPHT can be defined as: "the ongoing collection, integration, analysis, and interpretation of data about environmental hazards, exposure to environmental hazards, human health effects potentially related to exposure to environmental hazards. It includes dissemination of information learned from these data and implementation of strategies and actions to improve and protect public health".[9,10] The tracking approach strives to achieve its vision of "Healthy Informed Communities" by empowering environmental and public health practitioners, healthcare providers, community members, policy makers, and others to take information-driven decisions that affect their health, while maintaining appropriate data protection measures.[9,10]

Application of the EPHT approach has taken a number of forms, with a variety of terms used to describe it. For example, in Europe air pollution monitoring and modelling has been used as a tool for public health surveillance with little reference to EPHT terminology,[11] while comparable activities in the USA have been developed using EPHT as a descriptor.[12] Lead surveillance programmes in France and USA have been implemented as specifically designed surveillance activities,[13,14] while in England it is part of an EPHT programme.[15] In Italy, monitoring of mesothelioma as an indicator of exposure to asbestos has taken place, at times described as tracking,[16] with successful results in terms of identification and management of a newly identified hazard.[17] Other EPHT success stories of relevance to ICSs include using environmental health indicators for assessment and planning in Colorado.[18] The differences in terminology and topics across Countries reflect variation in history and culture. However, several shared dimensions have been agreed, such as the aim to provide public-health decision makers with timely, accurate, and systematic data to inform and develop policies that reduce environmental health burdens and prevent disease efficiently and cost-effectively.[19] EPHT has been proposed as part of the 'wicked' solutions to the prevention and management of NCDs and protection and promotion of planetary health.[20] Developing surveillance of ICSs using an EPHT approach may provide a framework for further documenting health and social impacts of existing sites, and for strengthening the capacity to attribute any changes in health to interventions in specific locations or across sites in the same sector.

In 2015, a COST Action on Industrially Contaminated sites and health Network (ICSNet, https://www.icshnet.eu/) was launched; its main objectives were: • to clarify knowledge gaps and research priorities; • to support collection of relevant data and information; • to stimulate development of harmonised methodology; • to promote collaborative research initiatives; • to develop guidance and resources on risk assessment, management, and communication in ICSs.[21] As part of this network, in this study we aimed to provide a background for understanding how public health researchers in surveillance studies have used health and environmental data, and what improvements would be necessary for accommodating new demands on these data sets to define a useful EPHT related to ICSs. We had the following specific objectives:

- to identify examples where environmental data were used in epidemiological surveillance studies in ICSs;
- to identify examples with different approaches for exposure assessment;
- to identify examples where routine health data were used in epidemiological surveillance studies in ICS.

The purpose was not to perform a systematic review, but to collect some case studies with different methodological approaches to identify strengths and gaps, with more emphasis to the European context.

METHODS

A literature search was conducted between February and March 2018 following a structured approach to identify examples of surveillance studies that used a range of methods for assessment of exposure and/or health effects reported in relation to ICSs. This search was conducted in PubMed, with no time limits, although publishing language was restricted to English.

The search strategy and keywords were truncated as follows: [(((contaminat*) OR pollut* OR waste) AND (site OR land) AND industr*) AND surveillance]

When using the term 'surveillance', PubMed automatically searches for the term 'epidemiology' as one of its synonyms, identifying articles where routine health data were used.

CRITERIA FOR THE SELECTION OF ARTICLES UNDER THE STRUCTURED SEARCH

The literature review was conducted over two screening stages: the first one was applied only to titles and abstracts, the second to the full texts (figure 1). All final selected papers had to fulfil the following four inclusion criteria, and were excluded if any of the four exclusion criteria were met.

Inclusion criteria:

1. English language abstract;
2. Five years as minimum period of follow-up for observations (relevance as surveillance public health activity);
3. Inhalation and ingestion as potential routes of exposures;
4. Reference to industrial activities.

Exclusion criteria:

1. Infections;
2. Animals not used as sentinel or food source;
3. Studies focusing on radiation;
4. Studies mainly focused on occupational exposure.

Considering the large extent of affected areas, the coexistence of numerous toxic substances and the concurrence of several exposure pathways that potentially occur in many ICSs,[4,8] the structured literature search used in this study was designed with the intention of identifying surveillance case studies where inhalation and ingestion exposure pathways were at least considered. Dermal contact was not intentionally excluded from the search. However, we did not look specifically for those articles focusing on dermal contact since this exposure pathway is mainly associated with occupational studies rather than with general public health.[4,6]

The defined search strategy generated 319 PubMed records that were transferred from Endnote to a file with the following format: "Annotated and numbered". To ensure a consistent approach when reviewing articles, a spread-

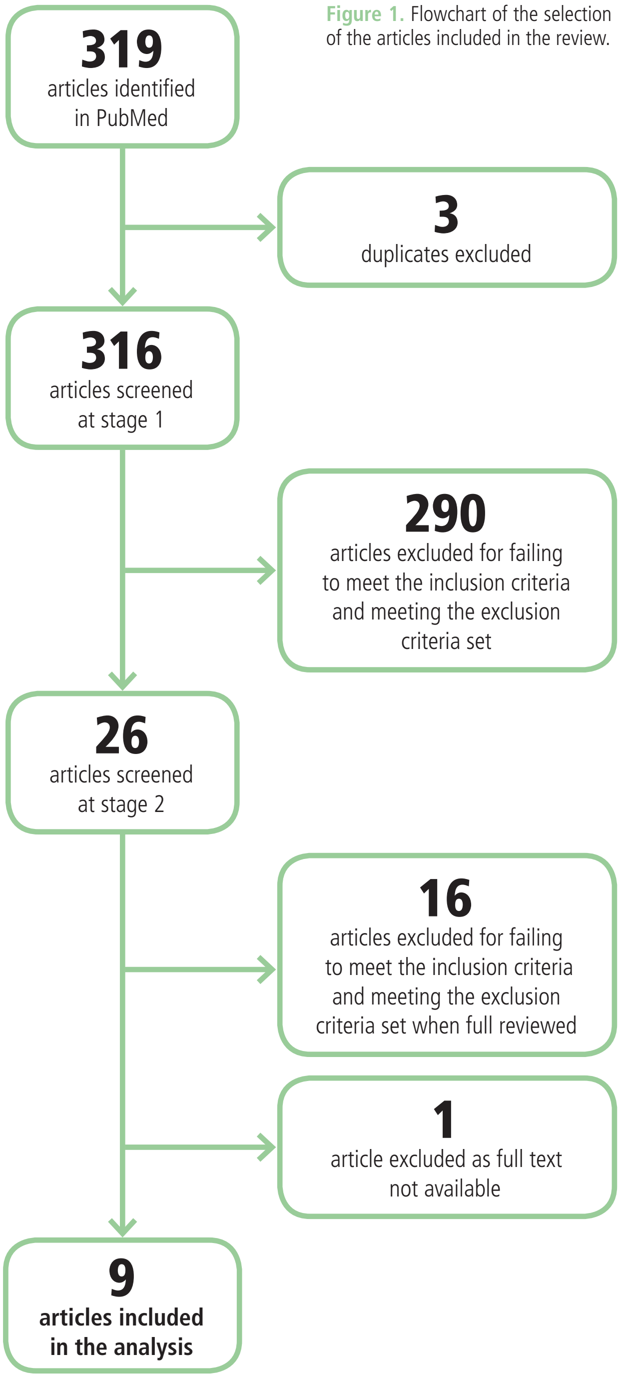

Figure 1. Flowchart of the selection of the articles included in the review.

sheet was created to record how each identified study accomplished the inclusion/exclusion criteria, as well as other study characteristics. Two researchers reviewed the first 40 abstracts and compared their analysis before one reviewer went on reviewing the remaining 279 articles.
A great majority of the 316 identified abstracts under the structured search mentioned only inhalation as the main route of exposure by comparison to those considering exclusively ingestion (146 versus 69), with only a few studies (41) suggesting both potential exposure pathways. The follow-up period was clear in 170 of the abstracts, out of which only 32% covered >5 years. Finally, 9 full-text articles were selected as meeting the inclusion criteria without violating the exclusion requirements.[22-30]

ADDITIONAL CASE STUDIES ADDED BY THE RESEARCH TEAM

In addition, the research team included 8 further studies[31-38] which were relevant to surveillance in ICSs, mainly centred on three European Countries (Spain, Italy, and France). Those case studies were selected based on the exchange of experience in the course of the ICSHNet, covering an important variety of environmental and health data sources as well as different indicators for exposure assessment, supporting in this way the analysis proposed under the specific objectives of the present paper. By no mean, authors consider those case studies the only reference papers on the topic. These case studies fulfil all previous selection criteria, although they mainly focus on the inhalation exposure pathway.

RESULTS

The 17 examples selected throughout both search strategies (structured and ad hoc) cover a heterogeneous variety of industrial activities that in many cases had been operating for several decades before the study period. They include complex sites, comprising multiple polluting sources (chemical plant, petrochemical, oil refineries, etcetera),[22-23,31-35] to more particular activities such as incinerators,[36-38] chemical plants[24-26] or waste disposal of industrial origin.[27,28] These examples include cross-national,[23,28] national,[31-33] regional,[35,37,38] and local approaches.[24-26,29,30,36]
A detailed description of each case study can be consulted in the on-line supplementary material (tables A1 and A2).

COLLECTED ENVIRONMENTAL DATA USED IN SURVEILLANCE STUDIES CONDUCTED IN ICSs

See table 1 to consult the data this paragraph refers to.
Only in two cases[35,38] continuous monitoring systems were used to provide information on real concentrations of ambient air pollutants, in combination with meteorological, topography, and geocoding information. In three cases,[31-33] considering multiple sites across a Country, the European Pollutant Emission Register (EPER), combined with the European Pollutant Release and Transfer Register (E-PRTR) was the source of data for emissions of pollutants and geocoding information of each industrial facility. In four other studies,[28,34,36,37] the type and concentrations of the environmental hazards released from the different sources were estimated based on the description of the industrial activity that took place in each site, supported by the expert opinion of professionals from different fields and, in some cases, also by short-term environmental monitoring campaigns. The remaining examples make reference to historical data gathered in different sampling surveys, affecting one or more environmental media (air, soil, agricultural local products, drinking water, etcetera), but not always supported by a qualified data source.

EXPOSURE ASSESSMENTS INDICATORS USED IN SURVEILLANCE STUDIES CONDUCTED IN ICSs

See table 2 to consult the data this paragraph refers to.
One of the papers did not provide an indicator for exposure, but a description of the environmental pollution in the affected area.[23] In the other 16 selected articles, we differentiated four main approaches for exposure assessment. The most common one, applied in 43% of cases, is a qualitative definition of exposure according to the presence/absence of a source or the presume delimitation of the ICS boundaries based on the compilation of historical data and/or the expert advice (i.e., local/regional environmental authorities).[22,24-27,30,34] A second exposure indicator (25% of cases) referred to a measure of distance, both on a continuous scale and by defining concentric areas around the site with arbitrary radius (from 1.5 to 10 km concentric rings).[28,31-33] The third one, involving 25% of cases, used atmospheric dispersion models supported by more or less completed sets of input data.[35-38] Only in one case, a biomonitoring approach was implemented, measuring PCDD/F in serum of a subsample of the exposed population (individuals who lived in the surroundings of a past polluted area).[29]
All the studies used residence as a reference to define the population distribution according to the exposure indicator, although different levels of detail were used in defining residence location (postcode of the municipality or community of residence, exact geographic coordinates of the residence address, or census/bloc unit).
Temporal variability, considered as the third dimension in defining exposure scenarios,[39] was not taken into account in most of the papers. Only in three cases[31,35,38] the fluctuations in exposure due to changes through time

TYPE OF SITE	COLLECTED ENVIRONMENTAL DATA	SOURCE OF DATA	REFERENCE(S)
Local site affecting ample area, including trans-national pollution	No direct monitoring conducted. Compilation of valuable historical environmental data of contamination of air, water, agriculture local products, and soil.	Geographic Academic institution	Kachur 2003[23]
Local, past intense polluting activity	No direct monitoring conducted. Reference to historical data for soil and air.	Not reported	Biggeri 2006[22] Eizaguirre-Garcia 2000[24]
	Reference to historical data for soil and groundwater.	Reports from Public Health and Environmental Protection Agencies	Karouna-Renier 2007[29]
	No direct monitoring conducted. Presumed distribution of past contamination in the surroundings of the main polluting activity.	Not reported	Mannes 2005[25]
	No historical data or monitoring. Reference to the contaminants potentially released from main polluting source.	Not reported	Pasetto 2013[30]
	Reference to punctual monitoring results referring to soil, interstitial soil gas, and ground water contamination.	Published report not available in English	Pukkala 2014[27]
Local, past, and ongoing intense polluting activities	Reported dioxin content in soil, local grown vegetables, drinking water, and cow's milk samples at different distances from the source. One single campaign.	Data produced by the research team Sampling and analysis procedure only described for cow's milk	Revich 2001[26]
20 landfill sites in 14 study areas from 5 European Countries	Valuable historical information referring to many characteristics of each site reported by local waste authority or their regulators, plus some past monitoring results of surface and ground water contamination or landfill gas.	Compilation of information throughout an ad hoc questionnaire design by the research team, and a consensus expert approach	Vrijheid 2002[28]
Multiple national ICS with different characteristics	Indirect quantification of multiple pollutants released to ambient air based on the emissions from industrial facilities. Geocoded information.	EPER and E-PRTR databases. A validation analysis of the geocoding of the industries reflected in the registry was previously conducted	Fernández-Navarro 2017[31] García-Pérez 2016[32] Castelló 2013[33]
	No direct monitoring conducted. Assumptions on the contaminants present in each site according to the type of polluting activity.	Prioritisation national list of ICSs defined by Ministerial decrees, which provide information about ICS boundaries, and documented qualitative and/or quantitative data on contaminants per site	Santoro 2017[34]
Ample region, comprising 13 active municipal solid waste incinerators	Few campaigns gathering real emission data from sources. Meteorological and topographic data.	Technical description of each source and a consensus approach (Delphi method) with experts to provide an estimate of emission flow rates from each polluting source	Viel 2008[37]
Local sites close to 2 active incinerators	Technical information about the polluting activity and emission inventories of all polluting activities in the site. Several ad hoc ambient air monitoring campaigns. Meteorological and geographic data.	Data provided by the industry and from the Regional Environmental Protection Agency	Ranzi 2011[36]
Ample region involving different active polluting activities	Continuous monitoring systems for ambient air pollutants. Meteorological and geographic data.	Data provided by monitoring stations linked to National or Regional Air Quality Network	Pascal 2013[35] Candela 2013[38]

Table 1. Environmental data collected in epidemiological studies of surveillance on ICSs.
EPER: European Pollutant Emission Register; **E-PRTR:** European Pollutant Release and Transfer Register

EXPOSURE INDICATOR	REFERENCE(S)
Geocoded information or residential register of potential exposed population according to the presumed/defined ICS boundaries	Biggeri 2006,[22] Eizaguirre-Garcia 2000,[24] Mannes 2005,[25] Revich 2001,[26] Pukkala 2014,[27] Vrijheid 2002,[28] Pasetto 2013,[30] Santoro 2017[34]
Distance between industrial facilities and potential exposed population based on geocoded information and an isotropic model (homogeneous dispersion of pollutants around the source), not adjusted by meteorological or topographical variables	Fernández-Navarro 2017,[31] García-Pérez 2016,[32] Castelló 2013[33]
Modelled concentration maps (Atmospheric Dispersion Model System adjusted with meteorological or geographical variables) of selected pollutants as proxy of being representative of the main industrial activity/ies and concentration maps of other pollutants assigned to other sources of contamination	Pascal 2013,[35] Ranzi 2011,[36] Viel 2008,[37] Candela 2013[38]
Biomonitoring	Karouna-Renier 2007[29]

Table 2. Exposure assessment indicators used in surveillance studies conducted in ICSs.

HEALTH OUTCOMES	PRIMARY SOURCE OF HEALTH DATA	STUDY DESIGN	REFERENCE(S)
Mortality	Routinely-collected vital statistics, cancer registries	Ecological	Kachur 2003,[23] Mannes 2005,[25] Revich 2001,[26] Fernández-Navarro 2017[31]
		Retrospective cohort	Biggeri 2006,[22] Pasetto 2013,[30] Ranzi 2011[36]
Morbidity	Specific morbidity registries	Descriptive; study specific collection	Kachur 2003,[23] Revich 2001,[26] Karouna-Renier 2007[29]
Hospitalizations	Routinely-collected hospitalization records	Ecological	Pascal 2013[35]
		Retrospective cohort	Biggeri 2006,[22] Ranzi 2011[36]
Cancer incidence (childhood)	Cancer registers and National Birth registries	Population based case-control	García-Pérez 2016[32]
Cancer incidence (adults)	Cancer registries and routinely vital statistics	Ecological	Mannes 2005,[25] Revich 2001,[26] Viel 2008[37]
		Retrospective cohort	Pukkala 2014,[27] Pasetto 2013,[30] Ranzi 2011[36]
Congenital anomalies and birth outcomes	Routinely collected vital statistics, congenital anomalies registries	Ecological	Eizaguirre-Garcia 2000,[24] Castelló 2013,[33] Santoro 2017[34]
		Retrospective cohort	Candela 2013[38]
		Multicentre case-control	Vrijheid 2002[28]

Table 3. Routine health data used in epidemiological studies conducted in ICSs.

in the emissions from the polluting sources were really considered. However, the possible variability in the residential history of the affected population throughout the follow-up period was not analysed. As a proxy to minimise this potential bias, some researchers defined a minimum residential time of five years for selected subjects.[27]

ROUTINE HEALTH DATA USED IN EPIDEMIOLOGICAL STUDIES CONDUCTED IN ICSs

See table 3 to consult the data this paragraph refers to.

The rationale behind the selection of health outcomes were influenced by the concerns of local residents due to their proximity to an ICS and perceived health impacts of the industrial activity and/or on previous studies showing increased incidence of cancer, mortality rates or certain morbidity outcomes.

Most of the studies (10/17) used an ecological design,[23-26,29,31,33-35,37] based on standardized mortality or morbidity ratios, hospitalization, cancer in adult population (CIAP), or congenital anomalies (CAs) and birth outcomes, searching for a possible excess in the incidence of mortality or any of the other health outcomes. Five studies used a retrospective cohort design[22,27,30,36,38] focusing on mortality ratios, CIAP, CAs or hospital admissions for several diseases, mostly related to cardiovascular diseases, ischemic heart diseases, respiratory diseases, and chronic pulmonary diseases. Two examples applied a population case-control design[28,32] centring in the incidence of childhood cancer and CAs. Poisson regression and similar statistical designs were used to assess a relationship between health indicators and exposure, taking into account confounding factors (mostly age, sex, and socioeconomic factors). In all cases, and independently of the study design, the follow-up period for the selection of the health outcomes was longer than five years, reaching up to 35 years.[27]

The most frequently investigated health outcomes were mortality and hospital admissions/morbidity records (in 7/17 and 6/17 studies, respectively) based on routinely collected vital statistics and hospitalization records. Other relevant health outcomes considered were cancer incidence in adult populations (6/17 studies), mostly lung cancer, non-Hodgkin's lymphoma, leukaemia, digestive cancers, and sarcoma, based on routine data gathered from national or regional cancer registries, and birth outcomes (5/17 studies) using data from routinely collected vital statistics and/or CA registers.

DISCUSSION

The number of selected papers is certainly small, but considering they cover a wide variety of industrial activities in different Countries, diverse health outcomes, and different study periods, we are still confident that the present study can provide a good overview of the type of environmental data, exposure approaches, and health data normally available for surveillance studies conducted in ICSs.

EPHT has been proposed as an approach to public health surveillance when environmental factors affecting health are involved. Development of a national EPHT network depends on the availability, quality, timeliness, compatibility, and utility of existing hazard, exposure, and health effect data.[9]

ENVIRONMENTAL DATA AND EXPOSURE ASSESSMENT IN EPIDEMIOLOGICAL STUDIES CONDUCTED IN ICSs

The requirements for optimum data collection of environmental hazards in a national EPHT system imply the development of a standardized routine process for data collection and reporting, in addition to the existence of an ongoing data quality control, appropriate geographic coverage for the population at risk, and timely data availability.[9,19,20]

In ICSs, the characterization of hazards denotes an important challenge due to the complexity of mixtures emitted from the sources, which can vary in composition and over time and space, affecting several environmental media (air, water, soil, food, and others).[8] The overall exposure depends on the time spent by fractions of the population in different environments (outdoor, indoor at home or at work), resulting of a cumulative exposure through inhalation, ingestion of contaminated water or food, and/or dermal contact.[8,39] The structured literature search used in this study was designed with this intention of identifying surveillance case studies where inhalation and ingestion exposure pathways were at least considered. However, very few papers complied with these criteria for inclusion, and, in fact, data for ingestion were poor, referring to historical data mainly related to soil sampling,[22-24,26,27] water,[22,26,28] and, in two cases, agricultural local products.[23,26]

Continuous data collection of environmental data tends to focus on air and drinking water quality monitoring networks, which are often restricted to urban areas, not covering the whole boundaries of ICSs where population might be exposed.[40] So, the existing monitoring networks should be better adapted to properly cover the area of the ICSs, recording not only pollutants typically from urban sites (i.e., particulate matter or nitrogen oxide), but also pollutants associated to the industrial activity.

Similar findings are recorded in the examples proposed by the research team, all focused on data from ambient air pollution, with only two cases using routine data from regional or national air quality networks.[35,38] However, even in those cases, modelling was necessary for estimating the emission/immission concentrations since, as mentioned above, the existing networks are not really designed to cover all the population potentially at risk in relation to ICSs. In their review, Pascal et al.[40] centred on epidemiological studies of the impact of health of major industrial sites, focused specifically on air pollution, reporting lack of environmental data as a major obstacle. They also identified, as in our examples, that complex epidemiological studies are driven by a high concern of the residents close to ICSs, but relying on poor environmental data, which limit extracting good conclusions about the associations between health outcomes and potential sources. Some authors also underline that environmental data collection is often designed according to regulatory purposes and that the procedure and frequency in which they are gathered may be optimal for enforcement activities, but less than ideal for public health surveillance practise.[9,40]

A large proportion of examples included in the present study suffers from poor exposure characterization, relying on a qualitative definition approach, which cannot account for the complexity of interactions of multiple pathways, not to discriminate between different levels of exposure. All residents of the study areas were classified as highly and equally exposed, which would have probably not been the case. A similar appreciation was reported by Cordioli et al.[39]

Some European databases with routinely collected environmental data could be useful for characterising – directly or indirectly – the exposure of population living near ICSs. The EPER, for example, is a public inventory which includes all industrial installations that have acknowledged exceeding the thresholds for one or more of the pollutants listed in the European regulatory framework for air quality and IPPC. This database provides not only data on pollutant emissions, but also the postal address and the geocoding of each industrial facility. This information, combined with the one from the E-PRTR, have been used[31-33] as a useful and inexpensive tool for proposing aetiological hypotheses about the risk related to living close to industrial settings, but also for performing preventive measures in the environment and/or conducting more specific public health actions. The challenge of using E-PRTR database as a tool for health impact assessment in ICSs has been addressed by the COST Action activities, with a practical example on landfills reported in the present issue.[41] However, prior to use these data within a Country, it is recommended to run a validation analysis of the geocoding of the industries reflected in the EPER registry, using orthophotos and detailed information provided by the new Internet tools (aerial images and street view application). Fernández-Navarro et al.[31] made a thorough analysis of several studies conducted using such approach, reporting further aspects that regard the utility and the assumptions to be taken for the interpretation of the obtained results. Among the limitations, it is highlighted that the use of an isotropic model could introduce an exposure misclassification, because the dispersion patterns of pollutants around the source is not normally homogenous, but depends on meteorological and topographical variables. It also fails in inferring that the whole municipal population is exposed to the same type and amount of pollutant substances.

Other studies have relied on measurements and modelling of a subset of pollutants to assess an integrated exposure, in an attempt to reduce exposure misclassification. However, several authors mentioned that environmental data and modelling are not easily accessed, especially when investigating past exposures.[39,40] The difficulties in getting good emission data for modelling were overcome by some groups by using a complex process on exposure judgment.[37]

Independently of the study design and the exposure approach applied, most of the examples fail in considering the mobility of persons, and assessing individual potential confounding or effect-modifying (smoking, diet, and occupation). Another limitation of current epidemiological studies in ICSs lies in assuming inhalation as the major exposure pathway, not measuring or modelling the possible exposure through ingestion of contaminated food or contact with contaminated soils.[8,39,40]

Exposure tracking of biomonitoring data provides information on the levels of chemicals or their metabolites in human biologic specimens such as blood or urine, and allows us to capture the footprint of combined chemical exposures in humans and its variation over space and time.[9] Currently, few biomonitoring data are being tracked, with only one example included in our revision.[29] In this sense, the Information platform for chemical monitoring (IPChem) might represent a step forward. IPChem is the European Commission's reference access point for searching, accessing, and retrieving chemical occurrence data collected and managed in Europe. The platform has been developed to fill the knowledge gap on chemical exposure and its burden on health and the environment (https://ipchem.jrc.ec.europa.eu)

ROUTINE HEALTH DATA USED IN EPIDEMIOLOGICAL STUDIES CONDUCTED IN ICSs

The final component in the conceptual model of an EPHT system is health effects tracking, which represents traditional public health surveillance efforts.[9] The considered health effects were those related to environmental factors according to the current scientific evidence, mainly birth defects, asthma and other chronic respiratory diseases, cardiovascular and ischemic diseases, cancer, and neurologic diseases, including Parkinson, multiple sclerosis, and Alzheimer.

Disease registries (cancer, congenital anomalies), vital statistics data, and hospital discharge data are the main sources used in all reported examples for tracking health conditions. Only in one example (Finland) authorities were able to access individual health records through mandatory personal identity codes, providing a summary of all of the individual healthcare usage through life.[27] Such a linking of health records across databases – from medical examinations with family practitioners, emergency department visits, hospital admissions, and death records at individual level – would lead to a greatly enhanced ability to identify special susceptible sub-populations for adverse health effects related to environmental hazards in ICSs.

There are several other important considerations when using routine data sources for surveillance purposes, such as accuracy, precision, completeness, timeliness, coverage, analysis, accessibility, confidentiality, and the original purpose of the data collection.[9] While some sources of routine health data are mandatory, such as registering a birth or a death, there are differences in the approaches taken between Countries (i.e., registered time for birth or death) or between regions within a Country. This will create data lags, which may need to be considered when using routine data for surveillance purposes at specific sites or making comparisons between Countries.[12]

Reviewing the different studies, we observed that the difficulties to gather health data at individual level, whereas protecting the privacy of patients, have restricted the ability of researchers to assign individual exposure estimates at smaller geographic units, or to investigate potential effect modifiers, such as race, ethnicity, health insurance coverage, and socioeconomic status.

IMPROVEMENTS NEEDED FOR DEFINING A USEFUL EPHT SYSTEM RELATED TO ICSs

Key dimensions of any public health surveillance system include clear definition of:

- purpose and objectives;
- health-related event under surveillance;
- legal authority for data collection;
- population under surveillance;
- time-period for data collection;
- data to be gathered and methods for analysis;
- dissemination-information-governance aspects.[42]

In the context of ICSs, the key elements for developing an EPHT would include the points already described above, setting up as "health-related event" the "monitoring of health consequences associated to the continuous exposure of a population to a hazardous chemical".

None of the epidemiological studies reviewed here comprised the continuous monitoring of either health or exposure events. Even in studies that analysed decades of health data, the purpose was typically to reach a conclusion based on a single analysis, rather than report on an ongoing, chronic situation with regular surveillance analyses. This may be a limitation of our search, and grey literature may contain examples of continuous analysis of ICS-related events, although our access to investigations conducted by national public health institutes in Italy, UK, and Spain did not bring up any reports of that nature. Therefore, it seems necessary to define surveillance programmes specifically aimed at the continuous analysis of ICS-related health impact.

The scarcity of surveillance programmes for ICSs could be interpreted in the light of the difficulty of designing, developing, and delivering an analysis that is repeated at regular intervals for an environmental situation of such large complexity. However, many of the results appear to indicate that epidemiology methods are capable of detecting harmful effects attributable to ICSs, although further improvement of exposure models are needed for improving the validity of the epidemiology or surveillance. The latter situation is well exemplified by the SENTIERI project, the Italian epidemiological surveillance system designed to monitor the health status of populations living in national priority contaminated sites (NPCSs).[43] SENTIERI is based on a multi-outcome approach addressing mortality, hospital discharges, congenital anomalies, and cancer incidence.[34,44,45] This is a first level descriptive approach, with the novelty of implementing an a-priori identification of health endpoints linked with pollution sources in each NPCSs. Its weakness is that it relies on a qualitative definition of exposure, mainly based on the presence of contamination sources (i.e., chemical and petrochemicals plants, refineries, steel plants, disposal sites, incinerators, etcetera), although its results contribute to identify needs for preventive action in Italian NPCSs.

Certainly, a key distinction between EPHT and traditional surveillance is the emphasis on data integration across health, human exposure, and hazard information systems. Such linkage would require standardising methods for data collection in order to maximize the spatial and temporal resolution of both health and environmental data related to ICSs.[9] This type of approach, as it has been proved in the USA, needs of a great governmental stewardship, providing funding and developing and maintaining partnerships between health and environmental agencies at the regional and Country level.[46,47] The present contribution indicates ICS as a suitable context for the development of such approach.

Therefore, for a EPHT at ICS to be successful, it is necessary not only further research on the association between exposure to environmental hazards and health, but a great political commitment and funding to contend with existing data silos. Furthermore, a tracking system needs to promote partnership, bringing together scientific information, technology, and health communication to make data accessible, usable, and understandable by a variety of users.[9,47] In this sense, it is quite important the role of open society as an audience for EPHT, particularly at local level, and their influence on political decisions.[47,48] Another critical factor to bear in mind for the establishment of an EPHT system is the socioeconomic conditions of regions and Countries. This would limit not only the required funding for data collection and exposure scenarios characterization (i.e., in low and middle-income Countries more people lives quite close to ICSs including waste disposal sites, being dermal contact a more relevant exposure pathway),[49] but also the culture for accessibility to data, transparency, and interdisciplinary collaboration. Promoting training at all levels seems the first step forward. The analysis of the influence of socioeconomic factors in the development of an EPHT system in ICSs deserves further research.

This contribution will support the ICSHNet COST Action main goal to produce guidance documents on how to face the complex environmental health scenarios of ICSs across Europe.

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REFERENCES

1. Brulle RJ, Pellow DN. Environmental justice: human health and environmental inequalities. Annu Rev Public Health 2006;27:103-24.
2. McMichael AJ, Friel S, Nyong A, Corvalan C. Global environmental change and health: impacts, inequalities, and the health sector. BMJ 2008;336(7637):191-94.
3. Gee GC, Payne-Sturges DC. Environmental health disparities: a framework integrating psychosocial and environmental concepts. Environ Health Perspect 2004; 112(17):1645-53.
4. Mudu P, Terracini B, Martuzzi M (eds). Human Health in Areas with Industrial Contamination. Copenhagen: WHO Regional Office for Europe; 2014. Available from: http://www.euro.who.int/__data/assets/pdf_file/0006/264813/Human-Health-in-Areas-with-Industrial-Contamination-Eng.pdf
5. Kihal-Talantikite W, Zmirou-Navier D, Padilla C, Deguen S. Systematic literature review of reproductive outcome associated with residential proximity to polluted sites. Int J Health Geogr 2017;16(1):20.
6. Fazzo L, Minichilli F, Santoro M, et al. Hazardous waste and health impact: a systematic review of the scientific literature. Environmental Health 2017;16(1):107.
7. WHO Regional Office for Europe. Contaminated sites and health. Report of two WHO workshops: Syracuse, Italy, 18 November 2011; Catania, Italy, 21-22 June 2012. Copenhagen (Denmark): WHO Regional Office for Europe; 2013. Available from: http://www.euro.who.int/__data/assets/pdf_file/0003/186240/e96843e.pdf?ua=1
8. Pasetto R, Martin-Olmedo P, Martuzzi M, Iavarone I. Exploring available options in characterising the health impact of industrially contaminated sites. Ann Ist Sanita 2017;52(4):476-82.
9. McGeehin MA, Qualters JR, Niskar AS. National environmental public health

tracking program: bridging the information gap. Environ Health Perspect 2004; 112(14):1409-13.
10. US Centers for Disease Control and Prevention. National Environmental Public Health Tracking. Tracking Terminology. Available from: https://www.cdc.gov/nceh/tracking/projects/home.htm
11. Medina S, Le Tertre A, Saklad M, Apheis Collaborative Network. The APHEIS project: Air Pollution and Health – A European Information System. Air Qual Atmos Health 2009;2(4):185-98.
12. Talbot TO, Haley VB, Dimmick WF, Paulu C, Talbott EO, Rager J. Developing consistent data and methods to measure the public health impacts of ambient air quality for Environmental Public Health Tracking: progress to date and future directions. Air Qual Atmos Health 2009;2(4):199-206.
13. Etchevers A, Glorennec P, Le Strat Y, Lecoffre C, Bretin P, Le Tertre A. Screening for elevated blood lead levels in children: Assessment of criteria and a proposal for new ones in France. Int J Environ Res Public Health 2015;12(12):15366-78.
14. Raymond J, Wheeler W, Brown MJ; Centers for Disease Control and Prevention (CDC). Lead screening and prevalence of blood lead levels in children aged 1-2 years – Child Blood Lead Surveillance System, United States, 2002-2010 and National Health and Nutrition Examination Survey, United States, 1999-2010. MMWR 2014;63(2):36-42.
15. Roberts DJ, Crabbe H, Close R, et al. Case epidemiology from the first 3 years of laboratory-based surveillance for children with elevated blood-lead concentrations in England, 2014-17. Proceedings of the Public Health England Research and Science Conference. University of Warwick; 2017.
16. Fazzo L, Minelli G, Santis MD, et al. Mesothelioma mortality surveillance and asbestos exposure tracking in Italy. Ann Ist Super Sanita 2012;48(3):300-10.
17. Comba P, Scondotto S, Musmeci L. The fibres with fluoro-edenitic composition in Biancavilla (Sicily, Italy): health impact and clues for environmental remediation. Ann Ist Super Sanita 2014;50(2):108-10.
18. US Centers for Disease Control and Prevention. National Environmental Public Health Tracking. Success Stories - Improving Surveillance. Colorado - Using environmental health indicators for assessment and planning. Available from: https://www.cdc.gov/nceh/tracking/success/improvingsurveillance.htm
19. International Network on Public Health & Environment Tracking (INPHET). Position Paper-Modena 2014. Available from: http://www.epiprev.it/INPHET/PP2014
20. Behbod B, Lauriola P, Leonardi G, et al. Environmental and public health tracking to advance knowledge for planetary health. Eur J Public Health 2016;26(6):900.
21. Pasetto R, Iavarone I (eds). First Plenary Conference. Industrially Contaminated Sites and Health Network (ICSHNet, COST Action IS1408). Istituto Superiore di Sanità. Rome, October 1-2, 2015. Proceedings. Rapporti ISTISAN 16/27. Available from: http://old.iss.it/binary/publ/cont/16_27_web.pdf
22. Biggeri A, Lagazio C, Catelan D, Pirastu R, Casson F, Terracini B. Report on health status of residents in areas with industrial, mining or military sites in Sardinia, Italy. Epidemiol Prev 2006;30(1) Suppl 1:5-95.
23. Kachur AN, Arzhanovaa VS, Yelpatyevskya PV, von Braunb MC, von Lindernc IH. Environmental conditions in the Rudnaya River watershed – a compilation of Soviet and post-Soviet era sampling around a lead smelter in the Russian Far East. Sci Total Environ 2003;303(1-2):171-85.
24. Eizaguirre-Garcia D, Rodriguez-Andres C, Watt G. Congenital anomalies in Glasgow between 1982 and 1989 and chromium waste. J Public Health Med 2000;22(1):54-58.
25. Mannes T, Emmett K, Wilmore A, Churches T, Sheppeard V, Kaldor J. Effect of a chemical manufacturing plant on community cancer rates. BMC Public Health 2005;5:34.
26. Revich B, Aksel E, Ushakova T, et al. Dioxin exposure and public health in Chapaevsk, Russia. Chemosphere 2001;43(4-7):951-66.
27. Pukkala E. A follow-up of cancer incidence among former Finnish dump site residents: 1999-2011. Int J Occup Environ Health 2014;20(4):313-17.
28. Vrijheid M, Dolk H, Armstrong B, et al. Hazard potential ranking of hazardous waste landfill sites and risk of congenital anomalies. Occup Environ Med 2002; 59(11):768-76.
29. Karouna-Renier N, Rao KR, Lanza JJ, Davis DA, Wilson PA. Serum profiles of PCDDs and PCDFs, in individuals near the Escambia Wood Treating Company Superfund site in Pensacola, FL. Chemosphere 2007;69(8):1312-19.
30. Pasetto R, Ranzi A, Togni A, et al. Cohort study of residents of a district with soil and groundwater industrial waste contamination. Ann Ist Super Sanita 2013;49(4):354-57.
31. Fernández-Navarro P, García-Pérez J, Ramis R, Boldo E, López-Abente G. Industrial pollution and cancer in Spain: An important public health issue. Environ Res 2017;159:555-63.
32. García-Pérez J, Morales-Piga A, Gómez-Barroso D, et al. Residential proximity to environmental pollution sources and risk of rare tumors in children. Environ Res 2016;151:265-74.
33. Castelló A, Río I, García-Pérez J, et al. Adverse birth outcomes in the vicinity of industrial installations in Spain 2004-2008. Environ Sci Pollut Res Int 2013;20(7):4933-46.
34. Santoro M, Minichilli F, Pierini A, et al. Congenital Anomalies in Contaminated Sites: A Multisite Study in Italy. Int J Environ Res Public Health 2017;14(3):E292.
35. Pascal L, Pascal M, Stempfelet M, Goria S, Declercq C. Ecological study on hospitalizations for cancer, cardiovascular, and respiratory diseases in the industrial area of Etang-de-Berre in the South of France. J Environ Public Health 2013;2013:328737.
36. Ranzi A, Fano V, Erspamer L, Lauriola P, Perucci CA, Forastiere F. Mortality and morbidity among people living close to incinerators: a cohort study based on dispersion modeling for exposure assessment. Environ Health 2011;10:22.
37. Viel JF, Daniau C, Goria S, et al. Risk for non Hodgkin's lymphoma in the vicinity of French municipal solid waste incinerators. Environ Health 2008;7:51.
38. Candela S, Ranzi A, Bonvicini L, et al. Air pollution from Iincinerators and reproductive outcomes: a multisite study. Epidemiology 2013;24(6):863-70.
39. Cordioli M, Ranzi A, De Leo GA, Lauriola P. A review of exposure assessment methods in epidemiological studies on incinerators. J Environ Public Health 2013; 2013:129470.
40. Pascal M, Pascal L, Bidondo ML, et al. A review of the epidemiological methods used to investigate the health impacts of air pollution around major industrial areas. J Environ Public Health 2013;2013:737926.
41. Shaddick G, Ranzi A, Thomas M, et al. Towards an assessment of the health impact of industrially contaminated sites in Europe. In: Pasetto R, Iavarone I (eds).Environmental health challenges posed by industrial contamination. The perspectives from ICSH Network. Epidemiol Prev 2018;42(5-6) Suppl 1:69-75.
42. German RR, Lee LM, Horan J, Milstein R, Pertowski C, Waller M. Updated guidelines for evaluating public health surveillance systems: recommendations from the Guidelines Working Group. MMWR Recomm Rep 2001;50(RR-13):1-35; quiz CE1-7.
43. Pirastu R, Pasetto R, Zona A, et al. The health profile of populations living in contaminated sites: SENTIERI approach. J Environ Public Health 2013;2013:939267.
44. Comba P, Ricci P, Iavarone I, et al. SENTIERI Project: rationale and objectives. Epidemiol Prev 2014;38(2) Suppl 1:15-20.
45. Comba P, Ricci P, Iavarone I, et al. Cancer incidence in Italian contaminated sites. Ann Ist Super Sanita 2014;50(2):186-91.
46. Fox MA, Baksh S, Lam J, Resnick B. Building the Future of Environmental Public Health Tracking: Proceedings and Recommendations of an Expert Panel Workshop. J Environ Health 2017;79(10):14-19.
47. Charleston AE, Wilson HR, Edwards PO, David F, Dewitt S. Environmental public health tracking: driving environmental health information. J Public Health Manag Pract 2015;21 Suppl 2:S4-11.
48. Ritz B, Tager I, Balmes J. Can lessons from public health disease surveillance be applied to environmental public health tracking? Environ Health Perspect 2005; 113(3):243-49.
49. O'Callaghan-Gordo C, Orta-Martínez M, Kogevinas M. Health effects of non-occupational exposure to oil extraction. Environ Health 2016;15:56.