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Urban redevelopment of contaminated sites

A review of scientific evidence and practical knowledge on environmental and health issues

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ABSTRACT

Across the WHO European Region, the urban population is growing steadily and demand for land is rapidly increasing. Revitalizing and/or remediating industrial sites and contaminated land present an opportunity for sustainable urban development and reduce pressure on undisturbed land resources. Redevelopment of contaminated sites entails various challenges, however, and may cause continued environmental and health consequences if contamination risks are not properly managed or remediated.

This report provides the results of an expert consultation on redeveloping contaminated sites for new urban functions, aiming to review the health and environmental impacts of conversion and redevelopment and to identify sound practices to support effective redevelopment while considering health and well-being. The consultation was structured as a discussion of the evidence on environmental and health impacts of remediation, a review of European redevelopment case studies and a reflection on the applicability of impact assessment tools during remediation and redevelopment processes. Summarizing the conclusions, this report identifies good practices and important elements that should be considered for remediation and redevelopment projects.

KEYWORDS

CONTAMINATED SITES, REMEDIATION, HEALTH IMPACT ASSESSMENT, URBAN PLANNING AND REDEVELOPMENT, URBAN ENVIRONMENTS, HEALTHY CITIES

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Case study compilation: lessons learned from redeveloping contaminated sites
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1. The health relevance of contaminated site redevelopment

1.1 Background

Across the WHO European Region, the urban population is growing steadily; its proportion of the total population is likely to reach 80% by 2050 (Eurostat, 2016). Urban areas stimulate migration from the countryside by providing employment opportunities, prospects for higher living standards and a vibrant city life. The growing urban population and associated urban sprawl pose several challenges to urban planners and local authorities, however. Demand for land is rapidly increasing, but undisturbed land is scarce, and taking over natural areas surrounding the settlements threatens natural habitats and biodiversity, increases environmental damage and may also affect social aspects (Cappai, Forgues & Glaus, 2019). In this context, it is important to note that urbanization is often associated with increasing social inequalities and unequally distributed environmental problems, directly affecting the life of a growing urban population (Czischke, Moloney & Turcu, 2015; Eurostat, 2016; WHO Regional Office for Europe, 2019).

A long industrial heritage and poor environmental management have left a legacy of contaminated sites across the Region. A recent European Commission Joint Research Centre report estimated the potential existence of around 2.8 million sites where polluting activities have taken or are taking place in the 28 countries of the European Union (as of 2016). Further, around 694 000 sites have been formally registered in national and/or regional inventories in 29 European countries. Some 240 000 of those sites are in need of investigation or are already being investigated to assess the risk posed to human health and environment (Payá Pérez & Rodríguez Eugenio, 2018).

For historical reasons, many contaminated sites are situated in or close to densely populated urban areas, making them relevant for urban development schemes. Evidence shows, however, that living on or near contaminated land is associated with adverse health impacts, shorter life expectancy and lower quality of life – for example, see Bech (2020). Contamination is associated with risk exposure pathways (such as inhalation, dermal absorption, soil contact and water ingestion) and psychosocial impacts affecting health and well-being (Bambra et al., 2014; Payá Pérez & Rodríguez Eugenio, 2018). Importantly, communities living on or close to contaminated sites are often socioeconomically deprived and vulnerable, and have a higher proportion of foreign nationals and elevated unemployment rates, pointing towards serious environmental injustice (Pasetto, Mattioli & Marsili, 2019).

Revitalizing previously developed land presents an opportunity for sustainable urban development by reducing pressure on and demand for natural land (Bleicher & Gross, 2010), and by solving longstanding environmental, social and health problems linked to real or perceived contamination. Cleaning up environmental pollution, removing neighbourhood eyesores and bringing back underutilized and often abandoned sites to the use of the community may provide opportunities for a sustainable answer to the challenge of urban sprawl. Depending on the new function of the site, it can create housing, commercial and public facilities; generate space for recreation; and increase green space in densely populated cities. Moreover, urban redevelopment projects can create jobs and improve the health, well-being and quality of life in the surrounding, often marginalized and vulnerable, communities.

Redeveloping contaminated sites presents technical, financial and organizational challenges, however, especially as the contamination can be complex and heterogeneous: it can be difficult to assess and characterize in terms of both environmental risks and associated health risks (Iavarone & Pasetto, 2018). Historical data related to the source of contamination and movement of contaminants beyond the boundaries of the site can create further complexities in the assessment process. If the contamination is not properly characterized, the site is not properly remediated and the risk is not mitigated for use of a predefined purpose, the site will continue to pose environmental and health risks that will affect and restrict future functions. In addition, contaminants emitted during the remediation process may expose site workers and neighbouring populations to additional health risks, which must also be considered. Complex redevelopment projects require active cooperation between public authorities at different levels and private stakeholders, with often divergent interests. It is therefore important to support local or regional entities early in the planning of and decision-making process for such activities. For sustainable development and public health, it is crucial to take into consideration potential environmental, social and health effects, as well as to inform and communicate with the communities living nearby.

1.2 Technical and policy context for contaminated sites

1.2.1 Technical context and recent work

Contamination creates significant risks to the environment. Unless managed properly, contaminated sites can lead to significant contamination of water, soil, air and food, which can directly threaten human health. For instance, heavy metals or pesticides from industrial sites and agricultural use can contaminate groundwater, surface water and sources of drinking-water, as well as soil (affecting crops and food products), the marine environment (affecting the marine food-chain and eventually fish and seafood) and in some cases also the air. Other examples are volatile organic compounds – fuels that have leaked from underground pipes or storage tanks to contaminate soil and groundwater, resulting in compounds that may be carcinogenic and cause vapour intrusion into nearby or overlying buildings. The implication of environmental contamination to human health and well-being occurs through direct exposure (for example, via ingestion, inhalation, skin contact and dermal absorption) or indirect exposure (for example, via contaminated drinking-water or food products); it may reduce the usability of the land for future sensitive functions (such as residential use) or affect ecosystem service functions. As shown in numerous studies, hazardous substances emitted into the environment from a contaminated site can cause acute or chronic illness in human beings, such as increased prevalence of cancer (Abrahams, 2002) or congenital anomalies and low birth weights in populations (Elliott et al., 2001), as well as higher mortality rates (Martuzzi et al., 2012). Less severe effects may include skin reaction or nausea (Swartjes, 2015).

The large volume of industrial activities and related waste production in such sites, together with increased use of chemicals and other hazardous materials and fuels during recent decades, as well as residual contamination in derelict military sites, have resulted in challenges for the future use of potentially contaminated sites (Panagos et al., 2013; Payá Pérez & Rodríguez Eugenio, 2018, Ellwanger & Reiter, 2019). This is especially important as growing cities have a continuous demand for land and cannot afford to leave abandoned sites (often referred to as brownfields) unused and undeveloped for current needs. The European Environment Agency (EEA) considers land one of the most precious natural resources and monitors land-use functions related to the continuing sprawl of urbanized areas and covered land surface. However, an EEA report indicated that land recycling and urban densification (such as converting industrial sites into urban functions and related infrastructure) accounted for only 13% of new developments and associated land take, identifying the increasing demand for land as a viable challenge for future sustainable development (EEA, 2019a).

Redeveloping contaminated sites for urban functions is necessary for land recycling in many European countries. Reflecting this urgency, the remediation and redevelopment of contaminated sites has been the focus of several activities lead by the European Commission, such as the 2015 and 2017 reports on remediated sites and brownfield redevelopment (Payá Pérez, Peláez Sánchez & Van Liedekerke, 2015; Payá Pérez & Peláez Sánchez, 2017). Moreover, a recent conference on brownfield redevelopment held in Brussels in 2019 showed how such conversion projects can be managed, and the benefits associated with them (European Commission, 2019a). Finally, over recent decades, a wide range of multilateral European concerted actions, research projects and information platforms (including, among others, TIMBRE, HOMBRE, HERACLES, EUGRIS, COMMON FORUM on contaminated land in Europe and the Industrially Contaminated Sites and Health Network [ICSHNet]) received European funding to develop technical support on sustainable land redevelopment (such as remediation technologies and tools for decision-making). Annex 1 provides a short overview of some of the available output produced by such international initiatives and networks.

The WHO European Centre for Environment and Health has led various projects on the health impacts of contaminated sites, focusing mostly on the health impacts of pollution caused by industrial activities. The first report addressed the potential mechanisms for impact and risk assessments of contaminated sites (WHO Regional Office for Europe, 2013); the second addressed the health and mortality impacts of industrially contaminated sites, based on a case study in Sicily (Mudu, Terracini & Martuzzi, 2014). Further work was done on the public health challenge of hazardous waste (Fazzo et al., 2017), and a fact sheet on waste and contaminated sites stressed that health impacts include cancer, respiratory disease and adverse reproductive outcomes (WHO Regional Office for Europe, 2017a). In recent years, WHO joined and co-led ICSHNet projects on sustainable land redevelopment and health impact assessment of industrially contaminated sites (ICSHNet, 2020), coordinated by the WHO Collaborating Centre for Environmental Health in Contaminated Sites. ICSHNet carried out an international survey of industrially contaminated sites across Europe to assess the availability of data, research and assessment tools. This provided insight into current needs and priorities; quality of environmental, population and health data; assessment and reporting of human health risks and impacts (Martin-Olmedo et al., 2019a). Furthermore, WHO actively supported an evidence review of inequalities related to industrially contaminated sites (Pasetto, Mattioli & Marsili, 2019).

1.2.2 Policy context

Land contamination – largely a memento of industrial heritage but also caused by past and present agricultural, military or other functions – has raised considerable attention across the Region in the last decade. Preventing future adverse impacts from potentially polluting activities and eliminating the adverse environmental and health impacts related to waste management and contaminated sites is one of the six priorities in the Declaration of Sixth Ministerial Conference on Environmental and Health, held in 2017 in Ostrava, Czechia, and signed by ministers of Member States in the WHO European Region and by high-level representatives of several United Nations agencies (WHO Regional Office for Europe, 2017b).

The EEA addresses soil contamination from local sources as one of two main issues related to its work on soil and land, and the recently established Green Deal by the European Commission announced a “zero pollution action plan for water, air and soil” by 2021 (European Commission, 2019b). In 2019, the European Commission addressed the relevance of brownfield redevelopment in the European Union (EU) through an international conference (European Commission, 2019a). In addition, various EU directives have direct relevance for contaminated site redevelopment, such as the EU Directives on Environmental Impact Assessment, on Strategic Environmental Assessment and on Environmental Liability (European Commission, 2020a; 2020b).

On a global scale, the problem of soil contamination is reflected in the Sustainable Development Agenda, which considers sustainable consumption and production patterns in Sustainable Development Goal (SDG) 12. To feed the world sustainably, producers need to grow more food – which requires healthy soils unaffected by negative environmental impacts and degradation. The Agenda covers, among others, hazardous waste and chemicals, as well as extraction of natural resources (United Nations, 2020). Soil-related aspects are also covered (for example in relation to land degradation, ecosystem services or soil resources) in various other SDGs. Promoting sustainable production and management of resources including soil is also the objective of the circular economy concept, which aims to mitigate waste and pollution by keeping material resources in use and supporting natural material regeneration. Changing from a linear economy (take, make, dispose) to a circular economy (renew, remake, share) is therefore expected to support the attainment of SDG 12 (WHO Regional Office for Europe, 2018). The circular economy concept has also been embedded into the EU Green Deal as one of its central components in achieving a climate-neutral economy by 2050 (European Commission, 2020c).

Finally, Resolution UNEP/EA.3/Res.6, adopted by the United Nations Environment Assembly in 2017, calls upon Member States and international organizations "to address soil pollution within the global environmental, food security and agriculture, development and health agendas in an integrated manner, especially through preventive approaches and risk management using available science" (UNEA, 2018).

2. Towards healthy redevelopment of contaminated sites

Against this background, WHO initiated a project on the topic of redeveloping contaminated sites for new urban functions such as residential neighbourhoods and public or recreational functions. The central component of the project was an expert consultation, which took place online between 28 September and 5 October 2020, to review the health and environmental impacts of conversion and redevelopment and to identify sound practices that can support effective redevelopment while considering health and well-being.

2.1 Expert consultation

Participants were welcomed to the expert consultation by WHO and thanked for their commitment to support the project.

The context of the consultation was outlined, and the key objectives identified:

- to discuss, review and conclude on a compilation of academic evidence and practical experiences associated with the assessment, remediation and redevelopment of contaminated sites for new urban functions; and
- to identify and extract good practice on conversion and redevelopment of contaminated sites.

The outcomes of the consultation would then be used to develop actionable evidence for public authorities, urban planners and other stakeholders and decision-makers dealing with such challenges.

In the opening presentation, Rainer Baritz of the EEA focused on soil contamination, presenting recent work on the status of contaminated sites across the Region. Based on a series of surveys among partners of the European Environment Information and Observation Network, he showed that almost 3 million potentially contaminated sites exist across Europe, but only 650 000 are formally confirmed as contaminated. Only a third of these had been remediated in the past, which indicates the magnitude of the challenge ahead. Furthermore, the survey indicated that only 28 of the 39 responding countries have established comprehensive inventories on contaminated sites over recent years. In a broader scope, the EEA report on the state and outlook of the environment (EEA, 2019b) continues to warn about the deteriorating trends of the soil condition in Europe; this includes diffuse pollution, air and water quality, as well as ecosystem condition, and highlights the multifunctional role of soils.

Piedad Martin-Olmedo (Andalusian School of Public Health, Spain) then set out a variety of methodological approaches that can be applied or considered for characterizing the health impacts associated with local contamination before redevelopment. Parts of the presentation drew from recent work by ICSHNet on methods and data needs to assess exposure and impact on health of chemicals in industrial contaminated sites (Iavarone & Pasetto, 2018; Martin-Olmedo et al., 2019b). She highlighted the complexity of contamination sources and pathways, and identified the key data required to assess related health threats. Specific emphasis was placed on the three essential steps for such an assessment, which cover:

- identifying potential exposure pathways (the course pollutants might take from a source to the portal of entry to the human body);
- exposure assessment (describing various approaches and metrics to quantify the exposure dose); and
- determining the probability of occurrence of health effects related to the exposure (based on descriptive or analytical epidemiological studies, or using an epidemiological or toxicological human health risk assessment approach).

In the second part of the opening plenary, three working papers prepared to support discussion among experts were presented by the lead authors. These had been produced by early September 2020 and distributed to participants of the consultation for review and discussion during the sessions. This part of the plenary session was opened up to external participants as a webinar; it was attended by 80 participants in addition to the consultation group.

The working papers were:

- a systematic review of scientific evidence on the environmental, health and social impacts of interventions to remediate and redevelop contaminated sites by Danielle Sinnett (University of the West of England, United Kingdom);
- a collection of case studies on European contaminated site redevelopment projects and associated lessons learned by Gergő Baranyi (University of Edinburgh, United Kingdom); and
- a review of impact assessment approaches related to redevelopment projects on contaminated sites by Thomas Fischer (University of Liverpool, United Kingdom).

After these presentations, Ivano Iavarone (National Institute of Health, Italy) provided an invited commentary on the presentations, and questions were taken from the webinar participants.

During the following days of the consultation, the participants attended working groups to discuss the papers, concluding with a plenary session at which rapporteurs presented the working group conclusions to plenary and overall conclusions were identified.

2.2 Project aims and objectives

The project aimed to review and discuss evidence and practice on the redevelopment process of contaminated sites, looking at health outcomes and lessons learned from existing redevelopments. Discussion at the expert consultation focused on how public authorities can provide effective management of such redevelopments for the benefit of their citizens and the local environment, and how they can ensure that the remediation and redevelopment process adequately considers and includes health dimensions.

The project outcomes are therefore intended to support local and regional entities by providing good practices and action priorities for planning and implementation of such redevelopments. Technical guidance on environmental engineering and specific technologies to characterize and mitigate site-specific contamination are beyond the scope of this report; readers interested in such information may wish to read the overview of international initiatives on contaminated sites and their remediation and redevelopment in Annex 1.

This project report presents scientific evidence and practical knowledge on environmental and health issues associated with the remediation, conversion and redevelopment of such sites. It aims to:

- compile and analyse practical experiences and case studies on the environmental and health implications associated with remediation and redevelopment of contaminated sites (including lessons learned);
- identify good practices from contaminated site redevelopment projects to produce an action brief for public authorities and urban planners or other stakeholders.

The report also aims to support Member States in implementing the Declaration of the Sixth WHO European Ministerial Conference on Environment and Health (WHO Regional Office for Europe, 2017b), in which governments committed to address waste and contaminated sites as a priority, and to support subnational action and work at the city scale, for example, by promoting the health relevance of planning-related impact assessment tools. Although this report’s main target groups are local/regional authorities and urban planning departments (which are often responsible for coordination of the remediation and redevelopment process), it may also provide useful information for various stakeholders participating in complex redevelopment projects at the national level.

The consultation process resulted in a range of conclusions on the current knowledge gaps and procedural constraints. Based on the case studies on on-site redevelopment and the use of impact assessments, the consultation identified good practices and important elements that should be considered for remediation and redevelopment projects. Knowledge and challenges in the area of redevelopment and repurposing of contaminated sites are growing and as such this topic requires an ongoing evaluation and update.

2.3 Terminology and structure of the report

In this report, the term “contaminated site” refers to an area that has hosted human activities that have produced environmental contamination of soil, surface water or groundwater, sediments, air or the food-chain, resulting (or being able to result) in adverse human health impacts (adapted from Martuzzi, Pasetto & Martin-Olmedo, 2014). A number of different terms are used to describe sites affected by contamination, and various terms and approaches exist to define steps and procedures to assess and deal with the contamination. For clarification, Annex 2 provides a glossary of the most relevant terminology used in this report. The use of these terms should not be understood as a technical guidance statement and may even be inappropriate in a given local context, or in relation to a specific legal framework or technical guidance document.

After this overall introduction to the theme and scope of the project, sections 3–5 present the discussions and conclusions of the three working group sessions (on the evidence review, practical case studies and impact assessment approaches) convened during the consultation, and section 6 summarizes the main conclusions of the project.

3. Evidence review – discussion

The first working group reviewed the evidence review of the environmental, health and social impacts of redevelopment of contaminated sites and discussed how the findings can support practical action. The resulting revised and extended working paper is available in Annex 3.

3.1 Summary of evidence

The review examined the extent to which remediation of contaminated sites reduces environmental and health risks to new and existing populations and ecological systems. It covered global academic and grey literature and identified 16 academic papers for the synthesis of environment and health outcomes of remediation projects. The majority of these were set in the United States (n = 9); only two were from Europe. No relevant reports from the grey literature category matched the search terms.

Most studies addressed the remediation of sites contaminated with lead (n = 12). Two studies examined the impacts of remediation on soil contaminated with chromium and sediments contaminated with polychlorinated biphenyls (PCBs). Most studies also focused on children living near remediation sites (n = 15), in which the remediation method was soil removal and replacement with clean soil and/or capping (n = 15). Furthermore, many studies presented the findings of a combination of soil remediation and public health campaigns to reduce exposure during the remediation works.

The study designs were found to be relatively weak, however. There is a relative paucity of evidence related to full-scale remediation and the environmental outcomes, although the studies reviewed indicated that applied remediation measures were successful.

Overall, the evidence is strong that remediation methods such as soil removal, capping and/or replacing lead-contaminated soil can result in reduced blood lead concentrations in children. Some limited evidence indicated that this can have a positive impact on cognitive performance in children. Further, some evidence showed that removal and replacement of soil contaminated with chromium can result in reduced chromium concentrations in urine of children, and that dredging sediments contaminated with PCBs can reduce umbilical cord PCB concentrations in infants. However, some studies also highlighted that a detailed understanding of the contaminant and site characteristics, as well as any capping materials, is essential in developing remediation strategies and long-term monitoring programmes. In two examples, contaminated soil was re-exposed following a period of flooding, demonstrating the importance of understanding the hydrology of the site and how this may change under future climates.

Several of the studies examining the impact of remediation of large areas of contamination resulting from aerial deposition of lead in existing neighbourhoods reported that area-wide remediation was more effective than targeted remediation of individual yards, as these quickly become recontaminated by dust from surrounding land. In addition, the review found that where populations remain in their homes, initial home cleaning followed by public health campaigns that seek to raise awareness of exposure routes and their mitigation are effective.

3.2 Peer review comments and considerations

After discussion of the review methodology and search strategy, the working group identified the following areas for revision and improvement of the evidence review paper:

- increased emphasis on the methodological limitations of the reviewed material and the partialness of the evidence on remediation impacts, requiring a clear statement that the evidence identified is not universally applicable;
- information on application of human biomonitoring (HBM) measures from the reviewed papers (including when this was applied, how and for what purpose);
- discussion on the lack of grey literature reports; and
- links to selected evidence-based technical guidance material in the discussion section (indicating additional sources of relevant information).

The authors amended the working paper in the light of the points above and the overall discussion at the consultation. The unedited final evidence review is enclosed in Annex 3 and includes additional material on environmental outcomes, based on a widened search approach.

3.3 Discussion of relevance and transferability of findings

3.3.1 Challenges in applying evidence about health effects

Although the review indicated that the applied remediation measures tended to be effective in reducing health risks or outcomes, challenges remain regarding the application of these findings as a general trend. The sites described in the studies often represented large American sites, which may not be representative of smaller European sites or remediation projects in different types of site elsewhere. Furthermore, the effectiveness of the interventions described does not necessarily translate to other types of contaminant, for which similar measures may be less effective or different techniques required. It was also unclear to what extent the reviewed studies (published 1996–2017, with a focus on removal of contaminants) still represent sustainable or current good practice, especially as on-site remediation techniques have often been prioritized in recent policy and regulation to avoid moving the contamination problem to other sites.

How success was assessed within some of the studies was also unclear – for example, whether a statistically significant reduction in blood lead levels was considered to prove the effectiveness of the intervention, or whether effectiveness depended on the reduction of levels beneath a threshold considered acceptable from a health perspective. Furthermore, the timing of health assessments plays a crucial role; this may have affected the results.

The discussion of the evidence review also highlighted two important details that were missing from the literature. First, there was an absence of information on mental health impacts of remediation and redevelopment measures. This is most probably because the reviewed studies focused on the direct physical effects of contamination, and therefore monitored for respective health outcomes only, while mental health or social aspects (such as fear of exposure to environmental risks or the stigma associated with contaminated sites) and related outcomes were not addressed. The lack of information in the reviewed papers should therefore not be interpreted as an indication that mental health impacts do not occur. Given the sensitivity of contaminated sites for the affected communities, mental health outcomes deserve targeted research activities in the future.

Second, the lack of grey literature coverage in the evidence review is a severe limitation, given that many reports (in various languages) by organizations and technical networks provide relevant information on such projects. The evidence review was designed to include such grey literature but did not identify any relevant material; different review mechanisms may therefore be required to compile evidence and lessons learned from such grey literature reports.

Finally, from the practice perspective, it was cautioned that academic evidence on effective remediation measures and redevelopment projects largely remains within the research community and does not benefit practitioners, unless translated into implementable standards to be applied on the ground by urban planners and environmental authorities.

3.3.2 Gaps in evidence and potential ways forward

Evidence on effective remediation measures is context-specific, and is only available for few interventions and a limited number of contaminants. Gaps therefore exist in the published literature, especially on the positive as well as the negative health impacts of remediation and redevelopment of contaminated sites, as the number of relevant studies is very limited (Xiong et al., 2018).

One reason for the low number of studies is that epidemiological studies of contaminated sites are not usually required by the regulator, and they are only useful only for certain kinds of sites and situations – for example, see Savitz (2018). Instead, site assessments and studies (such as site characterization) tend to focus on environmental aspects by conducting sampling of water, soil, soil gas or indoor air before remediation, while environmental and human health risk assessments aim to evaluate the site conditions against national standards or reference values. Only a fraction of such studies are likely to measure health-related variables. Further, health impacts of site-specific conditions are difficult to measure (owing to the multiple determinants affecting health status, irrespective of the site), and health outcomes associated with the site conditions may take many years to manifest; they may therefore not be visible in early studies during remediation or right after site interventions.

Finally, even when studies are carried out to identify the site status as reasonably safe from a health perspective, these tend to be documented within the relevant project and its approval scheme, but are not always published.

During the discussion of the evidence review, the following proposals were considered to improve the evidence base on the health impacts of contaminated site redevelopment.

- Publication of practical examples and knowledge may be helpful in addition to academic literature (here, reference is made to the material provided by the various international networks and projects – see Annex 1).
- Relevant work is done at the local level and by local authorities, but it is often not published, or is written in the local language. It could be possible to use city networks or similar regional/national forums to compile such material and make it available.
- For studies that include analysis and reporting of health outcomes (such as HBM), information about the project, the methods applied and the results should be shared through publication. This applies especially to companies and consultants involved in such projects. Funding options or other incentives may have to be considered, however, as – in contrast to academic researchers

– the time investment required for a publication may not always be feasible for consultants and private service providers.

- A collaboration between local authorities and practitioners (coordinating remediation and redevelopment projects) with academic partners (providing research knowledge and publication expertise) could provide mutual benefits. Researchers could have access to real projects to be measured and evaluated, and local actors could benefit from technical support on the project and the academic experience of publishing.

3.3.3 The need for remediation guidance

From the perspective of practitioners and public authorities managing contaminated site redevelopments in the field, the current published literature seems partial and fragmented, and is not universally applicable. There remains a need for further practical guidance on what measures and checks are needed at what point in the remediation and redevelopment process; specific examples mentioned were the application of HBM (when, how and for what purpose) and the effective implementation of screening and monitoring programmes. Given the diversity of sites and local situations, however, it is difficult to derive such generic guidance based on the compiled evidence.

Nevertheless, much guidance has been compiled by technical networks and expert communities on contaminated sites is already available (see Annex 1), focusing on practical experience but also overlapping with academic research. Without an overarching or widely accepted framework (such as a soil directive by the EU), however, many different procedures, methodologies and approaches exist in Europe for the implementation of site characterization, risk assessment and remediation and other risk management measures and procedures. This makes it necessary always to adapt the technical information to the local and national context.

Acknowledging the complexity of site remediation and redevelopment, and the lack of universally applicable guidance and tools, the working group emphasized two important requirements that should be established by national governments to ensure that the conversion of contaminated sites is done professionally.

- Professional consultants and contractors need to be accredited to carry out work on contaminated sites.
- Regulatory standards on environment and health need to be applied as a consistent and reliable baseline for both assessing the need for remediation and evaluating its success.

4. Case study compilation – lessons learned

A second working group reviewed the case study compilation report and discussed its summary of lessons learned and the good practice components derived from the material. The unedited final working paper is available in Annex 3.

4.1 Summary of case study findings

Owing to a lack of land resources, the availability of abandoned industrial sites and the growing understanding of the environmental and health implications of contaminated sites, urban growth and development across Europe increasingly considers reuse of these former production sites for various functions. This challenge is often referred to as land recycling or – more broadly, and with changing definitions – brownfield conversion. Depending on the former use and function of the sites (which could also have an agricultural, military or harbour background), they can be affected by contamination which, if not suitably remediated, can pose health risks to both nearby residents and the users of the new urban functions established after redevelopment.

The compilation explores the practical experience, and the lessons learned, from 28 European case studies covering remediation and redevelopment of contaminated sites with various former functions. It provides an overview of local and regional action on such sites, the scope and focus of the conversion projects, the actors and procedures involved, and the problems and obstacles that needed to be overcome.

The findings show that – irrespective of former use – almost all case study sites were polluted by multiple contaminants, affecting several environmental media. Many remediation projects took a long time and raised managerial and organizational challenges for the public authorities in charge, especially when unexpected contamination was found during remediation or redevelopment. Although risk and impact assessments on environment and/or health were carried out in almost all cases, public participation in the planning process was not a given feature in all projects. The results also showed that health authorities were only actively involved in less than half of the projects. An important finding is that a significant number of sites still had problems with contamination after the remediation was finished.

The experience derived from the case studies provided useful lessons – for example, on coordination and management procedures, public participation and communication, the application of legal frameworks and various other practical challenges on the ground. The lessons learned may be useful to support the coordination and implementation of future redevelopment projects across the WHO European Region, and to identify the crucial elements and practices enabling public authorities to ensure effective project management and adequate public health and environmental protection.

4.2 Peer review comments and considerations

After discussion of the working paper and its findings, the working group approved a set of key messages and action statements. Furthermore, the experts added some missing elements from their own experience (related to the specific relevance of small sites within an urban context, such as gas stations or dry cleaners; the financial aspects of redevelopment projects; and the adequate involvement of health actors in the process) to complement the lessons learned from the case studies. In addition, the group identified the following areas for revision and improvement of the case study paper (if possible, based on the collected data):

- modification of the abstract section to represent the findings better;
- fine-tuning and validation of the terms used in the report;
- acknowledgement that the case studies presented can only provide descriptive information, as they do not always represent up-to-date technologies and legal frameworks (as some interventions were performed decades ago), and because there may be an association between the type and intensity of remediation and the future use of the site.

Further suggestions and comments were made on the methodology and the coverage of case studies, pointing out how more case studies representative of different local contexts could be acquired. These suggestions will be helpful for future work in this field, but could not be implemented within the scope of the current compilation.

The authors amended the working paper in the light of the points above and the overall discussion at the consultation. The unedited final case study report is enclosed in Annex 3.

4.3 Discussion of relevance and transferability of findings

4.3.1 Legal frameworks and their implementation

During the discussion of the case study findings, the reliability and effectiveness of legal frameworks governing contamination and remediation was one of the most important points raised. This especially acknowledged the lack of European or international standards, which means that each country – or even subnational authority – is required to provide its own frameworks.

The experts agreed that it is important for national frameworks to provide implementable standards and criteria for the remediation of contamination, and that these standards should include both environmental and health considerations. This type of information is important for public authorities as the legal basis to manage such projects. At the same time, legal frameworks and regulations provide regulatory stability, which is a precondition for any type of investment (private or public); it also enables a foundation for the accreditation of specialized service providers and consultancies.

Owing to the many difficulties facing implementing the "polluter pays" principle, it was recommended that national regulations should clarify whether legal responsibility for contamination (and the associated impacts and remediation requirements) rests with the polluting entity. They should also ensure that legal frameworks enable local governments to carry out environmental investigations when sites are inactive or closed, and to request such site investigations when the site is sold or any other property transaction takes place. This information is also relevant for the financial market and the banking system, since the land is often used as collateral for a purchasing transaction. Further, continued and frequent monitoring of environmental and health risks should be a general standard for sites and activities with significant polluting potential to avoid potential spread of contamination for several years after redevelopment, depending on contamination and site characteristics. In this context, enforcing and implementing the EU Directive on Environmental Liability could be a first step. The need for an EU soil directive was also mentioned by various participants (especially in relation to the need for the European Commission's Directorate-General for Health and Food Safety to be involved in such regulation to assure adequate coverage of health aspects).

A specific challenge exists in relation to small local projects, for which no risk assessment requirements may be stipulated but a risk of contamination may remain. Implementation of environmental and health impact assessments as a mandatory part of urban or land-use planning could be a useful element of safeguarding planning processes and identifying the need for specific risk assessments. Another regulatory challenge is that various sectoral legal frameworks (such as planning laws and water or soil protection regulations) may affect contaminated sites in parallel, and can even be in conflict with each other, requiring harmonization and adjustment for each project.

Finally, a frequent comment was that prevention of contamination should be the key objective of any environmental regulation on emissions, aiming to reduce possible site contamination that may lead to subsequent remediation requirements.

4.3.2 The need for a shared vision

One key pattern identified by the case study review was the need for a shared vision by the relevant stakeholders and actors involved in the future development of the site, as this is often the only way common agreement can be reached by different sectors and stakeholders. Having such a shared vision can turn into a significant benefit when it comes to technical, procedural or regulatory conflicts of interest between stakeholders.

An open discussion about the future use of the site – early in the process – is necessary to understand the objectives and interests of all stakeholders involved; this is a prerequisite for finding common denominators. A shared vision can then represent a unifying goal that enables cooperation and harmonization between stakeholders from the planning phase onwards, including site owners, developers and public and private stakeholders. It may even be most important to enable coordinated and harmonized action among the competent authorities leading the project, given that different sectors and departments are bound to different regulatory frameworks and may have different – and partially conflicting – perspectives and priorities.

Early agreement on the future of the site enables quick action, and may facilitate an integrated approach, in which remediation of the site and redevelopment of the future site functions can go hand in hand as one larger project, offering many benefits (such as the ability to select the remediation techniques most suitable for the expected future site function). In most cases, however, remediation is done independently and before redevelopment and future functions are considered – especially when health and environmental risks are identified on the site and require immediate remediation activities. In addition, it takes time to decide about the future use of such a site and approve the relevant plans; this means that a two-stage process (remediation implemented before the future use of the site is decided) is common.

Practice shows that the presence of strong or hidden interests among stakeholders can be a major obstacle to achieving common goals, but it is important to reveal and address these at an early stage.

4.3.3 Recognizing site diversity

Although the review compiled 28 case studies with different backgrounds and from diverse locations in the WHO European Region, these fail to represent the full spectrum of contaminated sites and conditions; therefore, the list of good practices presented by these case studies should not be considered exhaustive. This was especially highlighted in relation to smaller sites (such as dry cleaners or petrol stations), which do not necessarily fall under the same regulations as large-scale or industrial sites but still may cause (or have caused) local or widespread contamination of soil and groundwater. Small sites may also – depending on their location – have low economic value, which makes them less attractive for developers to invest in, leading to vacant lots because no significant profit can be made. In such cases, naturally, a lack of follow-up action would result in fewer chances for such smaller remediation and redevelopment case studies to be submitted (indeed, only three of the 28 case studies reported a site size of less than 0.5 hectares). It is likely that European cities host many such small-scale sites with potential contamination history, and more policy attention should be devoted to investigating these.

Similarly, problems may occur when the level of contamination does not exceed national threshold concentrations that require remediation action (often governed by environmental standards) but may still affect future use of the site from a health perspective. Clean-up limits for remediation should therefore not only consider environmental risk assessment limits but also include human health risk assessments, according to site use. If confidence that a site is safe for human use is lacking, developers are unlikely to invest and local authorities may not be interested in redeveloping such sites.

Specific regulations, tools and funding sources for redeveloping small sites in local settings as well as less critically contaminated sites are required to address this often ignored issue.

4.3.4 Financial and economic aspects

An additional component significantly affecting contaminated site redevelopment is the financial elements. The case study compilation demonstrates the difficulty many projects had with making the polluter pay, and identifying the "responsible party" with legal obligation to remediate the site. Given these challenges, it is fundamental that economic aspects enter the discussion on the redevelopment of the site at an early stage to ensure solid funding of remediation and redevelopment. In specific cases, cost–benefit or cost–effectiveness analyses may even be carried out to identify the best solution.

Other relevant experiences on financial aspects relate to establishing a budget buffer for unexpected contamination discoveries, which may require significant changes to remediation and redevelopment plans and thereby increase project costs. Further, economic incentives could be considered to attract private sector investment in less attractive sites where the cost of remediation and redevelopment cannot be compensated by the future function. Similarly, incentives could be provided to public authorities to redevelop local contaminated sites with low economic value to support communities and their neighbourhood conditions. Such collaboration would enable the redevelopment of contaminated sites that might otherwise remain abandoned.

Finally, it was recognized that land recycling and redevelopment of contaminated sites is complex and costly, but it represents an inevitable challenge to be addressed in many cities and countries – to foster environmental protection and sustainability, but also to enable urban (re)development. It is therefore essential to establish funding mechanisms to support healthy and sustainable remediation and redevelopment of contaminated sites, whether through international schemes (such as those of the World Bank, European Commission, European Bank for Reconstruction and Development) or national programmes, as presented in the case studies from Aalst (Belgium) and Biancavilla (Italy).

4.3.5 Site assessment and background information

The importance of carrying out a proper site investigation/assessment at the beginning of the process was not only one of the main findings of the case study report; it was also reflected in the experience of the consultation participants. This requirement is essential for all sites. For sites with insufficient records and historical information on the former functions and potential contamination in particular, a thorough and detailed sampling plan of environmental media (such as water, soil, soil gas and indoor air) is of the utmost importance. Various case studies indicated that the lack of information on the site conditions affected and delayed remediation and redevelopment processes, and was responsible for significant budget increases.

The consultation group agreed that a proper and detailed site characterization and assessment is crucial for successful remediation, and must be performed as the first step of any remediation and redevelopment activity. It should include various data sources and mechanisms to compile background information on the site (for example, by involving different actors and stakeholders and their archives, undertaking interviews with long-term residents or former workers and employees, and applying on-site screening tools). Through these measures, a better understanding of the site's history, the potential contaminants present and the location of possible hot spots may be created; this will enable adequate and targeted measures to be put in place to plan the remediation work. In sites where historical data are incomplete or missing, it is necessary to start with preliminary site characterization via sampling to identify the contaminants and potential hot spot locations.

Looking at the challenge of data records in a prospective way, the consultation group proposed that public authorities should also think about the future and start to build up electronic archives with all relevant data on environmental pollution and site contamination (including documentation of past working procedures and practices in already closed sites where potentially polluting activities took place). They should also develop a suitable system for archiving such records so that information can be retrieved later by different actors and entities.

4.3.6 The impact of timelines

The case study compilation highlighted the importance of timelines. These affect the direction of the project in general; they also mean that – in many cases – former site activities and associated contamination, as well as their subsequent assessment, may have been carried out on the basis of older legal frameworks and performance standards. The consultation experts discussed this aspect further, and identified various impacts of different timelines on the remediation and redevelopment of contaminated sites in the following periods:

- from site closure to remediation/redevelopment;
- from remediation to redevelopment; and
- from exposure to health effects.

It is important to anticipate and prepare for the closure of contaminated sites, and to plan future functions (such as residential neighbourhoods, recreational facilities and public open space) and related redevelopments at an early stage. This allows public authorities and planners to be ready with redevelopment proposals when the original site function comes to an end, and to avoid longer periods of stagnation (possibly through an interim site management scheme). This is especially relevant when land functions are likely to be phased out in the near future, because of technical progress, changes in legal frameworks and governance or other factors. Political readiness to deal with a closed and potentially contaminated site also enables immediate assessment of contamination and related environment and health risks after site closure (or while it is still open and active) by the responsible authorities.

Once remediation has started, the duration of the work depends greatly on the thoroughness and reliability of the site investigation used as a basis for planning, the choice of remediation techniques and the funds available for the project. If the remediation work has to be scaled up because of the discovery of unexpected contamination, it affects the start date for redevelopment and may have financial implications. Similarly, discovering unexpected contamination may have an impact on the planned future function of the site and require changes and further planning time.

In addition to these timelines affecting conversion projects directly, the experts pointed out the relevance of a third related to health impacts. Depending on the type, spread and magnitude of contamination, the size of the site and various other factors, health effects may only occur years after contamination and exposure has taken place – and possibly even after remediation and redevelopment, as shown in the case study from Biancavilla (Italy). Similarly, it may be difficult to confirm that individual cases are associated with site contamination unless a cluster of cases can be linked to the site conditions. It is therefore important to establish environmental and health monitoring of redeveloped sites, making sure that health impacts related to environmental conditions of the site are identified and addressed.

4.3.7 Community involvement

Public participation is one of the most important ways to involve residents and local communities in the planning of their immediate surroundings, and to ensure that urban conditions meet the needs of the community. This is especially the case for decisions related to contamination and pollution, as these are very sensitive topics for most local communities. Although it is widely accepted that public participation measures are important, the case studies show that few projects included comprehensive community engagement. The expert group therefore reiterated that, even though it may be difficult, decision-making on remediation of local contaminated sites – as well as selection of the future site functions/uses – needs to be done with the active involvement of residents. In this context, the following aspects were considered relevant:

- involving the community as early as possible and making sure all relevant groups (not only the most vocal groups) are involved in the planning process and can engage in real discussion, rather than just being informed about decisions already made;
- attracting communities' interest in the site and its future use– for example, by showing the benefits of remediation and/or redevelopment for the community and its environment, making sure that the site is and remains available for public use, and demonstrating how public participation can have an influence on the decision-making;
- providing transparent and evidence-based risk communication and information about the environmental risks and the implications of the possible remediation and redevelopment scenarios in a clear and reliable way; and
- establishing methodological competence within public authorities to manage public participation processes and benefit from them.

4.3.8 The role of public authorities

In line with the case study report, the experts assessed the role of public authorities as critical. On a formal level, this is because – as the competent authority – they are in charge of managing remediation and redevelopment on public grounds, and of overseeing, regulating and approving similar activities on private sites. This role includes, among others, ensuring protection of environment and health, requesting data and monitoring site conditions, and coordinating or approving assessments and project plans. Public authorities are accountable for all decisions made in this context.

Alongside this role, however, public authorities can support the process in other ways and contribute to a successful outcome, especially as they know the community and understand local priorities; they can also influence many other contextual factors of relevance for an individual project or redevelopment. As indicated above, the efficiency of internal collaboration across public authority departments (despite potentially different departmental objectives) is important to expedite redevelopment projects. Authorities' quick and factual responses to public requests and concerns regarding the redevelopment process can further help to keep the community's trust in local decision-making.

Many local authorities may lack the required capacities to coordinate remediation and redevelopment of contaminated sites effectively, however – in terms of both human resources and technical capacity. Empowering local authorities is thus a most important step towards supporting adequate and sustainable land use. This could include:

- establishing specialized public entities (possibly at higher spatial levels or as collaborations of individual authorities) with adequate expertise and experience;
- identifying focal points or case managers to oversee site-specific projects and coordinate/harmonize activities across authority departments;
- providing training and capacity-building on technical and procedural aspects of site assessment, remediation and redevelopment; and

- developing tools and frameworks to support cooperation within and across the public sector and to enhance collaboration with the private sector and investors.

4.3.9 Involvement of health actors

Only few case studies reported the active involvement of health and safety departments in the remediation and redevelopment process. Acknowledging this limitation, the experts reviewed various options for involving health actors effectively. The general expectation was that health aspects should be considered across all stages of conversion projects – from site closure and first investigations to monitoring of environmental conditions and health status after the redevelopment. At the same time, noting that health information is sensitive, the experts warned that active collection of health data should be done in a targeted way to support assessments and decision-making. The following requirements were discussed.

- Procedures and regulatory frameworks for site remediation and redevelopment need to include health aspects beyond the human health risk assessment of the sites' contamination status; they should ideally involve health authorities across the planning, remediation and redevelopment process.
- Capacities and resources of health authorities need to match the specific requirements and conditions of conversion projects and contamination histories, aiming to complement and support the responsible environmental authorities.
- Health surveillance measures and administrative records should be applied to understand and monitor the potential health impacts of remediation.
- Health data should be applied to support site-specific risk assessments and to inform strategic environmental and health impact assessments.
- Health actors can support the identification of potentially suitable HBM approaches and advise on the interpretation and implications of results.

5. Impact assessment approaches and their applicability

A third working group reviewed and discussed the report on the application of impact assessments as a part of the site conversion process, and at what stages they affected the planning and implementation. The unedited final working paper is available in Annex 3.

5.1 Summary of findings on the use of impact assessments

The working paper presents the current practice of impact assessment procedures applied to the identification, assessment and mitigation of environmental and health (and possibly equity) effects of remediation and redevelopment of contaminated sites. First, these include risk assessments, which are used to identify site-specific risks and decide on measures for remediation. These are often required to obtain environmental permits or licenses. Second, they include the participatory impact assessment processes of environmental impact assessment (EIA), strategic environmental assessment (SEA) and health impact assessment (HIA) as an element of spatial planning and related programme and project consent procedures.

The main focus of the working paper is on the use of the participatory assessment approaches for converting contaminated sites into new residential developments and other public or recreational functions, including those adjacent to residential areas. Scopus and Google searches, an expert survey within the impact assessment community and the case study compilation on redeveloping contaminated sites were used to identify case examples of EIA, SEA and HIA. The paper reviews nine such examples from five countries (Germany, Portugal, Spain, The Netherlands and the United Kingdom); three SEAs, two HIAs and four EIAs.

The findings illustrate that risk assessments usually covered environmental and health risks of contaminated sites (including human health and environmental risk assessments). Among other objectives, the results provided helpful information to decide whether remediation and other risk management measures were required (although it should be noted that smaller contamination cases may not always trigger a full risk assessment). The findings also assisted decisions about remediation permits or licenses for the use of specific equipment or techniques on site to achieve the remediation targets. In the cases reviewed, the risk assessments did not tend to focus on the specific future use of a site, which in most cases was decided upon at a later stage.

Participatory assessment approaches, on the other hand, were more likely to consider the future of the site. SEA in particular was applied to consider contaminated sites in the preparation of local land use or smaller-scale development plans within or next to existing residential areas, with a focus on their future use. Conversely, EIA was mostly applied in major redevelopment projects on contaminated sites, at times also considering the site clean-up and remediation phase – frequently for developments outside existing residential areas. Participatory HIA processes were exclusively applied in the context of planning for future use of remediated sites. Only one of the reviewed impact assessments, however, was found to include monitoring provisions for the redeveloped site (which is usually done when some non-remediated contamination is left on site). The default assumption by the assessments dealing with the future use of contaminated sites therefore appeared to be that sites are safe once they are remediated, and that no further cautionary measures are needed.

5.2 Peer review comments and considerations

During discussion of the working paper and the application of the various assessment approaches, the working group highlighted the importance of using consistent terminology for the different processes of a conversion project: more careful rephrasing of some of the conclusions was also recommended (especially acknowledging that the sample size of nine cases is somewhat limited). It was further suggested that additional focus should be put on risk assessment and site investigations. These are important steps of the remediation process and risk management plan and have an impact on the redevelopment process, but do not fall under the category of participatory impact assessments.

The authors amended the working paper in the light of the points above and the overall discussion during the consultation. The unedited final report on assessment approaches is enclosed in Annex 3, and further work is being carried out by WHO on the specific aspect of risk assessments and site investigation approaches.

5.3 Discussion of relevance and transferability of findings

5.3.1 Applicability of assessment approaches

The compiled impact assessment projects showed that assessment approaches were used to identify a need for remediation, and sometimes to support the remediation or redevelopment process itself. Impact assessments are rarely used to identify continued or new environmental or health risks after remediation and redevelopment, however. In this context, the expert group noted that impact assessments may inform decision-making on the need for remediation, and the scope of it. The experts also suggested, though, that in too many cases impact assessments are seen rather as a burden; they are often implemented only superficially, instead of being considered as opportunities to improve the process and related outcomes. A missing health focus in SEAs and EIAs was further viewed as problematic, especially as in some cases contamination may not represent an environmental risk but may be of concern from a health perspective.

The group recommended that the authors develop a flowchart to illustrate current options for triggering different instruments, derived from the compiled assessment examples (see Annex 3). An understanding of the current application of the assessment approaches was considered essential for improving practice: this will assist in preventing the artificial layering of assessment upon assessment – instead, considering optimal stages of integration.

The expert group discussed current weaknesses in the relationship between risk assessment and participatory impact assessment during the problem identification stage, and how this does or does not inform the post-development follow-up stage. Regarding the scope of the assessments, the experts also noted that the legal frameworks regulating assessment approaches mostly focus on larger sites and are usually less applicable to smaller ones.

An additional point raised during the discussion was the need to distinguish methodologically between assessment of site conditions against environmental standards and assessment of environmental conditions for health, and to be aware of the objectives of such assessments and their implications for the process. Overall, SEA, EIA and HIA should be approached as a framework to support decision-making for on-site redevelopment. It is therefore mandatory to identify which decisions are to be made, and to apply assessment approaches accordingly. One suggestion was to consider development of an overall impact assessment framework to avoid the independent implementation of separate assessments, and to create linkages between the more technical risk assessments applied for site characterization and risk management, using the participatory impact assessment approaches as a planning tool.

5.3.2 Benefits of assessment approaches for site conversion

Further discussion took place on the wider benefits of applying participatory assessment approaches to support the planning of contaminated site conversions, specifically looking at the ability to involve local communities in the process. Implementing such assessments also enables improved and direct risk communication to local residents, which may be especially relevant for contaminated sites (as they tend to be a highly sensitive issue for the community). Impact assessments can therefore offer a useful mechanism into which public participation and outreach can be embedded, combining an information component (from public authorities to the community) with a feedback and engagement component (from the local community to authorities).

Furthermore, implementation of assessment approaches may also support the harmonization of sectoral regulations and objectives. Given that most technical assessments and decisions are likely to focus on contamination and its mitigation, wider determinants (such as greening a site, long-term implications, future site function or job creation) may not be addressed, although they are of high relevance for the local community. These wider perspectives are dealt with through the spatial planning system, which may not necessarily be involved in and connected with site-specific decisions. Bringing these two dimensions (site remediation and the wider perspective of site use) together through impact assessments with a broader approach could therefore establish an important link and exchange between them. As highlighted above, an impact assessment framework would be a suitable way to ensure that both site-specific remediation aspects and long-term development objectives are adequately considered. The latter may especially include environmental and/or health monitoring schemes, aiming to assure that redeveloped sites pose no risk to local citizens.

As the authors of the working paper highlighted, however, evidence and information on applied impact assessments and their results are scarce. The expert group therefore called for more investment in compilation and review of assessment projects to establish a portfolio of assessment case studies and to identify related gaps and success factors.

6. Project conclusions

The conclusions of the individual working groups were reconfirmed in a final plenary. They were reviewed and partly complemented based on the overview of all working group discussions, creating linkages between the discussions and overlapping key messages of individual working groups. These included, among others, the relevance of small urban contaminated sites that may not be covered by legal frameworks on contamination and the need to conduct a proper and reliable site investigation as a foundation for decision-making on necessary remediation action.

Overall, the closing plenary confirmed and agreed on the working conclusions and mainly discussed how the individual conclusions could be merged to provide a bigger picture. In this context, the need to translate evidence into action was highlighted, along with the importance of providing public authorities with the adequate resources, tools and frameworks to manage such processes and clarify the crucial question of whether a site is safe for its planned functions. To support such decision-making, the expert group concluded that a compilation of existing guidance and tools on technical measures would be helpful (see Annex 1). A need for guidance on the application of HBM as part of remediation measures was also identified, discussing when its use is justified, and how it is best applied – see also Colles et al. (2019).

Further discussion related to the fact that the technical approach to remediation has changed significantly over the years, with current practices favouring on-site approaches (when feasible) to safeguard the environment by, for example, isolating or neutralizing contamination and reducing it to the simple removal of contaminated material, which then needs to be stored safely at another site.[1] Ideally, the future function of the site should already be known before remediation, so that the measures applied can be harmonized with the proposed site use.

The use of impact and risk assessment approaches was considered essential, although their application depends greatly on the specific context and the project phase – from identification of the problem through the remediation phase to redevelopment and future use. In that context, it was noted that participatory assessment approaches (such EIAs) should also be considered as a useful tool to support decision-making processes by providing input and perspectives from the local community, and by considering the wider context and implications of the decisions made on a contaminated site. Furthermore, the experts highlighted that assessments of environmental conditions and local citizens' health status should not be restricted to the remediation and redevelopment phase, but should also take place in form of standardized monitoring – adapted to the site's history – after the redevelopment.

[1] Depending on the site condition, type of contamination and other factors, removal of contaminated material may still be the best option to assure adequate remediation. This may be applicable when a complete on-site remediation is not possible, or when remediation and redevelopment projects are implemented under time pressure and on-site approaches are not applicable as they may take longer to accomplish the remediation goals.

The expert group highlighted that international frameworks governing contamination and its remediation would be an essential step forward, especially when:

- providing legal requirements for remediation;
- enforcing accountability of the polluter or other responsible parties; and
- ensuring adequate integration of health aspects.

In this context, the need for a soil directive within the EU was also raised.

Finally, the working groups' reports back to plenary identified the general need to consolidate the terms used across the reports, especially as important terms may have different meanings across sectors and disciplines. In response to this request, Annex 2 of this report provides a glossary, rather than producing glossaries within each of the unedited working papers (Annex 3).

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Annex 1

OVERVIEW OF EUROPEAN INITIATIVES AND NETWORKS PROVIDING TECHNICAL INFORMATION ON CONTAMINATED SITE REMEDIATION AND REDEVELOPMENT[3]

Name (project duration)	**Objective and target audience**	**Links to project website and/or individual publications of relevance**
Industrially Contaminated Sites and Health Network (ICSHNet) (2015–2019)	ICSHNet aimed to identify needs and priorities; compile available information, methods and data; and develop guidance and resources on risk assessment, management and communication associated with industrially contaminated sites across Europe.	Project website: https://www.icshnet.eu/ Publication: http://www.epiprev.it/environmental-health-challenges-from-industrial-contamination_edit
Contaminated Land: Applications in Real Environments (CL:AIRE) (1999 to date)	CL:AIRE is an independent not-for-profit organization established in 1999 to stimulate the regeneration of contaminated land in the United Kingdom by raising awareness of, and confidence in, practical and sustainable remediation technologies.	Project website with compilation of (United Kingdom-specific) technical guidance on managing contaminated land: https://www.claire.co.uk/information-centre/water-and-land-library-wall
European groundwater and contaminated land remediation information system (EUGRIS) (2003–2005 and beyond)	EUGRIS is a web-based user-friendly information platform for sustainable management of contaminated land and groundwater in Europe. It was funded by the European Commission from March 2003 to August 2005, but is kept operational.	Portal website and library database with relevant national and international reports and guidance documents: http://www.eugris.info/index.asp; http://www.eugris.info/library.asp
European Soil Data Centre (ESDAC) at the European Commission Joint Research Centre	ESDAC is the thematic centre for soil-related data in Europe. Its ambition is to be the single reference point for and to host all relevant soil data and information at the European level. It contains a number of resources that are organized and presented in various ways. One theme of the data centre is soil contamination.	Data centre website with link to reports, publications and technical guidance: https://esdac.jrc.ec.europa.eu/themes/soil-contamination
Network for Industrially Coordinated Sustainable Land Management in	NICOLE is a leading forum on industrially coordinated sustainable land management in Europe, promoting cooperation between industry, academia and service providers on the development and application of sustainable technologies.	Network website with thematically sorted reports and guidance documents: https://nicole.org/

[3] The list does not indicate any endorsement or recommendation of the materials by WHO. It is provided only as an (non-exhaustive) information service to readers interested in the technical and engineering aspects of remediation and redevelopment, which are not addressed by this report.

Europe (NICOLE) (1996 to date)		
Holistic Management of Brownfield Regeneration (HOMBRE) (2011–2014)	HOMBRE focuses on strategies, technologies and solutions for brownfield management that emphasize the positive value of available resources and potential social, economic and environmental benefits. The project was funded by the EU Seventh Framework Programme.	Project website with technical reports: http://www.zerobrownfields.eu/content.aspx?wp=2&p=233
Tailored Improvement for Brownfield Regeneration in Europe (TIMBRE) (2011–2014)	The EU Seventh Framework Programme's TIMBRE supports end-users in overcoming existing barriers by having developed customized problem- and target-oriented packages of technologies, approaches and management tools for a megasite's reuse planning and remediation.	Project website with publicly accessible tools and guidance reports: http://www.timbre-project.eu/outcomes.html
COMMON FORUM on Contaminated Land (1994 to date)	The COMMON FORUM on Contaminated Land is a network of contaminated land policy-makers, regulators and technical advisors from environment authorities in EU Member States, and provides a platform for exchange of knowledge and experience on contaminated land.	Forum website with links to many projects, networks and publications: https://www.commonforum.eu/
Human Health and Ecological Risk Assessment for Contaminated Land in EU Member States (HERACLES) (2004–2010)	HERACLES was established by the European Commission Joint Research Centre as an international network of research institutions to improve the consistency of risk assessment tools applied for the appraisal of contaminated sites in EU countries.	The project delivered two major reports: https://esdac.jrc.ec.europa.eu/content/derivation-methods-soil-screening-values-europe-review-and-evaluation-national-procedures; https://rivm.openrepository.com/handle/10029/256036

Annex 2

GLOSSARY

Bioremediation	A process used to treat contaminated media such as water or soil by changing environmental conditions to stimulate growth of microorganisms and degrade the target pollutants to non-toxic substances.
Brownfield	Originally a term used for urban planning to define a vacant or unused property or site that may be affected by the presence of hazardous substances. The term "brownfield" is applied differently in various countries, but is mostly used for abandoned commercial and industrial properties.
Contaminated site	An area that has hosted human activities that have produced environmental contamination of soil, surface water or groundwater, sediments, air or the food-chain, resulting (or being able to result) in adverse human health impacts.
Human biomonitoring (HBM)	A scientific technique to assess whether and to what extent substances from the environment, food items or consumer products have entered a human body, and how exposure may be changing over time.
Impact assessment	A combination of procedures, methods and tools by which a programme or project may be judged on its potential effects on the environment (environmental impact assessment) or on the health of a population, and the distribution of those effects within the population (health impact assessment). A related assessment approach is the strategic environmental assessment (see below).
Land recycling	The reuse of abandoned, vacant or underused land for redevelopment by urban infrastructures.
On-site remediation	This indicates that remediation measures occur on the contaminated site without the removal of contaminated material (for example, on-site bioremediation is a technique that dissolves and purifies contaminants through microorganisms present in the soil).
Phytoremediation	The use of living green plants for on-site removal, degradation and containment of contaminants in soil, surface water and groundwater.

Potentially contaminated sites	Sites that may be contaminated due to their historic function and use, but in which the presence of contamination has not yet been verified.
Redevelopment	The replacement or functional change of use and infrastructure on an already developed site, with the aim to revitalize the physical and social fabric of the site in a wider urban context.
Remediation	The process of reducing health and environmental risks by removing or degrading contaminants found in contaminated soil, sediment, surface water or groundwater to non-toxic substances, to reduce the impact on people or the environment.
Risk assessment	The overall process or method to identify hazards and risk factors that have the potential to cause harm (hazard identification) and to analyse and evaluate the risk associated with that hazard (risk analysis and risk evaluation). Risk assessment is often a requirement of obtaining permits or licenses for future land use and development.
Risk management	Measures to reduce environmental and health risks on a given site (such as through remediation), with the selection of measures depending on the severity of risk and informed by a preceding risk assessment.
Site investigation	The process of collecting information, environmental sampling of the site, assessment of the data and reporting potential hazards of a site which are unknown.
Strategic environmental assessment (SEA)	A systematic process for evaluating the environmental implications of a proposed policy, plan or programme, which provides means for looking at cumulative effects and addressing them appropriately at the earliest stage of decision-making alongside economic and social considerations.

Annex 3

WORKING PAPERS

Evidence review of the environmental, health and equity impacts of remediation and redevelopment of contaminated sites[1]

Across Europe there is a vast legacy of contaminated sites from past industrial, commercial and military activity, waste disposal, mineral extraction and others. This review examined the extent to which the remediation of contaminated sites reduces environmental and health risks to new and existing populations and ecological systems. Following full-text screening sixteen papers were included in the evidence synthesis of outcomes related to health. The majority of these were set in the US and were focused on reductions in blood lead concentrations in children, following a combination of soil remediation and/or public health campaigns to reduce exposure. Two further studies examined the impacts of remediation on soil contaminated with chromium and sediments contaminated with polychlorinated biphenyls (PCBs). Overall, the evidence suggests that remediation via removal, capping, and replacing soil, with planting vegetation on bare soils is effective at reducing concentrations of lead and chromium in blood and urine in children, although this approach to remediation is not considered to be sustainable. There is also evidence that sediment dredging can reduce PCB concentrations in umbilical cords in infants. Overall, study designs are relatively weak, and some recommendations are provided for those wishing to examine the health impacts of remediation projects. There is a paucity of evidence related to full-scale remediation and the environmental outcomes, but the studies that were reviewed tend to report that remediation has been successful, particularly where techniques such as stabilisations/solidification or those that degrade organic contaminants have been employed.

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1. Introduction

Land can be affected by contamination from many different land uses, either current or previous, on site, or nearby, and may include chemical, textile, timber, printing and coating industries, those involved in generation of energy or management of waste, mining and processing of metals, transport and engineering (Souza, Pomarolli and da Veiga, 2020). These industries may result in contaminated land through disposal of waste materials, accidental spillage or release of pollutants or the deposition of air pollution (Coelho *et al.*, 2011; Yang *et al.*, 2020). Although in many countries regulation reduces the risk of land becoming contaminated, activities prior to this regulation resulted in a substantial legacy of contaminated sites globally. For example, the EEA estimated that in 2018 there were 2.8 million potentially contaminated sites across the EU-28, with only around 650,000 of these having been formally registered, an increase of 76,000 since the previous assessment in 2014 (Payá Pérez and Rodriguez Eugenio, 2018). This assessment categorises sites at different stages of the assessment and remediation process, from Site Status 1 where polluting activities took/are taking place, through to those in Site Status 6 where remediation has taken place and they are under aftercare; around 65,000 sites (Payá Pérez and Rodriguez Eugenio, 2018).

Across the EU-39, municipal and industrial wastes contribute most to soil contamination (38%), followed by the industrial/commercial sector (34%), storage (11%), spills on land during transport (8%), military (3.4%) and others (8%) (EEA, 2019). Overall, the production sectors contribute more to local soil contamination than the service sectors, while mining activities are important sources of soil contamination in some countries. In the production sector, metal industries are reported as most polluting whereas the textile, leather, wood and paper industries are minor contributors to local soil contamination (EEA, 2019). Gasoline stations are the most frequently reported sources of contamination for the service sector. In terms of budget, the management of contaminated sites is estimated to cost around 6 billion Euros (€) annually (EEA, 2019).

Countries develop their own legal definitions and frameworks for the management of contaminated land, generally based on a risk assessment approach (Payá Pérez and Rodriguez Eugenio, 2014; Martin-Olmedo *et al.*, 2019). A contaminated site is defined here as: *"areas having hosted or being affected by human activities which have produced environmental contamination of soil, sediment, surface or groundwater, air, or food-chain, resulting or being able to result in harm to human health, the environment or ecological systems"* (adapted, based on Martuzzi et al., 2014).

Contaminants include a range of inorganic metals and metalloids (e.g. arsenic, cadmium, lead) and organic substances (e.g. oils, polyaromatic hydrocarbons (PAHs), benzene, toluene, ethylbenzene and xylenes (BTEX), methyl tert-butyl ether (MTBE), polychlorinated biphenyls (PCBs), pesticides, chlorinated solvents, dioxins, volatile and semi-volatile organic compounds (VOCs; S-VOCs), and tars), as well as acids and alkalis, asbestos, gases (e.g. methane), and radioactive substances. Contaminated sites are a problem because these substances can migrate into groundwater and surface water or be taken up by plants, contaminating drinking water and food, damaging crops and livestock, as well as harming ecological systems. They can also damage property (e.g. through corrosion or explosion), reduce soil function, and cause direct toxicity to humans via ingestion of soil and food, inhalation of dusts, gases and vapours, and dermal contact. The health and environmental impacts of contaminants are varied, but include cognitive impairment and neurological damage, cancers, adverse impacts on respiratory, renal, reproductive and digestive systems, reduced foetal growth and miscarriages, acute poisoning in humans (Prasad and Nazareth, 2000; Reisinger *et al.*, 2005; Engelhaupt, 2008; Coelho *et al.*, 2011; Tirima *et al.*, 2016; Green *et al.*, 2017; Kalsi *et al.*, 2020; Souza, Pomarolli and da Veiga, 2020), and damage to ecological systems (Gomez-Ros, Garcia and Penas, 2013; Kalsi *et al.*, 2020; Souza, Pomarolli and da Veiga, 2020). It is difficult to assess the impacts of contaminated land on human health as they are often associated with other factors such as other sources of pollution (e.g. air pollution), deprivation and lifestyle (Farmer and Jarvis, 2009), and affect the whole local population making it challenging to include appropriate control groups.

Generally, land affected by contamination is prioritised for remediation where it is adversely impacting, or likely to adversely impact a 'receptor' (e.g. humans, water bodies, crops, property, specific ecological systems). Contaminated sites do not necessary pose a risk to protected receptors, for example, if they are not in close proximity, or the contaminants are relatively immobile in the soil (Reisinger *et al.*, 2005; Gomez-Ros, Garcia and Penas, 2013; Gong *et al.*, 2018; Kalsi *et al.*, 2020). However, contaminated sites located in or close to urban centres may pose a risk to people living nearby, although the multiple sources of contamination in such areas often make it challenging to demonstrate a direct link between a source and a health impact even where a risk assessment has identified a likely impact (Farmer and Jarvis, 2009; Eckley *et al.*, 2020). These sites, if inactive or closed, are also often unattractive, derelict and a waste of land (i.e. brownfields), and their redevelopment can help prevent urban sprawl (Wcisło *et al.*, 2016) so the same arguments are put forward for their redevelopment as for brownfield sites in general. It is often via redevelopment that contaminated sites are remediated (Rodrigues *et al.*, 2009), for example, in England and Wales around 90% of sites remediated are done so through redevelopment (EA, 2009). Therefore a risk assessment will consider not only the risks posed by the site in its existing state, but also any the risks that may occur through redevelopment, for example, to site workers, new populations moving on to the site, and remediate accordingly taking newly introduced pathways and receptors into account. The focus of this report is on sites that have been remediated (i.e. Status 6 sites; Payá Pérez and Rodriguez Eugenio, 2018) and have an impact on urban areas, either due to their proximity to existing neighbourhoods, or because their redevelopment may result in urban functions being introduced on to the site.

1.1. Process of risk assessment

Most countries in Europe have adopted their own legislative frameworks for dealing with contaminated sites (Payá Pérez and Rodriguez Eugenio, 2018; Martin-Olmedo *et al.*, 2019). These generally involve an assessment of risk, starting with a preliminary investigation of the history of the site, for example, previous uses of the sites and an assessment of any contaminants that may be present based on these uses, followed by site investigations using environmental sampling of increasing complexity to determine risk from the site to different receptors (Payá Pérez and Rodriguez Eugenio, 2018). Risk assessment is often carried out on the basis of a 'conceptual model' (Figure 1) that identifies the sources of pollution on site, the receptors that may be adversely affected by this pollution and the pathways by which the receptors may be exposed to the pollution (Wcisło *et al.*, 2016). Each stage of the risk assessment is focussed on testing the conceptual model.

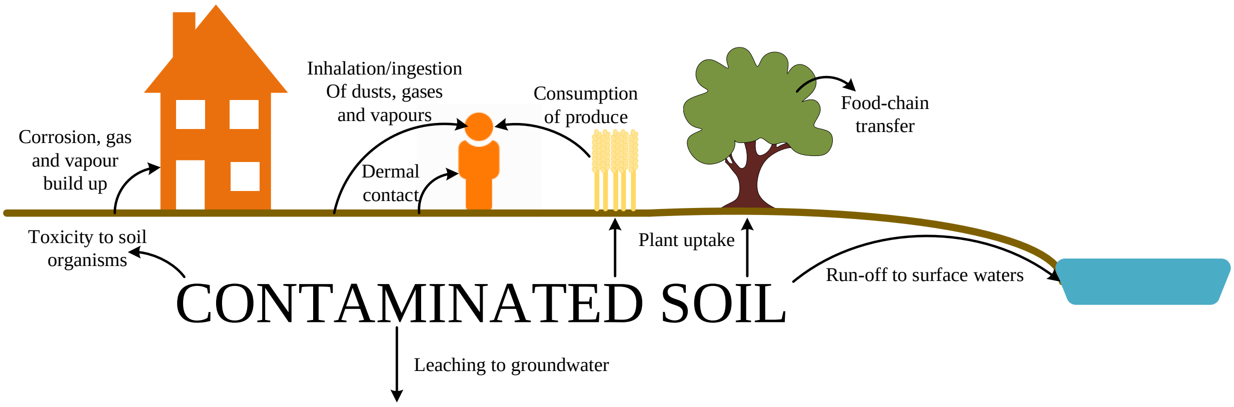

Figure 1. Indicative pathways and receptors from contaminated sites.

Impact assessment is covered in more detail in Working Paper 3, and risk assessment in the Final Report. Of relevance to this report is to acknowledge that risk assessment of contaminated sites is often based solely on whether soil, water and/or indoor air concentrations are above environmental reference values set to be protective of human or ecological health (Wcisło *et al.*, 2002; Gore, Preston and Fryirs, 2007; Hashim *et al.*, 2011; Gomez-Ros, Garcia and Penas, 2013; Martin-Olmedo *et al.*, 2019; Eckley *et al.*, 2020; Kalsi *et al.*, 2020). Where a site investigation finds that concentrations are above these levels then a remediation strategy (Wcisło *et al.*, 2002) is developed or further risk assessment takes place that may involve additional site investigation, modelling or measurement of outcomes related to human and ecological health (e.g. through biomonitoring). A human health risk assessment (HHRA), often includes an exposure assessment, to estimate the contribution of different pathways to overall exposure to contaminants (Martin-Olmedo *et al.*, 2019). Risk assessments generally progress iteratively, increasing in complexity and expense, in order to provide an accurate picture of the risk the site poses to relevant receptors and inform the remediation strategy. It is often more cost effective to remediate a site on the basis of soil, water and soil gas/sub-slab vapour concentrations and modelled exposure and risk to other receptors to risk-based acceptable levels, as opposed to undertaking a more detailed risk assessment, so direct measurement of outcomes in human populations or ecological systems are less common. Where a population is identified as being at risk, remediation may be combined with a public health campaign to reduce exposure (e.g. through increased cleanliness and hygiene to reduce household dust exposure, cessation of vegetable growing) (Prasad and Nazareth, 2000) or residents may be advised to move (Yaffee *et al.*, 2019). In very extreme cases, such as Love Canal, US, the residents may be permanently evacuated from the site, homes demolished and the contamination managed (Engelhaupt, 2008). There is a wide range of remediation technologies available, generally falling into physical (e.g. placing a barrier between a source and a receptor), chemical or biological methods (e.g. those that remove, degrade or immobilise the contaminants), for example, using chemical additions to soil, plants or micro-organisms (Souza, Pomarolli and da Veiga, 2020). These methods are still the subject of research and development and often a combination of several methods will provide the most effective solution, particularly where a cocktail of contaminants is present (Jing, Fusi and Kjellerup, 2018; Kalsi *et al.*, 2020; Souza, Pomarolli and da Veiga, 2020).

In addition to an HHRA, or as part of this, epidemiological or surveillance studies may also be undertaken to measure outcomes related to human health (Martin-Olmedo *et al.*, 2018; Martin-Olmedo *et al.*, 2019). Although such studies are not the norm, the exception may be where an adverse health outcome has been noted in a population and a link to a source or evaluation of remediation is sought (Sheldrake and Stifelman, 2003; Greene *et al.*, 2006; Engelhaupt, 2008), or where the contaminant is a known toxin and the impacts on a population investigated (McCarron *et al.*, 2000; Mielke *et al.*, 2007; Spurgeon *et al.*, 2011). In addition, given that the majority of sites are remediated as part of the redevelopment process there is not a 'before' population on which to examine pre-remediation health outcomes, although neighbouring populations may be included in monitoring programmes. Remediation strategies often include post-remediation monitoring to ensure that the objectives of the remediation have been met (Gore, Preston and Fryirs, 2007) and that risk-based accpetable levels were achieved, but these are usually focused on the media assessed in the original risk assessment (e.g. soil, soil gas, water, air or dust concentrations) so will also not commonly include a requirement for human or ecological outcomes to be monitored. In addition, these reports are often held by consultants and are not necessarily in the public domain (Jain, Townsend and Johnson, 2013).

This means that academic publications tend to focus on development and testing of remediation technologies using laboratory experiments (Jiang *et al.*, 2018), or small-scale pilot demonstrations on site (Hashim *et al.*, 2011; Gong *et al.*, 2018). Academic publications examining outcomes related to human and ecological health tend to cover the pre-remediation risk assessment and/or rely on data modelling exposure pathways or risk (e.g. Wcisło *et al.*, 2002, 2016; Bandli and Gunter, 2006; Coelho *et al.*, 2011; Yang *et al.*, 2016; Burger *et al.*, 2019; Yang *et al.*, 2020). However, there is a need to review the academic evidence that does exists to examine whether remediation of contaminated sites is effective at reducing harm to environmental and human health, particularly where this is carried out in order to redevelop the site.

2. Aims and objectives

This report is one of three background papers for a WHO expert consultation in September 2020 on the redevelopment of contaminated sites:

I. Review of scientific evidence on the environmental, health and equity impacts of remediation and redevelopment of contaminated sites;
II. Case study collection on European contaminated site redevelopment projects;
III. Review of risk and impact assessments related to redevelopments.

The aim of this working paper 1 is to present the findings of an evidence review on the environmental, health and equity effects of the remediation and redevelopment of contaminated sites in urban or residential contexts within the WHO European Region. It is therefore focussed on studies concerning sites that have been remediated (Site Status 6; Payá Pérez and Rodriguez Eugenio, 2018) and, in the context of health outcomes, those that report results from epidemiological or surveillance studies.

The review sought to answer the question: to what extent does the remediation and subsequent redevelopment of contaminated sites reduce environmental and health risks to new and existing populations and ecological systems, and are there any effects on equity in terms of the distribution of risks and outcomes or the identification of disadvantaged groups either pre- or post-remediation?

The objective of the review is to identify cases where the remediation and redevelopment of the contaminated site has effectively reduced or abolished environmental hazards and health risks, and those cases where contamination, **if not effectively remediated**, can pose health risks to:

- urban residents living close to remediated sites, either those where residential settlements or related functions already existed in close proximity to the site or were introduced during the redevelopment process;
- users of urban functions (e.g. residential, recreational, service consumption) on redeveloped land.

The focus of this review is evidence that relates to the use of contaminated sites for new residential neighbourhoods and public or recreational functions. Due to the anticipated scarcity of studies that evaluate post-redevelopment outcomes with specific reference to the remediation of contamination the scope also includes the remediation of contaminated sites to reduce or prevent health and environmental risks in existing urban areas in close proximity to the site. This means that studies that report on the outcomes of social and economic regeneration from development (e.g. changes in employment, access to amenities or housing quality) that do not make a specific connection to the contamination are not considered.

The purpose of this review was not to evaluate the efficacy of different remediation options from a technological perspective, as well as it did not aim to assess suitability and effectiveness of indicators and criteria to assess associated health impacts. The review is therefore restricted to present the findings of the interventions carried out in the covered publications, and is therefore not an exhaustive compilation of applicable remediation or assessment methods.

The vast majority of academic publications examining remediation technologies are however focused on the technical details of the intervention, or on its development through batch and column experiments, with some also presenting small-scale pilot or demonstration projects in the field, all of which are not considered in this review.

Table 1 provides a summary of the former uses and sources of contamination and the new and existing uses considered in this review.

Table 1. Summary of the former uses and contamination sources, and new uses considered in the evidence review

Former use / pollution source	New use
Any land (potentially) affected by contamination: • Industrial activities (production, mining or service sector) • Commercial (e.g. retailers, dry cleaners) • Storage (e.g. oil, chemicals, waste) • Military activity and deposits • Agricultural (including livestock) • Transport infrastructure-related (e.g. spills, fuel stations, train depots, repair stations and garages)	Any urban function with public access, or a mix of functions: • Residential areas / housing (private or public stock) • Recreational functions (e.g. play areas, sports areas, cinemas, parks and public gardens) • Urban supply functions (e.g. shopping areas) • Public services (e.g. day care centres, nursing homes, schools, hospitals, libraries)

Accidental contamination (e.g. Chernobyl, industrial accidents and related pollution/flooding) Exclusion: already existing urban functions (see listed under **New use**)	• Business areas (e.g. office space) Excluded were sites with the new use being industrial, commercial or military (see listed under former use). Also excluded were remediation of contaminated areas for ecological reasons, where no urban space with public access has been established / no existing residential setting close-by is affected

3. Methods

The review focuses on contaminated sites of any kind as shown in Table 1. The approach taken is summarised below, but briefly this followed a systematic research strategy, followed by title and abstract screening, full-text screening of selected papers, and quality appraisal and data extraction.

3.1. Search strategy for outcomes related to human health

A search strategy was developed that brought together three sets of terms related to the remediation and development of contaminated sites, based on those used in De Sario *et al.* (2018). The first set of terms focussed on the contaminants (e.g. lead, polyaromatic hydrocarbons) and the land uses that lead to contamination (e.g. mining, industrial), the second on terms related to remediation and redevelopment of these sites and the third on the outcomes related to health (e.g. mortality, cancer). The full list of terms is presented in Annex 1. This was not limited to WHO Europe Regions as an initial search identified that much of the literature was based in the United States.

The following databases were searched: Ovid (Embase, Medline, Global Health, PsycINFO, Cab Abstracts), Scopus, Open Grey, and ProQuest (theses database, ASSIA). The PRISMA flow chart for the health searches is provided in Annex 2.

3.2. Eligibility criteria

A total of 6903 papers based on a search of outcomes related to human health were subjected to title and abstract screening based on the following criteria:

- Reported changes in outcomes related to human health as a result of the remediation and subsequent redevelopment of contaminated sites;
- Reported changes in outcomes related to health of existing populations as a result of the remediation of contaminated sites.

Papers were also screened for environmental outcomes as these were also in the scope of the review (see section 3.4); some studies appeared to measure environmental outcomes but only model outcomes related human health. These studies were then included for the extraction of environmental outcomes, but are not included in the health outcomes analysis.

For a study to have been included there must have been:

- A site known to have contamination in the soil either as a result of a land use or disposal of waste on or adjacent to the site, or deposition of pollution from surrounding land uses.

  AND

- Remediation of the site or portions of the site by any means.

  AND

- An evaluation of outcomes related to human health or ecological systems or environmental media following the remediation and/or redevelopment.

Studies were excluded where:

- They reported on the general exposure from diffuse sources (e.g. vehicular traffic);
- They only reported changes following laboratory or field experiments as opposed to full scale remediation of a site;
- They reported on the outcomes of modelling and/or risk assessment studies where risk to humans and environmental systems was estimated either before or after remediation had taken place;
- They reported on post-development of contaminated sites, but focussed on outcomes related to regeneration (e.g. employment, inward investment, deprivation) as opposed to those associated with the remediation of contamination.

There were very few papers that appeared to meet these criteria following title and abstract screening (n=50; 14 that included new development and 36 that considered existing populations). The vast majority of studies report soil and water concentrations, outcomes related to ecotoxicological or human health, or risk assessments pre-remediation, the findings from laboratory or field scale experiments testing the efficacy of remediation technologies, the results of studies that model exposure or provide commentaries or reviews of remediation technologies. Screening was carried out by DS, with a 15% sample of these also being screened by IB.

Following abstract/title screening each paper was read in a full-text screening against the above criteria. This process identified a small number of papers (n=6) where we did not have access or they were not in English (the abstracts were). A substantial number of studies were excluded (n=32) after full-text screening because they only presented modelled or measured pre-remediation human outcomes, or modelled human health risk following remediation or presented the same data as another study.

Twelve papers based on outcomes related to health were therefore taken forward for evidence synthesis, with a further four papers being identified through these papers; giving sixteen papers in total. This meant that although we synthesised evidence considering outcomes related to equity as per the PRISMA approach we were not in a position to prioritise studies that report on equity outcomes, instead taking them all through to evidence synthesis.

3.3. Evidence synthesis for outcomes related to human health

Sixteen papers were included in the evidence synthesis. These papers were assessed for quality using the Effective Public Healthcare Panacea Project's Quality Assessment Tool for Quantitative Studies (https://www.ephpp.ca/quality-assessment-tool-for-quantitative-studies/). Quality assessment was carried out by IB and DS and there was strong agreement between the scores (94% for global scores; 82% for individual components). Disagreement between scores was confined to how representative the sample was of the overall population and the study design (where this was not stated explicitly), in these cases IB's scores were used following a re-examination of the papers. No studies were excluded based on quality, as the nature of contaminated land research meant that almost all studies were judged as 'weak' using this tool, yet reflect the realities of working with communities exposed to contamination. The discussion section provides a summary of these findings and suggestions for those designing future studies to evaluate the impact of remediation.

Following the quality assessment, the following data were extracted from each paper:

- Contaminant/s of interest and source/s of contamination;
- Remediation technique/s;
- Objective/s;
- Location;
- Study design and comparator;
- Sample size and population/s;
- Considerations of equity;
- Timing of sampling;
- Approach, methods, design;
- Measured outcomes;
- Results (including CI and p values);
- Limitations, risks, bias.

The completed data extraction forms were used to synthesis the evidence.

3.4. Search strategy for outcomes related to the environment

The search strategy outlined in section 3.1 was repeated, but replacing the outcomes related to health (e.g. mortality, cancer) with those related to environmental outcomes (e.g. water quality, ecological risk). A further 1901 papers were identified and were also screened against the eligibility criteria in section 3.2, this identified 45 papers. Full-text screening revealed that the majority of these studies reported the results of pilot-scale demonstrations, or testing of remediated materials held in storage for a number of years, or were not available or in English. Fourteen studies were initially included in the review of environmental outcomes.

During the review and discussion of the draft evidence review, reviewers commented on the lack of variation in contaminants and remediation technologies in the reporting of full-scale remediation. In response to these comments, additional the searches were conducted, but removing the terms related to environmental outcomes (i.e. only those related to contaminants and remediation were included), and excluding the studies with terms related to experimental or laboratory studies. This generated an additional 25,082 publications, and this was further reduced by limiting the searches to title and keywords only to ensure a manageable number for title/abstract screening. As a result, following removal of duplicates, an additional 2232 papers were screened against the study criteria, with 60 papers being identified for full-text screening. This identified a further seventeen studies, and the findings from these as well as the initial fourteen papers are summarized in Chapter 5; giving a total of 31 papers (see Annex 2); eighteen concerning inorganic contaminants and thirteen focused on organic contaminants.

The design of these studies means that the use of the Quality Assessment tool was not appropriate, as they do not use human populations.

4. Impact on outcomes related to human health

4.1. Study characteristics

Sixteen studies were considered in the evidence synthesis. The majority of studies were based in the US (n=9), with others from Australia (n=1), Canada (n=2), Nigeria (n=1), Chile (n=1), Italy (n=1) and Finland (n=1). In addition, most of the studies (n=12) reported on remediation of sites contaminated with lead, from smelters in Finland (Louekari *et al.*, 2004), the US (Maisonet, Bove and Kaye, 1997; Lanphear *et al.*, 2003; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003), Canada (Hilts *et al.*, 1998), a lead reclamation plant in Canada (Goulet, Messier and Gaudreau, 1996), informal gold mining in Nigeria (Tirima *et al.*, 2016), a copper mine in the US (Schoof *et al.*, 2016), a lead mine in Australia (Boreland, Lesjak and Lyle, 2008) and multiple sources in the US (Aschengrau *et al.*, 1997; Mielke *et al.*, 2013). One study reported on the remediation of chromium waste sites in the US (Freeman *et al.*, 1995), and another on the dredging of a harbour in the US to reduce exposure to polychlorinated biphenyls (PCBs) (Choi *et al.*, 2006). The remaining two studies reported on sites contaminated with several metals, one focussing only on reporting blood lead levels (BLLs) from a waste disposal site in Chile (Burgos *et al.*, 2017) and the other on cadmium, chromium, copper, manganese, lead and zinc from mining and industrial sources in Sardinia, Italy (Madeddu *et al.*, 2013).

As indicated above these fell into three categories:

- Studies that examine the outcomes related to the health of new residents following remediation and redevelopment of contaminated sites, all of which focussed on lead (n=3) (Louekari *et al.*, 2004; Mielke *et al.*, 2013; Schoof *et al.*, 2016);
- Studies that examine the outcomes related to the health of children in existing neighbourhoods as a result of exposure to lead (n=8) (Goulet, Messier and Gaudreau, 1996; Aschengrau *et al.*, 1997; Maisonet, Bove and Kaye, 1997; Hilts *et al.*, 1998; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003; Boreland, Lesjak and Lyle, 2008; Tirima *et al.*, 2016) and chromium (n=1) (Freeman *et al.*, 1995) following remediation and public health campaigns;
- Studies that examine the outcomes related to health in existing populations following remediation of contaminated sites (n=3) (Lanphear *et al.*, 2003; Choi *et al.*, 2006; Madeddu *et al.*, 2013; Burgos *et al.*, 2017).

Three studies focused on the same site: Bunker Hill Superfund Site in Idaho, US (Maisonet, Bove and Kaye, 1997; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003). Other studies were identified in the search that also presented analysis of this site and the Broken Hill mine in Australia (Boreland, Lesjak and Lyle, 2008), however, the full-text screening revealed that these relied on the same data as the papers included so did not provide any additional insights into the impact of remediation on outcomes related to health.

In terms of study design, most papers presented the results of cross-sectional studies (Table 2, n=8) (Freeman *et al.*, 1995; Lanphear *et al.*, 2003; Sheldrake and Stifelman, 2003; Louekari *et al.*, 2004; Madeddu *et al.*, 2013; Schoof *et al.*, 2016; Tirima *et al.*, 2016; Burgos *et al.*, 2017), others included a randomised control trial (n=1) (Aschengrau *et al.*, 1997), cohort analytic (n=2) (Choi *et al.*, 2006; Mielke *et al.*, 2013), cohort pre- and post-remediation (n=1) (Goulet, Messier and Gaudreau, 1996), case-control (n=1) (Maisonet, Bove and Kaye, 1997) and interrupted time series (n=3) (Hilts *et al.*, 1998; Von Lindern *et al.*, 2003; Boreland, Lesjak and Lyle, 2008).

Most studies (n=15) focussed on children living near sources of contamination, a reflection of the vulnerability of this group to exposure from soils both due to hand-to-mouth behaviours and the toxicity of contaminants, particularly lead (Mielke *et al.*, 2011). Only one study examined blood concentrations in adult populations (Madeddu *et al.*, 2013).

The quality assessments found that all studies would be categorised as weak according to the Quality Assessment Tool for Quantitative Studies (Table 2). In some aspects of the assessment, this reflects the realities of contaminated land remediation, which is often carried out very soon after exposure is uncovered making it unethical to withhold treatment to vulnerable populations (consequently, there is no control group). Most of the studies analyse data from screening programmes set up by government agencies to monitor blood levels. As a result, study designs tend to be (repeat) cross-sectional or cohort studies, and only one study was randomised. Some other areas of the quality assessment that these studies scored poorly on are less important for studies of remediation, for example, the importance of blinding of both outcome assessors and participants is less in studies of objective measures, like blood concentrations, as these are unlikely to be influenced by the assessor or participant knowing their intervention/exposure status. However, there are other areas of the quality assessments that the studies underperformed in, which could have been improved through better reporting which will be discussed later and some recommendations provided for those wishing to report on similar studies.

Most studies (n=15) reported the results of human biomonitoring (HBM) studies that measured concentrations of contaminants in blood (Goulet, Messier and Gaudreau, 1996; Aschengrau *et al.*, 1997; Maisonet, Bove and Kaye, 1997; Hilts *et al.*, 1998; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003; Lanphear *et al.*, 2003; Louekari *et al.*, 2004; Boreland, Lesjak and Lyle, 2008; Madeddu *et al.*, 2013; Mielke *et al.*, 2013; Schoof *et al.*, 2016; Tirima *et al.*, 2016; Burgos *et al.*, 2017), with two studies reporting concentration in urine (Freeman *et al.*, 1995; Burgos *et al.*, 2017) and one in umbilical cord serum (Choi *et al.*, 2006). Concentrations were then compared to controls or post-remediation concentrations or thresholds set to be protective of health (e.g. a blood lead level of 5 µg/dl) (Freeman *et al.*, 1995; Goulet, Messier and Gaudreau, 1996; Aschengrau *et al.*, 1997; Maisonet, Bove and Kaye, 1997; Hilts *et al.*, 1998; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003; Lanphear *et al.*, 2003; Louekari *et al.*, 2004; Boreland, Lesjak and Lyle, 2008; Mielke *et al.*, 2013; Madeddu *et al.*, 2013; Schoof *et al.*, 2016; Tirima *et al.*, 2016; Burgos *et al.*, 2017). In several studies the proportion of children exceeding these concentrations was also used as a population-level outcome to assess the impact of remediation (Goulet, Messier and Gaudreau, 1996; Lanphear *et al.*, 2003; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003; Mielke *et al.*, 2013; Schoof *et al.*, 2016). Generally, remediation aimed to reduce soil concentrations to an acceptable level, but in one study this was also reported as a specific outcome in addition to heakth outcomes (Tirima *et al.*, 2016). Household dust is also reported to be an important exposure pathway from contaminated soil to humans, and two studies also reported concentrations in household and/or day care centre dusts as an additional outcome (Lanphear *et al.*, 2003; Louekari *et al.*, 2004). Only one study examined the impact of contaminant exposure and subsequent remediation on a clinical outcome (Burgos *et al.*, 2017), this examined cognitive performance in children born pre- and post-remediation of a waste disposal site. This presumably reflects the relative simplicity of collecting and analysing, particularly blood, samples as part of a population-level screening programme.

4.2. Evidence synthesis

The evidence synthesis reports on the studies based on the broad categories outlined above:

- Studies that examine the outcomes related to the health of new residents following remediation and redevelopment of contaminated sites (n=3);
- Studies that examine the outcomes related to the health of children in existing neighbourhoods previously exposed to lead (n=8) and chromium (n=1) following remediation and public health campaigns to reduce exposure (e.g. by removing hand to mouth behaviour in children, improved hygiene and home cleaning);
- Studies that examine the outcomes related to the health in existing populations following remediation of contaminated sites (n=4).

Some papers have far less detail on the remediation and/or redevelopment of the sites than others, but this is reported here where possible.

4.2.1. Remediation followed by redevelopment

Three studies examined blood lead levels in children following remediation with subsequent redevelopment. The focus of all studies is the impact of the remediation so the description of the redevelopment is fairly superficial (Table 3). All three studies report that blood lead levels have declined following remediation (Louekari *et al.*, 2004; Mielke *et al.*, 2013; Schoof *et al.*, 2016). Lead is toxic to humans. Although, in adults, it can cause damage to a number of organs and is associated with hypertension, diabetes and heart disease, it is the impact on children that is the most common cause for concern where it is associated with reduced cognitive performance and increased behavioural problems (Mielke *et al.*, 2011).

The sources of lead contamination differ between the three studies; a former lead smelter in Tikkuila, Vantaa, Finland in operation between 1929 and 1984 (Louekari *et al.*, 2004), a copper mine in Butte, Montana, US from which the primary contaminant of concern in terms of human health was lead (Schoof *et al.*, 2016) and multiple sources affecting soil lead concentrations in New Orleans, US which included point sources from industry and incinerators as well as diffuse pollution of vehicular traffic and paint (Mielke *et al.*, 2013).

The remediation of the sites generally all involved the removal and replacement of surface soils. However, the criteria used to decide which soils should be remediated and the catalyst for doing so varied between the studies. It appears that some contaminated soil in Tikkurila was removed and replaced during the redevelopment of new apartments, built since 1990, but also the yards of schools and day care centres were prioritised for remediation, leaving other neighbourhoods in close proximity to the smelter site with soil lead concentrations in excess of the Finnish threshold concentration of 300 mg/kg (Louekari *et al.*, 2004). In New Orleans, however, some replacement of soils with concentrations exceeding 1000 mg/kg in homes, childcare centres and parks had taken place as part of an area-wide remediation programme due to elevated blood levels in children, however, this was expanded to public housing projects that were reconstructed after the devastation caused by Hurricane Katrina (Mielke *et al.*, 2013). In Butte the former mine site was subjected to a large-scale restoration which saw the mine waste relocated, stabilised and capped, contaminated soils in residential yards removed and replaced, sedimentation ponds constructed to manage stormwater runoff, and the creation of public parks, activity centres and walking and cycling trails (Schoof *et al.*, 2016). Although they all include some form of redevelopment the focus of all studies is blood lead levels in existing populations.

The objectives of the studies are quite different as well. The study in Finland sought to examine the different exposure routes from the remaining contaminated soils and ascertain whether children living in the area are at risk, to inform any further remediation (Louekari *et al.*, 2004). Similarly, the study in New Orleans investigated the remaining disparities in blood lead levels to identify areas were remediation was still required post-Katrina (Mielke *et al.*, 2013). In Butte, the focus was on assessing changes in blood lead levels following the remediation programme (Schoof *et al.*, 2016).

The study in Finland (Louekari *et al.*, 2004) was the only one that measured blood lead levels for the study, whereas the two US studies used data from area-wide screening programmes (Mielke *et al.*, 2013; Schoof *et al.*, 2016). In their cross-sectional study of children, aged 0 to 6 years living near the former smelter Louekari *et al.* (2004) measured blood lead levels in 52 children from Tikkurila, ten of whom lived in the unremediated area with soil concentrations above 300 mg/kg, and 11 children from a remote reference site. They used secondary data collected between one and four years prior to the reported study to estimate the exposure from soil, air, water and consumption of vegetables and berries grown in gardens. In addition, they measured lead concentrations in household dust from the children's homes and most of the day care centres (Louekari *et al.*, 2004). In their analysis they used Student's t-test to compare blood lead levels between the 10 children in the unremediated areas, the 42 children in the remediated areas and the 11 children in the reference area (Louekari *et al.*, 2004). They also compared the blood lead levels in their sample, collected in 2000, with those collected in 1981 prior to the smelter closing and subsequent remediation (Louekari *et al.*, 2004). This comparison found that the average blood lead level fell from 6.7 µg/dl in 1981 to 2.2 µg/dl in 2000, and the maximum blood lead levels fell from 13 µg/dl to 5 µg/dl over the same period (Louekari *et al.*, 2004).

Air and water were not found to be an exposure route from the contaminated soils, and although the lead concentrations in lettuce and berries were elevated, compared with the reference site, they were reported to have declined in the most recent samples (Louekari *et al.*, 2004). In non-remediated areas the soil lead concentrations were often above 300 mg/kg (average = 242 mg/kg; range = 160-434 mg/kg), including in some residential areas and between 1000-5000 mg/kg in a nearby recreational forest. However, the soil concentrations in new apartment blocks were usually low at approximately 20 mg/kg, the average in other areas of Tikkurila was 40 mg/kg (range = 15-81 mg/kg), and in the reference area was 20 mg/kg (Louekari *et al.*, 2004). Blood lead levels across the sample varied between <2.1 and 5.0 µg/dl, with children in the unremediated areas having a significantly greater average concentration at 2.7 µg/dl (median = 2.5 µg/dl, range <2.1-5 µg/dl) than those in remediated areas near the site at 2.1 µg/dl (median = 2.1 µg/dl, range <2.1-4.1 µg/dl) ($p=0.027$) (Louekari *et al.*, 2004). The blood lead levels in children from the remediated areas were not significantly different from those in the reference areas at <2.0 µg/dl (median = 2.1 µg/dl, range <2.1-2.5 µg/dl) (Louekari *et al.*, 2004).

The study in New Orleans reported children's (age not reported) blood lead levels from a city-wide screening programme over two time periods: 55,551 samples collected 2000 to 29th August 2005 (pre-Hurricane Katrina) and 7384 samples collected 2006 to 2008 (post-Hurricane Katrina) (Mielke *et al.*, 2013). Blood lead levels were discussed in the context of soil concentrations measured between 1991 and 2001 prior to any remediation with census tracts being categorised as low (<100 mg/kg) and high (>100 mg/kg) lead areas (Mielke *et al.*, 2013).

Soil concentrations were related to different locations (play areas, busy streets, residential streets and house sides) but as it is not clear how these relate to the remediation efforts they are not discussed further here. Instead we focus on the changes in blood lead levels between the two time periods, assumed to be representative of pre- and post-remediation. Differences between soil and blood lead levels are significant ($p<0.001$) between high lead (median = 425 mg/kg; range = 106-1789) and low lead areas (median = 45 mg/kg; range = 6.2-99) (Mielke *et al.*, 2013). Blood lead levels in the high lead areas were significantly ($p<0.001$) lower post-Katrina (median = 3.0 µg/dl; range=0.9-40 µg/dl), compared with pre-Katrina (median = 5.6 µg/dl; range = 0-107 µg/dl), as were the percentage of children with blood lead levels greater than 5 µg/dl (58.5% vs. 29.6%) and 10 µg/dl (21.8% vs. 6.5%) (Mielke *et al.*, 2013). Similarly, in the low lead areas the blood lead levels post-Katrina were significantly ($p<0.001$) lower (median = 3.0 µg/dl; range = 0.9-38 µg/dl) compared with pre-Katrina samples (median = 3.0 µg/dl; range=0-117), as were the percentage of children with blood lead levels greater than 5 µg/dl (24.8% vs. 7.5%) and 10 µg/dl (3.0% vs. 1.0%) (Mielke *et al.,* 2013).

The study in Butte, Montana also used blood lead data collected from children, aged one to five years, as part of a screening programme (Schoof *et al.*, 2016). However, this study used a reference dataset as the comparator as all children in Butte were exposed to the pre- and post-remediation period between 2003 and 2010. In total 2796 samples from Butte were included in the analysis, and matched to the reference dataset by sex, age, season of blood test, year residence was built, and race/ethnicity (Schoof *et al.*, 2016). In addition, address location was used to incorporate neighbourhood level sociodemographic information not available in the dataset, which was then included in the analysis. Some children were represented in the dataset over consecutive years and these were counted as repeated measures in the analysis (Schoof *et al.*, 2016).

Mean blood lead levels in Butte in 2010 were less than half the levels of 2003 (Schoof *et al.*, 2016). Percentage of children with blood lead levels above 10 µg/dl declined from 3.4% to 1.5%; and the percentage with blood lead levels above 5 µg/dl declined from 33.6% to 9.5% over the same time period (Schoof *et al.*, 2016). A weighted linear mixed regression model suggested that Butte geometric mean blood lead levels were significantly greater ($p<0.05$) than reference blood lead levels in 2003-2004 (3.48 vs. 2.05 µg/dl), 2005-2006 (2.65 vs. 1.80 µg/dl), and 2007-2008 (2.2 vs. 1.72 µg/dl), but comparable for 2009-2010 (1.53 vs. 1.51 µg/dl).

Also, based on the results of a Chi-squared test, the Butte geometric mean blood lead levels declined by 24% per 2-year increment from 2003 to 2010, whereas the decline in the reference dataset was significantly slower at 9% per 2-year increment ($p=0.0001$) (Schoof *et al.*, 2016). The results suggest that the remediation and restoration of the mine has resulted in reduced blood lead levels in the children in Butte. The study also reported significant neighbourhood differences. The mean blood levels were greater in the uptown historic area closer to mine, than in the area known as 'the flats' but only significantly so in 2007-2008 and 2009-2010 ($p=0.001$ and $p=0.02$, respectively). Although there was no significant difference in rate of decline between the two areas, in uptown it was 11% per 2-year period compared with 14% in 'the flats' (Schoof *et al.*, 2016). The decline in the percentage of children with blood lead levels greater than 5 µg/dl was also comparable between areas.

Although these three studies report on changes in blood lead levels following redevelopment as well as remediation, their findings are primarily concerned with the impact on existing populations living on or adjacent to the contaminated site. They provide consistent evidence that soil remediation can lower lead levels in the blood of children living close to contaminated sites.

However, with the exception of the study in Butte (Schoof *et al.*, 2016), the reporting of these studies makes it difficult to relate the remediation activities to the changes in blood lead levels.

Table 3. Summary of studies reporting outcomes related to health of people living near remediated sites following remediation and redevelopment (BLL = blood lead level)

Reference	Contaminant and source	Remediation	Location	Study design and comparator	Population and sample size	Outcomes	Results
Louekari et al 2004	Pb from a smelter active 1929 to 1984	Surface soil replacement of area with Pb > 300 mg/kg prior to construction of new apartments, and in school and day care centre yards.	Tikkurila, Vantaa, Finland	Cross-sectional; comparators are unremediated areas and remote reference site. Existing environmental data used to estimate exposure.	Population is 678 children aged 0 to 6 years living near smelter. Sample is 52 children from population and 11 from reference area.	Pb in air, water, lettuce, berries, and dust in household and day care centre. BLL	Air and water not important exposure route. Soil Pb ~20 mg/kg in remediated and reference areas, and >300 mg/kg in unremediated areas. BLLs in unremediated areas = 2.7 µg/dl, which was greater than in remediated areas (2.1 µg/dl); remediated areas comparable to reference areas of <2.0 µg/dl.
Mielke et al 2013	Pb from multiple sources including industry and incinerator	Surface soil replacement of soils with >1000 mg/kg in homes; childcare centres (also had geotextile beneath soil), eleven public parks and 9 out of 10 public housing projects (during reconstruction).	New Orleans, US	Cohort analytic; comparator is low soil Pb areas.	Pre-Katrina:55,551 blood Pb samples from children. Post-Katrina: 7384 blood Pb samples from children.	BLL Percentage of children with BLL >10 µg/dl. Percentage of children with BLL >5 µg/dl.	Differences between soil and BLLs are significant (p<0.001) between high Pb (425 mg/kg) and low Pb (45 mg/kg) areas. BLLs pre-Katrina: high Pb areas = 5.6 µg/dl (58.5% of children >5 µg/dl; 21.8% of children >10 µg/dl); low Pb areas = 3.0 µg/dl (24.8% of children >5 µg/dl; 3.0% of children >10 µg/dl). BLLs post-Katrina: high Pb areas = 3.0 µg/dl (29.6 % of children >5 µg/dl; 6.5% of children >10 µg/dl); low areas = 3.0 µg/dl (7.5% of children >5 µg/dl; 1.0% of children >10 µg/dl). BLLs significantly reduced post-Katrina, in low and high Pb areas (p<0.001), but disparity between these areas has increased.
Schoof et al 2015	Pb from copper mine	Stabilising, capping or removing waste and contaminated soils. Redevelopment to parks, activity centers and trails. At time of study remediation ongoing.	Butte, Montana, US	Repeat cross-sectional; comparator is reference dataset.	Children ages 1 to 5 years (n=2796) from 2003 to 2010 covering pre- and post-remediation.	BLL Percentage of children with BLL >5 µg/dl and >10 µg/dl.	Decline in children with BLLs >10 µg/dl from 3.4% to 1.5%; and BLLs >5 µg/dl from 33.6% to 9.5%. A weighted linear mixed regression model showed Butte geometric mean BLLs greater than reference BLLs for 2003-2004 (3.48 vs. 2.05 µg/dl), 2005-2006 (2.65 vs. 1.80 µg/dl), and 2007-2008 (2.2 vs. 1.72 µg/dl), but comparable for 2009-2010 (1.53 vs. 1.51 µg/dL). Butte mean declined by 24% per 3-year increment, reference dataset by 9% (p<0.001). Mean BLL greater in the uptown historic area closer to mine, than 'the flats' area but only significantly so in 2007-2008 (p=0.001) and 2009-2010 (p=0.02).

4.2.2. Existing populations with remediation and public health intervention

In addition to the studies that include some form of redevelopment of contaminated land, there are a suite of studies that examine the impacts of remediation on existing populations without considering any new uses or redevelopment of the site. Contamination from industrial emissions (e.g. smelters), mining and waste disposal has often occurred over many years. In some areas, homes have been constructed on or near waste disposal sites, or the deposition of emissions and windblown dusts has contaminated soils in the surrounding area. Remediation of large sites, contaminated over long periods of time, particularly where this spreads to nearby land uses is extremely complex, taking several years of sampling and risk assessment, followed by remediation. Where existing populations are present it may not be practical or desirable for them to leave their homes, and therefore public health interventions are employed to reduce exposure. These campaigns often focus on reducing exposure via household dust, which has a high proportion of soil, and reducing hand to mouth behaviours in young children. This section considers those studies that included both remediation of contaminated soils and public health campaigns to reduce exposure.

As with the previous section these studies are dominated by lead contamination in the US (Table 4), with one study that examines chromium contamination in the US (Freeman *et al.*, 1995), and four that consider lead exposure in other countries: Canada (Goulet, Messier and Gaudreau, 1996; Hilts *et al.*, 1998), Australia (Boreland, Lesjak and Lyle, 2008) and Nigeria (Tirima *et al.*, 2016). The remaining three studies all consider the same site, the Bunker Hill Superfund Site in Idaho, US, the first covering the initial period of remediation (Maisonet, Bove and Kaye, 1997), and two others published in the same year that provide a detailed analysis of the impact of the different interventions (Von Lindern *et al.*, 2003), and a helpful review of the remediation and its impact on blood lead levels against the objectives for the site (Sheldrake and Stifelman, 2003).

In all nine studies the contamination came from a mixture of waste disposal and deposition from industrial activities. In Hudson County, New Jersey waste from chromium manufacturing and refining has been disposed on site, and the waste also used as an infill material in construction (Freeman *et al.*, 1995), and in Quebec, Canada a lead reclamation plant which shut down in 1989 had resulted in elevated lead concentrations in surrounding soils (Goulet, Messier and Gaudreau, 1996). In Nigeria informal artisanal gold mining taking place over a relatively short period in response to a global increase in gold prices, often involving processing in homes and modified flour mills, and unregulated waste disposal, had resulted in lead contamination in eight villages (Tirima *et al.*, 2016). In Broken Hill, New South Wales, Australia a lead mine operating since 1884 resulted in lead contamination in the area (Boreland, Lesjak and Lyle, 2008). At Bunker Hill a mine and smelter operating between 1917 and 1981 caused widespread contamination across five communities with 7000 inhabitants (Maisonet, Bove and Kaye, 1997; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003). The impacts of remediation of lead deposition from a lead/zinc smelter in Trail, Canada (Hilts *et al.*, 1998) were also examined. In one study, the source/s of the lead contamination in Boston were not clear, but were assumed to be multiple urban sources including traffic and lead-based paint (Aschengrau *et al.*, 1997).

As with the previous studies, the remediation methods primarily involved removal and capping of the contaminated soil. At the chromium waste site in New Jersey, the sites were capped and/or soils removed and replaced, alongside a public health campaign that focussed on the importance of reducing dust in the home to lessen exposure (Freeman *et al.*, 1995). In Quebec, the yard of the reclamation yard was capped, and contaminated dusts removed from roads and pavements (Goulet, Messier and Gaudreau, 1996). In ‘area 1’, which had the greatest levels of contamination, the surface soils in all accessible areas as well as those of grass and gravel with lead concentrations above 500 mg/kg were all removed and replaced, in ‘area 2’ surface soils in accessible areas with concentrations greater than 400 mg/kg and areas with grass and gravel that exceeded 1000 mg/kg were also removed and replaced (Goulet, Messier and Gaudreau, 1996). To remove exposure from dusts, 115 homes of children with blood lead levels greater than 15 µg/dl were professionally cleaned, and in the following two years professional cleaning was also offered to all households with children aged 0 to 6 years (Goulet, Messier and Gaudreau, 1996). Similarly, the remediation following artisanal gold mining in Nigeria involved soil and waste removal from residential and common areas, and ponds in eight villages, with disposal in purposively constructed landfills (Tirima *et al.*, 2016). In Boston, the soil remediation involved removal of the topsoil, installation of a geotextile membrane and soil replacement (Aschengrau *et al.*, 1997). In addition, homes were subjected to deep cleaning and loose paint removed and primed to reduce exposure from lead-bearing dusts (Aschengrau *et al.*, 1997). In Broken Hill, Australia, contaminated soils were capped with clean soil, concrete, mulch and some areas revegetated to reduce dusts (Boreland, Lesjak and Lyle, 2008). In Trail, Canada the soils were also capped with asphalt, concrete, gravel or vegetation, and a dust suppressant used in remaining unpaved areas (Hilts *et al.*, 1998).

The extent of contamination across five communities in the Bunker Hill Superfund Site resulted in phased remediation over two decades in response to two Remedial Action Objectives: that less than 5% of children have blood lead levels of 10 µg/dl or greater and that less than 1% of children have blood lead levels above 15 µg/dl (Sheldrake and Stifelman, 2003). First, targeted soil capping took place in parks and school yards (1986), followed by a programme of soil removal and replacement in residential yards, commercial properties and rights of way, and indoor dust removal (1989 onwards). Yard remediation was prioritised using risk-based criteria to identify the homes of pregnant women and children under 12 years, and particularly children with blood lead levels of 10 µg/dl or greater, so that 100 yards were remediated each year between 1989 and 1993 (Sheldrake and Stifelman, 2003). However, in 1991 it was found that there was re-contamination of household dusts from unremediated outdoor spaces in those homes remediated in 1990 (Sheldrake and Stifelman, 2003). Therefore, in 1994 the programme was expanded so that contiguous parcels of land including homes, commercial properties, parks, playgrounds and rights of way with soil lead concentrations above 1000 mg/kg were remediated irrespective of occupant vulnerability, in addition to the risk-based programme which targeted the homes of pregnant women and children under six years with soil concentrations above 1000 mg/kg so that 200 residential yards were remediated each year (Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003). This meant that by 2001 80% of homes with soil lead concentrations of above 1000 mg/kg had been remediated (Von Lindern *et al.*, 2003).

Public health campaigns focussed on reducing exposure via dusts, providing information on home and personal hygiene and the importance of discouraging hand to mouth behaviours in children to reducing the consumption of soil (pica). Often it is not clear in the articles when public health campaigns took place in relation to the remediation. In Quebec, the public health campaign consisted of individual meetings with parents of children under six years of age in area 1, information distributed in prenatal classes, to paediatricians and homeowners, a telephone information line and articles in the local press on the sources and dangers of lead contamination (Goulet, Messier and Gaudreau, 1996). In Nigeria, lead exposure was exacerbated by the informal and reactive nature of the gold mining, resulting in widespread lead poisoning and loss of life in children. This prompted an emergency response by Medicines San Frontiers, and regulation to improve mining practices and reduce exposure (e.g. location of processing areas outside of villages to reduce childhood exposure), with a programme of awareness raising and guidance, for example, to encourage washing and changing clothes before returning home from the mines (Tirima *et al.*, 2016). In Bunker Hill Superfund Site a public health campaign running concurrently with soil remediation aimed to reduce exposure, this focussed on improving home cleaning and personal hygiene (Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003). In Trail, Canada the focus appears to have been on educating young children in schools and day care settings, and new mothers in prenatal classes, as well awareness raising in the community through newsletters and providing doormats and cleaning materials to residents (Hilts *et al.*, 1998). In addition, children aged over or under 20 months with blood lead levels above 10 µg/dl or 15 µg/dl, respectively, were included in a case management programme that included counselling, information on nutrition and hygiene, cleaning materials, sand boxes and materials to cover the ground (Hilts *et al.*, 1998). In Broken Hill, Australia the public health programme consisted of health promotion and education and case management based on individual blood lead levels (Boreland, Lesjak and Lyle, 2008). The study in Boston makes reference to an education programme to reduce exposure, but this is not detailed (Aschengrau *et al.*, 1997).

The purpose of the studies reported here was to evaluate the effectiveness of the remediation and public health campaigns. In addition, some also aimed to determine the impact of exposure pathways on levels of lead in blood or chromium in urine of local children (Freeman *et al.,* 1995; Maisonet, Bove and Kaye, 1997).

As with the studies reported previously, the majority of those studies summarised here utilised blood lead levels collected as part of screening programmes. There are two exceptions to this. The first is the cross-sectional study in New Jersey, which measured chromium in household dusts and urine of 41 children from Lafayette Gardens, a public housing project surrounded on three sides by chromium disposal sites, and 23 children, matched by age and sex, from three comparator neighbourhoods which included a public housing project and a more affluent neighbourhood (Freeman *et al.*, 1995). Whereas trivalent chromium is an essential nutrient in humans, hexavalent chromium is a known carcinogen, and it is this form that was found to be elevated in the soil (Freeman, Lioy and Stern, 2000). Chromium levels in dusts and urine were compared between the different neighbourhoods and with concentrations reported prior to the interventions, and combined with data from a household questionnaire on various behaviours and home factors related to exposure (e.g. home construction, heating and ventilation, lifestyles and outdoor activities) in a multiple regression (Freeman et al., 1995). The study found that concentrations of chromium in household dusts post-remediation were reduced compared to those reported in the pre-intervention study (7.5±4.2 vs. 26.5±18.4 mg/sample in Lafayette; 14.6±19.4 vs. 27.5±25.5 mg/sample in Grand Street in Summer) and comparable with those in the control neighbourhoods. Concentrations in dusts were reduced in samples collected in the Fall (4.4±3.5 mg/sample in Lafayette Gardens and 4.3±2.5 mg/sample Grand Street) (Freeman *et al.*, 1995). In the pre-remediation study all apartments in Lafayette had chromium at detectable concentrations in dust samples, but this declined to 45% of homes post-remediation in Summer and 10% in Fall (Freeman *et al.*, 1995). Chromium concentrations in urine (median age=9 years; 67% male) were found to be age-dependent and related to home location. Controlling for personal rate of excretion and age, exposure status was found to predict chromium concentration (regression coefficient=-0.347, standard error=0.155, p=0.03). However, the study could not confirm a clear relationship between children's activities, time spent outdoors, and chromium concentration in urine (Freeman *et al.*, 1995). Although concentrations of chromium in urine in children from Lafayette Gardens were greater than those from the control neighbourhood in Summer (median = 0.28 µg/l vs. 0.17 µg/l), and approached significance (p=0.055), there was no significant difference in Winter. There was also no correlation between time spent outdoors and urine concentrations in children from Lafayette Gardens (Freeman *et al.,* 1995). The authors suggest that parental presence during the questionnaire may have made children reluctant to admit playing on the waste sites (Freeman *et al.*, 1995).

The second study that was not based on a screening programme was the study in Boston (Aschengrau *et al.*, 1997). This consisted of a randomised trial with three groups in the first phase, although groups 2 and 3 were later combined: those receiving soil remediation, home cleaning and interior loose-paint stabilisation (group 1; n=54), those with only home cleaning and paint stabilisation (group 2; n=51) and those receiving paint stabilisation (group 3; n=47) (Aschengrau *et al.*, 1997). In the second phase of interventions the soil remediation was offered to groups 2 and 3, and exterior and interior paint hazard remediation offered to all groups; this was more substantial than the earlier phase, involved the residents vacating the property and only being able to return once dust concentrations were within permissible limits (Aschengrau *et al.*, 1997). The study found that following the second phase of interventions, mean blood lead concentrations in group 1 children whose homes received only paint hazard remediation was 2.6 µg/dl (CI=-0.6-5.9 µg/dl) greater than those children received no interventions in the second phase. In group 2/3 the mean blood lead concentrations of children whose homes received both paint hazard remediation and soil abatement was 1.4 µg/dl (CI=-0.7-3.5 µg/dl) greater than that of children whose homes received only soil abatement in the second phase. After adjustment for significant confounding variables, which included socioeconomic status, the number of lead painted interior and exterior surfaces and floor-dust lead levels, group 1 children receiving paint hazard remediation had 6.5 µg/dl greater blood lead concentrations than those who did not (p=0.05), there was no significant difference between the blood lead levels in group 2/3 children who did or did not receive paint hazard remediation (p=0.36), suggesting that soil remediation was beneficial in reducing blood lead levels. An earlier study of the first phase only found that a 2060 mg/kg decline in soil lead concentrations was associated with a 2.25 to 2.70 µg/dl decline in blood concentrations (Aschengrau *et al.*, 1997).

The cohort study measured blood lead levels in children living within 600 m of a lead reclamation plant and delivered a post-remediation follow-up survey to 101 children, aged 6 months to 10 years (79.2% of population) (Goulet, Messier and Gaudreau, 1996). Of the 101 children in the follow-up, 75 (74.3%) were also in the initial sample (11 were born after 1989; 9 had moved to area after 1989 and 6 were not in the original sample). Pre-remediation soil samples had also been collected 150 m (area 1) and 150-600 m (area 2) from the plant as had dust samples 30 m and 230 m from the plant, and compared with those taken from a control site 3 km away. Prior to remediation, the median soil lead concentrations in area 1 was 520 mg/kg (range=7-5040 mg/kg) and in area 2 was 185 mg/kg (range=40-2300 mg/kg) compared with the control site of less than 10 mg/kg. Similarly, pre-remediation the lead concentration in dust samples was 1200-2500 mg/kg, compared with 193 mg/kg at the control site (Goulet, Messier and Gaudreau, 1996). In children who had participated in both surveys blood lead levels declined from 9.7 µg/dl (95% CI=8.6-10.9) to 5.0 µg/dl (CI=4.5-5.6) ($p<0.001$); children 6 months to five years decreased from 9.8 µg/dl (CI=8.6-11.2) to 5.5 µg/dl (CI=4.9-6.3) ($p<0.001$). The percentage of children with blood lead levels above 15 µg/dl declined from 21.3% pre-remediation to zero in the post-remediation sample. In addition, in the post-remediation sample there was no significant difference in blood lead levels between children regardless of whether they were living in area 1 pre-remediation (new residents = 4.7 µg/dl; compared with 5.0 µg/dl for residents present pre-remediation) (Goulet, Messier and Gaudreau, 1996). A questionnaire also sought sociodemographic and behavioural information, and this found that the percentage of children engaged in pica fell from 35.5% pre-intervention to 18.8% post-intervention (p=0.004); and putting things in mouth fell from 46.2% to 31.7% (p=0.03) suggesting that the public health campaign had been effective at reducing oral exposure (Goulet, Messier and Gaudreau, 1996).

The study in Trail, Canada consisted of a repeated cross-sectional survey carried out between 1989 and 1996 on children aged 6 to 72 months living near a lead/zinc smelter that was in operation for almost a century (Hilts *et al.*, 1998). The aim of the study was to explore the effects of the community-wide and the case management interventions on children of under and over 20 months with blood lead concentrations of more than 10 µg/dl and 15 µg/dl, respectively (Hilts *et al.*, 1998). Blood lead concentrations were analysed separately between those children tested for the first time in each year and those subject to repeat testing due to their inclusion in the case management programme. The regression analysis showed a declining trend of 0.6 µg/dl (or about 5%) per year, however an analysis of soil lead concentrations suggested that the decline in blood concentrations was not due to any improvement in soil concentrations (Hilts *et al.*, 1998). The authors highlight that lead concentrations have declined nationally following the removal of lead from vehicle fuel, but to a lesser extent than that measured in Trail, so it is likely that the dust control, greening and public health messaging is likely to have had a positive effect (Hilts *et al.*, 1998). In the case management children, a decline in blood lead concentrations (range=2.3-4.0 µg/dl) in the year following the intervention was significant for those receiving the intervention in 1991 ($p<0.001$), 1992 ($p<0.001$) and 1994 ($p=0.001$).

The study in Broken Hill, New South Wales sought to evaluate the changes in children's blood lead concentration between 1991 and 2007 (Boreland, Lesjak and Lyle, 2008). Mining had taken place at Broken Hill since 1884, and in 1991 a survey found that the majority of children had blood lead concentrations that exceeded the guideline concentration of 10 µg/dl (Boreland, Lesjak and Lyle, 2008). Lead management commenced in 1994 and consisted of the capping of contaminated soil on public land with clean soil, clay, mulch, concrete or crushed metal, planting in areas of bare soil to reduce dust, and works to reduce the risk of stormwater or vehicles mobilising materials (Boreland, Lesjak and Lyle, 2008). Children aged 1 to 4 years were involved in a voluntary screening programme, with analysis treated as an interrupted time series taking into account geographical areas with different levels of risk. The analysis found that age-sex standardised geometric mean blood lead levels declined by 65% between 1991 and 2007, from 16.3 µg/dl to 5.8 µg/dl (Boreland, Lesjak and Lyle, 2008). In the area with the greatest risk the mean blood lead concentrations declined by 70% over the same period, from 27.3 µg/dl to 8.3 µg/dl (Boreland, Lesjak and Lyle, 2008).

The study in Nigeria focused on emergency measures taken in response to lead poisoning of 17,000 people in eight villages as a result of unregulated artisanal gold mining (Tirima et al., 2016). This prompted an area-wide remediation programme carried out in four phases, alongside emergency screening in 4,399 children under 5 years old and blood chelation to treat 2,349 children found to have blood lead levels above 45 µg/dl (Tirima et al., 2016). The mean blood lead levels pre-remediation reduced from 149 µg/dl to 15 µg/l over the four-year remediation period (Tirima *et al.*, 2016). Phase 1 of the remediation in two villages resulted in soil lead concentrations declining by 98% and 96% to 83 mg/kg and 179 mg/kg respectively, and blood lead levels in children declining from a mean of 149 µg/dl ($n=74$) to 76 µg/dl ($n=230$) (Tirima *et al.*, 2016). Phase 2 took place in five villages where mean soil lead concentrations ranged from 300 mg/kg to 1343 mg/kg and were reduced by 77% and 93% respectively. In these villages, 3,326 children were screened and first draw blood lead levels declined from around 48 µg/dl to around 25 µg/dl. In phase 3 where one village and an industrial area were remediated the mean soil lead concentrations reduced by 87% from 670 to 90 mg/kg, and the first draw blood lead levels reduced from 25 to 15 µg/dl (Tirima *et al.*, 2016).

The three studies at Bunker Hill Superfund Site (Maisonet, Bove and Kaye, 1997; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003), presented differing timeframes or analysis of the blood screening programme of children, aged 9 months to nine years, in the five communities with elevated lead concentrations. The first is a case-control study of children, aged 1 to 9 years, who participated in the 1992 screening with blood lead levels above 10 µg/dl, matched by age and sex with children with blood lead levels of less than 10 µg/dl (Maisonet, Bove and Kaye, 1997). The population size was 295 children and the final sample consisted of 69 matched pairs (43 male and 26 female); 65 of whom were above 6 years (Maisonet, Bove and Kaye, 1997). Logistic regression analysis was used to rank risk factors, adjusting for household income and education of 'head of household', with children considered to be in the remediated group if their yard had been remediated between 1989 and 1991 (Maisonet, Bove and Kaye, 1997). Yard remediation and having pets going in and out of house had strongest association with blood lead levels in the crude analysis. The logistic regression suggested that yard remediation was the best predictor of blood lead levels after adjustment for income and education (reference level is no yard remediation OR=0.28, CI=0.08-0.92, $p<0.05$); all other variables were not significant, although the authors excluded variables if the direction of the effect was inconsistent with their expectations (Maisonet, Bove and Kaye, 1997).

The review by (Sheldrake and Stifelman, 2003) provides a detailed overview of the remediation and blood lead screening programme at Bunker Hill, and draws on some of the analysis of Von Lindern *et al.* (2003). The blood screening data are presented as a repeat cross-sectional survey of blood lead levels in children, aged 9 months to 9 years. Recruitment is via an annual door to door survey; there was a focus on increasing participation in disadvantaged children so payment was provided to each participant (Von Lindern *et al.*, 2003). Children with blood lead levels in excess of 25 µg/dl between 1988 and 1990, 20 µg/dl in 1991, 15 µg/dl in 1992 and 10 µg/dl between 1993 and 2001 receive a nursing follow-up (Von Lindern *et al.*, 2003). An assessment of bias in 1998 examined school records between 1989 and 1998 and suggested that the survey identified 73% of all children aged 9 months to 9 years, and of these around two thirds participated; equating to a sample collected from an estimated 50% of the population (Von Lindern *et al.*, 2003). Screening began in 1983 when over 80% of children including those born since 1981 had blood levels above 10 µg/dl, and this was related to parental income, socioeconomic status and education level, home hygiene practices, smokers in the home, nutritional status of child, use of locally grown produce, exposed soil in the yard, number of hours spent outside, pica behaviour and age (Sheldrake and Stifelman, 2003). At Bunker Hill, blood lead levels have declined over the remediation period, with the exception of in one year where a flood event exposed previously capped contamination. Household dust concentrations have also declined over this period (Sheldrake and Stifelman, 2003). The percentage of children with blood lead levels of 10 µg/dl or greater; decreased between 1989 and 2001 in all children (46% vs. 3%), 1-year olds (57.1% vs. 4.4%), 2-year olds (60.9% vs. 9.8%), 3-year olds (62.1% vs. 2.5%) and 4-year olds (36.8% vs. 4.3%) (Sheldrake and Stifelman, 2003). The blood lead levels suggest that the remediation objectives have been achieved following completion of only 70% of the soil remediation (Sheldrake and Stifelman, 2003). In young children blood lead levels were associated with presence of bare soil in play area, number of hours spent outside, pica, and smokers in the home (analysis not presented), with a decrease being associated with increased parental income, socio-economic status, parental education level, home hygiene, nutrition status of child, presence of vegetable garden, and age of child (Sheldrake and Stifelman, 2003).

The study by (Von Lindern *et al.* (2003) used the same dataset as that presented in Sheldrake and Stifelman (2003), but focussed on children who were screened in consecutive years, so is effectively an interrupted time series with the previous year's blood lead levels as the comparator. In total 4,000 samples were used in a step-wise multiple regression using 1: age, dust concentration in vacuum cleaner dust, soil concentrations in yard, city, and within 200 foot of yard, and 2: age, interactions between dust concentration and age class (0-1, 2-4, 5-6, and 7-9 years), city concentrations and age class, soil concentration within 200 foot and age class, and yard concentrations and age class. Blood lead levels for children with repeated measures in consecutive years were then used in a mixed model with groups describing whether they had received home yard remediation, whether they had received behavioural intervention or no intervention (control), and whether the blood lead concentrations relate to pre- or post-intervention (Von Lindern *et al.*, 2003). In this sample the percentage of children with blood lead levels above 10 and 15 µg/dl decreased from 45% to 3.1% and from 15% to 1.2% between 1988 and 2001 (Von Lindern *et al.*, 2003). As indicated by Sheldrake and Stifelman (2003), there was a slight increase in 1989 due to flooding with 56% and 26% of children having blood levels above 10 µg/dl and 15 µg/dl respectively (Von Lindern *et al.*, 2003). Average blood lead levels were significantly different ($p<0.05$) from the previous year between 1989 and 1994, and in 1998. The proportion of children living on contaminated yards (>1000 mg/kg) decreased from 80% in 1988-1989, to 43% in 1990 and 25% in 1991, fluctuated between 18-29% between 1992 and 1996 despite remediation of additional 551 homes (see below), but by 1999 only 4% of children lived on contaminated yards (Von Lindern *et al.*, 2003). Over the time period blood lead levels declined by 50 to 60% with the greatest decreases corresponding with initial home yard remediation (Von Lindern *et al.*, 2003).

The regression analysis reported significant differences between pre- and post-intervention blood lead levels for each group (remediation, behavioural intervention and control), controlling for child's age, and also between groups. Blood lead levels in the control group decreased by a mean of 0.4 µg/dl, by 2.5 µg/dl in the remediation group and by 4.8 µg/dl in the behavioural intervention group ($p<0.001$). Across the time period 1989 to 2001, the analysis suggested that remediation is associated with a reduction in blood lead levels of 7.5 µg/dl for a typical 2-year old child, comprised of 1.0 µg/dl from yard remediation, 0.7 µg/dl from a home-specific effect of yard remediation, 0.6 µg/dl from remediation of neighbourhood soil, 5.0 µg/dl for remediation of community soil and 0.2 µg/dl from a reduction in lead in house dust (Von Lindern *et al.*, 2003). In addition, over the intervention period a typical 2 year old would also have an additional 3.9 µg/dl reduction due to behavioural intervention (Von Lindern *et al.*, 2003). The modelling also found that blood lead levels tend to increase by approximately 0.9 µg/dl per 1000 mg/kg of lead in dust and not having vacuum cleaner adds approximately 0.6 µg/dl to the blood lead levels (Von Lindern *et al.*, 2003). This study provides a detailed account of the different impact of remediation and a public health campaign, finding that, although the greatest reduction came from area-wide soil remediation the impact of the intervention to reduce exposure via hand to mouth behaviour and increase personal hygiene and home cleaning was substantial.

Overall, there is consistent evidence that remediation of contaminated soils is effective at reducing both direct and indirect exposure to pollution in nearby populations. The studies from Bunker Hill suggest that remediation of yards alone is not sufficient as the resuspension of soils from other locations will result in recontamination of soils and elevated concentrations of metals in household dusts, and inward migration means that new families moving into unremediated homes are at risk (Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003). In addition, contaminated areas accessible by children present another direct exposure pathway (Freeman *et al.*, 1995; Tirima *et al.*, 2016). It is therefore necessary to prioritise area-wide remediation instead of focussing efforts on individual properties, particularly after immediate risks to vulnerable populations have been mitigated; the study by Von Lindern *et al.* (2003) suggested that area-wide remediation was responsible for around three times more reduction in blood lead levels that individual yard remediation. These studies also present some evidence that, where populations are living alongside contamination and remediation programmes, public health campaigns are also effective at reducing exposure pathways. These provide information on the risks from contamination and the importance of cleaning dusts from homes, good personal hygiene, such as hand washing before food preparation and mealtimes, and discouraging hand to mouth behaviour and pica in children (Goulet, Messier and Gaudreau, 1996; Sheldrake and Stifelman, 2003). Most of the studies do not report specifically on the impact of public health campaigns but the reduction in pica and hand to mouth behaviour reported by Goulet, Messier and Gaudreau (1996), and the estimated effectiveness of this intervention by Von Lindern *et al.* (2003) suggests that this can be an effective mechanism to reduce exposure while remediation is carried out.

Table 4. Summary of studies reporting outcomes related to health of people living near contaminated sites after remediation and public health campaigns (BLL = blood lead level)

Reference	Contaminant and source	Remediation	Location	Study design and comparator	Population and sample size	Outcomes	Results
Freeman et al 1995	Cr, wastes from Cr manufacturing and refining	Sites capped and/or soil replaced (early 1990 to late 1991). Public health campaign to reduce dust exposure.	Hudson County, New Jersey, US	Cross-sectional; comparator is control areas (both public housing and more affluent neighbourhoods) and pre-remediation data.	64 children: 41 children from Lafayette Gardens (public housing project surrounded on three sides by Cr waste sites) and 23 children from three control areas.	Cr levels in urine.	Concentrations of Cr in urine in children from Lafayette Gardens in Summer greater than controls (median 0.28 µg/l vs. 0.17 µg/l) ($p=0.055$). Cr concentrations in urine were found to be age-dependent and related to home location. Controlling for personal rate of excretion and age, exposure status was found to predict Cr (regression coefficient = -.347, SE 0.155, $p = 0.03$). Clear relationship between activities and Cr levels was not confirmed.
Aschengrau et al 1997	Pb from unspecified sources in soil, and house paint	Phase 1: soil removal, addition of geotextile and soil replacement, dust abatement in homes and loose-paint stabilisation. Phase 2: soil remediation and interior and exterior paint remediation. Public health campaign.	Boston, US	Randomised control trial with three groups (Phase 1: 1: all treatments, 2: dust abatement and paint stabilisation, 3: paint stablisation; Phase 2: groups 2 and 3 offered soil remediation; all groups offered paint remediation.	152 children aged less than 4 years, with blood lead levels 7-24 µg/dl.	BLL	After Phase 2: group 1 children whose homes received only paint hazard remediation had mean BLLs 2.6 µg/dl (CI=-0.6-5.9 µg/dl) greater than those children who received no intervention. Group 2/3 children whose homes received only paint hazard remediation and soil remediation had mean BLLs 1.4 µg/dl (CI=-0.7-3.5 µg/dl) greater than that of children whose homes received only soil abatement. After adjustment for confounding variables: group 1 children receiving paint hazard remediation had 6.5 µg/dl greater BLLs than those who did not ($p=0.05$), there was no significant different between the BLLs in group 2/3 children who did or did not receive paint hazard remediation ($p=0.36$).
Goulet et al 1996	Pb from Pb reclamation plant (closed 1989)	Asphalting plant yard, removing dust from roads and sidewalks, soil replacement, professional home cleaning (1989-1990). Public health campaign to raise awareness in those	St-Jean-sur-Richelieu, Quebec, Canada	Cohort, one group pre- and post-remediation.	Children who lived 200 m from plant in 1991. Sample of 101 children aged 6 months to 10 years (79.2% of population), 75 children in 1989 and 1991 sample.	BLL Percentage of children with BLL >15 µg/dl.	In children who had participated in both surveys BLLs dropped from 9.7 µg/dl (95% CI=8.6-10.9) in 1989 to 5.0 µg/dl (CI=4.5-5.6) in 1991 ($p<0.001$); children 6 months to 5 years decreased from 9.8 µg/dl (CI=8.6-11.2) to 5.5 µg/dl (CI=4.9-6.3) ($p<0.001$). In 1991 zero children had blood Pb >15 µg/dl whereas 21.3% did in 1989. Percentage of children engaged in pica fell from 35.5% (1989) to 18.8% (1991) ($p=0.004$); and putting things in mouth fell from 46.2% to 31.7% ($p=0.03$).

		with young children.					
Hilts et al 1998	Pb from a Pb/Zn smelter	Dust abatement including capping soils, use of a dust suppressant and greening. Public health campaign to raise awareness and provide cleaning materials.	Trail, Canada	Interrupted time series, screening programme, comparator is previous year's BLL.	Children aged 6 to 72 months. Numbers tested each year declined from 169 in 1989 to 46 in 1996.	BLL	BLLs declined by 0.6 µg/dl (or about 5%) per year between 1989 to 1996. In the case management children, a significant decline in BLLs (2.3 to 4.0 µg/dl) in the year following the intervention was significant for those receiving the intervention in 1991 ($p<0.001$), 1992 ($p<0.001$) and 1994 ($p=0.001$).
Boreland et al 2008	Pb from Pb mine	Capping of soil material, greening of bare soil. Public health campaign to raise awareness.	Broken Hill, New South Wales, Australia	Interrupted time series, screening programme, comparator is previous years' BLL.	Children aged 1 to 4 years, participation declined from 72% in 1994to 46% in 2007.	BLL Dust Pb levels.	Mean BLLs declined from 16.3 µg/dl in 1991 to 5.8 µg/dl in 2007. Mean BLLs in the highest risk zone declined from 27.3 µg/dl in 1991 to 8.3 µg/dl in 2007. Dust concentrations were significantly greater in 1991 to 1994, compared with 1995 to 1999 ($p<0.05$).
Tirima et al 2016	Pb from informal artisanal gold mining	Soil removal from residential and common areas, and ponds; disposal in 14 landfills. Public health campaign to reduce exposure through better mining practices.	Eight villages in northern Nigeria	Repeat cross-sectional, screening programme to identify at risk children, run concurrently with phased remediation.	4399 children aged < 5 years.	BLL Soil Pb levels.	Mean BLL reduced from 149 µg/dl to 15 µg/l over four-year period. Phase 1 (2 villages) soil Pb levels reduced by 98% and 96% to 83 mg/kg and 179 mg/kg respectively; 74 children screened before and during remediation had mean BLL of 149 µg/dl and 230 screened after remediation had mean BLL 76 µg/dl. Phase 2 (5 villages) soil Pb between 300 mg/kg and 1343 mg/kg reduced by 77% and 93% respectively; 3326 children screened and BLLs drop from ~48 µg/dl to ~25 µg/dl. Phase 3 (1 village with industrial area) mean soil Pb concentrations reduced by 87% from 670 to 90 mg/kg; BLL reduced from 25 to 15 µg/dl.
Maisonet et al 1997	Pb from mine and smelter (closed 1981)	Yard remediation; new yards remediated each summer since 1989.	Bunker Hill Superfun d Site, Idaho, US	Case-control study, comparator is age and sex-matched children with BLL <10 µg/dl.	Population is 295 children aged 1 to 9 years, sample is 138 participants (69 matched pairs).	BLL	Logistic regression: yard remediation was most related to blood Pb levels after adjustment with income and education (OR=0.28, CI=0.08-0.92, $p<0.05$), pets in and out of house, hours spent playing outdoors, smoking inside house, child washes hands before bed, child puts dirt in mouth all not significant.
Sheldrake and	As above. Pb from mine and	Soil capping in parks and schools	As above. Bunker	Repeat cross-sectional,	Children aged 9 months to 9 years	BLL	In 1983 over 80% of children had BLL >10 µg/dl.

Stifleman 2003	smelter (closed 1981)	(1986), soil removal in residential yards, commercial properties and rights of way, and indoor dust based on child BLLs, soil concentrations and risk (1989-). Program expanded (1994-) to clean up contiguous parcels of land and areas with soils with >1000 mg/kg. Public health campaign to raise awareness to reduce exposure. By 2001 80% of homes exceeding 1000 mg/kg remediated.	Hill Superfund Site, Idaho, US	comparator is pre-remediation.	in the area offered annual BLL screening; percentage of eligible in sample exceeded 50% each year.	Percentage of children with BLL >10 µg/dl. Percentage of children with BLL >15 µg/dl.	Percentage of children with BLL >10 µg/dl; decreased from 57.1% in 1998 to 4.4% in 2001 in 1 year olds, 2 year olds 60.9% to 9.8%, 3 year olds 62.1% to 2.5%, 4 year olds 36.8% to 4.3%; all children (<9 years) 46% to 3%.
Von Lindern et al 2003	As above. Pb from mine and smelter (closed 1981)		As above. Bunker Hill Superfund Site, Idaho, US	Interrupted time series, comparator is previous year's BLLs	Children in the area which is home to 7000 people in 5 communities; 230 to 445 children aged 9 months to 9 years tested each year between 1988 and 2001; estimated as 50% of children on school records. 4000 paired BLL and environmental samples.	BLL Percentage of children with BLL >10 µg/dl. Percentage of children with BLL >15 µg/dl.	Percentage of children with BLL >15 µg/dl decreased from 15% to 1.2% between 1988 and 2001; percentage with >10 µg/dl decreased from 45% to 3.1% between 1988 and 2001. Average BLL different (p<0.05) from previous year in 1989-1994, and 1998. BLLs decreased 50-60% with greatest decrease corresponding with initial home yard remediation. Proportion of children living on contaminated yards (>1000 mg/kg) decreased from 80% in 1988-1989, to 43% in 1990 and 25% in 1991, fluctuated between 18-29% between 1992 and 1996 despite remediation of additional 551 homes due to inward migration, by 1999 only 4% lived on contaminated yards. BLLs in control, remediation and public health intervention group decreased by 0.4 µg/dl, 2.5 µg/dl and 4.8 µg/dl respectively (p<0.001). Suggests remediation overall has 7.5 µg/dl effect in reducing typical 2-year olds BLLs between 1989 and 2001 (1.7 µg/dl from individual yard, 5.6 µg/dl from community and neighbourhood), and public health intervention results in an additional 3.9 µg/dl reduction.

4.2.3. Existing population with remediation only

The final four studies examined the impact of remediation of contaminated soils on the health of existing populations. These studies reported only on remediation; there was no public health campaign reported alongside remediation, although this may have taken place.

As with the previous examples, these studies relate to sites contaminated from waste disposal (Choi *et al.*, 2006; Burgos *et al.*, 2017), mining and deposition of metal pollution from industry (Lanphear *et al.*, 2003; Madeddu *et al.*, 2013). All of the previous studies have focussed on one contaminant, primarily lead, whereas these studies consider a mix of inorganic pollutants (Lanphear *et al.*, 2003; Madeddu *et al.*, 2013; Burgos *et al.*, 2017) and polychlorinated biphenyls (PCBs) (Choi *et al.*, 2006).

The remediation technologies employed in these studies were quite mixed. The abandoned waste disposal site in Arica, Chile was active between 1984 and 1999, and during remediation the wastes were removed, the site capped and fenced and the roofs of nearby homes cleaned (Burgos *et al.*, 2017). In Midvale, Utah mine tailings were capped with clay, and a remediation programme removed soils from yards with lead concentrations greater than 500 mg/kg and replaced these with clean soil (Lanphear *et al.*, 2003). The PCBs in New Bedford Harbour Superfund Site, Massachusetts, US were caused by waste disposal from industry, including a capacitor, between the 1940s and 1977; the remediation of this site involved the dredging and removal of contaminated sediments between 1994 and 1995 (Choi *et al.*, 2006). The study in the industrial Sulcis-Iglesiente area of Sardinia, Italy focuses on metals from an active industrial area, and three mines restored in the 1990s, two lead/zinc mines and one coal mine (Madeddu *et al.*, 2013), however there is no detail on the exact remediation measures employed at these sites.

The study in Midvale, Utah is similar to those presented in the previous section; a repeat cross-sectional survey carried out in 1989 (n=112) and 1998 (n=215) was used to examine changes in blood lead concentrations in children aged 6 to 72 months between those whose yards had been remediated and a control group (Lanphear *et al.*, 2003). In addition, lead and arsenic concentrations in soil and interior dust in homes were also measured in both years. Yard remediation was targeted at households with lead concentrations above 500 mg/kg, and as one would expect the study found that in 1989, prior to remediation, soil and dust concentrations of both lead and arsenic were significantly greater in homes that received soil remediation compared with those that had not (p=0.0001), as were interior and exterior paint concentrations (p=0.004 and p=0.006 respectively). Children living in homes eligible for yard remediation also had significantly greater blood lead concentrations than those in the control group (5.6 µg/dl vs. 3.9 µg/dl; p=0.0001) (Lanphear *et al.*, 2003). However, by 1998 there were no longer significant differences between the intervention and the control groups for blood lead concentrations (3.0 µg/dl vs. 2.6 µg/dl), dust arsenic and lead concentrations and soil arsenic concentrations (Lanphear *et al.*, 2003). The only parameter that was significantly different in 1998 was soil lead concentration, which was significantly greater in the control homes, compared with those with yard remediation (95 vs. 54 mg/kg, p=0.02) (Lanphear *et al.*, 2003). In 1989, 11% of children in homes eligible for yard remediation had blood lead concentrations greater than 10 µg/dl, compared with 2.6% in the control group, but in 1998, this had fallen to 1% of children in homes with yard remediation (Lanphear *et al.*, 2003). After adjustment for potential confounders (age, mouthing behaviour, socioeconomic status, and year), there was an estimated 2.3 µg/dl (CI=1.8-2.9 µg/dl) decline in blood lead concentration associated with soil remediation, and the blood lead concentration in children ages 6 to 72 months who lived in homes with yard remediation declined 42.8% faster than children whose yards were unremediated (p=0.14), with blood lead concentrations declining faster in children aged 6 to 36 months (2.5 µg/dl, CI=1.8-3.5 µg/dl; p=0.03) than those aged 36 to 72 months (2.0 µg/dl, CI=1.3-

3.0 µg/dl; p=0.03) (Lanphear *et al.*, 2003). The authors suggest that the slower decline in older children may be due to their greater body burden of lead, following a longer period of exposure, and their reduced tendency to mouthing behaviours, compared with younger children (Lanphear *et al.*, 2003).

The study in Arica, Chile is interesting as it is the only study that considers a health outcome, cognitive development in children (Burgos *et al.*, 2017), as opposed to concentrations of contaminants in blood or urine. This cross-sectional study of children, aged 6 to 15 years, selected to represent those born pre-, during and post-remediation used the Wechsler Intelligence Scale for Children to assess cognitive performance in 180 randomly selected children from a population of 735 (Burgos *et al.*, 2017). It is not clear how many children were approached so the response rate cannot be calculated. A range of sociodemographic data were collected from the parents via questionnaire, as well as information on the child's health, location and time living in the home, and the mother's cognitive performance using the equivalent scale for adults. Blood lead levels and arsenic in urine collected in a previous study were provided as secondary data. Sociodemographic data were compared using a $\chi 2$ test; age, maternal intelligence, education of parents, concentrations of lead in blood and arsenic in urine were compared with Kruskal-Wallis tests and the cognitive performance of children compared between cohorts with ANOVA, followed by linear regression adjusted for confounders (Burgos *et al.*, 2017). There were no differences between groups in IQ of mothers, birth position between siblings or socioeconomic characteristics such as income and home ownership (Burgos *et al.*, 2017). The median blood lead level was 2 µg/dl and similar between groups (p=0.059), and there was no significant difference between levels of arsenic in urine across the groups (Burgos *et al.*, 2017). In the crude analysis, cognitive performance was greater in post-remediation group (91.1 points) compared with the pre-remediation cohort (81.9 points). Processing Speed Index and ADI were the only sub-components of the intelligence scale that were not significantly different between groups (Burgos *et al.*, 2017). After adjusting for age, sex, maternal IQ and paternal education, there is evidence of a difference in total IQ between groups (reference: pre-remediation group; during remediation $\beta = 9.97$; 95% CI 0.82 to 19.13; post-remediation $\beta = 16.14$; 95% CI 1.53 to 30.74) (Burgos *et al.*, 2017).

The cohort study of PCBs in infants born near New Bedford Harbour Superfund Site used umbilical cord serum obtained at birth and analysed for 51 PCB congeners (Choi *et al.*, 2006). The sample consists of 720 mother infant pairs, with mothers aged over 18 years, and infants born between March 1993 and December 1998, covering the pre-, during, and post-remediation periods. The PCB outcome measures included the sum of 51 congeners, selected based on toxicity, persistence and presence in New Bedford Harbour, and divided into light and heavy PCBs, with PCB-118 selected for individual assessment due to its toxicity and prevalence locally (Choi *et al.*, 2006). PCBs accumulate in fatty tissues, thus enabling a dietary pathway, and they can also cross the placenta; toxic effects on children and infants include reduced birthweights, growth and cognitive performance (Choi *et al.*, 2006). Information on maternal diet, consumption of local produce, before and during pregnancy, occupation, gardening and other PCB-exposure activities were collected via questionnaire in order to assess the impact of dietary, occupational and environmental exposure pathways. Addresses were geocoded to estimate exposure from contaminated soils, house age was used as a proxy for indoor exposure (% of homes built 1940-1979), and neighbourhood socioeconomic indices constructed based on proportions of crowding, poverty, high education, income and low education (Choi *et al.*, 2006). Log PCB concentrations in cord serum were analysed against continuous covariates using scatter plot smoothing, exposure risk factors divided into exposure pathways (dermal, inhalation and dietary) and related to individual characteristics (maternal age and birthplace, smoking during pregnancy, previous lactation, child's date of birth and sex, dredging period, and household income). Maternal education and race were also included in models assessing neighbourhood socioeconomic indicators and PCB levels. Multivariate models for log PCBs included core individual characteristics, and exposure pathways significant ($p<0.10$) in at least one of the individual pathway models (Choi *et al.*, 2006).

The analysis found that concentrations of PCBs in cord serum increased with maternal age ($p<0.001$), was slightly greater in female infants for total PCB ($p=0.07$) and heavy PCBs ($p=0.06$) (Choi *et al.*, 2006). Concentrations were greater in infants born before dredging, followed by during dredging, with those born after dredging having the lowest concentrations ($p<0.001$). Infants whose mother's birthplace was Portugal/Azores/Cape Verde had greater PCB concentrations in cord serum than those whose mothers were born in other countries, with those with US-born mothers having the lowest concentrations ($p<0.001$). Maternal consumption of organ meats, local dairy products, and dark fish was associated with greater PCB concentrations in infant serum ($p<0.05$), but occupational/home exposure was not significant. In the multivariate models maternal age and birthplace were the strongest predictors of PCB levels ($p<0.001$), and infants born late in the study had significantly lower concentrations of PCBs than those born early in the study (Choi *et al.*, 2006). Even after adjustment for birth date, infants born after dredging had significantly lower light PCB and PCB-118 levels with near significance for total PCBs. Despite this, there was no evidence that living closer to the harbour was associated with greater concentrations of PCBs in cord serum (Choi *et al.*, 2006). There were modest increases in PCB concentrations during dredging, presumed to be due to the volatility of the compounds and their mobilisation during dredging, but these then declined after dredging particularly for light PCBs and PCB-118 (Choi *et al.*, 2006).

The final study examined cadmium, chromium, copper, manganese, lead and zinc concentrations in the blood of adults living in the industrial region of Sulcis-Iglesiente, Sardinia, Italy (Madeddu *et al.*, 2013). In contrast to the other studies, this cross-sectional study reports on exposure from different sources of contamination in comparison to a control site (Madeddu *et al.*, 2013). Very little information is provided on the remediation employed, only that the mines were restored. Healthy adults, aged over 18 years (n=265; 149 female), were recruited from five locations in the region, blood samples were analysed for metal concentrations and sociodemographic and lifestyle data collected via questionnaire. Sub-group analysis was conducted using Mann-Whitney and Kruskal-Wallis tests and correlations based on location, age, sex, smoking, number of cigarettes, and alcohol consumption, followed by regression analysis (Madeddu et al., 2013). Analysis found that concentrations of metals in blood were greater in the those living with 5 km of the active industrial plants (n=29) compared with those living in the control area (n=27; cadmium $p=0.05$, copper $p=0.031$, manganese $p=0.05$ and lead $p<0.001$), within 2 km of the restored coal mine (n=48; cadmium $p=0.036$, manganese $p=0.005$, lead $p=0.006$ and zinc $p=0.005$), within 4 km of the restored lead/zinc mine (n = 129; cadmium $p=0.041$, manganese $p=0.037$, lead $p=0.005$ and zinc $p=0.004$), and those living within 3 km of a second restored lead/zinc mine (n=32, manganese $p=0.022$) (Madeddu *et al.*, 2013). The study does not appear to consider whether these elevated concentrations are a result of the industrial plants that process cadmium, lead or zinc or associated vehicular traffic. In addition, blood copper and lead levels in those living within 3 km of the restored lead/zinc plant were significantly greater than those living in the control area ($p=0.019$ and $p=0.011$, respectively). There was no significant difference between metal concentrations in those within 2 km of the restored coal mine, within 4 km of the restored lead/zinc mine and the control area. It is important to note for this study, that in contrast to the studies above that reported elevated blood lead levels in children, the average blood cadmium levels in this study were below recommended limits in all sites; and 95% of residents living within 5 km of the active industrial area were below this. Similarly, 95% of population in the sample has blood lead levels below recommended levels, with 5% of the sample having concentrations greater than this in the non-control sites (Madeddu *et al.*, 2013).

Overall, these studies suggest that remediation of soil contamination alone can result in reduced exposure and improvements in health outcomes. The studies in Midvale and Arica provide more information on the remediation methods employed and report consistent declines in the blood lead concentrations or improved cognitive performance (Lanphear *et al.*, 2003; Burgos *et al.*, 2017). The study in New Bedford Harbour suggests that although dredging of contaminated sediments can be successful in reducing PCB exposure, the volatility of these contaminants means that there may be a short-term increase during remediation which should be considered in developing remediation strategies (Choi *et al.*, 2006).

Table 5. Summary of studies reporting outcomes related to health of those living near contaminated sites after remediation (BLL = blood lead level)

Reference	Contaminant and source	Remediation	Location	Study design and comparator	Population and sample size	Outcomes	Results
Lanphear et al 2003	Pb and As from a mine and smelter.	Tailings capped with clay, soil removed from yards with Pb concentrations <500 mg/kg and replaced with clean soil.	Midvale, Utah, US	Repeat cross-sectional, comparator is yards without remediation.	Children aged 6 to 72 months in 1989 (n=112) and 1998 (n=215)	BLLs As and Pb in soil and dust.	1989: Greater levels of As and Pb soil and dust concentrations (p=0.0001), interior and exterior paint Pb concentrations (p=0.004 and p=0.006 respectively), and BLLs in children (5.6 µg/dl vs. 3.9 µg/dl; p=0.0001) in homes eligible for soil remediation compared with those that were not; 11% of children in homes eligible for yard remediation had BLLs >10 µg/dl, compared with 2.6% in the control group. 1998: no significant differences between the intervention and the control groups for BLLs (3.0 µg/dl vs. 2.6 µg/dl), dust As and Pb concentrations and soil As concentrations; soil Pb concentrations greater in the control homes, compared with those with yard remediation (95 vs. 54 mg/kg, p=0.02); 1% of children in homes with yard remediation had BLLs > 10 µg/dl. After adjustment for potential confounders (age, mouthing behaviour, socioeconomic status, year) BLL declined by 2.3 µg/dl (CI=1.8-2.9 µg/dl), BLLs intervention group declined 42.8% faster than control group (p=0.14), BLLs declined faster in children aged 6 to 36 months (2.5 µg/dl, CI=1.8-3.5 µg/dl; p=0.03) than those aged 36 to 72 months (2.0 µg/dl, CI=1.3-3.0 µg/dl; p=0.03).
Burgos et al 2017	Pb (with As, Cd, Cu) in abandoned waste site (active 1984 to 1999)	Waste removed, roofs of homes cleaned and decontamination of other areas of the city, site fenced and covered (1999 to 2003).	Arica, Chile	Cross-sectional, comparator is children born post-remediation.	735 children aged 6 to 15 years; sample is 180 children selected at random.	BLLs As levels in urine. Cognitive performance measured using Wechsler Intelligence Scale for Children.	BLLs 2 µg/dl and similar between cohorts (p=0.059), no significant difference in As in urine (p=0.369). Cognitive performance greater in post-remediation cohort (91.1 points) compared with pre-remediation (81.9 points). Processing Speed Index and ADI were the only components that were no different between cohorts, other components were mostly significant. After adjusting for age, sex, maternal IQ, paternal education average different in total IQ between cohorts increases (pre-remediation is reference): during remediation $\beta = 9.97$; 95% CI 0.82 to 19.13; post remediation $\beta = 16.14$; 95% CI 1.53 to 30.74.

Choi et al 2006	PCBs, waste disposal from local industry (1940s to 1977)	Dredging of contaminated sediments (1994 to 1995).	New Bedford Harbour Superfund Site, Massachu-setts, US	Cohort analytic study of infants, comparator is infants born pre-remediation.	Population is 788 mother-infant pairs where mother >18 years old; sample is 720 with 69 being excluded due to various factors.	Umbilical cord PCB levels; total PCBs, light PCBs, heavy PCBs, 51 congeners and PCB-118.	In multivariate models, maternal age and birthplace were the strongest predictors of ΣPCB levels ($p<0.001$). Maternal consumption of organ meat and local dairy products was associated with higher, and smoking and previous lactation with lower, ΣPCB levels ($p<0.05$). Infants born later in the study had lower ΣPCB levels than infants born earlier in the study. There was a 17% change (-3 to 40%) in ΣPCB for infants born before/during dredging compared with those born after dredging ($p<0.10$).
Madeddu et al 2013	Cd, Cr, Cu, Mn, Pb and Zn. Two former metal mine, one former coal mine, and one active industrial area.	Mines restored 1990s.	Sulcis-Iglesiente, Sardinia, Italy	Cross-sectional study, comparator is a control area with no industry or mining.	Sample is 265 healthy adults.	Cd, Cr, Cu, Mn, Pb and Zn blood levels (BLs).	Those within 5 km of active industrial site (n=29) have greater BLs than those in the control area: Cd ($p=0.05$), Cu ($p=0.031$), Mn ($p=0.05$) and Pb ($p<0.001$); within 2 km of coal mine (n=48): Cd ($p=0.036$), Mn ($p=0.005$), Pb ($p=0.006$) and Zn ($p=0.005$); within 4 km of Pb/Zn mine (n=129): Cd ($p=0.041$), Mn ($p=0.037$), Pb ($p=0.005$) and Zn ($p=0.004$); and within 3 km of Pb/Zn mine (n=32): Mn ($p=0.022$). Those within 3km of Pb/Zn mine restored (n=32) have greater BLs than control: Cu ($p=0.019$) and Pb ($p=0.011$). Cd, Pb and Zn positively correlated with age.

4.3. Impact on equity outcomes in studies of outcomes related to the health

Very few of the studies explicitly considered equity in their study design or reporting of outcomes. It is well reported in the environmental justice literature that disadvantaged groups are more likely to live near contaminated sites (Pasetto, Mattioli and Marsili, 2019). As a result some studies did collect data on socioeconomic variables and take these into account in their analysis (Aschengrau *et al.*, 1997; Maisonet, Bove and Kaye, 1997; Lanphear *et al.*, 2003; Choi *et al.*, 2006; Madeddu *et al.*, 2013; Schoof *et al.*, 2016; Burgos *et al.*, 2017), others collected these data but did not include them in the analysis (Goulet, Messier and Gaudreau, 1996) or discussed their findings in relation to socioeconomic factors (Freeman *et al.*, 1995; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003; Mielke *et al.*, 2013). Only one study appeared to consider equity in their study design by including control groups from neighbourhoods with both similar and more affluent socioeconomic profiles (Freeman et al., 1995).

The seven studies that considered equity impacts in their analysis used different variables, often related to the exposure or outcome. In the study in Butte, Montana, the analysis took race/ethnicity, age, house age and socio-economic status into account in the model (Schoof et al., 2016), providing an examination of neighbourhood differences and discussing inequalities by ethnicity, although the ethnic diversity in the sample was relatively low. The study of the impact on cognitive performance of living near a waste dump in Arica, Chile took age, sex, number of siblings, birth order among siblings, number of household members, education level of the parents, family income, address, type of school attended (public, subsidised, private) into account in the analysis (Burgos et al., 2017). Although this study does not include a control sample without exposure with same birth years, the 9.16-point difference in IQ between pre and post-remediation years is compared against a national dataset, where it was 0.06 points, and a low socioeconomic city comparable to Arica, where it was 2.11 points. The authors highlight that pre-remediation children in Arica have a 20-point difference in IQ compared with the same age nationally (Burgos et al., 2017). The study in Boston tested a number of equity-related confounders for significance, but found that only socioeconomic status was significant, and this was included in the analysis (Aschengrau *et al.*, 1997).

In the study of PCB concentrations in infants the analysis considered maternal age, birthplace, race, education, marital status, reproductive history, pregnancy smoking and alcohol consumption, residential history, household income, and infant's race and sex (Choi et al., 2006). This study reported that concentrations in infants whose mothers had not smoked during pregnancy were greater for total PCBs ($p<0.001$), and heavy PCBs ($p<0.001$) and PCB-118 ($p<0.001$), but lower for light PCBs ($p=0.002$). Concentrations were also greater in those with greater household incomes for total PCB ($p=0,010$), and heavy PCBs ($p=0.10$) and PCB-118 ($p=0.02$) (Choi *et al.*, 2006). However, in the multivariate models only maternal age and birthplace, prior lactation and household income were significant, with higher income being associated with lower PCB concentrations (Choi et al., 2006).

In the case-control study of child blood levels near the lead smelter at Bunker Hill, Idaho participants were matched by age and sex, and analysis adjusted for household income and the education level of the head of the household (Maisonet, Bove and Kaye, 1997). This paper reports that more of the control households had a head of household with more than 12 years of education, and more case households had a lower income. Other variables examined included pets going in and out of house, hours spent playing outdoors, smoking inside the home, child washing hands before bed, and child putting dirt in their mouth, but none were significant in the multivariate analysis (Maisonet, Bove and Kaye, 1997). In this study some variables were excluded from the analysis if the direction of the association in the univariate analysis was unexpected, which was not adequately justified (Maisonet, Bove and Kaye, 1997). In the study of the industrialised area of Sicily, the age and sex of participants, and whether they were smokers and consumed alcohol was considered in the analysis as these factors are related to exposure and uptake of metals (Madeddu et al., 2013). They found that blood cadmium, lead and zinc levels were positively correlated with age; cadmium and lead levels were positively correlated with age for females, and lead for males, and sex; blood copper levels were greater in females and lead levels were greater in males (all $p<0.001$). Smokers had greater blood cadmium levels than ex- and non-smokers ($p<0.001$), and heavier smokers had greater cadmium and lead levels than lighter smokers ($p=0.01$ and $p=0.02$, respectively), and association reported in other studies (Madeddu et al., 2013). Those classified as ‘drinkers’ had greater blood lead levels than non-drinkers ($p=0.005$) (Madeddu et al., 2013).

The study of child blood levels near a lead smelter in Quebec presented data on the sex, parental smoking, maternal education and single parenthood of their participants, but these were not taken into account in the analysis (Goulet, Messier and Gaudreau, 1996). This was despite there being a significant difference between the proportion of children living in single parent households and those living in older homes between the sampling years (Goulet, Messier and Gaudreau, 1996).

The study in Midvale, Utah found that those children in homes eligible for yard remediation in 1989 were more deprived, using the Hollingshead 4 Factor Scale, than those in the control group (31.8 vs. 22.9; $p=0.0001$) (Lanphear *et al.*, 2003). In 1998 children living in homes with remediated yards were still more deprived than those in the control groups, although the difference was smaller (29.2 vs. 24.6; $p=0.03$) (Lanphear *et al.*, 2003). Multivariate analysis adjusted for socioeconomic status in their analysis (Lanphear *et al.*, 2003).

The remaining studies that provided some consideration of equity did this in the discussion and interpretation of their findings. For example, in the study of child blood levels pre- and post-Katrina in New Orleans it is acknowledged that there are substantial socio-economic disparities between the neighbourhoods characterised as low and high lead; poorer African American populations are more likely to live in the high lead areas and wealthier white populations in the low lead areas (Mielke et al., 2013). They also report that the disadvantaged neighbourhoods are associated with lower life expectancy and educational attainment, and behavioural problems (Mielke et al., 2013). Similarly, the study of child chromium concentrations in New Jersey reported that the African America population are more likely to live in the public housing project consisting of multiple household blocks, which was surrounded on three sides by the chromium waste dumps, and their control areas were matched to include similar neighbourhoods as well as participants from more affluent areas with predominantly white, middle income households in single dwellings (Freeman et al., 1995).

The two studies of Bunker Hill Superfund Site, Idaho both provide a detailed interpretation of how socioeconomic factors have affected their findings and the achievement of the remediation objectives (Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003) which highlight some of the challenges in large-scale remediation projects. They report, for example, that these communities are relatively disadvantaged with around thirty percent living below the poverty line (Sheldrake and Stifelman, 2003), and that the high mobility of the residents, who are not home owners and move as often as every six months, complicated the findings (Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003). For example, in one of the towns, Kellogg, 30 to 50% of the children had lived at their current address for less than a year across the study period, with particularly high levels of in-migration to the area observed in 1989 and between 1992 and 1995 as higher rents in nearby areas forced families to move into the area (Von Lindern et al., 2003). The remediation objectives were based on proportions of children having blood lead levels below 10 or 15 µg/dl, with soil remediation prioritised according to children and pregnant women being present in the household; the high mobility of residents meant that the percentage of children living with contaminated yards remained between 15 and 30% from 1991 to 1996 offsetting the 200 yards being remediated each year, but this declined to 4% in 1998 following implementation of area-wide remediation (Sheldrake and Stifelman, 2003). In addition, the high levels of in-migration observed in these years meant that families were not aware of the contamination and therefore the behavioural interventions necessary to reduce exposure; some children had greater blood lead levels than would have been expected and these tended to be from disadvantaged, highly mobile families where childcare often took place in multiple locations (Von Lindern et al., 2003). These children also tended to exhibit lower levels of personal hygiene and greater hand to mouth activity and exposure to high dust and soil lead concentrations in play areas or away from home (Von Lindern et al., 2003). In young children blood lead levels were associated with presence of bare soil in play area, number of hours spent outside, pica, and smokers in the home, with a decrease being associated with increased parental income, socioeconomic status, parental education level, home hygiene, nutrition status of child, presence of a vegetable garden, and age of child, although the detailed analysis is not presented as this is a review paper summarising the remediation of the site (Sheldrake and Stifelman, 2003).

We can see that relatively few studies provide a detailed assessment of the relationship with equity. Often, this is implicit as the populations located near contaminated sites tend to be more disadvantaged. The studies that consider socioeconomic factors as confounders tend to do so because these variables are likely to affect the exposure to soils either directly (e.g. length of residence, diet) or indirectly (e.g. income), or because they may impact on the outcome (e.g. maternal education, income in the study examining cognitive performance).

Some studies reported on changes in soil concentrations following remediation, with one also reporting changes in water and produce concentrations (Louekari *et al.*, 2004). The lack of variation between the studies in terms of the outcomes, contaminants and remediation hampered a review of the environmental outcomes. As a result, a second search was conducted focussed solely on environmental outcomes.

5. Impact on environmental outcomes and exposure pathways

This section summarises the evidence from 31 studies related to environmental outcomes following full-scale remediation and/or redevelopment of contaminated sites.

5.1. Environmental outcomes associated with the remediation of inorganic contaminants.

In total eighteen studies examined various environmental outcomes following remediation of inorganic contaminants, including metals and metalloids, and asbestos. Three studies reported on environmental outcomes or exposure pathways at the same sites considered in the review of health impacts. At the chromium waste site in New Jersey, US a follow up survey of chromium concentrations in household dusts between 1996 and 1998 found a significant decline between pre- and post-remediation in homes where high and medium concentrations of chromium had previously been recorded ($p<0.002$ and $p<0.005$, respectively), so that there was no longer a significant difference between these and control homes (Freeman, Lioy and Stern, 2000). At the Broken Hill lead mining area in Australia a randomised control trial examining only the household dust concentrations pre- and post-remediation, reported an approximately 50% decline in lead dust concentrations after 4 and 10 months in dusts in entry floors and internal windowsill (all $p<0.01$) (Boreland and Lyle, 2006). There were various aspects to the remediation of lead contaminated soils in New Orleans considered in the study by (Mielke *et al.*, 2013), but an earlier study reported only on the remediation of childcare centres by removing contaminated surface soil, adding a geotextile barrier and replacing with uncontaminated alluvium (Mielke *et al.*, 2011). This found that soil lead concentrations declined significantly from a median of 558 to 4.1 mg/kg, and that the lead loading on the soil surface decreased from 4887 to 398 µg/m^2 (Mielke *et al.*, 2011).

Removal of contaminated soils and disposal, often in landfills ('dig and dump'), has been used extensively in the remediation of contaminated land, as highlighted in the studies of outcomes related to health. In addition to these studies, one study in France examined the effectiveness of soil removal on reducing the metal content of vegetables grown in garden soils (Douay *et al.*, 2008). In this study, the topsoil from three kitchen gardens exposed to aerial deposition from the Metaleurop Nord smelter was removed and replaced with an uncontaminated topsoil; the urban gardens were 200 m and 400 m from the smelter, a suburban soil 900 m from the smelter was also remediated (Douay *et al.*, 2008). Cadmium and lead concentrations at 0-20cm depth in the garden soils were 10.4 and 682 mg/kg, respectively, in the suburban soil and 23.0-24.3 mg/kg and 1572-3280 mg/kg, respectively, in the two urban soils. The urban soils were replaced with soils with concentrations of 0.59 mg/kg of cadmium and 35.9 mg/kg of lead, and the suburban soils with those with 0.37 mg/kg cadmium and 18.2 mg/kg lead (Douay *et al.*, 2008). In each garden an area of contaminated soil was left to provide a control. Householders were provided with seven types of vegetables to grow over three years. Concentrations of metals in vegetables were compared to legislative limits; 85% of those grown in contaminated soils exceeded these limits, whereas only 17% of those grown in the replacement soils exceeded the limits possibly due to aerial deposition from the waste and demolition on the smelter site since its closure in 2003 (Douay *et al.*, 2008). Although the concentrations of metals in vegetables were significantly lower in the replaced soils, the authors found that soil metal concentrations increased over the study period and highlight the importance of area-wide remediation to prevent recontamination (Douay *et al.*, 2008), as was also reported at the Bunker Hill Superfund Site (Sheldrake and Stifelman, 2003).

Four studies examined the effectiveness of remediation at metal mines using a clean soil cover and/or semi-permeable membrane. The first study reports on the remediation of soil contaminated by a former lead smelter in Boolaro, New South Wales (Harvey *et al.*, 2016). At this site, residential yards were covered with clean soil and revegetated to differing degrees where lead concentrations exceeded the guideline value of 300 mg/kg, soils were only excavated where concentrations exceeded 1500 mg/kg (Harvey *et al.*, 2016). The follow up survey of soil concentrations in yards found that in all but one yard the soil still exceeded guideline concentrations and that the lead concentrations in vacuum cleaner dust were also above guidelines (Harvey *et al.*, 2016). In addition to the lack of soil removal in yards with concentrations between 300 and 150 mg/kg, there was also not remediation of soils in public areas (Harvey *et al.*, 2016), found to be crucial to the success of remediation at Bunker Hill (Sheldrake and Stifelman, 2003). The authors conclude that the use of cap and cover in Boolaro was 'inadequate' to reduce risk from lead exposure (Harvey *et al.*, 2016).

Although the other three sites employing soil covers are not urban, these studies have been included as the techniques bear some similarity to the remediation practices reported in the health studies, and often mines sites are restored for recreational access as in Butte, Montana (Schoof *et* *al.*, 2016). The first study reported on the remediation of the Conrad Mine in New South Wales, Australia, exploited for arsenic, copper, lead, silver, tin and zinc (Gore, Preston and Fryirs, 2007). This mine was operational until 1957, prior to regulations on the restoration of mines, when it was abandoned leaving acid generating wastes and high levels of metal contamination in soils, sediments and nearby surface water (Gore, Preston and Fryirs, 2007). The site was remediated by the state in 2003, with objectives to improve water quality in surrounding creeks and a reservoir, reduce instability in the spoil heaps and exposure to a protected habitat. Remediation methods included infilling and placing physical barriers in streams to prevent upstream migration of contaminated sediments, capping of some wastes using geotextiles and clays, and regrading of the site to improve stability and improve water management, constructing channels and drains, and vegetation establishment (Gore, Preston and Fryirs, 2007), However, during the remediation some waste materials were left in streams, and some contaminated material was used in the remediation to repair tracks and in regrading the profile. The survey of the site post-remediation found that copper and zinc concentrations generally complied with soil guideline values, however across the different sections of the site between 60 and 80% of samples exceeded arsenic and lead guideline concentrations (Gore, Preston and Fryirs, 2007). The proportions of samples exceeding guideline values for sediments were even greater; 10 to 50% of sample breeched copper and zinc guidelines, and more than 90% failing arsenic and lead guidelines, and the majority of streams exceeded water concentrations set to protect ecosystems (Gore, Preston and Fryirs, 2007). Despite this, the water concentrations in the reservoir generally comply with drinking water standards. The authors highlight a number of lessons from the rehabilitation that could inform future mine remediation, including adequately characterising soil and waste materials on site to prevent contaminated material being used as infill, developing an understanding of the geomorphology and hydraulics to ensure the appropriate movement of water on site, and ensuring that remediation is followed according to the plan as an unnecessary barrier was created with contaminated waste, increasing erosion from the site (Gore, Preston and Fryirs, 2007). As with Bunker Hill, the Conrad Mine also experienced a storm event shortly after remediation, which washed contaminated material downstream (Sheldrake and Stifelman, 2003; Gore, Preston and Fryirs, 2007), highlighting the importance of considering extreme weather events in remediation strategies, particularly in the context of climate change. Ultimately the study found that “the site presents an ongoing environmental hazard, particularly regarding arsenic and lead” (Gore, Preston and Fryirs, 2007).

The second study evaluates the ecological restoration of the Sierra Minera, Spain 30 years after the works were completed (Gomez-Ros, Garcia and Penas, 2013). This restoration was carried out by the mining company, who capped the mine tailings with an uncontaminated soil to a depth of 0.5 m to enable the colonisation of vegetation (Gomez-Ros, Garcia and Penas, 2013). This study examined the concentrations of metals in the topsoil and vegetation on the site. They reported that there was very little soil development on site, and metal concentrations were elevated in topsoil with cadmium at 12 mg/kg, lead at 4616 mg/kg, arsenic at 67 mg/kg and zinc at 3635 mg/kg (Gomez-Ros, Garcia and Penas, 2013). These concentrations exceeded guideline concentrations for human and ecological health, and suggest there has been upward migration of metals from the mine tailings below. The concentrations of metals in plant tissues were also elevated compared with those growing in other mining areas, suggesting that the metals are relatively mobile despite the high pH (Gomez-Ros, Garcia and Penas, 2013). The authors suggest that the use of physical barriers, such as geotextiles, should be used to prevent movement of metals to clean capping soils (Gomez-Ros, Garcia and Penas, 2013). It is worth noting here that a minimum depth of cap (e.g. 60 cm) or a break layer, comprised of gravel or geotextiles, for example, is often required nowadays.

The third study examines the geochemistry of two tailings management facilities (TMF) in the Republic of Ireland subject to different remediation strategies (Perkins *et al.*, 2016). The TMF of one of the lead/zinc mines was capped with a 30 cm layer of diamicton and revegetated in 1997, whereas the other was constructed in 1967 while the mine was in operation but abandoned in 1982 when the mining stopped, with some attempt at revegetation in 1985 to reduce fugitive dusts (Perkins *et al.*, 2016). Soil sampling at the remediated site revealed elevated concentrations of arsenic (2-3200 mg/kg), cadmium (0.25-122 mg/kg) and lead (11-21,400 mg/kg), however, the maximum concentrations were present below 50 cm depth (i.e. below the capping material). Concentrations in surface material (0-50 cm depth) were lower for arsenic (3-267 mg/kg), cadmium (0.3-5.7 mg/kg) and lead (19-985 mg/kg), although these were still above reference limits (Perkins *et al.*, 2016). The abandoned site had lower concentrations of arsenic, but greater concentrations of cadmium and lead, including in the surface soil (Perkins *et al.*, 2016). Despite the elevated concentrations of metals in the soil and tailings, the concentrations of metals in vegetation was within normal ranges for plants, with the exception of lead at the abandoned site (Perkins *et al.*, 2016).

Metal and metalloid contamination is often hard to remediate as these contaminants do not degrade, hence the propensity to remove or cap soils at these sites where feasible. However, as the landfilling of contaminated soils has become more challenging in many countries, remediation techniques that keep contaminated materials on site have become more common. One example is the chemical alteration of the contaminants to render them immobile in soils (Khan, Husain and Hejazi, 2004), for example, using phosphate. One such study used Phosphate-Induced Metal Stabilization (PIMS™) at the Camp Stanley Storage Activity (CSSA) in Boerne, Texas, where lead contamination was leaching to groundwater (Wright *et al.*, 2004). A total of 2300 m^3 of soil was mixed with phosphate and placed back on site, reducing the leaching of lead from an average of 0.373 mg/l to 0.003 mg/l, and ensuring it was within guidelines for bioaccessibility (Wright *et al.*, 2004). Interestingly, in the context of the Bunker Hill and Conrad Mines, the technology withstood an extreme flooding event that took place one year after remediation (Wright *et al.*, 2004). The use of PIMS was also the most cost-effective remediation option available (Wright *et al.*, 2004).

Similarly, a study of a former industrial area in Shenyang, China reported that although metal levels remained elevated following excavation and lime stabilisation of contaminated soils from some portions of the site they were unlikely to pose a risk to human health (Ren *et al.*, 2015). However, they did suggest that lead and arsenic concentrations on unremediated portions of the site may pose a risk, particularly to children given the plans for additional residential uses in the future, and that phytoremediation should be considered (Ren *et al.*, 2015).

Another study, summarising decades of research at a site used for sewage disposal near Berlin, Germany reported that the mixing of contaminated material with clean glacial till from a nearby construction project enabled the successful remediation of the site (Wessolek *et al.*, 2018). They reported that following remediation the soil structure, water availability, microbial activity, pH and plant nutrient concentrations all improved. In addition, the availability of metal contaminants, their uptake into plant tissue and mobility all decreased (Wessolek *et al.*, 2018). The success of the remediation is also evident in that the trees planted on site are thriving, whereas previous attempts to revegetate the site had failed, with increased variety of vegetation and soil fauna (Wessolek *et al.*, 2018). New walking and cycling paths, sculptures, activity areas and signs have now also been incorporated into the site and it is now a recreational resource used regularly by local residents, although data on these aspects are not reported (Wessolek *et al.*, 2018).

In addition to the use of soil amendments to immobilise contaminants, the solidification/stabilisation (S/S) of contaminated soil with materials such as Portland cement has also been used extensively in remediation (Wellman *et al.*, 1999). Two studies considered the use of S/S. The first is a study of a 2 ha former crude oil storage facility in California, US, that used S/S to remediate elevated arsenic concentrations in soil prior to redevelopment (Wellman *et al.*, 1999). The facility operated from the 1920s until the 1970s, resulting in soils contaminated with arsenic from corrosion inhibitors, TPH and small amounts of BTEX; it was the arsenic-contaminated soils that were subject to S/S (Wellman *et al.*, 1999). Total arsenic concentrations of 0.76 to 2240 mg/kg were measured in the upper 15 cm, and 4.8 to 1300 mg/kg at a depth of 30-45 cm, with leachable arsenic concentrations in a subsample of soils of 0.34 to 9.6 mg/l (0-15cm), and 0.29 to 9.6 mg/l (30-45 cm) (Wellman *et al.*, 1999). A total of 1800 m^3 of arsenic-contaminated soils were excavated to a depth of 0.5 to 2 m, mixed with Portland cement and 'other ingredients' in stockpiles before being used in the manufacture of asphalt paving (Wellman *et al.*, 1999). The remediation target to reduce leachable concentrations of arsenic to less than 5.0 mg/l was achieved (Wellman *et al.*, 1999).

The second study reporting on the use of S/S is concerned with a 1.8 ha former industrial site contaminated with heavy metals from glass production in Murano-Venice, Italy (Scanferla *et al.*, 2012). Average concentrations of antimony (11.3 mg/kg), arsenic (21.2 mg/kg), copper (438 mg/kg), mercury (5.4 mg/kg), lead (593 mg/kg) and tin (45.2 mg/kg) were above reference limits for residential use and maximum concentrations of copper, mercury and lead were also above those for commercial/industrial use (Scanferla *et al.*, 2012). The site is adjacent to a botanical garden and was due to redeveloped for residential use (Scanferla *et al.*, 2012). Following pilot testing, S/S with Portland cement and an additive was used to stabilise 8,000 m^3 of soil (Scanferla *et al.*, 2012). Leachate analysis after treatment found that lead, mercury and tin concentrations were below detection limits, and antimony, arsenic and copper concentrations had decreased by 63±15%, 91±5% and 75±11% to below reference limits (Scanferla *et al.*, 2012). The stabilised soil has been used on site and the concentrations in leachates will continue to be monitored (Scanferla *et al.*, 2012).

One study examined the diversity of plant species following the restoration of a vanadium-titanium magnetite mine in Panzhihua City, Sichuan Province, China (Chen *et al*., 2019). The study focusses on five areas of the restored mine, where the mine wastes received a soil cover, and different planting regimes due to changes in local policy and regulation. Three mined areas were included in the study; two that were reclaimed 10 years earlier, one using both local species and 'rehabilitative plants', selected for their phytoremediation potential, and the second used local species only, and one reclaimed 17 years earlier using rehabilitative plants where there has also been natural succession of native species (Chen *et al*., 2019). In addition, two unmined areas planted with local species only 10 and 17 years before the study were also included in the study (Chen *et al*., 2019), that presumably had elevated metal concentrations due to deposition of metals. They found that the diversity index at the sites restored with rehabilitative and local species was 14.74% greater in the site restored 17 years earlier compared with the 10-year-old site, and that these had more than double the diversity of the areas planted with either rehabilitative species or local species only (Chen *et al*., 2019). In these sites vegetation height and density are greater than at the remaining sites, and the use of rehabilitative plants with local species resulted in a 3.33% improvement in metal concentrations compared with the use of local plants only after 10 years, and a 5.92% improvement after 17 years (Chen *et al*., 2019). However, the use of local species only was more beneficial in terms of soil fertility. The authors highlight that the succession of local species requires careful management as this may reduce the efficacy of the phytoremediation (Chen *et al*., 2019).

Two studies considered the remediation of soil contaminated with mercury. The first examined the total gaseous mercury emissions following remediation of a former typewriter factory in Syracuse, New York (Meng *et al*., 2020). Following the closure of the factory in 1962, the site was redeveloped for commercial uses, but this was subsequently demolished and redeveloped as a commercial property, which opened in 2010 (Meng *et al*., 2020). The study focuses on the removal of 135,000 tonnes of soil contaminated with mercury (50-230 mg/kg) and construction of a car park on the site adjacent to the commercial property in 2015 (Meng *et al*., 2020). Total gaseous mercury concentrations were measured before and after the remediation and construction of the car park, at two heights at the adjacent commercial building. Following remediation total gaseous mercury concentrations at ground (1.8 m) and upper levels (42.3 m) significantly reduced by 32% (1.6±0.6 to 1.1±0.3 ng/m^3) and 22% (1.4±0.4 to 1.1±0.2 ng/m^3) respectively (Meng *et al*., 2020).

The second mercury study uses thermal desorption to remediate a 3 ha former alkali chlorice factory in Taipei operating until 1985 (Chang and Yen, 2006). Thermal desorption uses heat to volatilise mercury, which was then collected and treated with activated carbon (Chang and Yen, 2006). The study reports on a bench and pilot tests, as well as the full-scale remediation of site. In total 4174 m^3 of soil were remediated over 14 months, and removal efficiencies of between 96.1 and 99.8% achieved (95.0 to 1.0 mg/kg), resulting in mercury concentrations within reference limits (Chang and Yen, 2006).

Two studies reported on the treatment of asbestos; one from an industrial site in Italy, and the other from former mines in South Africa. The first concerned the removal of asbestos from an asbestos-cement manufacturing plant covering 15.7 ha in Bagnoli, Naples, including yard, indoor, roads and green areas (Cecchetti *et al*., 2005). All asbestos materials, including the surface soil (0-20 cm) were removed, washed and encapsulated in a liquid in a decontamination unit, before being disposed of in polythene bags to either a sewage disposal plant or a thermodesconstruction facility (Cecchetti *et al*., 2005). Monitoring of site activities reported that the concentrations of fibres in air complied with the WHO limit of 1 fibre/l (Cecchetti *et al*., 2005). In total almost 5 million tonnes of material including asbestos cement residues and wastes, soils and shrubs were removed from a densely populated area of Naples. The authors highlight the importance a detailed site characterisation to design the treatment strategy and monitoring of removal activities to ensure safe operation for workers and residents (Cecchetti *et al*., 2005).

The second study concerned with asbestos reported on the concentrations of asbestos in dusts in two settlements located at least 5 km from asbestos mine wastes in Northern Cape Province, South Africa (Mashalane *et al.*, 2018). One site had been rehabilitated and revegetated, although was not well maintained, and the other site was not rehabilitated. Although the dustfall at both sites complied with the limits for residential areas, the non-rehabilitated waste was a source of airborne fibres, including asbestos. In addition, high concentrations of asbestos were recorded on the rehabilitated waste, which the authors suggested was associated with ‘a lack of maintenance, run-off and strong winds’ (Mashalane *et al.*, 2018).

In these eighteen studies the removal and capping of inorganic contaminants dominate the remediation activities in the literature. Despite this, remediation technologies that aim to reduce the leachability of inorganics, thus restricting their mobilisation to groundwater or plant uptake, are effective at reducing the environmental risks associated with these contaminants.

5.2. Environmental outcomes associated with the remediation of organic contaminants.

In total thirteen studies examined the environmental outcomes following remediation of organic contaminants including pesticides, PCBs, TPH, PAH and BTEX compounds. In contrast to the inorganic contaminants, only one study reports on the outcomes associated with the removal of contamination. In this study, soil had been contaminated with PCBs from a former ordnance plant that was subsequently used for the manufacture of electrical insulators (Spears *et al.*, 2009). The site is part of the 17,800 ha Crab Orchard National Wildlife Refuge in Jackson, Illnois, US, and previous studies had recorded elevated concentrations of PCBs in wildlife as well as adverse physiological impacts (Spears *et al.*, 2009). Between 1995 and 1997 around 120,000 m^3 of contaminated soil and sediment were removed from the site, and in 2004 and 2005 PCB concentrations in the egg shell and chicks of tree swallows (*Tachycineta bicolor*) were assessed and compared to concentrations at a reference site (Spears *et al.*, 2009). The study found that PCB concentrations in eggs and chicks were greater at the remediated site, compared with the reference site (4,452±761 versus <1000 mg/kg, and 3,994±515 versus <100 mg/kg) in both years and that there was no significant difference between the years (Spears *et al.*, 2009). Data collection in 2004 uncovered an unremediated source of PCB contamination, demonstrating the value of long-term monitoring of ecological indicators (Spears *et al.*, 2009). Additional remediation of the site was therefore carried out in 2004, and concentrations of PCBs in chicks in 2005 were reduced compared with 2004, although not significantly, but growth dilution in the chicks declined substantially between the years (Spears *et al.*, 2009). The authors suggest that this may be due to the remedial work reducing dietary exposure routes, either by reducing PCB concentrations in aquatic insects or their populations locally resulting in changes in parental foraging (Spears *et al.*, 2009). Concentrations of PCBs in the eggs were within the range of no adverse effect, however, the concentrations in chicks were within the range where adverse effects may be observed (Spears *et al.*, 2009).

One study employed on-site solidification at a former manufactured gas plant in Norwich, New York, US surrounded by residential and commercial land uses (Underhill *et al.*, 2012). This 0.4 ha site ceased operation in 1953, and is contaminated with BTEX and PAHs (Underhill *et al.*, 2012). Following treatability studies, on-site solidification was used to remediate around 39,835 m^3 of sand and gravel, and recover around 210,000 litres of NAPLs. Following their recovery, treatability studies suggested that hydrogen peroxide and enhanced bioremediation will reduce BTEX, naphthalene and TPH concentrations further, but this phase was not included in the study (Underhill *et al.*, 2012).

Two studies examine the effectiveness of 'pump and treat'. This technology remediates contamination from soils when it has migrated to groundwater, essentially pumping polluted groundwater to the surface where it is treated and either injected back to the groundwater or discharged to surface water (Khan, Husain and Hejazi, 2004). The first study focusses on the outcomes from the remediation of an unlined landfill in Escambia County, Florida that was causing benzene and vinyl chloride pollution to groundwater (Jain, Townsend and Johnson, 2013). The groundwater was successfully remediated using pump and treat, however, the majority of the study examines the excavation of the waste from the unlined sections of the landfill (Jain, Townsend and Johnson, 2013). This waste was screened, with soil material being separated from whole tyres and other wastes; tyres were sent to a management plant, screened waste was disposed of in newly lined sections equipped with leachate collection to prevent any further groundwater contamination and soil materials were reused on site (Jain, Townsend and Johnson, 2013). The study reports substantial financial benefits from the creation of additional airspace in the landfill (230,600 m^3), with a cost:benefit ratio of around 3:1 from the creation of this capacity alone (Jain, Townsend and Johnson, 2013).

The second study focusses on the modification of pump and treat to overcome its reported low efficiency (DeGisi and Notarnicola, 2016). This study examined the efficacy of combining pump and treat with an oil belt skimmer to remove heavy hydrocarbons from the groundwater contaminated by an industrial site used for the vehicle maintenance and refuelling in Taranto, Italy

(DeGisi and Notarnicola, 2016). The groundwater was being remediated with traditional pump and treat as an emergency measure, with the oil belt skimmer technology trialled as part of this ongoing programme. The skimmers were used to supplement the pump and treat by targeting areas with thicker layers of heavy hydrocarbons in the groundwater. They found that in the most polluted area the thickness of the hydrocarbons was reduced from 40-50 cm to 20 cm after one year of treatment, with others areas being reduced to 1-5 cm thickness, with the oil belt skimmer being more effective where the oil layer exceeded 2 cm (DeGisi and Notarnicola, 2016). Because the two systems were running concurrently the oil belt skimmer was not tested in isolation, however, the authors report that the oil belt skimmer produced far less waste requiring further treatment, as it targets only the oil layer, compared with the pump and treat (48.2 l vs. 596.0 l), but that as the latter was operating for longer, the amount of oil recovered per unit of time was comparable at 825.4 l/hr for the oil belt skimmer and 813.2 l/hr for the pump and treat (DeGisi and Notarnicola, 2016).

Four studies reported on the extraction of VOCs from contaminated soil and groundwater. In the first study, soil vapour extraction was used to remove VOCs and semi-VOCs from the soil (Labianca *et al.*, 2020). The site was a 275 ha refinery in Taranto, Italy, contaminated with BTEX, which is still in operation since opening in 1967 (Labianca *et al.*, 2020). The study reports on one area of the overall site that was remediated between 2014 and 2018 using soil vapour extraction. Here, wells were installed and air pumped through the soil, removing the contaminants, where they were then treated with activated carbon and released (Labianca *et al.*, 2020). Over this period around 540 kg of VOCs were removed from the soil, with the removal rate declining after the first year of operation (Labianca *et al.*, 2020). The remediation targets were reached within four years for light hydrocarbons, but six heavy hydrocarbon samples were still above these levels resulting in a further two years operation (Labianca *et al.*, 2020). In the first four years, 73% of hydrocarbons have been removed, but the authors highlight the substantial variation in removal rates between different locations and contaminants from 12.2 to 99.6% in light hydrocarbons to 13.5 to 99.9% in heavy hydrocarbons (Labianca *et al.*, 2020).

The second study reports on the use of two-phase extraction (also known as dual-phase extraction) to remove tetrachloroethene (also known as perchloroethene; PCE), trichloroethene (TCE), vinyl chloride and BTEX from a petrochemical site operating since the 1960s (Baric *et al.*, 2003). Elevated concentrations in the soil were generally restricted to the upper 1 to 2 m, with concentrations of hydrocarbons, chlorinated solvents and BTEX reaching 1000, 200 and 100 mg/kg respectively (Baric *et al.*, 2003). Wells were installed to allow air to be pumped through the saturated and vadose zones, removing the contaminants, where they were contained and treated; the study reports on the results of the first 300 days of operation (Baric *et al.*, 2003). The remediation goals were achieved and the concentrations of most contaminants were below limits of detection (Baric *et al.*, 2003).

The third study reports on the use of air sparging, a technique similar to soil vapour extraction but operating to remove contaminants in groundwater via volatilisation and biodegradation, and which has come to replace pump and treat (Aivalioti and Gidarakos, 2008). Here, in-well sparging was used in a Greek refinery site, also still in operation, to remove BTEX, TPH and methyl tertiary-butyl ether (MTBE) from groundwater that was posing a risk to coastal waters and an ecologically-important lake (Aivalioti and Gidarakos, 2008). Following pilot testing, air sparging using existing wells was employed over a five-month period (Aivalioti and Gidarakos, 2008). During this time, TPH and BTEX concentrations were reduced to below 0.5 and 0.01 mg/l respectively (maximum reported concentrations were 2 and 7.88 mg/l respectively; Aivalioti and Gidarakos, 2008). However, the higher solubility of MTBE in groundwater meant that no significant reduction in concentration was apparent in this time frame, and as a result the treatment was extended and the air flow increased (results not reported; Aivalioti and Gidarakos, 2008).

The fourth study uses biosparging, which relies on wells spaced close enough to oxgenate the soil and enhance aerobic degradation of contaminants. In this study, biosparging with native microorganisms was used to remediate groundwater contaminated with a plume of BTEX (780 x 270 m) from an abandoned petrochemical manufacturing facility (Kao *et al.*, 2008). Following 300 days of biosparging, BTEX concentrations decreased in the source (benzene = 190 to 41 µg/l, toluene = 6430 to 124 µg/l, ethylbenzene = 125 to 38 µg/l, xylenes = 244 to 66 µg/l) and downgradient monitoring wells (benzene = 25 to 3 µg/l, toluene = 657 to 14 µg/l, ethylbenzene = 17 to 0.8 µg/l, xylenes = 33 o 0.5 µg/l; Kao *et al.*, 2008). The increased populations of heterotrophs and decreased population of anaerobes and methanogens suggests that the biodegradation is the primary mechanism for this decrease (Kao *et al.*, 2008).

Three studies focus on the use of emulsified zero-valent iron (EZVI) to remediate chlorinated hydrocarbons; often in conjunction with other remediation techniques as is common in practice. This technology relies on chlorinated hydrocarbons partitioning preferentially on to vegetable oil, where they will come into contact with iron and subsequently degrade (Huff, 2011). The first study reports on the use of EZVI at four sites in the US:

- A 24 ha manufacturing facility in Ohio, contaminated with PCE and naphtha from cleaning solvents. EZVI was used with dual-phase extraction and soil vapour extraction to remediate a groundwater plume (61 x 37 m) over four years. The final monitoring event 12 months later found that at source: there were no acetylene compounds, PCE and TCE concentrations had fallen to below detection limits, DCE concentration had declined from 40 to 3.754 mg/l and vinyl chloride had stayed at around 0.653 mg/l, and downgradient: PCE concentrations had decreased from 88 to 0.705 mg/l with similar patterns in TCE, DCE concentrations has declined from 400 to 50 mg/l and vinyl chloride decreased from 4.85 to 3.25 mg/l.
- A grain terminal in Louisiana contaminated with carbon tetrachloride (CT) from the release of a fumigant in 1977. EZVI was employed to aid biodegradation and reduced the mass of CT in the vadose zone by 98.7% from 1674 kg to 21 kg, and overall chlorinated VOCs by 98.7% from a concentration of 480 to 6 mg/kg.
- A grain terminal in Texas also contaminated with CT from fumigant storage. EZVI initially reduced the CT concentrations in groundwater from 150 to 30 mg/l, whereas chloroform and methylene chloride concentrations initially increased to a peak of 60 mg/l and 8 mg/l, respectively, before declining. However, a second injection of EZVI was required after CT concentrations began to increase to 80 mg/l, following which they decreased to 0.646 mg/l and remained low.
- A former heating plant in Illinois, due to be redeveloped, contaminated with PCE and its degradation products. The first EZVI treatment reduced PCE concentrations by 66%, and a second treatment targeting inaccessible areas and hotspots increased this to 99.7% over the 21-month period (Huff, 2001).

The second study concerns the use of zero-valent iron (ZVI) with an organic carbon amendment to remediate groundwater contaminated with chlorinated solvents from an active automobile parts manufacturing facility in Shanghai Pudong New Area, China (Yang *et al.,* 2018). Between 1989 and 2008 solvents were released directly to the surface, resulting in elevated concentrations of trichloroethane (TCA; up to 240.1 mg/l), DCE (up to 15.9 mg/l) and vinyl chloride (up to 10.5 mg/l) as well as dichloroethane (DCA) and chloroethane (CA; Yang *et al.,* 2018). Following a successful pilot study, the full-scale remediation focused on an area of 1000 m^2, with a concentration of TCA of 18.1 mg/l at the centre of the plume (Yang *et al.*, 2018). Removal rates of TCA, DCA and DCE were 98.2, 98.9 and 76.8% respectively within 180 days. However, lower removal rates of CA and vinyl chloride were recorded (39.5 and 32.6% respectively), as well as increases in their degradation products ethane and ethylene (Yang *et al.*, 2018). Concentrations of TCA declined to below the Dutch Intervention Values by 90 days and the plume was removed. The plumes of the co-contaminants also shrank; DCE concentrations were below Dutch Intervention Values, and although DCA and vinyl chloride concentrations were above Dutch Intervention Values in 2 or 3 out of 13 monitoring wells they were within site specific remediation targets (Yang *et al.*, 2018).

The third study employing EZVI combined this with excavation in order to achieve the cost-effective remediation of a 16 ha fluoropolymer and chlorofluorocarbon (CFC) solvent manufacturing site in an industrial seaport in Elizabeth, New Jersey, US that closed in 2001 (Robinson and Angyal, 2008). The soil and groundwater on site were contaminated with CFCs, chloroform, TPH, CT, DCE, DCA, TCE, PCE and metals (Robinson and Angyal, 2008). The TPH originated from an oil spill and this area was excavated, treated with edible oil to increase biodegradation and the groundwater treated with EZVI (Robinson and Angyal, 2008). The remaining contaminated areas were excavated and/or capped. The excavation treated around 14.5 million litres of groundwater and removed 8792 m^3 of soil from the oil spill area (Robinson and Angyal, 2008). This soil, along with a further 7645 m^3 soil contaminated with VOCs from other areas, was treated and reused on site under future car parks (Robinson and Angyal, 2008). Following excavation and treatment concentrations of contaminants declined by more than 50%, but further treatment with EZVI injections achieved reductions of more than 90% for chloroform, CT, TCE and Freon TF, and more than 70% reductions in methylene chloride, and enabled soils to be reused on site, reducing the amount of waste and need for imported material (Robinson and Angyal, 2008).

Another option for contaminated groundwater is Monitored Natural Attenuation (MNA) where natural processes are utilised and monitored to reduce contaminant concentrations or their mobility (Khan, Husain and Hejazi, 2004). Extensive site investigation is used to ensure that natural attenuation is taking place, for example, assessing the degradation of organic contaminants, or the dilution or immobilisation of inorganic pollution, and long-term monitoring verifies that this is continuing (Khan, Husain and Hejazi, 2004). It is often not deemed to be suitable if the contamination is posing a risk to human health or ecological systems, or the timescale required is too great (Khan, Husain and Hejazi, 2004; Reisinger *et al.*, 2005). Three studies reported on the use of MNA; the first focussed on arsenic contamination in groundwater at Superfund Sites in the US (Reisinger *et al.*, 2005). This reported on four Superfund Sites where approval was provided for the use of MNA, primarily reporting on the factors that led to this approval as opposed to the final remediation of the groundwater. For example, at a cattle dipping site, investigation revealed that the arsenic plume had only moved 15 m in the decades following the cessation of activities, and the soil contamination was removed thus preventing any further migration into the groundwater (Reisinger *et al.*, 2005). A study in New Zealand reported on the natural attenuation of two leaks of around 10,000 litres of unleaded petrol from underground storage tanks at two former service station in Hororata and Otorohanga (Vidovich et al., 2001). In Hororata the monitoring wells detected BTEX compounds both on and off-site up to 450 m downgradient, however, elevated concentrations were only present in off-site wells around 150 m from the source, with the greatest concentrations being found in those 100 to 120 m downgradient (Vidovich et al., 2001). At Otorohanga, elevated concentrations of BTEX were found 140 m downgradient, with the greatest concentrations at around 20 m, but these have declined over the monitoring period (Vidovich et al., 2001). Long-term monitoring at both sites suggests that contaminant plume migration rates have declined and that natural attenuation of contaminants is taking place with degradation rates of between 0.0045 and 0.0097 litre/day (Vidovich et al., 2001). A further study examined the efficacy of MNA at a site in Jilin Province, China contaminated with petroleum hydrocarbons from oil wells (Lv *et al*., 2018). The total petroleum hydrocarbon (TPH) concentrations at the site were 500 to 2000 mg/kg, mainly in the vadose zone at around 0.5 to 1.5 m depth, but concentrations were lower in the aquifer at 20 to 50 mg/kg at a depth of 3.5 m, reducing as the distance from the source increased (Lv *et al*., 2018). This study found that over four years of monitoring the TPH concentration in the vadose zone decreased by 50%, but increased at a depth of 2 m due to infiltration of contamination (Lv *et al*., 2018). Overall, they reported an attenuation rate of 0.0015 litre/day, with degradation being primarily due to sulphate reduction and microbial degradation, which reduced the area of the plume by almost 60% over four years (Lv *et al*., 2018).

As already highlighted there is a paucity of studies that report on the full-scale remediation of contaminated sites. This has also been reported in previous reviews, focussed on the treatment of PCBs (Jing, Fusi and Kjellerup, 2018), mercury (Eckley *et al.*, 2020), and metals and metalloids (Gong *et al.*, 2018). There are more examples available in government reports and case studies produced by industry. For example, a report from the US Environmental Protection Agency provides a detailed summary of the different bioremediation techniques used in their Superfund Sites (USEPA, 2002) and CL:AIRE (2020) provide case studies detailing remediation of sites to members.

6. Discussion

Overall, there is consistent evidence that, when best practice is employed, remediation of contaminated soils is effective at reducing both direct and indirect exposure to pollution in nearby populations and for reducing environmental risk. The evidence for human populations is dominated by studies of lead contamination, with some notable exceptions that consider chromium and PCB contamination. However, the studies from Bunker Hill (Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003), Boolaro (Harvey *et al.*, 2016), and Spain (Gomez-Ros, Garcia and Penas, 2013) suggest that a) soil cover alone is not sufficient, there needs to be excavation of contaminated surface soils to prevent upward migration, and b) area-wide remediation is required to prevent recontamination of the yards. The experiences at Bunker Hill also suggest that this is particularly important where existing populations are present and mobile, as families may move into contaminated properties, and that ongoing monitoring is essential so that shortcomings of remediation activities can be addressed during the programme (Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003).

Although it appears that soil remediation is largely responsible for the declines in soil, water, dust and blood concentrations, there is also consistent evidence that public health campaigns are effective at reducing exposure pathways where existing populations are present (Goulet, Messier and Gaudreau, 1996; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003).

Only one study reviewed examined the health impacts of remediating organic contamination. This study also highlights the importance of ongoing monitoring during the remediation programme (Choi *et al.*, 2006). In this study, the umbilical cord samples collecting as part of the screening programme found that PCB concentrations increased during the dredging, before decreasing post-remediation (Choi *et al.*, 2006); although it is not clear whether this increase represents an increased health risk it is something that should be considered during remediation to ensure that any mitigation measures can be implemented. For example, this remediation does not appear to have included a public health campaign, which may have reduced exposure during pregnancy while remediation was being carried out.

Despite the declines in health impacts reported, several of the studies of environmental outcomes report inadequate remediation. As mentioned above this is generally due to the remediation being focused on covering contaminated soils, as opposed to removal or treatment. However, the study in Conrad Mine also highlights the importance of ensuring that remediation plans are followed correctly so as not to increase exposure pathways (Gore, Preston and Fryirs, 2007). This example and the Bunker Hill studies also demonstrate the importance of considering the sustainability of remediation, especially as the climate changes; in both these examples remediated material was exposed following extreme storm events (Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003; Gore, Preston and Fryirs, 2007). It is probably worth noting that it is failures of full-scale remediation that are likely to generate academic interest so there may be an element of reporting bias in the literature.

Overall, the sixteen studies that examined health impacts found that:

- There is good evidence that the removal, capping and/or replacement of soil contaminated with lead can result in reduced blood lead concentrations in children;
- There is some evidence that this reduced blood lead concentration can have a positive impact on cognitive performance in children;
- There is some evidence that the removal and replacement of soil contaminated with chromium can result in reduced urine concentrations in children;
- There is some evidence that dredging sediments contaminated with PCBs can reduce umbilical cord PCB concentrations in infants;
- Area-wide remediation is more effective than targeted remediation of individual yards, which quickly become recontaminated from surrounding dusts;
- A detailed understanding of the contaminant and site characteristics, as well as any capping materials, is essential in developing remediation strategies and long-term monitoring programmes;
- Where populations are remaining in their homes, public health campaigns that seek to raise awareness of exposure routes and their mitigation, for example, through parental education, improved hygiene, home cleaning, and reducing hand to mouth behaviours in children, are effective, although these should be combined with an initial home cleaning programme to remove contaminated dusts;
- Annual screening and monitoring during the remediation programme can identify problems (e.g. recontamination of yard soils; inadequate degradation rates) and allow the adaptation of both remediation and public health messages;
- A number of studies highlighted the importance of multiple public agencies collaborating effectively in the site investigation, remediation and public health campaigns (Goulet, Messier and Gaudreau, 1996; Greene *et al.*, 2006; Yaffee *et al.*, 2019);
- The importance of effective communication with residents was also highlighted in terms of gaining their trust to ensure high levels of participation (Sheldrake and Stifelman, 2003) (Yaffee *et al.*, 2019), and that data collection, remediation and public health campaigns are sensitive to their needs and experiences (Greene *et al.*, 2006; Farmer and Jarvis, 2009).

The nature of research and development of remediation methods for contaminated land mean that there are very few studies in the academic literature that report on the outcomes related to human and environmental health following full scale remediation. This should not be taken that these technologies are unreliable, only that the monitoring and evaluation programmes in place do not often report in the academic literature. The search terms generated far more studies that reported on pilot studies, and several of those included in the review reported on the results of bench and pilot studies as well as the full-scale remediation. In many countries, detailed remediation strategies, with well-defined success criteria and long-term monitoring programmes, require regulatory approval prior to the commencement of remediation; these are not often easily accessible.

6.1. Gaps in evidence

Although the studies reported here generally find that blood or urine concentrations of contaminants decline following remediation, only one study reported on a clinical outcome. Human Biomonitoring is an effective means to assess exposure to contaminants, as it is relatively simple to measure concentrations, particularly of metals in blood or urine, and it may detect elevated concentrations prior to the development of clinical outcomes (Colles *et al.*, 2019). In addition, different countries have different frameworks and threshold concentrations for soil, water and blood concentrations which hampers a direct comparison between studies. However, the majority of the studies included were based in the US and focused on lead contamination, lessening the lack of comparability.

The studies examined here are mainly concerned with lead pollution, often from a single source. There is a lack of variety of studies examining the outcomes related to health of remediation, both in terms of the contaminants and the remediation employed. This may be due to the complexities associated with measuring organic contaminants in biological matrices as well as their prevalence in the environment from multiple sources. In addition, there is a lack of evidence related to the mental health impacts of site remediation and redevelopment. Our search strategy found a small number of papers that examined mental health and wellbeing outcomes of living in close proximity to a site affected by contamination but these were not in the scope of the review as they did not include assessments of the outcomes post-remediation. Similarly, there are likely to be studies that report on the impacts of regeneration initiatives on mental health and wellbeing outcomes, but not related specifically to the remediation of contamination.

There is a lack of reported longer term follow ups from some of the remediation programmes. Given that several reported recontamination of soils in a relatively short time period (Sheldrake and Stifelman, 2003) and the study in Spain reported an upward migration of metals 30 years after restoration (Gomez-Ros, Garcia and Penas, 2013), it would seem prudent for screening programmes to continue, which they may well be doing. However, it is likely that there is some reporting bias in the literature; it may be unlikely that commercial organisations will publish findings from unsuccessful projects, conversely academics may be more likely to seek to investigate sites where a problem is suspected.

There is a lack of long-term trials on full-scale remediation in the academic literature. Although this is to be expected given the nature of remediation research and development, this does appear to be reported as a gap in a number of literature reviews (Gong *et al.*, 2018; Jing, Fusi and Kjellerup, 2018; Eckley *et al.*, 2020) and hampers an evaluation of the outcomes of remediation in general terms. There were very few studies that examined outcomes related to health following both remediation and redevelopment. This is likely due to a number of factors, for example, the evaluation of full-scale remediation is not common, and the timescales involved between remediation and redevelopment and the different actors involved make a long-term study of this nature extremely challenging. As already highlighted, there are methodological challenges with health assessments; populations are often not present pre-remediation, or are also exposed to a range of contaminants in the urban environment reducing the ability to disaggregate the impacts of one site, and finding a reliable control group is challenging. This may explain the over representation of studies in the US and Australia where population densities are lower and urban areas are more likely to have been developed around one industry making the pathway between site and population simpler to assess. There are studies that report on the outcomes of neighbourhood regeneration, but these do not consider the impacts of contamination and its remediation, instead focusing on socioeconomic outcomes such as employment rates, neighbourhood satisfaction and crime. Often it might not be desirable to remind a new population of the contamination history of their site (Farmer and Jarvis, 2009), especially if remediation objectives have been met and there do not appear to be ongoing impacts.

6.2. Limitations and recommendations for future studies

All sixteen studies examining outcomes related to health were scored as 'weak' in the quality assessment. For some quality criteria, this was unavoidable given the nature of these studies. For example, few studies were blinded, but this is because participants are likely to be aware of the research question as the existence of contaminated sites tends to be well known in a neighbourhood. Similarly, the outcome assessor is likely to know whether participants live in a neighbourhood close to a contaminated site, particularly where household dust samples are being collected or door to door surveys are conducted. This could be mitigated by requiring participants to attend a test centre or clinic, however, this may reduce participation. These criteria are also of less importance for the studies reported here as they tend to use objectively-measured outcomes (e.g. blood lead levels) that are unlikely to be impacted by the participant knowing what the research questions are or the assessor knowing the exposure status of the participant. In these situations, there is less justification for attempting to blind participants. Where it may become more important is where data were also collected on behaviours related to exposure such as outdoor play, hygiene and hand to mouth activity, or lifestyle factors (e.g. diet, smoking). For example, in the study of chromium concentrations in children's urine, playing on the waste sites was not reported by the children, despite having been observed by the researchers to be taking place, and the authors suggest this was perhaps due to the parents being present during the survey (Freeman et al., 1995). Similarly, the earlier study at Bunker Hill reported that there may be recall issues of activities over a 9-month period and parents of children with higher blood lead levels may be more likely to remember behaviours related to greater levels of exposure (Maisonet, Bove and Kaye, 1997).

Other areas where papers scored poorly could perhaps have been avoided through better reporting of the study design. For example, it was usually not possible to tell from the studies how representative participants were of the target population or the percentage that agreed to participate. Studies that report analysis of data from area-wide screening programmes (e.g. Von Lindern *et al.*, 2003; Choi *et al.*, 2006; Mielke *et al.*, 2013; Tirima *et al.*, 2016) are likely to be relatively representative of the population, yet several studies did not report this information. Some studies could also have provided a greater clarification of their sample demographics, for example, it is not clear what age range of the children is included in the study from New Orleans (Mielke et al., 2013). Several studies highlight selection bias as a limitation in their designs (Aschengrau *et al.*, 1997; Maisonet, Bove and Kaye, 1997; Sheldrake and Stifelman, 2003; Von Lindern *et al.*, 2003); generally participation in the studies is voluntary and some studies provide some justification for this. For example, in Bunker Hill and Quebec, it was noted that some parents did not feel it was necessary for their children to be tested as they had low blood levels in previous years (Goulet, Messier and Gaudreau, 1996) (Sheldrake and Stifelman, 2003), meaning that the bias is likely to be towards those with greater blood lead levels (Von Lindern et al., 2003). One study from Bunker Hill highlights a practical and ethical consideration implicit in many of these studies; that the screening and remediation efforts deliberately target those deemed to be most at risk of adverse health effects (Von Lindern et al., 2003). This means that sampling will be biased, but that this is justified on ethical grounds (Von Lindern et al., 2003), particularly where the urgency to treat a population overrides other considerations as in the lead poisoning as a result of artisanal gold mining in Nigeria (Tirima *et al.*, 2016). One interesting observation from Bunker Hill Superfund Site was that previous experience had found that if screening of blood lead levels was characterised as an academic study or experiment, there was an adverse impact on participation rates (Von Lindern et al., 2003).

The number and reasons for withdrawals of participants from the studies was not always consistently reported, despite this information presumably being available. Another area where better reporting could have improved the scores was related to the data collection methods, where it was not possible to tell whether data collection methods were valid and/or reliable. Studies that did include this information reported, for example, the precise methods of blood sampling and analysis, referencing standard protocols, or the use of standard tools (e.g. for cognitive performance). For example, one study reported the different sampling methods used during a blood lead screening programme, including the proportion where this is unknown (Mielke et al., 2013).

Several studies collected data on confounding variables, but either did not provide any analysis of the differences between groups, take them into account in the analysis or provide a justification for why some confounders were included in the analysis and others were not. Again, this would be a relatively straightforward issue to address in the analysis and reporting of the study. For example, in the study in Vantaa, Finland dust concentrations and exposure from the consumption of berries and vegetations were assessed but not considered in the analysis (Louekari et al., 2004). The study in Quebec reported that a greater proportion of children were living in houses built prior to 1945 and in single parent households in 1991 compared with 1989 ($p<0.05$), and that pica and putting things in mouth behaviours decreased ($p<0.05$) between the two sampling periods, but did not take this into account in the analysis (Goulet, Messier and Gaudreau, 1996). In the case of behavioural factors this is particularly unfortunate as it means that the impacts of the public health programme cannot be assessed separately from the remediation. One of the strengths of the later studies at Bunker Hill is that the impact of remediation and public health campaigns has been estimated (Von Lindern et al., 2003).

The shortcomings in the study design is difficult to address in studies of contaminated sites. Often there will not be resources available to provide a control group or randomised sample, and this may divert funds from assessing outcomes in at risk populations or remediation actions (Von Lindern et al., 2003). As a result, most of the studies considered here were cross-sectional. In several studies this was overcome by analysing outcomes before and after remediation (Goulet, Messier and Gaudreau, 1996; Choi *et al.*, 2006; Mielke *et al.*, 2013), meaning these study designs were rated as moderate. Similarly, the analysis of the Bunker Hill Superfund site included a case-control study (Maisonet, Bove and Kaye, 1997), and also by using samples from participants screened in multiple years an interrupted time series (Hilts *et al.*, 1998; Von Lindern *et al.*, 2003; Boreland, Lesjak and Lyle, 2008). Most studies had relatively large sample sizes, but in a few cases the sample size limits the usefulness of the data (Louekari *et al.*, 2004; Madeddu *et al.*, 2013). Although the study in Boston was a randomised controlled trial (Aschengrau *et al.*, 1997), the between group comparisons were based on treatments received rather than randomised groups, so were not determined by 'intention-to-treat', thereby losing the benefits of randomisation.

Finally, the focus of several of the studies included in the review was on the outcomes related to health, and therefore there was a lack of clarity on exactly what remediation activities were carried out. This hampers our ability to assess the effectiveness of specific remediation strategies. For example, in the study in New Orleans, reference is made to areas having been remediated both pre-Katrina (but after the first sampling campaign) and as part of the reconstruction following Katrina, but it is not clear what the timing of these activities was or if it applied to all the ‘high lead’ areas, and this is not considered in the analysis (Mielke et al., 2013). Similarly, the study in Italy refers to the mines as having been ‘restored’ but it is not clear exactly what this involved (Madeddu et al., 2013).

The remediation of contaminated sites can be described as ‘complex interventions’ (MRC, 2019), and there is guidance available for their evaluation. What is clear from this review is that some of the limitations discussed above could have been addressed relatively straightforwardly, and we would recommend that those examining the impact of remediation of contaminated sites (or public health campaigns to reduce exposure) consider including:

- Data from participants measured both before and after remediation that can be matched to individuals, or if resources allow control participants matched at least on age, sex and socioeconomic status, although this is likely to prove challenging for organic contaminants;
- Data on the target population, sample size and the percentage of participants who agreed to participate;
- Information on how participants were recruited;
- Data on withdrawal and drop-out rates between measurements, and the numbers and reasons for withdrawal from the study;
- An analysis of whether key confounding variables (e.g. sex, age, socioeconomic status, time spent outdoors, occupational exposure, diet, smoking) are different between participant groups;
- Confounding variables in the analysis, and a justification for those that are not included;
- A statement on whether the outcome assessor was aware of the exposure status of the participant, and whether the participants were aware of the research question, particularly if non-objective outcomes or confounding variables relating to exposure pathways are being assessed;
- Information on the validity and reliability of the data collection methods, for example, referencing the use of standard tools or analysis methods, or reporting on the analysis reference materials;
- A detailed account of the remediation activities and public health campaign, including the timing of these, any changes to them over time on large-scale remediation projects, where they took place and how this relates to the location of participant households.

In addition, Colles *et al.* (2019) provide further guidance on HBM, based on the lessons learned from six case studies in Europe.

7. Conclusion

This review aimed to examine the extent to which the remediation of contaminated sites reduces environmental and health risks to new and existing populations and ecological systems. The sixteen papers included in the evidence synthesis of health outcomes suggest that there is good evidence that remediation via removal, capping, and replacing soil, with planting of bare soils is effective at reducing concentrations of lead and chromium in blood and urine in children. There is also some evidence, from one study, that remediation of soils can improve cognitive performance in children living near waste dumps. There is also evidence, again from one study, that sediment dredging can reduce PCB concentrations in umbilical cords in infants. However, the removal of soil is not often considered to be a sustainable option for dealing with contaminated land with a preference now for technologies that reduce the environmental consequences of remediation. There are a substantial number of studies, not included in this review, that examine the pre-remediation health outcomes associated with contaminated sites, and an opportunity therefore exists to follow up some of these sites where remediation has now taken place. Priority should be given to those that examine organic contaminants or inorganics contaminants other than lead. Similarly, there is a need to publish the findings from long-term epidemiological or surveillance studies where they exist.

The evidence is almost solely restricted to studies of the impacts of remediation on existing populations, although there is no reason to assume that these methods would not be effective in the context of new developments. The majority of these studies also included public health campaigns to reduce exposure, particularly in children, while the remediation was taking place. These public health campaigns were also reported to be effective, with a small number of studies examining their impact separately. However, it is clear from the evidence that area-wide remediation of contaminated soils is the most effective mechanism of reducing exposure.

There is also very little consideration of assessing impact on equity in the study design, although several studies do acknowledge that those in disadvantaged groups are more likely to live in areas with greater levels of contamination, and respond to public health campaigns differently.

There is a paucity of evidence related to full-scale remediation, but the studies that were reviewed tend to report that remediation has been successful. Approaches that immobilise inorganic contaminants or degrade organic compounds, often employing several technologies on one site, appear to be those where the most effective remediation is reported. The exception to this is studies of three sites, which may be useful learning for those wishing to restore such sites, or assess the efficacy of previous remediation. This gap is likely to reflect the development of remediation technologies and their reporting in the academic literature as opposed to their effectiveness at reducing risk to human and environmental receptors. The treatment of contaminated sites has developed over decades and in many countries remediation outcomes are assessed and monitored over the long-term, although this is not published in the academic literature. Studies of the health outcomes of contaminated sites prior to remediation have often failed to detect significant impacts on existing populations, potentially due to their exposure to a multitude of sources of pollution.

8. References

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Annex 1 Search strategy

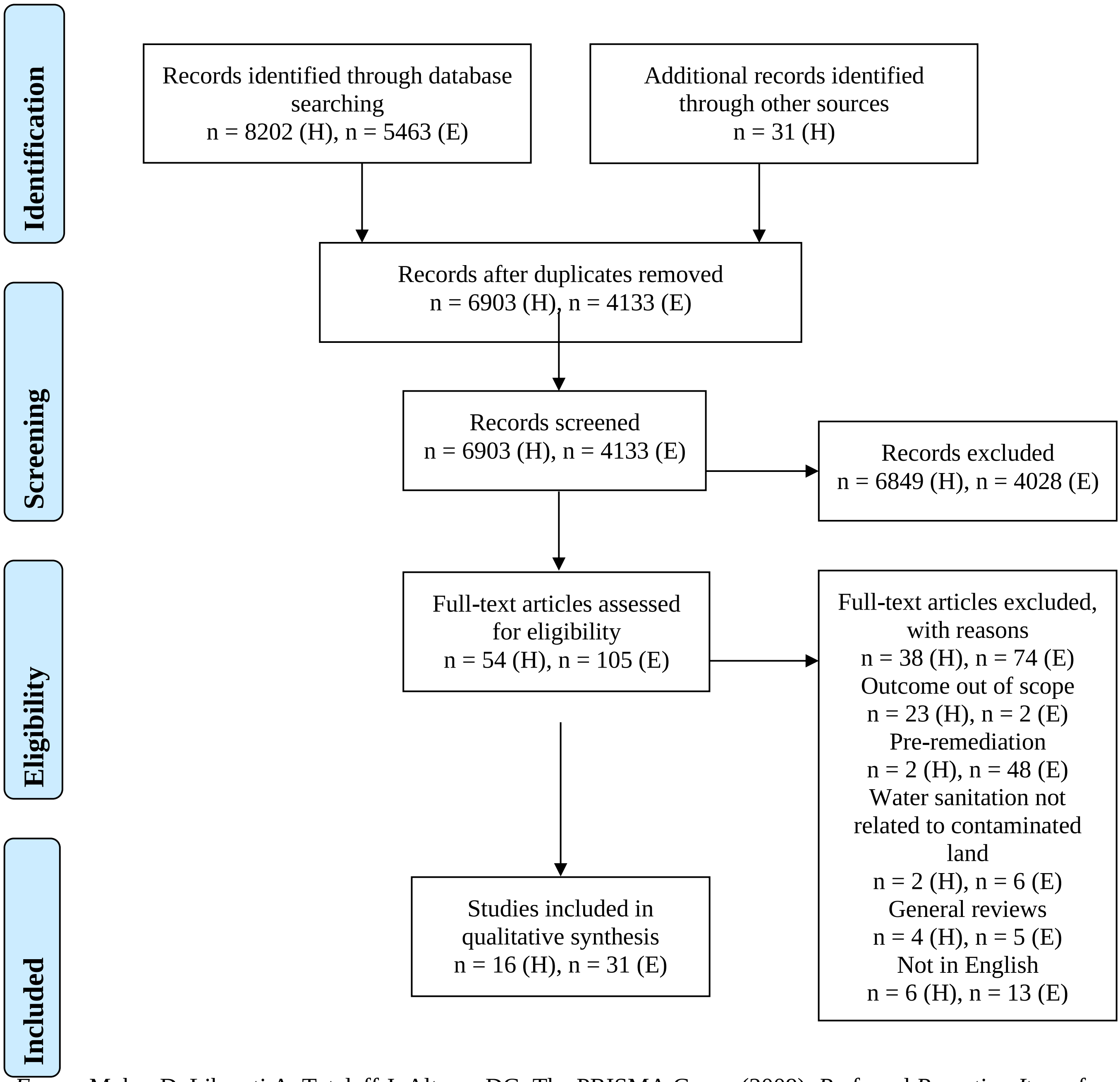
Contamination and land use, remediation and redevelopment, and health outcomes.
Carried out on 4th June 2020.

#	Searches
1	((industr* OR mining OR mine OR quarries OR quarry OR waste OR incinerat* OR landfill* OR port OR harbor OR harbour OR ship OR dock OR superfund OR brownfield OR contaminat* OR site OR plant OR plants OR mill OR farm* OR agricult* OR land OR soil OR rail* OR derelict) AND (petro* OR pesticide* OR polymer* OR organochemical* OR colouring OR pharmaceutical OR paper OR metallurg* OR potter* OR fertilizer* OR footwear OR shoe* OR lindane OR plastic OR rubber OR detergent* OR lubricant* OR lubricating* OR weapon* OR glass OR iron OR steel OR asbestos OR fluoroedenite OR fluoro-edenite OR amosite OR erionite OR balangeroite OR tremolite OR crocidolite OR chrysotile OR serpentine OR antigorite OR anthophyllite OR actinolite OR ferroactinolite OR amphibole* OR lead OR cadmium OR arsenic OR nickel OR tin OR mercury OR chromium OR polyaromatic hydrocarbons OR cyanide OR polychlorinated biphenyls OR phenol OR BTEX OR benzene OR toluene OR ethylbenzene OR xylene OR trichloroethane OR vinyl chloride OR blue billy OR leblanc OR methane OR sewage sludge OR metal* OR gasworks OR filling station OR coal tar OR pulverised fly ash OR furnace bottom ash OR chemical OR oil OR chlorinate* OR volatile organic compound*)).mp
2	"data mining"
3	1 NOT 2
4	(remediat* OR conver* OR renewal OR regenerat* OR rehabilitat* OR redevelop* OR reclamat* OR reuse OR re-use OR "clean-up*" OR restorat* OR cleanup* OR "clean* up*").mp
5	3 AND 4
6	(health* OR mortality OR morbidity OR disease OR chronic OR infection OR syndrome* OR irritation OR ache* OR headache* OR nausea* OR sick OR pain OR sclerosis OR dent* OR neoplasm* OR tumor* OR tumour* OR cancer* OR lymphoma* OR leukaemia* OR leukemia* OR myelodysplas* OR myalgia* OR neuralgia* OR respirator* OR heart OR cardio* OR vascular OR stroke OR pulmonary OR lung OR respiratory OR renal OR kidney* OR bone OR digestive OR congenital OR reproductive OR semen OR retard* OR fetal OR foetal OR preterm OR pre-term OR miscarriage OR abort* OR pregnan* OR birth* OR death* OR neuro* OR muscl* OR urin* OR blood OR serum OR hair OR gland* OR throat OR eye* OR genotoxic* OR muta* OR biomonitoring OR bio-monitoring OR psych* OR brain OR skin OR epiderm* OR quality of life OR QoL OR satisfaction OR depression OR anxi* OR nervous OR stress OR sleep OR insomnia OR concentrat* OR cognitive).mp
7	5 AND 6
8	remove duplicates from 7

Searches limited to: English only, Title, Abstract and Keyword, in Scopus they were also limited to studies including the terms: human, humans, male, female, and adult; adj=adjacent.

Annex 2 Flow diagram for studies examining outcomes related to human health (H) or the environment (E)

PRISMA 2009 flow diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Annex 3 Summary of the results of the quality assessment

Criteria	Scores		
A) SELECTION BIAS			
(Q1) Are the individuals selected to participate in the study likely to be representative of the target population?	Very likely = 11 Somewhat likely = 2 Can't tell = 3		
(Q2) What percentage of selected individuals agreed to participate?	80 to 100% = 4 Less than 60% = 3		60 to 79% = 3 Can't tell = 6
B) STUDY DESIGN	Randomised control trial = 1 Cohort analytic = 2 Cohort (one group pre + post) = 1 Case control = 1 Interrupted time series = 3 Cross-sectional = 8		
C) CONFOUNDERS			
(Q1) Were there important differences between groups prior to the intervention?	Yes = 10	No = 0	Can't tell = 6
(Q2) If yes, indicate the percentage of relevant confounders that were controlled (either in the design (e.g. stratification, matching) or analysis)?	80 to 100% = 7 Less than 60% = 2		60 to 79% = 1
D) BLINDING			
(Q1) Was (were) the outcome assessor(s) aware of the intervention or exposure status of participants?	Yes = 4	No = 1	Can't tell = 11
(Q2) Were the study participants aware of the research question?	Yes = 3	No = 1	Can't tell = 12
E) DATA COLLECTION METHODS (Q1) Were data collection tools shown to be valid?	Yes = 7	No = 1	Can't tell = 8
(Q2) Were data collection tools shown to be reliable?	Yes = 3	No = 1	Can't tell = 12
F) WITHDRAWALS AND DROP-OUTS			
(Q1) Were withdrawals and drop-outs reported in terms of numbers and/or reasons per group?	Yes = 2	No = 2	N/A = 12
(Q2) Indicate the percentage of participants completing the study. (If the percentage differs by groups, record the lowest).	80 to 100% = 1 Less than 60% = 1		60 to 79% = 2 N/A = 12

	Strong	Moderate	Weak
A) SELECTION BIAS	4	6	6
B) STUDY DESIGN	1	7	8
C) CONFOUNDERS	7	1	8
D) BLINDING	1	0	15
E) DATA COLLECTION METHODS	3	4	9
F) WITHDRAWALS AND DROP-OUTS (N/A = 12)	1	1	2
GLOBAL RATING	**0**	**0**	**16**

Case study compilation: lessons learned from redeveloping contaminated sites

Across Europe, urban settlements are changing and expanding. Due to lack of land resources, urban growth and development often relies on the re-use and conversion of land that had different former functions. This challenge is often referred to as land recycling or brownfield conversion. Depending on the former use and function of the site, they can be associated with contamination which, if not isolated or suitably remediated, can pose health risks to urban residents and users of urban functions after the redevelopment.

This paper explores 28 European case studies on the remediation and redevelopment of contaminated sites, compiling an overview of local and regional action on such sites and the scope and focus of the respective conversion projects. The findings show that almost all case study sites were contaminated by multiple pollutants, affecting several environmental media. Many remediation projects took a long time and raised managerial and organisational challenges to the public authorities in charge, especially when unexpected contamination was found during remediation or redevelopment. Although impact assessments were carried out in almost all case studies, active involvement of the public as well as health actors in the planning process is not a given.

The case studies provide useful lessons learned, supporting the coordination and implementation of conversion projects and identifying crucial elements for effective management and public health protection.

1. Introduction

1.1. Background

Across Europe the urban population is steadily growing with their share in the total population likely to reach 80% by 2050 (Eurostat, 2016). Urban areas stimulate migration from the countryside by providing new arrivals better employment opportunities, prospect for higher living standards and a vibrant city life. However, growing population and urban sprawls pose several challenges to urban planners and local authorities. Demand for land is rapidly increasing, but free land is scarce and taking over surrounding natural areas threatens biodiversity and increases environmental pollution in the cities (Cappai et al., 2019). Urbanisation is characterised with increasing social inequalities and environmental problems, directly affecting the life of a growing urban population (Czischke et al., 2015; Eurostat, 2016).

The long industrial heritage and poor environmental management has left around 2.8 million sites in Europe where polluting activities took or are taking place, with 240 000 of them in need of further investigation to assess risk posed to human health and environment (Payá Pérez et al., 2018). Many of them are situated in densely populated urban centres. Living on or nearby contaminated land is associated with deteriorated health, shorter life expectancy and lower quality of life (e.g. Bech, 2020), linking real or perceived contamination thought toxicological (e.g. inhalation, dermal absorption, soil eating) and psychosocial pathways to health and wellbeing (Bambra et al., 2014; Payá Pérez et al., 2018). Importantly, communities living in or close to contaminated sites are often socioeconomically deprived and vulnerable, have higher proportion of foreign nationals and show elevated unemployment rates pointing towards serious environmental justice issues (Pasetto et al., 2019).

Revitalising previously developed land present an opportunity for sustainable urban development by reducing land consumption (Bleicher & Gross, 2010) and solving longstanding environmental, social and health problems linked to real or perceived contamination. Cleaning up environmental pollution, removing neighbourhood eyesores and bringing back the underutilised and often abandoned site to the life of the community may provide a sustainable answer for urban sprawls. Depending on the new function of the site, it can create housing, generate space for recreation and increase green space in densely populated cities. Moreover, urban redevelopment projects can generate jobs and improve the health, wellbeing and quality of life in the surrounding, often marginalised and vulnerable communities (White et al., 2017).

However, redeveloping contaminated sites presents technical, financial and organisational challenges, and poses environmental and health risks, if contamination is not properly remediated. During remediation, working with contaminants may expose workers and local populations to additional health risks, which has to be taken into account as well. Complex redevelopment projects require an active cooperation between public authorities at different levels and private stakeholders, with often divergent interest. Therefore, supporting actors at local level – who are usually responsible for the projects - in the decision-making process on redeveloping a particular contaminated site, coordinating and overseeing work activities, while taking into consideration potential environmental, social and health effects as well as giving voice for the communities living nearby, is crucial for sustainable development and public health.

1.2. Policy context

Land contamination, a memento of industrial heritage, has raised considerable policy attention across Europe in the last decade. Preventing and eliminating the adverse environmental and health effects related to waste management and contaminated site is one of the main priorities of the Declaration of Sixth Ministerial Conference on Environmental and Health, held in 2017 in Ostrava, Czech Republic, and signed by the ministers and responsible of member states in the European Region of WHO and by high representatives of several United Nations' agencies (*Declaration of Sixth Ministerial Conference on Environmental and Health*, 2017).

Redeveloping contaminated sites became also the focus of several reports and activities lead by the European Commission, such as the 2015 report on "Remediated sites and brownfields: success stories in Europe" (Payá Pérez et al., 2015) or the 2017 report on "European achievements in soil remediation and brownfield redevelopment" (Payá Pérez et al., 2017). The topic was also the main focus of a recent conference held in Brussels in 2019 (Brownfield Redevelopment in the EU, 2019), showing an ongoing policy attention. The European Environment Agency (EEA) considers land as one of the most precious natural resources and monitors land use functions, especially related to the continuing sprawl of urbanized areas and covered land surface. However, an EEA report indicated that land recycling and urban densification (such as converting industrial sites into urban infrastructure) accounted for only 13% of new developments and associated land take, and identified the increasing demand for land as a viable challenge for future sustainable development (EEA, 2019). Moreover, several multilateral European research projects and platforms (e.g. CLARINET, CABERNET, TMBRE, EUGRIS, HERACLES, HOMBRE, COMMON FORUM on contaminated land in Europe or the Industrially Contaminated Sites and Health Network [ICSHNet]) have aimed to provide technical support (e.g. remediation technologies, tools for decision making) on sustainable land redevelopment (ICSHNet, 2020).

On a global scale, the problem of contamination is reflected by the Sustainable Development Agenda, which considers sustainable consumption and production patterns in SDG12. The work covers e.g. hazardous waste and chemicals, as well as the extraction of natural resources (United Nations, 2020); but soil is referred to and affected by many other SDG. Promoting sustainable production and management of resources is also the objective of the circular economy concept, which aims to mitigate waste and pollution by keeping material resources in use and supporting natural material regeneration. Changing from a linear economy (take, make, dispose) to a circular economy (renew, remake, share) is therefore expected to support significantly the attainment of SDG 12 on responsible consumption and production (WHO Regional Office for Europe, 2018). The circular economy concept has also been embedded into the EU Green Deal as one of its central components in achieving a climate-neutral economy by 2050 (European Commission, 2020).

Finally, resolution 3/6 adopted by the UN Environment Assembly in 2017 calls upon Member States and international organizations *"to address soil pollution within the global environmental, food security and agriculture, development and health agendas in an integrated manner, especially through preventive approaches and risk management using available science*" (United Nations Environment Assembly, 2018).

1.3 Aims and objectives

Extending already existing knowledge, the overall project aim was to compile evidence on environmental, social and health issues related to redeveloping contaminated sites, as well as collect local experiences associated with these processes. The current working paper is the second in the row and presents one of the three main pillars of this larger project:

I. Systematic review of scientific evidence on the environmental, health and social impacts of remediation and redevelopment of contaminated sites;
II. Case study collection on European contaminated site redevelopment projects;
III. Review of risk and impact assessments related to redevelopments.

The main objective of this working paper (II) was to compile local practices and experiences on the conversion and redevelopment of contaminated sites, in order to provide better understanding of potential challenges public authorities face, derive guidance for action and highlight best practices in the field. More precisely, by including European case studies with varying geographical size, background and level of contamination, submitted by public authorities at local, regional or national level as well as other stakeholders involved in remediation and redevelopment of contaminated areas, the objectives were to:

(1) Collect local experiences in redevelopment projects;
(2) Identify best practices for local authorities and urban planners;
(3) Describe limitations and potential caveats throughout the conversion and redevelopment process; and
(4) Identify lessons learned and highlight areas of further improvements.

Although the report's main target groups are local / regional authorities and urban planners (which have the role of coordinating and are legally responsible for the remediation and redevelopment process), it may also include useful information for different stakeholders participating in redevelopment projects.

1.4 Structure of the report

This introduction chapter aims to set the research (1.1) and policy context (1.2) of contaminated site redevelopment, and highlights the rationale and objectives of the case study collection (0). The following chapter presents the methods applied to collect information on redevelopment projects: first, after determining eligibility to case study inclusion (2.1), we describe how the case study questionnaire was developed (2.2) and distributed widely across profession networks and expert groups (2.3). Then, based on completed submissions, case studies were selected for more detailed exploration and follow-up interviews were conducted (2.4). The results section presents general information on the case studies included in the report (3.1), followed by a synthesis of the quantitative case study data (3.2) and the qualitative interview data (3.3). Finally, the report finishes with a discussion on the findings and draws main conclusions (4.1 and 4.2) for public authorities to better deal with the conversion and redevelopment of contaminated sites.

References are provided at the end of the report (5), as well Annex 1 providing an overview of all case studies and Annex 2 with the detailed results on the general evaluation of the case study impacts, as derived from the survey questionnaire.

2. Methods

2.1. Eligibility Criteria

This working paper aimed to collect case studies reporting redevelopment of contaminated sites into new urban functions. Case studies were **included**, if:

(1) Former use before redevelopment included agricultural, industrial, commercial, storage, waste disposal, military or transport-related functions, or the area was contaminated due to an industrial accident or similar somewhere else;
(2) New use of the site included any urban functions with public access, such as residential areas, commercial or retail functions, indoor recreational and entertainment facilities, outdoor recreational spaces, cultural or community spaces, or mixed functions;
(3) Redevelopment project was carried out within a country belonging to the European Region of WHO;
(4) Redevelopment was at least partly finalized in or before 2018, making the redeveloped site accessible to the public.

Case studies were **excluded**, if:

(1) Former use included urban functions (e.g. residential area);
(2) New use of the area was not – at least partly - accessible to the public (e.g. for industrial or military functions);
(3) Redevelopment has not taken place by 2018.

2.2. Case study questionnaire

The case study questionnaire comprised a set of closed and open-ended questions structured around eight topics. The first part (Section I) collected information on the case study contributor[1]. Section II asked general information about the submitted case study. Taking a historical timeline, the next part focussed on the former use of the site (Section III), followed by the description and impacts of contamination, site investigation and the legal context (Section IV). Section V gathered data on the remediation activities, unexpected difficulties occurring during the remediation and on the country-specific legal context of remediation. Section VI focussed on the redevelopment: new urban functions established on the cleaned site, application of impact assessments, and potential unknown contaminations occurring during the process of redevelopment. Changings in the social, environmental and health dimensions related to the redevelopment were assessed in Section VII, with a special focus on targeted monitoring activities after the project was finalised. The closing part of the questionnaire reflected on the entire redevelopment process by asking for key experiences and lessons, with the option of uploading and/or providing links to published materials and photographs related to the site redevelopment (Section VIII).

Two main types of questions were developed to collect information on the redevelopment experience of contaminated sites:

- closed questions with predetermined response options for factual and technical details, and
- open-ended questions with text boxes to capture personal experiences and opinions.

[1] Few case study authors asked to remain anonymous in the WHO report, due to potential sensitivities associated with the conversion project. In such case, name and affiliation and/or exact site location are not provided.

Based on given responses, page skip logics were built in the questionnaire to help to better target questions and decrease respondent burden.

After internal review of the questionnaire, the first draft was sent out to external reviewers including the EEA, the WHO Collaborating Centre for environmental health in industrially contaminated sites, and the Common Forum on contaminated land in Europe as well as technical and scientific experts on soil contamination, site remediation and urban planning, and to public servants working for local authorities. The reviews helped to finalise the questions, provided a technical check for terms and definitions, assessed the relevance of the questions, and determined the time needed to fill out the questionnaire.

The questionnaire was uploaded and distributed through an online survey platform after a thorough testing phase.

2.3. Distribution and data collection

A call for case studies was distributed to individuals identified as experts in the field, and circulated in technical and professional networks:

(1) Authors of earlier case study collections on urban redevelopment projects (Payá Pérez et al., 2015, 2017; EU brownfield conference, 2019);
(2) Authors of reports and scientific papers on urban redevelopment and/or soil contamination from countries underrepresented in previous case study collections;
(3) Technical networks and projects on soil contamination and remediation (CL:AIRE, EUGRIS, IMPEL, COMMON FORUM, timbre, HOMBRE, CLARINET, GreenerSites, ICSHNet);
(4) Health networks (EUPHA, EuroHealthNet, HEAL);
(5) Networks on impact assessment (IAIA, EUPHA HIA network);
(6) City networks (EuroCities, C40, URBACT, ICLEI, EuroTowns, UCLG, SSRE-CEMR);
(7) Other networks (EEA, JRC, IFLA, ISOCARP, WHO networks such as Healthy Cities or Regions for Health).

The survey was opened for the public on the 7th of May 2020 and closed on the 10th of June 2020; regular reminders were sent out to those started to enter information in the online template *(Table 1)*.

Table 1: Survey collection

Action	Date	Details
Survey opened	07.05.2020	Email on case study call were distributed among identified experts and networks.
Reminder I	18.05.2020	Reminder email sent to contributors started to enter information in the survey.
Reminder II	25.05.2020	Reminder email sent (a) to contributors who started to enter information in the survey; and (b) as general reminder to experts receiving the original call for case studies.
Reminder III	01.06.2020	Reminder email sent to contributors started to enter information in the survey.
Survey closed	10.06.2020	Survey collectors were closed.

Incoming case studies were checked against the eligibility criteria, and where inclusion criteria did not match, contributors were first followed up for further clarification and eventually informed about study exclusion. After the survey was closed, all uncompleted entries as well as excluded case studies were removed from the collection.

2.4. Follow-up interviews

2.4.1. Selection of interviews

Selected case studies submitted by local or regional authorities, public or state agencies and researchers were followed up in order to gain more information on selected topics. A priori, four criteria were identified to suggest a potential follow-up interview:

(1) The case study presented relevant content related to managing unexpected problems occurring during remediation and redevelopment;
(2) The case study involved public participation before and/or during redevelopment;
(3) The case study presented relevant content on assessments of health and environmental risks and impacts;
(4) The case study identified relevant lessons learned for local authorities;

Contributors of selected case studies were contacted by email and asked for participation in a semi-structured follow-up interview.

In addition to the follow-up interviews on submitted case studies, an additional expert interview was held with the German Regionalverband Ruhr on a regional network of cities faced with the challenge of converting former mining sites into new urban functions.

2.4.2. Interview structure

Semi-structured interviews started with an introduction about the WHO project aims and the rationale of the follow-up interview, followed by seven thematically selected blocks which were adapted to the respective case study and its specific experience:

(1) Identifying the role of the interviewee in the redevelopment project and understanding the initiation of the project, the role of stakeholders and general public in the decision making;
(2) Gathering information on the physical and social context of the redeveloped site, with special focus on the community living nearby;
(3) Exploring previously recorded and unknown contaminations, how site investigation was conducted and whether these affected the overall redevelopment process;
(4) Identifying potential environmental and health risks of contamination, as well as assessing negative and positive impacts of the redevelopment;
(5) Exploring project budget and share of costs between stakeholders, as well as unexpected changes in the budget;
(6) Summarising the project-related experiences of public sector stakeholders in planning, implementation, regulatory frameworks, and identifying suggestions for improvements;
(7) Exploring intersectoral cooperation and communication, in particular between stakeholders in public and private sector, and identifying best practices in workflow.

Interviews were recorded after permission, and the interviewer prepared a short summary about the interview, which needed to be approved by the interviewee before analysis.

3. Results

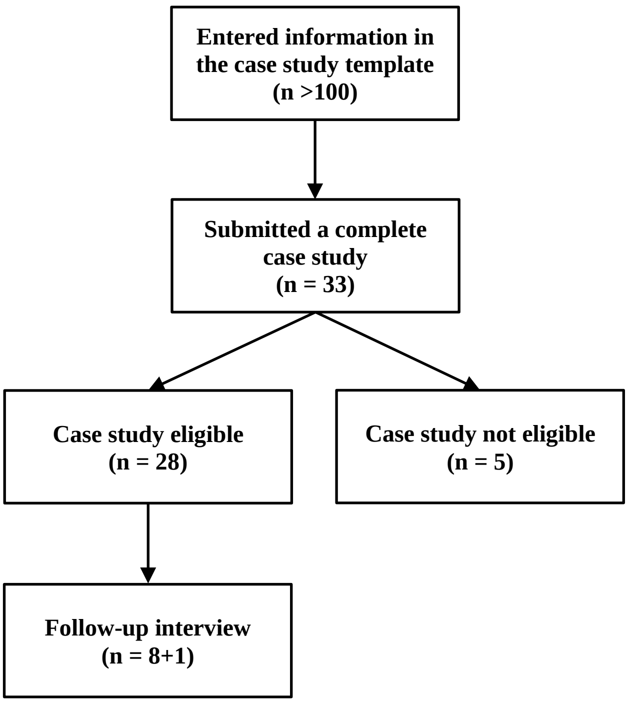
3.1. Descriptive results

Over the survey period, more than 100 individual survey entries were recorded, though with very different levels of completeness. 33 case studies were finalised and submitted until the deadline.

5 submitted case studies were excluded as they did not meet the eligibility criteria or did not provide the required amount of information to reconstruct and assess the case study. The synthesis of case study information in section 3.2 is therefore based on a sample of 28 cases.

From the 28 eligible submissions, 8 case studies were followed up with a semi-structured interview and one additional qualitative interview[2] was held *(Fig. 1)*. The information from these nine interviews is summarized in section 3.3.

Figure 1: Flow chart on case study submissions and follow-up interviews



A descriptive overview of the 28 submitted case studies is shown in *Annex 1*. As some case study contributors preferred not to publish their name or not to provide exact location of the case study site, respective details were anonymised for this report.

3.2. Synthesis of case study data

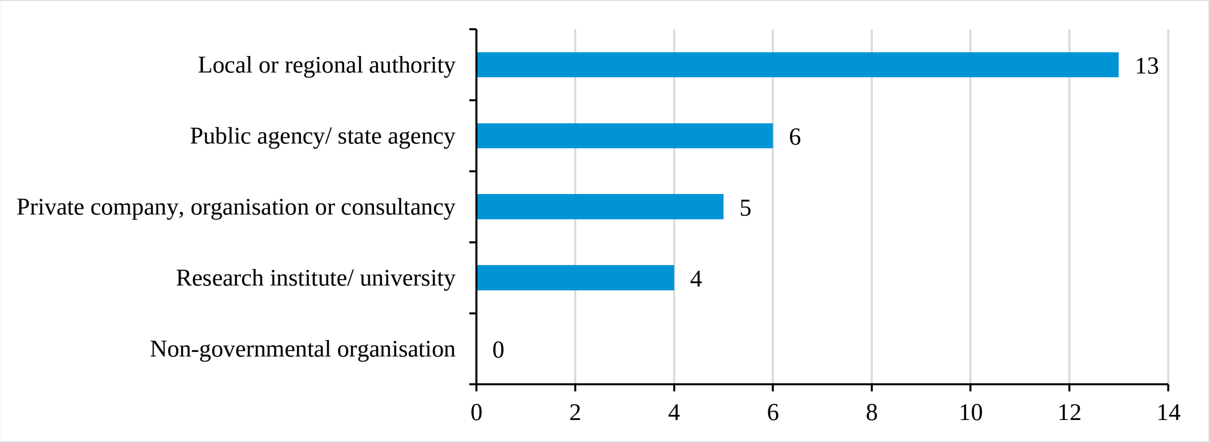
3.2.1. General information on the site and the conversion process

The overwhelming majority of case studies were submitted by public stakeholders, mainly from local or regional authorities (n = 13) and from public or state agencies (n = 6). Five submissions

[2] One additional expert interview was made with the German "Regionalverband Ruhr", a city/region network focusing on the redevelopment of former mining sites.

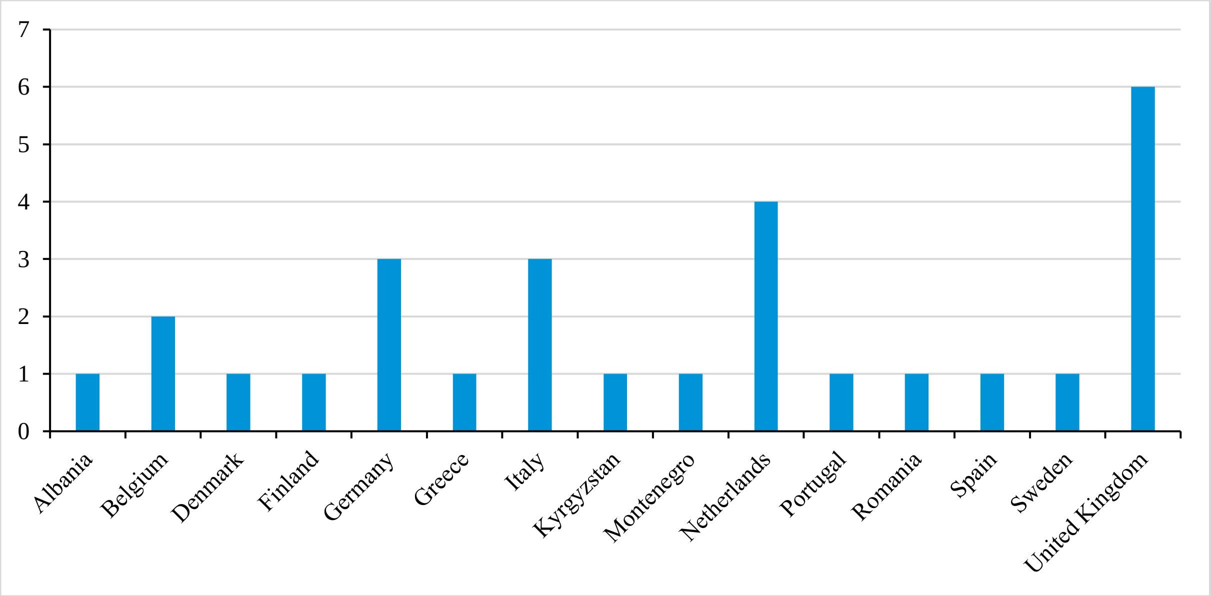
came from private companies, organisations and consultancies active in remediation and redevelopment of contaminated sites. There was also a handful of submissions from universities and research institutes (n = 4) *(Fig. 2)*.

Figure 2: Type of affiliation of case study contributors (n = 28)



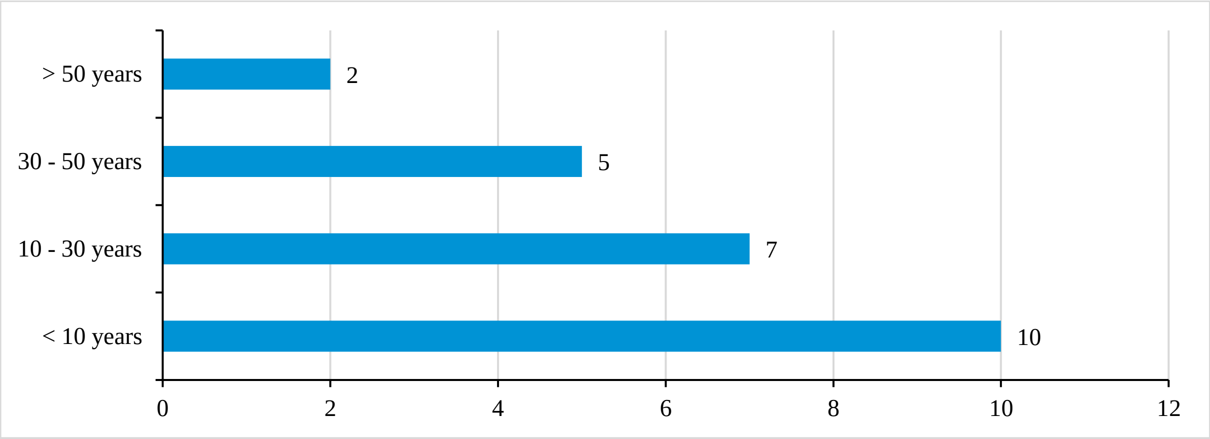
The 28 case studies were submitted from 15 countries across the WHO European region. There was a shift towards western high-income European countries, as more than one case study was submitted from the United Kingdom, the Netherlands, Germany, Italy, and Belgium. However, we also received submissions from countries often underrepresented in case study collections, such as Albania, Montenegro, Romania and Kyrgyzstan *(Fig. 3)*.

Figure 3: Country of case study (n = 28)



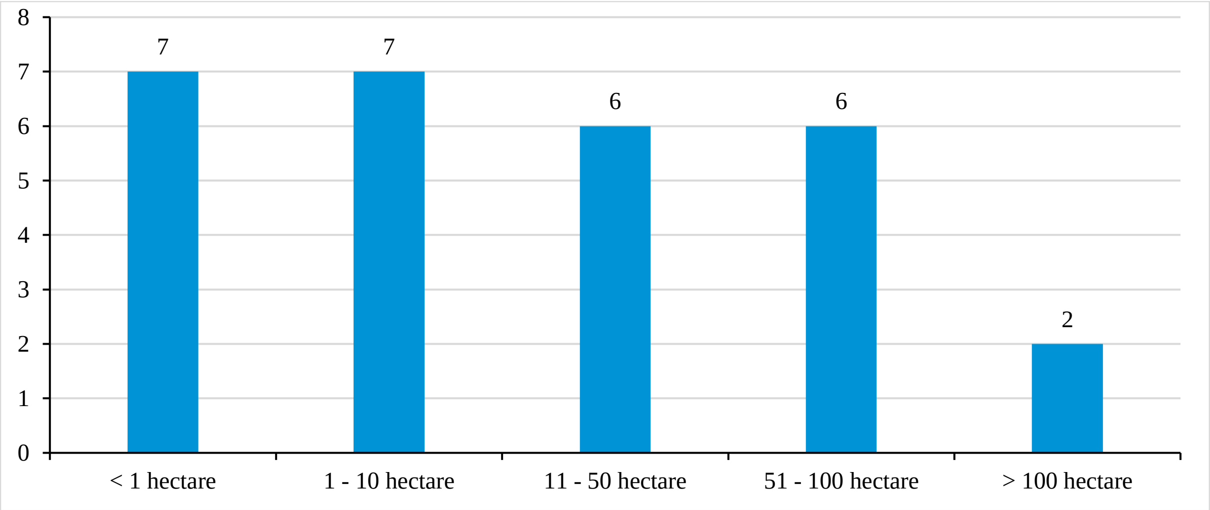
It is important to note that many case studies are redevelopment projects of older contaminated sites. These sites may have been abandoned decades ago and then left for a long time before they got touched again for remediation and conversion. Figure 4 shows the timespan between site closure and start of remediation, which is beyond 10 years for just more than half of all case studies and can reach up to 50 years and more. These timelines are important for the interpretation of the survey results. For instance, it could explain why some survey respondents could not provide responses to specific questions - especially regarding information on the former use of the site, or the legal frameworks and risk assessments carried out when the site was closed.

Figure 4: Timespan between site closure and start of remediation (n = 24)



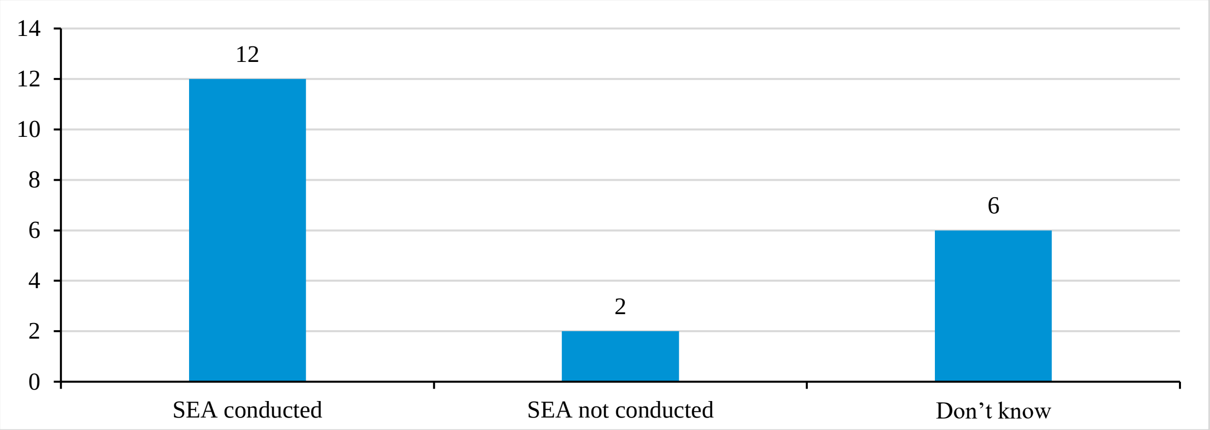
The redeveloped sites varied evenly between less than one and 100 ha and only two sites were bigger than 100 ha *(Fig. 5)*. With regard to the population density, five studies described their site as sparsely populated, ten as moderately populated and most sites (n = 13) were described as densely populated, so that a large number of citizens were affected by the redevelopment project. This indicates that contaminated sites can be small and local, but may also have large dimensions calling for urban or even regional planning approaches.

Figure 5: Geographical scale of the redeveloped site (n = 28)



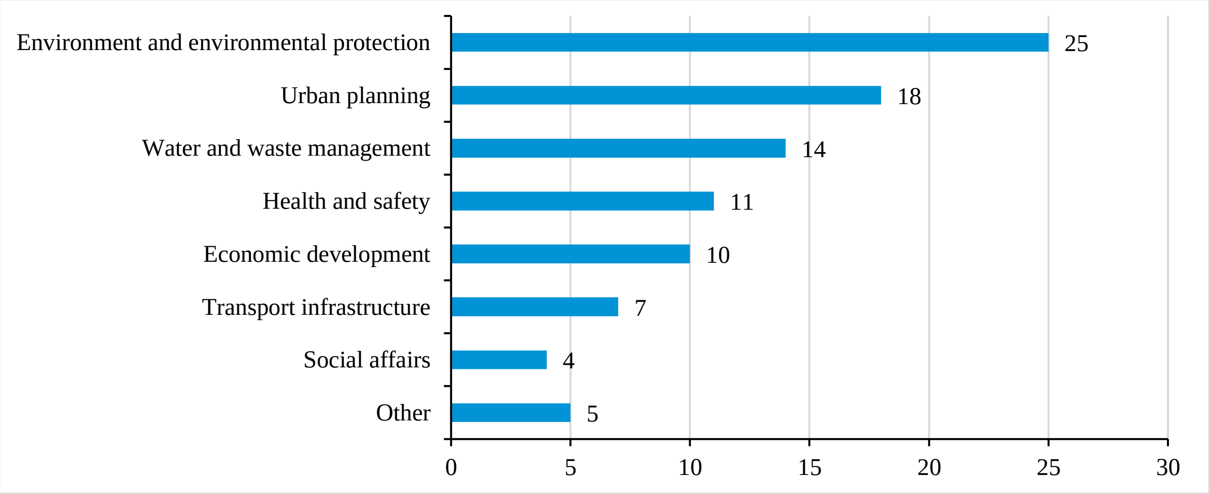
Planning approaches are reflected by the fact that 20 case studies have been embedded in spatial development strategies – 14 in local development schemes and six as a part of regional, state or national development strategies. Only eight case studies were implemented as an individual project. However, there was no relationship between the size of the redeveloped site and being part of a larger (local, municipal, regional or countrywide) development strategy. Of the 20 case studies that were part of a larger development strategy, twelve conducted a strategic environmental assessment (SEA) on the respective spatial plan (*Fig. 6*). Two stated no and six where unsure about the use of a SEA.

Figure 6: Implementation of strategic environmental assessment (n = 20)



Given the complexity of contaminated site conversion and redevelopment, more than three local authority departments were involved in the projects on average (Ø = 3.3). Mostly, these were environment and environmental protection authorities (n = 25), followed by urban planning authorities (n = 18) and water and waste management authorities (n = 14) *(Fig. 7)*. Less frequent was the involvement of authorities from health and safety, economic development, transport as well as social affairs with eleven, ten, seven and four cases respectively. Five case studies reported involvement of other actors, such as entities especially established for the project or local community groups *(Fig. 7)*. Given the health-related aspects of contaminated sites, the involvement of health authorities in only less than half of the projects is worth a discussion.

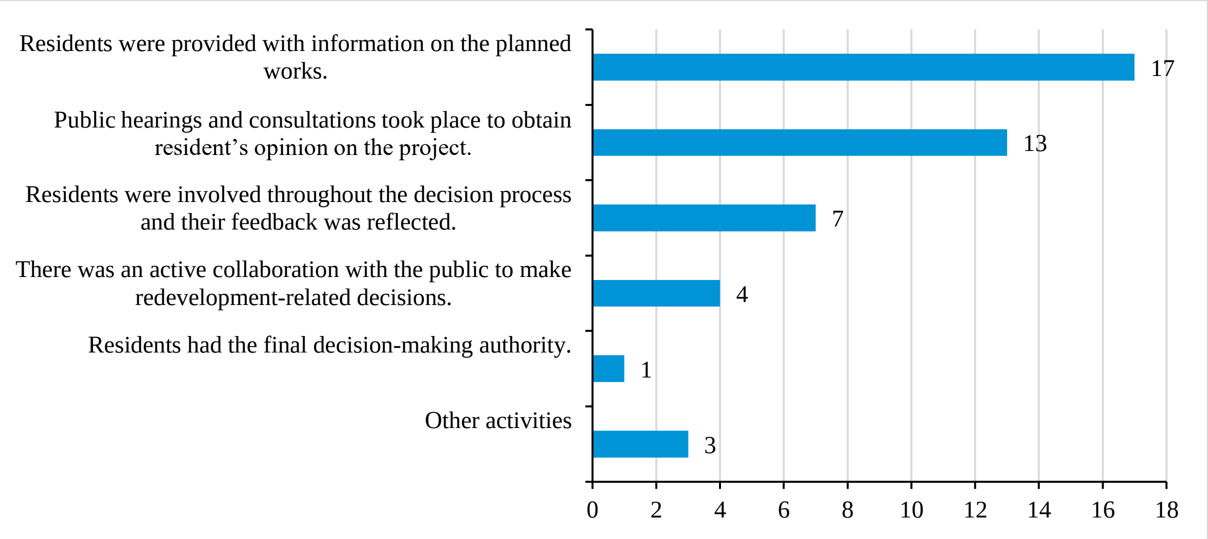
Figure 7: Local authority departments involved (n = 28, multiple response)



Regarding the implementation of public participation measures, most case studies (n = 18) applied some form of participation procedures, whereas five case studies could not provide information on this topic. Another five case studies indicated that no public participation measures were implemented, and the data analysis suggests that this is more likely to occur in (a) smaller-size case studies and (b) case studies reported by consultancy companies that were directly involved in the remediation work (and may simply not be aware of public participation measures carried out before remediation started).

Figure 8 points out that virtually all case studies with public participation organized at least the most basic form of participation, which is providing residents with information on the planned works (n = 17). 13 cases organised public hearings, seven included the residents in the decision process and four in active public collaboration. Only one study reported the implementation of the most elaborate public participation measure, which is allowing the residents decisive influence on the final decision-making. "Other activities" (n = 3) included measures such as the implementation of a committee or a celebration of the finished project.

Figure 8: Public participation measures (n = 18, multiple response)

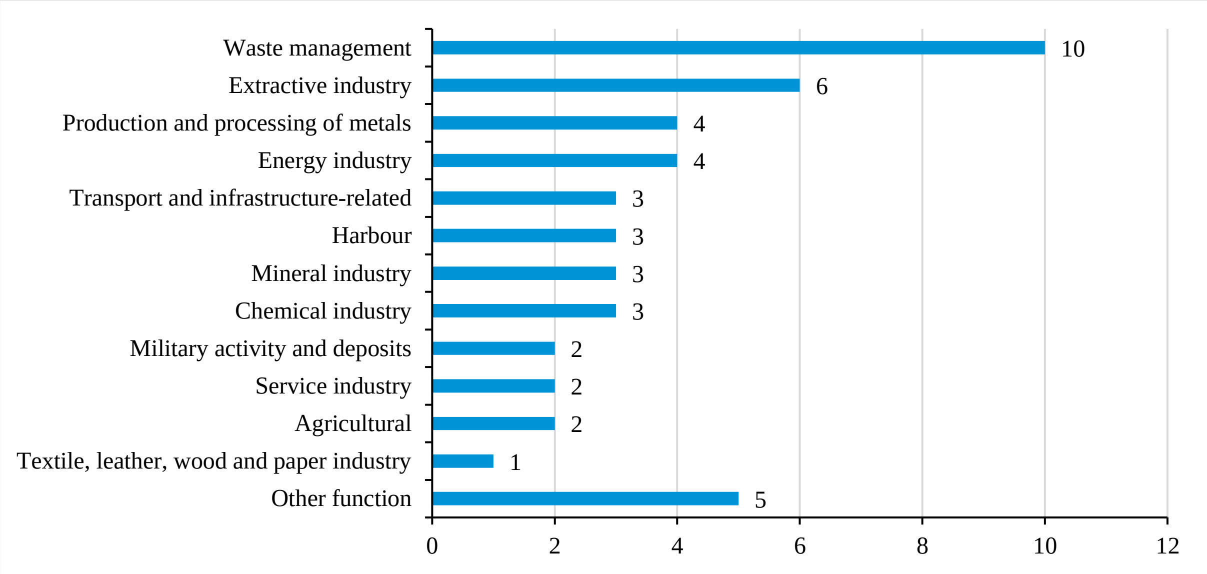


3.2.2. Former use of the sites

The former function of the redeveloped sites were quite diverse *(Fig. 9)*. Most sites were used for waste management (n = 10), followed by extractive industry (n = 6) and metallurgic or energy industry (n = 4 each). Altogether, there were more than twelve different functions of the sites, with an average of 1.7 functions per site.

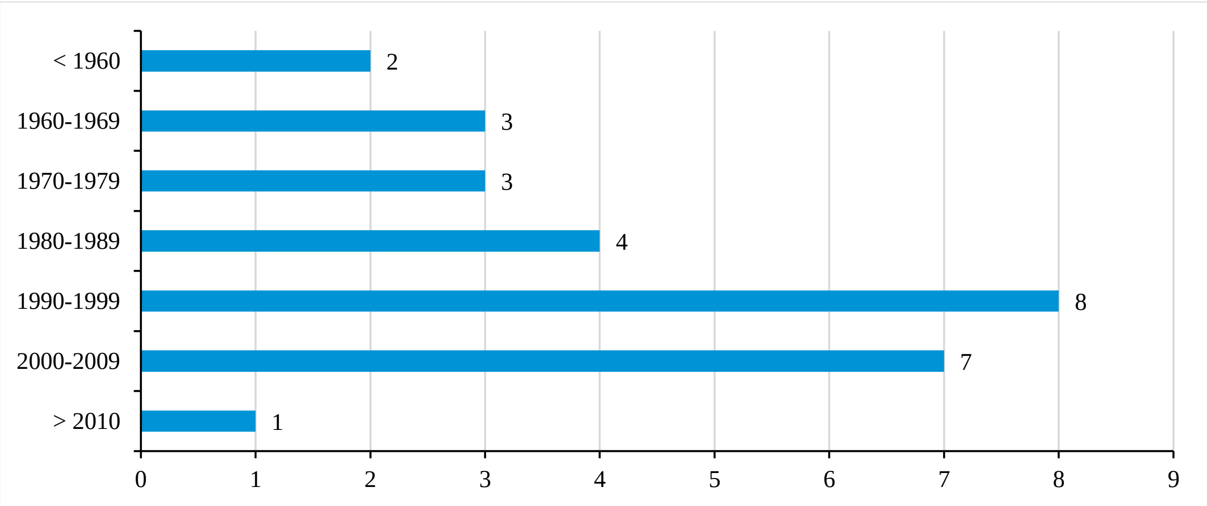
Originally, the study sites were mainly quarries, landfills and waste dumps, mining sites, industrial factories processing metals, chemicals or fuels and warehouses. The functions of the former sites seem to be related to the former owners of the sites. Waste management was e.g. carried out by public or partial public owners in seven of ten cases. On the other hand, former privately owned sites were mainly used for extractive and metallurgic industry.

Figure 9: Former functions of the sites (n = 28, maximum of three responses)



As mentioned before (*Fig. 4*), the closure of the sites can go back decades. The year of closure ranges between 1881 and 2015, though only two shutdowns occurred earlier than 1960. Three sites closed in the 60s and in the 70s respectively, while four closed in the 80s (*Fig 10*). Most case studies reported a closure in the 90s (n = 8) and in the 2000s (n = 7).

Figure 10: Date of closure (n = 28)

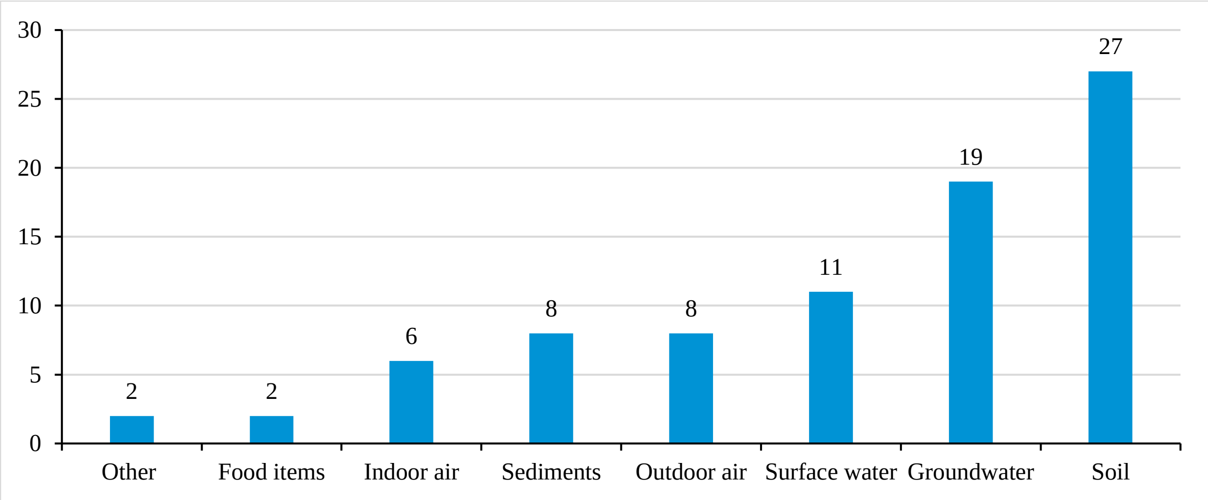


As a reason for site closure, two main factors were mentioned. For one, an obvious environmental problem existed or was suspected there. For another, the original function was no longer cost-efficient. Both reasons were given independently of each other, it was not possible to assess whether environmental issues may have potentially contributed to the economic evaluation. In one study case, protests from the community (because a landfill has been misused) have led to the closure of the site. Other reported reasons for closing down the sites were urban restructuring, housing projects and privatization.

3.2.3. Contamination and its (risk) assessment

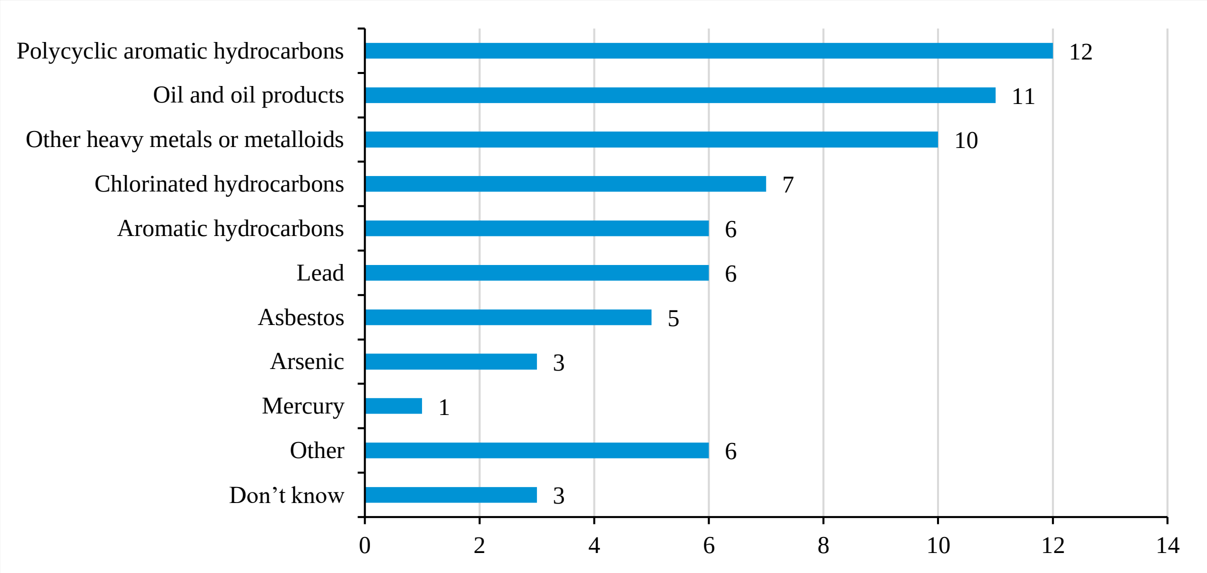
Contamination of the soil and sediments were reported in 27 and 8 case studies respectively (*Fig. 11*). This suggests that soil is almost inevitably affected in case of contamination. However, ground- and surface water were affected in 19 and 11 sites respectively. Outdoor as well as indoor air were affected less frequently (n = 8, n = 6 resp.); contaminated food was reported twice. Furthermore, the findings of the survey show that contamination of environmental media often occur simultaneously, with an average of three contaminated media per site. The most polluted sites showed simultaneous contamination in five or six media, always including soil, groundwater, sediments, outdoor air and indoor air, and in some cases also surface water.

Figure 11: Media of contamination (n = 28, multiple response)



A large variety of contaminants were reported for all redevelopment sites. Regarding the main groups of contaminants, the case studies mentioned polycyclic aromatic hydrocarbons (PAHs) most frequently (n = 12), followed by oil products (n = 11) and heavy metals or metalloids excl. lead, arsenic or mercury (n = 10). Less frequent contaminants were chlorinated hydrocarbons, lead, aromatic hydrocarbons, asbestos, arsenic and mercury *(Fig. 12)*. The “Other” category included e.g. methane gas, sulphates or physical hazards like glass or metal rebars. On average, 2.5 contaminant categories were reported per site, indicating that contamination is seldom caused by one types of compound only and thus generating challenges for remediation and redevelopment.

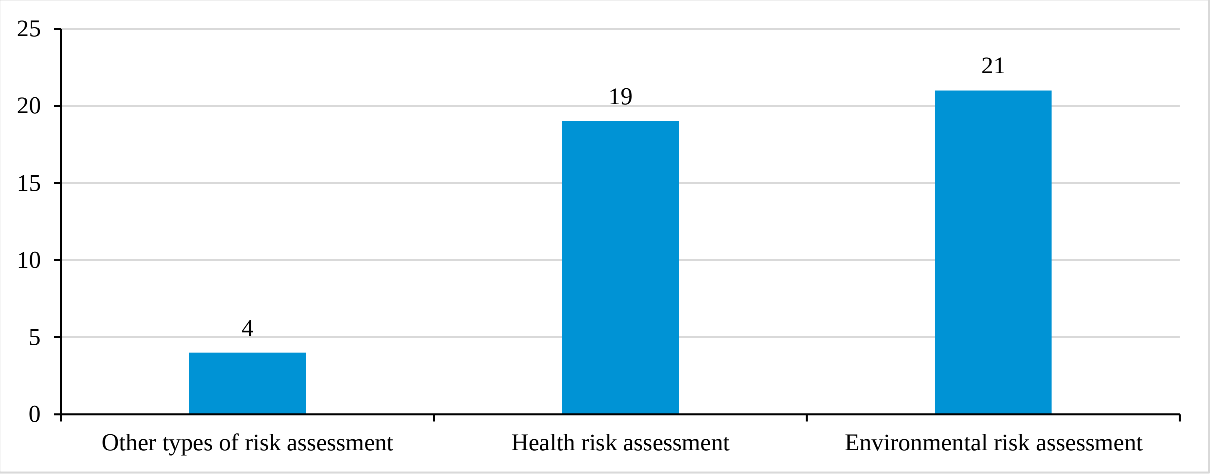
Figure 12: Main contaminants (n = 28, maximum of three responses)



The survey also revealed a strong diversity of the contamination context and its causal factors. The most frequently mentioned conditions which fostered contamination were “Ineffective technologies and practices” (n = 13) as well as “Lack of or weak environmental regulations” (n = 11), both indicating that the contamination could have been prevented by better technical and regulatory standards. This also applies to the further mentioned reasons “Illegal waste dumping” (n = 9), “Non-compliance with environmental regulations” (n = 6), “Lack of monitoring or emission control” (n = 6) and “Unsuitable site closure procedures” (n = 4). Only “Accident on the site itself” (n = 4) seems to be a less preventable factor, but this was never the only reason for contamination. Therefore, adequate site management and strict enforcement of environmental regulations could have possibly prevented contamination in many cases.

Regarding site investigations and/or risk assessments, 25 case studies reported that these measures were carried out after site closure and before remediation, aiming to identify potential contamination and to assess the risks for human health or the environment (three case studies did not know). From the 25 reported investigations, 21 included environmental risk assessments, 19 covered health risk assessments and four investigations were classified as “Other types” *(Fig. 13)*. Legal frameworks for risk assessment during site investigation existed for all but two case studies, while one study could not provide any information on this issue. The frameworks were mostly based on national level (n = 16); however, also regional (n = 4) and international (n = 2) frameworks were reported. From 22 case studies reporting on regulatory frameworks for risk assessment, 16 rated them as effective, while three stated that the regulations were not strong enough.

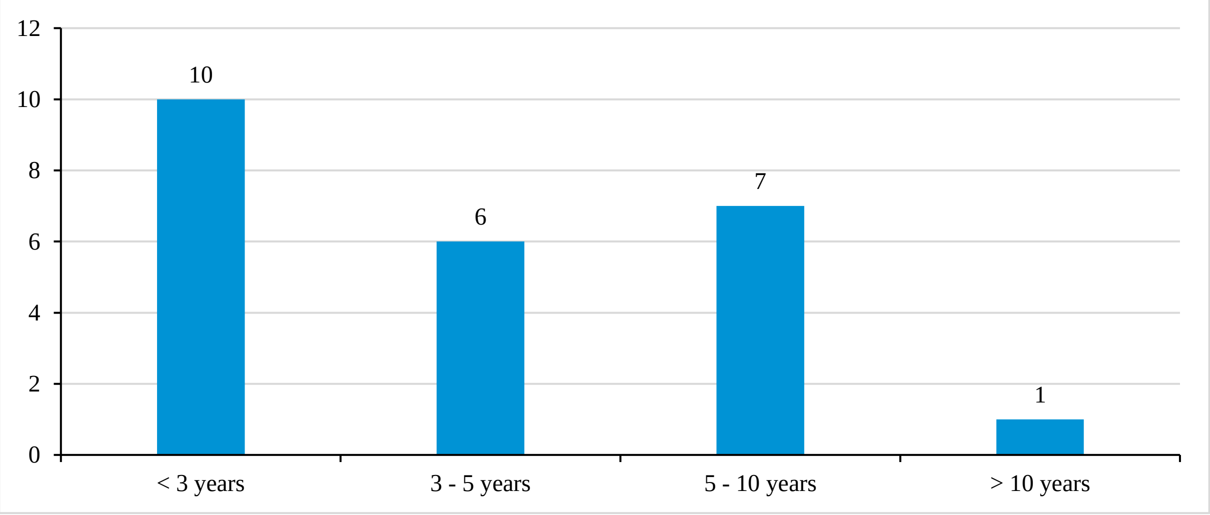
Figure 13: Type of risk assessment (n = 25, multiple response)[3]



3.2.4. Remediation

Remediation[4] measures were conducted in nearly all redeveloped sites (n = 24), only two case studies negated the answer and two did not know. This shows that in most cases, remediation steps are necessary before new functions can be established. Figure 14 depicts that most remediation projects took less than three years (n = 10), the remaining ones ranged between 3-5 years (n = 6) and 6-10 years (n = 7). Only one remediation project lasted for more than ten years, due to the detection of unexpected contaminations on a large site and the associated delays.

Figure 14: Timespan of remediation (n = 24)



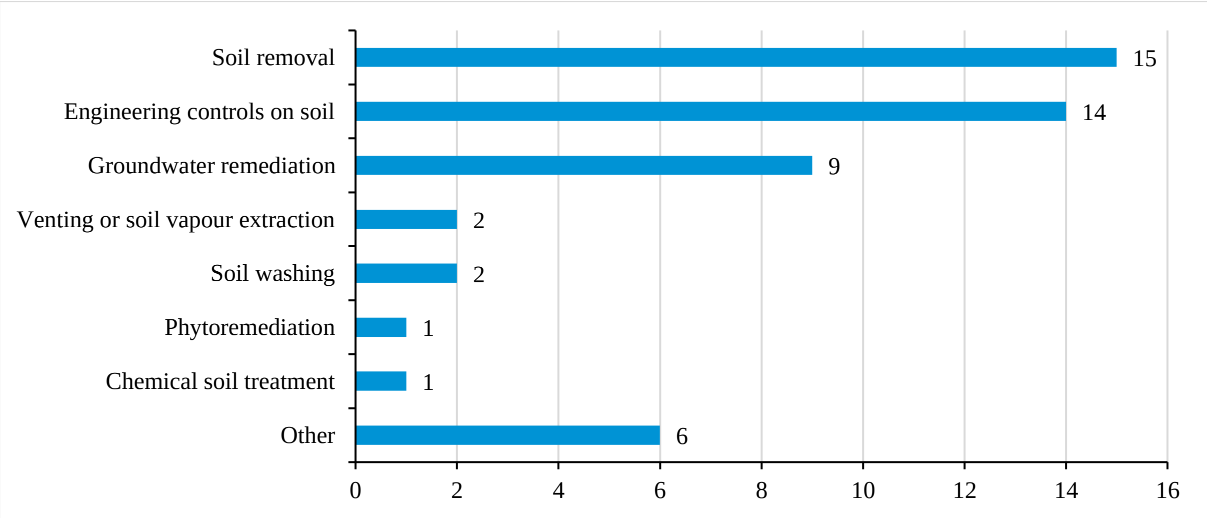
[3] The results may be affected by various factors, such as different terminology and understanding of assessment approaches used in different countries, or the time span between the implementation of the respective assessments and the reporting in the case study.

[4] Remediation is an umbrella term that includes a variety of different technologies, such as physical removal of contaminants from the site or on-site measures such as engineering controls or bio- and phytoremediation (aiming to manage the contamination on-site and prevent/reduce the risk by isolating the contaminants or degrading them to non-toxic substances). Information on remediation techniques is beyond the scope of this report.

The remediation costs, which spanned from ten thousand to 100 million Euros, were largely borne by regional/national (n = 15) or local (n = 8) public institutions. Two cases stated that a public-private partnership financed the remediation and in one case, the private investor for the redevelopment took over the costs. Only in two cases, the previous owner responsible for the contamination financed the remediation work, and in one of these two cases this owner continued to use the site after the remediation. Yet, these findings indicate that it is difficult to implement the “polluter pays principle” in practice. In contrast to the remediation costs, which are mainly financed by public institutions, private companies were most often responsible for the technical remediation work (n = 14). However, local or regional authorities were involved in 12 case studies as well. Less frequent was an involvement of public or state agencies (n = 7) or research institutes (n = 2).

As soil contamination was prevalent in nearly all case studies (see *Fig. 8*), most of the remediation techniques focussed on soil removal (n = 15) and engineering controls on soil (n = 14), the latter including for example capping, soil sealing, or physical barriers to isolate the contamination. Groundwater was remediated in nine cases (e.g. through extraction wells) and six case studies reported “other” techniques (additional soil treatments or specific techniques related to specific compounds). Less often, remediation included soil washing (n = 2), venting or soil vapour extraction (n = 2) and phytoremediation or chemical soil treatment (n = 1) *(Fig. 15)*.

Figure 15: Remediation techniques (n = 24, multiple response)



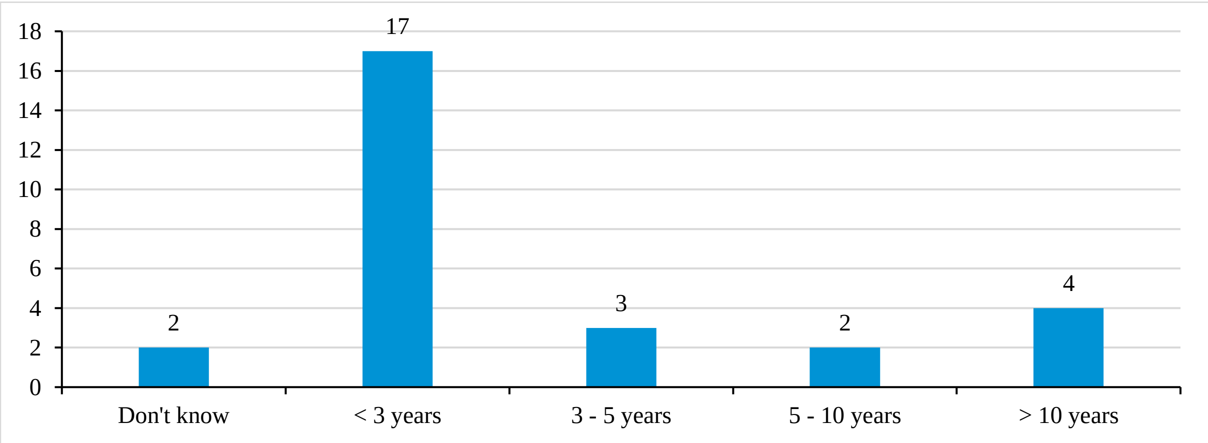
Legal frameworks were applied in 21 case studies to guide the execution of remediation. Six of those originated from regional and 15 from national level. Only in one case, no legal framework was available, and two respondents could not respond to the question. The reception of the legal frameworks was overwhelmingly positive, with 16 case studies stating that they helped to facilitate the remediation process. No negation of this statement was reported, but three cases did not know. Two case studies reported that there were only legal frameworks for parts of the remediation process, and that they would have appreciated more guidance.

Case studies reported different challenges during remediation. One major challenge during the process was coordinating the work of authorities and stakeholders and establishing their involvement in the decision-making process. Another challenge mentioned in three studies was gaining the confidence of residents who had concerns about contamination. Some case studies specifically reported unexpected challenges during the process of remediation. These referred to aspects of the work process, such as unexpected ground conditions, limited access to the site, or the development of appropriate and economical recycling processes for the removed material. In two cases, additional funds had to be obtained to repair unexpected damage to the site and to conduct health risk assessments. In one case study, vandalism caused an unexpected release of asbestos. Two studies reported that the timeframe for remediation was very short.

3.2.5. Redevelopment

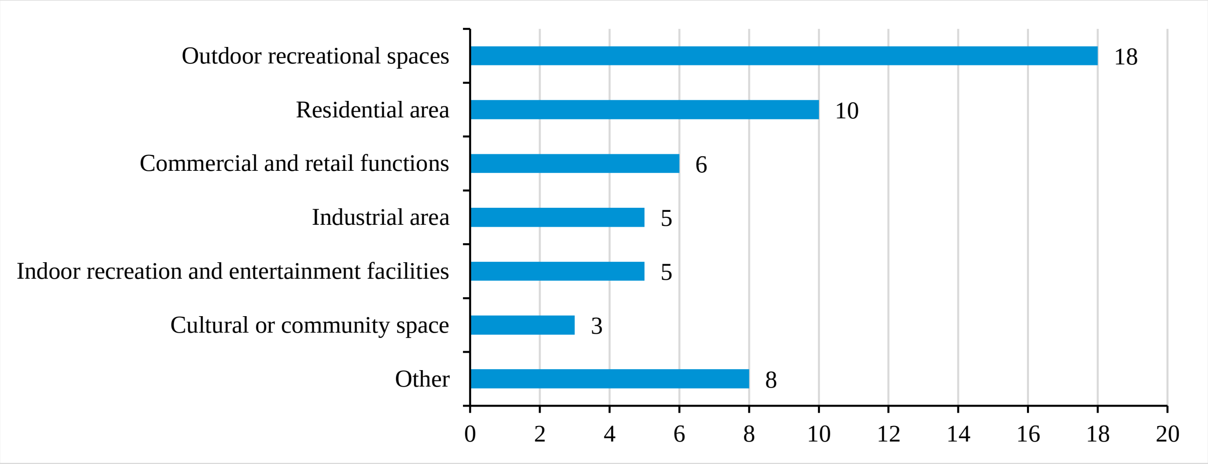
In all but three sampled study cases, redevelopment started in the 2000s or later. The earliest start of redevelopment was dated to 1984. In most cases, the redevelopment of the sites took between one and two years (n = 17). Three cases stated a period from three to five years and two cases reported five to ten years. At four sites, redevelopment took longer than ten years. In two cases, respondents did not know about the exact time span *(Fig. 16)*.

Figure 16: Timespan of redevelopment (n = 26)



After redevelopment, the sites had on average two functions. The majority of sites are currently used as outdoor recreational areas (n = 18) or indoor recreation and entertainment facilities (n = 5). Common new functions are residential areas (n = 10), followed by commercial and retail functions (n = 6) or industrial areas (n = 5). (Note: industrial functions are never the only function of the redeveloped site, as defined by our eligibility criteria.) Only few sites are used as cultural or community space after redevelopment (n = 3). Interesting is the high number of the “Other function”-category (n = 8) *(Fig. 17)*, however, almost all of these can be assigned to the existing categories (e.g. the utilisation of the former contaminated site as mineralogical park, a lake with water sports, a recycling park, a natural reserve or a comprehensive inclusion into the urban environment in form of an area for hospitals, hotels, schools and universities).

Figure 17: Usage after redevelopment (n = 28, multiple response)

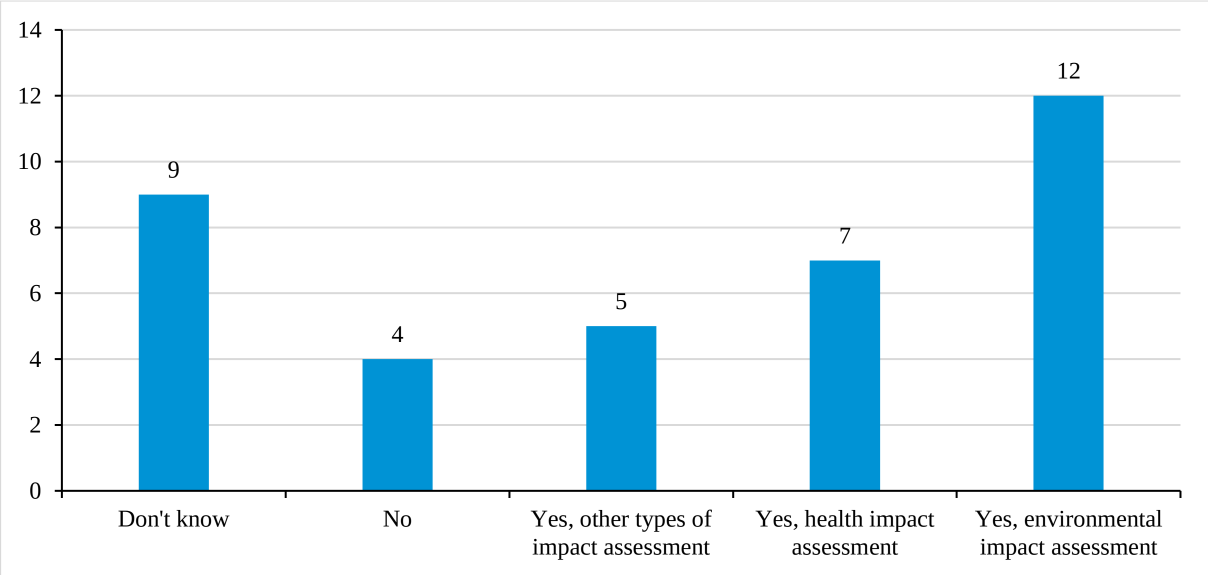


Only eight projects were able to provide insights about the cost of redevelopment. The values range from around 150.000 up to two billion Euros, showing an enormous variation. However, many respondents cautioned that project costs for remediation and/or redevelopment were hard to separate.

The distribution of ownership between public and private entities slightly changed after the redevelopment, which is much related to the fact that the redeveloped sites are often split up into individual lots with different functions and thus can have more than one owner. The biggest difference in ownership is seen in 22 sites now including public authority ownership, compared to 15 previously. The number of sites including ownership by private companies (n = 6) and public-private partnerships (n = 3) remained the same. In addition, four sites included an ownership by private individuals, which was never the case before redevelopment and is mostly associated with the new establishment of residential homes. Vice versa, only two locations are now exclusively owned by private companies, compared to six previously. On average, the study sites were owned by 1.4 parties, indicating a diversification of ownership structures after redevelopment.

Focusing on the impact assessments, 12 case studies applied environmental impact assessments as part of the redevelopment process, while seven case studies carried out a health impact assessment. In five cases, the respondents mentioned other types of assessments (e.g. required by a legal framework or a yearly monitoring system). Only four case studies reported that no assessments were done during the redevelopment and a relatively high number of respondents were unsure about it (n = 9). In two cases, the remediation phase assessments were simply updated or considered as sufficient.

Figure 18: Type of impact assessment for redevelopment (n = 28, multiple response)

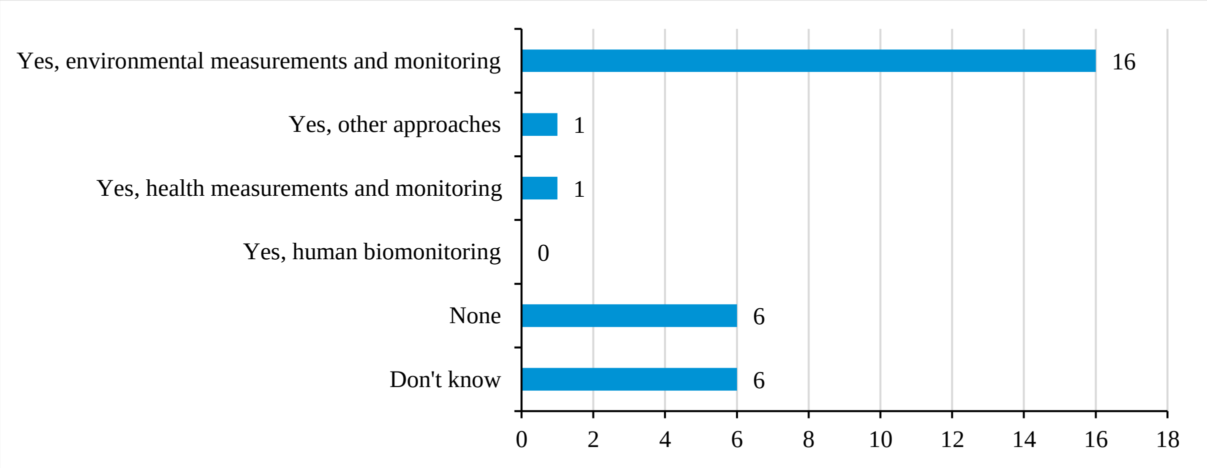


Despite the implementation of risk assessments across almost all projects, previously unknown contamination was discovered during redevelopment in every fourth case study (n = 7). Only fifteen case studies reported that this was not the case, while it remained unclear in six cases. Among the previously unknown contaminations, case studies reported soil contamination (e.g. with hydrocarbons), mercury in coal tar, fluoro-edenitic fibres or methane. Most of these discoveries have likely resulted from an insufficient site assessment before, during or after remediation. This shows the complexity of remediation and redevelopment as well as the importance of well-planned risk assessments and regular site monitoring.

3.2.6. Monitoring of risks after redevelopment

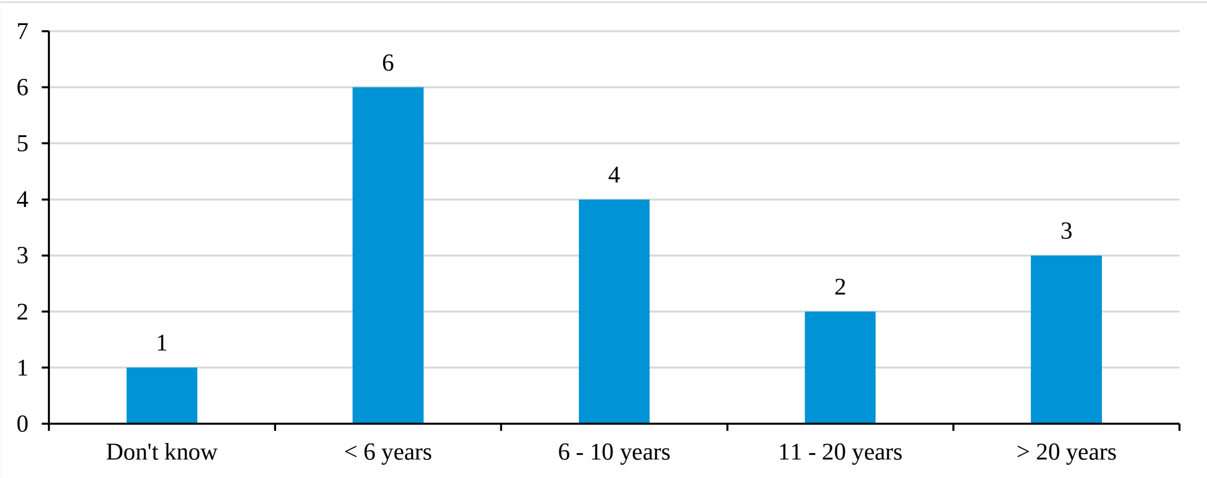
To avoid and detect potential environment and health risks early after redevelopment, more than half of the case studies have installed monitoring schemes (n = 16). Six case studies did not implement monitoring, and six did not know. Most of the established monitoring was in form of environmental measurements and monitoring (n = 16), while only one case study applied health measurements and monitoring. One case study restricted the residents in their daily use of their plot, such as not pumping groundwater and the prohibition to dig deeper than a meter in the garden. Human biomonitoring was not used by any of the case studies *(Fig. 19)*.

Figure 19: Types of monitoring (n = 28, multiple response)



The 16 case studies gave further information on their monitoring schemes, specifying the period and the monitored media and/or substances. Regarding the time frame, most monitoring was set for a duration less than six years. Four case studies indicated six to ten years, while five monitoring processes were planned for more than ten years, of which three case studies even reported no fixed end date *(Fig. 20)*. Monitoring is mostly carried out continuously and ongoing, although at different frequency. Not all studies specified this, but examples ranged from one to six-year cycles. The monitoring approaches included ground- and surface water quality controls (n = 11), pollutant analysis of the soil (n = 4), air quality controls (n = 2) and water plant, aquatic species and bird control (n = 1). Only one study reported on health monitoring, which included collecting data on the incidence of diseases such as mesothelioma.

Figure 20: Length of monitoring (n = 16)



From all 28 case studies, there were three sites where environmental risk or health problems – possibly associated with the former contamination – remained active after redevelopment, which shows the relevance of continued monitoring after redevelopment. The reported problems concerned the expected increase of disease cases (mesothelioma) that is likely to take place despite remediation efforts, and a possible leakage of contaminants to a drinking water aquifer. Another case study highlighted that natural cleaning processes in contaminated sites take a long time and environmental health issues can arise especially when these processes are hindered and cause potential threats to residents, livestock and the environment. In addition, other non-natural waste management processes, such as burning, can cause additional damage due to pollutants generated during combustion.

3.2.7. Potential wider implications of redevelopment projects

As part of the survey, case study contributors were asked to rate the wider urban, environmental, and social and economic impact of the redevelopment across 15 questions, where their approval to certain statements were measured on a five-point Likert-scale from "Strongly disagree" (1) to "Strongly agree" (5) with an additional "Don't know"-option. One question measured the overall success of the redevelopment project, while the remaining 14 items were *a priori* categorised into three topics. The social and economic dimension comprised seven items describing changes in the social texture of community (i.e. gentrification, effects on vulnerable communities), increasing social liveability (i.e. drop in crime, space for social interaction), and wider economic aspects of the redevelopment (i.e. job opportunities, further investments, increasing property values). Four items captured changes in the physical environment including items on green space, transportation, accessibility to recreational and cultural activities, and cleanness of the neighbourhood. Finally, the health and wellbeing dimension included items on quality of life, wellbeing and physical activity among residents. The full overview of the ratings, and the mean values per question, are provided in *Annex 2*.

The majority of the case study contributors agreed that the redevelopment is *"overwhelmingly seen as successful by the public"*, suggesting a high acceptance of the projects within the community (Ø = 4.3). Responses across specific items and dimension, however, largely varied indicating varying impacts on different dimensions[5]:

- **Social and economic dimension**: While the respondents generally suggested positive changes in this aspect (Ø = 3.8), some statement were more contested than others. Opinions were diverging and inconclusive whether redevelopment led to gentrification in the area (Ø = 3.2), and the majority of the case study contributors did not know (n = 16) whether crime – an important indicator of social liveability – has changed in response to the redevelopment. Project impacts on equity (i.e. benefits for vulnerable groups) were also less known, with the highest number of respondents being undecided (n = 9). The only social aspect with substantial agreement was the creation of new place for community interaction and exchange (Ø = 4.2).
  On the other hand, respondents were more confident about project impacts linked to further investments (Ø = 4.4), job opportunities (Ø = 4.0), and increased property values (Ø = 3.9); representing economic aspects that the case study contributors may have been more familiar with and which can also be better judged by external persons not residing in the neighbourhood.
- **Physical environment**: Respondents agreed on positive changes in the physical environment following the redevelopment (Ø = 4.0) and were particularly positive about greater availability of green space (Ø = 4.3) and recreational and cultural activities (Ø = 4.3). Also, they perceived that the area became cleaner after the project has been finished (Ø = 4.0). Improvement in public transportation (Ø = 3.5), however, did not necessarily follow redevelopment projects, or respondents knew less about these initiatives.
- **Health and wellbeing:** Participants were overwhelmingly positive about the health and wellbeing impacts of redevelopment, with the highest average score across the three dimensions (Ø = 4.4). They suggested that the quality of life of the residents has

[5] It is to be acknowledged that these ratings are based on one response per site and might be affected by the very different project timelines with some redevelopments being finished rather recently, and others decades ago.

significantly increased (Ø = 4.5), and so did their wellbeing (Ø = 4.4). Moreover, it was reported that residents became physically more active after the redevelopment finished (Ø = 4.3), which might be linked to the greater availability of green space and recreational activities indicated above.

In conclusion, the redevelopment projects were seen as largely successful for most of the sites, with beneficial health and wellbeing impacts and positive changes in the physical environment, supporting healthy urban spaces and providing wider economic opportunities for the residents. The social impacts of the redevelopment seemed more difficult to assess for case study contributors, potentially because of missing information.

3.2.8. Lessons learned

Key experiences

Key experiences, main challenges and enabling factors mentioned by the participants are manifold. An integrated and comprehensive remediation process, in which cooperation between authorities, residents and other stakeholders is promoted, was mentioned by many as a way of enabling the pursuit of different objectives and thus promoting both acceptance and willingness to cooperate. In this context, remediation and redevelopment have been described as a *"social, political as much as a technical project"*, highlighting the benefits and importance of a comprehensive approach. In this way, a variety of objectives can be pursued, maximizing the benefits for as many stakeholders and persons involved as possible. In one case study, remediation and redevelopment enabled local companies to avoid relocation and to develop urban living spaces close to schools, shops and restaurants [24]. Participation also encourages stronger commitment, which was seen as particularly important for successful implementation. In this context, the consideration of the public was often seen as a particular challenge. This involves taking away the public's concerns about health issues and additional contamination caused by the remediation and finding compromises, for example when residents had to move. The study respondents saw successful involvement and commitment as well as transparency towards the residents as a key factor.

Another challenge was not harming the environment or reducing the harm through the remediation process. This involves the potential release of pollutants that may be discharged into groundwater, or the destruction of vegetation and animal habitats. The reuse of destroyed material was in one case used to create new habitats to compensate for any damage caused by the remediation. The need for a legal and regulatory framework was also expressed, as it did not exist for all case studies and makes it a great challenge to assign responsibilities and implement processes.

Role of public authorities

In most cases, local or regional authorities have been attributed a central role, as they often assume supervisory functions and steer decision-making processes. They are also attributed a decisive and responsible role in communicating with the population. Often, local/regional authorities themselves initiate rehabilitation processes, which sometimes would not have been possible without their participation.

Despite their central role, many public authorities have insufficient capacities to coordinate contaminated site remediation and redevelopment projects. The question of whether the public authorities should have more or less responsibilities was answered directly by only a few, suggesting that the roles should either be further developed or remain the same.

What worked well

Several case study contributors indicated what they would carry out the project in the same way as they did. One aspect mentioned by many was the focus on sustainable environmental protection during remediation and redevelopment. This included proper waste management and recycling methods such as biodegradation instead of physical treatment / removal as an example of sustainable remedial solutions. In order to pursue this focus, cooperation with local authorities and technical experts as well as adherence to legal guidelines was highlighted as helpful and beneficial.

Many case study contributors highlighted that they made good experiences with informing the local community about the remediation. This way concerns about pollution and contamination could be allayed. In general, involving the local community and site users was considered positive. This is also related to the fact that many case studies indicated that they would put the focus back on the community and neighborhood needs when redeveloping a site. This includes, for example, the creation of green parks and good accessibility to the site.

The creation of a common vision for redevelopment was considered essential for the cooperation of the various parties involved in such projects. For an effective coordination, a close supervision and the engagement of a project manager were found to be good and useful as well.

What to do differently

Identifying the lessons learned on less successful approaches and processes, case studies stressed the necessity for an early and detailed environment and health investigation, and adequate measures to protect health and safety of workers on-site. This also includes efforts for the sustainable use of resources, for example the reuse of old buildings instead of destroying them, and the creation of a legal framework for waste management.

Some case studies underestimated the time needed to introduce and maintain an integrated approach on the redevelopment, which requires good communication between involved actors and stakeholders. It was also mentioned that project timelines can be significantly affected by unforeseen external factors and that this should be considered.

Another lesson learned was to pay more attention to publicity and informing and involving the local community earlier. One idea, for example, was to hold events where different stakeholders and local communities are brought together. In this context, it was mentioned that in general an involvement between the community and the site should be established, perhaps through an interim use before or after the remediation (such as making the site available for public events or community groups) or through active engagement of the community in the discussion on the future function of the site.

Some case study contributors mentioned that there should have been better inclusion and coordination of the parties involved, and that the capacities of all stakeholders should have been brought together in a more harmonized way, including the distribution of financial resources to public administrations.

As for the preservation of the site's history, some case study authors reported that more attention should have been paid to it, as much infrastructure has now been destroyed. Other aspects mentioned were the need to establish a centralized data storage system and tighter document control, more proactive supervision on remediation and redevelopment projects, and the importance of securing long-term maintenance after site redevelopment.

Transfer and outlook for future projects

The case study contributors presented a list of helpful experiences, which they gained in the course of remediation and redevelopment. These experiences often refer to challenges in the initial phase and to the cooperation between interest groups and stakeholders throughout the remediation-redevelopment process. Listed below are the essential recommendations of the participants for future projects:

- Examine and monitor the site detailed and carefully before taking action;
- Study health data for the affected population to identify problem clusters that can be associated with the site's history;
- Involve experienced staff and technical experts in assessment and decision-making;
- Focus on and include local residents and their needs early in the planning process;
- Active involvement of different parties leads to various solutions and overall benefit;
- Clearly allocate responsibilities for project management;
- It is essential to enable good communication between stakeholders throughout the process;
- Consider the sites historical background and use it as a potential opportunity for redevelopment.

3.3 Synthesis of follow-up and expert interviews

A total of nine semi-structured interviews were held after the case study compilation, aiming at a better understanding of the on-site situation and the local challenges that had to be addressed, and what processes were applied to manage the process and coordinate all stakeholders. Semi-structured interviews were carried out through online conference calls with the case study providers, sometimes including additional local experts knowledgeable on the site.

The purpose of this section is to summarize the key findings and common patterns from these expert interviews, and to derive lessons learned as well as "good practice elements" that may provide useful insight for other public authorities dealing with the conversion and redevelopment of contaminated sites.

The analysis of the interview data identified six general themes which were recognized by several interview partners:

(1) Shared vision
(2) Legal frameworks and their implementation
(3) Technical aspects of contamination assessment, remediation and monitoring
(4) Impact of timelines
(5) Community involvement and participation
(6) Role of local authorities

This section is hence structured around these six themes, presenting the local challenges and solutions and aiming to provide actionable information to decision-makers.

3.3.1 Creating a shared vision

Almost all interviewees stressed the importance of establishing a commonly shared objective for the project site and its future functions. Consensus by various actors and stakeholders on how the site shall be redeveloped would then provide the guiding principle for

(1) technical collaboration and planning, and
(2) the implementation and interpretation of sectoral regulations, tools and requirements.

This can help to smoothen the implementation of projects that, due to the involvement of many sectors and regulations, can often be complex and affected by conflicting regulatory frameworks (e.g. when the regulations aim to protect different environmental media, or foresee different procedural requirements – see section 3.3.2 on legal frameworks and 3.3.6 on the role of local authorities)(5, 16, 20, 23). Naturally, such a shared vision should include environmental and health aspects, assuring adequate and remediation and safe future functions, as a counterpart to commercial interests that may possibly dominate the discussion.

To establish a shared perspective, interviewees considered it important to involve all relevant stakeholders at an early stage (14, 29) and establish consensus on remediation and redevelopment – a process that takes time and requires openness to other sector's positions and requirements (16). However, without the establishment of a shared understanding of the future for the site, individual sectors and their regulations can block each other, leading to delays and a potential focus on side issue conflicts (6, 20). It is therefore paramount that actors do not lose sight of the shared vision.

The expert interviews suggested that a commonly shared perspective can be more easily developed when external stakeholders and investors have a genuine interest in successful site remediation as a precondition for any further development (6, 14, 16, 23, 29). Several of the interviews showed that the development - and subsequent implementation - of a shared vision can be supported by institutionalized arrangements, bringing the different actors and stakeholders together through a more or less formalized platform and establishing formal consensus on the site and its redevelopment (5, 16, 20, 29). Such approaches can also help to provide legal and procedural security for large conversion projects that may take many years and thus be affected by political changes (see sections 3.3.2 on legal frameworks and 3.3.4 on timelines). Examples of such arrangements are shown in Box 1 below.

Box 1: Examples of intersectoral platforms and agreements

- Establishment of specific public bodies (at local and/or regional level) to coordinate conversion, remediation and redevelopment on behalf of local authorities has been successfully applied in case studies from Rutherglen (UK) (5) and in Barcelona (Spain) (20). These entities can provide a more comprehensive approach and compile valuable capacities on site conversion.

- Current legislation on brownfield conversion in Flanders, Belgium foresees the establishment of a tailored agreement (called "covenant") signed by developers, public authorities and the Flemish Government (16). As part of the covenant, a neutral public sector negotiator is appointed to facilitate the project.

- An agreement on the redevelopment of former mining sites has been signed between the German Federal State of North Rhine-Westphalia, mining companies and affected communities (29). The agreement provides legal and procedural security to the participating entities and enables the establishment of consensus-based redevelopment scenarios.

3.3.2 Improving legal frameworks and their implementation

In many interviews, the relevance of a functional legal framework was stressed. National frameworks and regulations are relevant for

(1) local and public authorities, as such frameworks provide the mandate for action on contaminated sites,
(2) public and private stakeholders, as the frameworks establish technical and performance standards to be implemented (and which can be prosecuted in legal conflicts) (12), and

(3) companies and remediation consultancies, as clear frameworks can help to "create a stable market" for professional companies offering services or investing in remediation sites, based on a firm legal framework and procedural security (16).

Detailed and clear regulations and standards enable effective implementation and allow local authorities to redevelop contaminated sites without too much uncertainty (16). In parallel, a reliable regulatory framework also provides attractive opportunities and a safe market niche for consultancy companies offering specialized services (6, 16, 20). Vice versa, the lack of national frameworks exposes all interventions and decisions to case by case negotiations between the involved stakeholders, and creates challenges because of the absence of standards or procedures (12, 16). This provides a challenge specifically for smaller municipalities that do not have the capacities to deal with such complex projects on their own (17). In addition, strong norms and standards reduce power games and procedural disagreements between different actors, protect ongoing site remediation against political changes and preferences within local governments, and decrease undue influence by polluters or investors who are mainly interested in limiting the expenses for cleaning and remediation. A sound regulatory frame should therefore include rules for managing possible legal conflicts with ascertained or suspected polluters (17).

Several interviews indicated that the diversity of sectoral regulations (soil, water, air, chemicals…) is difficult to handle, especially as site remediation requires many approvals and bureaucratic procedures and some of the sectoral frameworks may even be in conflict (5, 6, 14, 20, 23), calling for harmonized approaches (see section 3.3.1). In some places, there may also be restriction to the adequate enforcement and implementation of the legal framework due to limited resources and capacities (12). Some interviewees were also concerned that the focus on environmental regulations and standards leads to an insufficient coverage of health aspects or other impacts (12, 23), which is also reflected by the rather low involvement of health authorities in the case studies (see section 3.2). This is particularly relevant when a remediation site has low levels of contamination and low value economically, which means it can still affect people’s health but is not necessarily a local priority for cleaning and redevelopment (23).

It was suggested to consider the legal framework on remediation in the context of the future use of the site, focusing on the new functions to be redeveloped and targeting the clean-up measures that provide the best match with the redevelopment plans. In some cases, remediation and redevelopment may even go hand in hand technically, especially on larger sites with overlapping project timelines for remediation and redevelopment (14, 16).

Various shortcomings of legal frameworks were identified, such as the fact that they cannot be easily applied and enforced in private settings so that local authorities can only provide recommendations (17). In specific cases, such as asbestos contamination, the protection of workers´ health may also be a challenge as respective regulations focus on building demolition and cannot be fully transferred to soil remediation (20). Furthermore, legal frameworks may provide a good basis for managing contamination but – at least based on the situation when the case studies were implemented - were potentially less helpful in preventing the contamination itself (14). In that context, it is necessary that legal frameworks (a) allow for a better control of site closures or sales of potentially contaminated land, enabling environmental investigations and interventions at an early stage (6, 12, 16, 20, 23), and (b) cover all kinds of contaminating industries or activities (including landfills) rather than only larger plants or specific industrial sectors (14, 20). This would also enable local authorities to better implement the “polluter pays principle” by requiring the responsible entity to clean-up the site, which was not the case for most of the interviewed case studies (5, 6, 12, 16, 17, 20, 23). However, next to the availability of a legal framework, there is also a need for public authorities to fully implement and enforce the regulations, which again depends on resources and capacities (6, 14, 20, 29).

Box 2 below provides selected examples of the benefits that can be realized by adequate legal frameworks and regulations.

Box 2: Examples of benefits associated with adequate legal frameworks

- Experiences made during a remediation project in Barcelona (Spain) contributed to incorporating due diligence investigations as a good practice when potentially polluted land changes ownership. This practice enables identification of unknown or unreported pollutants and allows for regulations making the polluter, or the owner collaterally, accountable (20).
- In the Netherlands and in Flanders (Belgium), regulation changes enabled the development of new methods (6) and an increasing expertise in external service providers (16) due to the provision of a solid legal framework. This changed the feasibility for action and remediation, lowered the costs and enabled remediation that was considered too expensive before (6).
- The establishment of a new soil remediation policy in Flanders (Belgium)(6) and the Italian national action programme on priority contaminated sites (17) were associated with the provision of standardised operating procedures, making case management more consistent and enabling local actors to fall back on these standards.

3.3.3 Supporting contamination assessment, remediation and monitoring

The findings in section 3.2 indicated that site investigations were performed in all of the 25 case studies for which information was available. This shows the relevance of assessing the contamination before starting any remediation work, and highlights the role of local authorities to assure such investigations are carried out before further use of the site. The challenges identified by the expert interviews include

(1) the lack of records and information on the contamination status of the site (see section 3.3.4), making detailed site investigation a necessity,
(2) failure to implement a thorough risk assessment before remediation and redevelopment, resulting in unexpected surprises, project delays and budget increases, and
(3) the potential risk of activating and mobilizing contaminants during the remediation process.

Many expert interviews identified the unexpected presence of contaminants as a key problem for the local conversion project (5, 6, 12, 20, 23), which in some cases even affected the process of redevelopment (14). Most often, this is due to a lack of information on the site status in general, but can also be caused by weak legal standards or their enforcement (12), and the illegal dumping of e.g. compounds that are not matching the former use of the site (5, 6). Gathering information on the site from different sources and stakeholders is therefore a most important task, aiming to get a basic overview of the potential contamination sources and pathways that can inform a proper site investigation with measurements (16). A site-specific investigation should be the basis for any further action, making sure that no contamination is overlooked when preparing the remediation plans (5, 16) and that health-based assessments complement the legally required environmental assessments (12). A failure to carry out such a detailed site investigation can affect the whole remediation schedule as well as the budget (23), and create additional challenges when the contaminated land is already sold to different owners for redevelopment (14, 20). Furthermore, it is necessary to have legal standards and regulations based on which environmental risks can be assessed and quantified, a lack of such guidance may lead to both inconsistent and inadequate results (12).

Another practical issue raised was that, especially on larger sites, there can be mixed contamination in various spots and with different concentration levels, making it difficult to apply the appropriate procedures across the affected site (14, 17). It is therefore necessary for any risk assessment to understand how contaminants may have spread beyond the site, especially if ground water and aquifers were affected (16).

At various sites, problems arose in relation to contaminants such as asbestos / asbestiform fibres or some chemicals that could - if mobilized or activated - lead to environmental or health risks for the local population and especially for on-site remediation workers (5, 14, 16, 17, 20). In two studies, the safest remediation technique was to isolate and cover the contamination, rather than physically remove it (6, 20). A specific case study in that context is the city of Biancavilla (Italy), where much of the local infrastructure and housing stock has been built with a local stone contaminated by an asbestos-like fibrous mineral (17). Therefore, next to the local quarry, the whole city represents a contaminated site; removing the material (where feasible) will be an expensive long-term project requiring specific protection measures for both workers and local residents. This shows that monitoring and frequent measuring of environmental risks is often needed during the remediation process, and especially (a) when asbestos contamination occurred and (b) for larger projects where remediation may be at different phases and possibly overlaps with first stages of redevelopment, raising an additional need to protect workers (5, 14, 17, 20). Similarly, remediation projects in or close to nature areas need to specifically consider the environmental impact of the remediation, involving nature protection legislation and requiring specific studies and measures as well as environmental monitoring (6).

Many of the follow-up interviews indicated that monitoring of environmental conditions took place after the remediation (6, 14, 16, 17, 20). It is important to note that the monitoring is not an indication of unsuccessful remediation, but rather a precautionary approach that is often stipulated by environmental regulations and, therefore, an integral part of the remediation concept (14, 16, 17, 20). This may especially be the case when parts of the contamination have been left on the site and any potential risk to groundwater is to be excluded (6, 16, 20). Former waste sites may still have a production of methane gas in the soil (e.g. as a degradation product of chemical compounds), which needs to be monitored (6, 14). The timelines for monitoring vary from a few years (16) to very long time periods, potentially without end date and depending on the pollution levels (6, 14). In the specific case of Biancavilla (Italy), both environmental and health monitoring were implemented after the quarry remediation and clean-up activities in the city – looking at the exposure to the contaminants as well as monitoring the incidence of mesothelioma cases in the local population (17). Similarly, health issues of the population living nearby or on redeveloped sites may be a potential monitoring indicator to be considered, requiring local authorities to assure that e.g. a pattern of headaches in a day care centre is not associated with former contamination (14). Applied and communicated accordingly, monitoring can be an essential component to gain the trust of local communities that the site is safe, and any potential concerns are immediately followed up (14, 17). To that extent, it is important that monitoring is not considered as tick-box exercise, but also leads to action if necessary.

For the implementation of risk assessment, remediation and monitoring, specific capacities may be required. In this context, various case studies indicated the need and associated benefits of working together with external experts and specialized actors or laboratories with adequate background and experience in assessing and presenting contamination levels (5, 17, 20). To assure that local authorities and project coordinators involve and subcontract competent experts and consultancies, a national system of accreditation is very helpful (14, 16) (also see section 3.3.2 on legal frameworks and creating a market).

Box 3 below shows some examples on technical actions carried out in relation to risk assessment, remediation and monitoring.

Box 3: Examples of risk assessment, remediation and monitoring approaches

- Before starting the Cunningar Loop remediation in Rutherglen (UK), local authorities carried out a full site investigation to assure that no contamination was overlooked (5). Similarly, a remediation project in Aalst (Belgium) was reported to go smooth because a thorough risk assessment was done before, looking at contamination sources as well as its spread (16).

- The contamination occurring in Biancavilla (Italy) was identified through health surveillance approaches, showing a disease cluster in the city that could not be explained. Local investigations found that the material extracted from the local quarry was contaminated by fibres similar to asbestos. To assess and mitigate the contamination, environmental and health monitoring go hand in hand (17).

- In Amsterdam (Netherlands), the contamination by waste was identified to be fixed and not spreading. Therefore, rather than actively removing it, the decision was made to cover and cap the contamination and disconnect the pollutants from nature and humans. A monitoring system was installed to assure no impact on ground water (6).

3.3.4 Reducing the impact of timelines

The conversion and redevelopment of contaminated sites deals, by definition, with sites that have a history of contamination. In many cases, contaminating activities may have stopped several decades ago, and the sites were left unattended before redevelopment and conversion projects were confronted with the legacy of the past. The impact of site-specific timelines is therefore of high relevance, and can cause a variety of challenges for redevelopment projects. Based on the expert interviews, the following challenges could be identified:

(1) lack of or weak legal frameworks at the time of contamination and site closure, leading to unexpected and/or unreported contamination levels,
(2) extensive time periods between site closure and remediation works, increasing the risk of further damage on the site as well as the establishment of an interim flora and fauna, and decreasing the likelihood that former owners and polluters can be made accountable for the contamination, and
(3) access to historic site-specific information, which – even if it was recorded and archived – may not be available or accessible.

Remediation projects of older sites are more or less affected by all of these challenges (5, 6, 12, 14, 16, 20, 23).

The lack of records and information on contamination levels may have diverse causes: they may not exist at all, which often relates to weak environmental regulations (12), or they may be irretrievable for a variety of reasons such as changed filing systems, re-structuring of local authority departments, lack of digitalization, lack of a common identifier between different departments, data not being digitalized, or changes to the municipal jurisdiction boundaries (5). Furthermore, even if records are available and accessible, they may not provide adequate information to enable a decent risk assessment of the contamination status, partially because legal standards at that time may have been very different. The older the site, and the less recent the closure, the more difficult it can be to compile the respective information that are required for a sound assessment of the site status. In addition, after a long time period it is increasingly unlikely to make the former owners and polluters legally accountable for the contamination and the related remediation cost (6, 12, 16, 20, 23).

Several case studies pointed out that long periods without action on abandoned sites can also raise practical issues, such as continued dispersion of contaminants, establishment of new flora and fauna, or vandalism and additional pollution on-site (14, 16). Quick action on potentially contaminated sites after the close-down of their former functions is therefore important, and if this cannot be done local actors should consider interim site management and maintenance measures (14, 16). As many of the expert interviews have shown, this is a crucial challenge as the decision-making on remediation and redevelopment, and especially the selection of the new site functions, can take many years – or even up to a decade and beyond (5, 6, 16, 17, 23). This is also reflected by the case study findings, indicating that on average there was a time gap of more than 20 years between site closure and remediation for the 24 case studies with respective data. The German example of the coordinated management of coal mining site closures (29) shows the benefits of being able to anticipate industrial changes and allowing for timely planning of regional and local restructuring before site closures actually occur.

While local governments have little influence on the availability of records for old sites, they do have a significant influence on the compilation and archiving of data on active sites where polluting activities may still be carried out. They can also reach out to the respective actors and companies to learn about their future plans and be better prepared for forthcoming functional changes, and establish local or regional entities specifically dealing with contaminated sites and compiling respective data, as suggested in Box 4.

Box 4: Practice examples on managing the impact of timelines

- In Germany, the Federal State of North Rhine-Westphalia has signed an agreement with mining companies and affected communities on the redevelopment of former mining sites (29). The agreement predicts the phasing-out for the mining sites and therefore enables local authorities to plan future functions and redevelopment plans in due time.

- Experiences on the remediation of a contaminated site in Rutherglen (UK) has led to the understanding that a central data archive on contaminated sites is needed to enable more effective archiving of records over long time periods, and a first step in that direction is taken by involving the Scottish Land Commission as advisor on contaminated site projects (5).

- In Frankfurt (Germany) and Barcelona (Spain), remediation activities were started by local/regional governments rather soon after site closure. When unexpected contamination was discovered, it was therefore possible to identify the (still operational) former owners and make them accountable. In Frankfurt, the duty to remediate was transferred back from numerous land buyers to the former owner (14), while in Barcelona the previous owner assumed the costs of remediation work due to a signed agreement with the responsible public authority on the land condition (20).

3.3.5 Assuring community involvement and public participation

The redevelopment of contaminated sites is often associated with fears and concerns in the local community, resulting from past experiences and potentially enhanced by the perception of lack of action and commitment by responsible authorities. It is therefore important to reach out to the local communities, informing about and actively involving in the process. In this context, the experiences made by the interviewed case studies indicate the following points:

(1) There is a strong sensitivity in local communities when it comes to contamination and the establishment of new functions on contaminated sites;
(2) Community perceptions may not necessarily be based on evidence, but must still be respected and dealt with;
(3) Local authorities need to provide consistent and trustworthy information throughout the process.

Several interviews showed that local citizens are increasingly aware and active about the environmental conditions in and around their neighbourhoods, and that local civil society organizations play an important role in representing the community's expectations (6, 12, 16, 20, 23). In one case, public pressure was even decisive for site closure and remediation (6), while in another case the community was very vocal in their preferences regarding the new function of the site (23). It was therefore considered paramount to actively involve local residents at an early stage of such projects to better understand their fears and preferences regarding the conversion process (5, 6, 16, 17, 23). It was noted that adequate involvement in the remediation and redevelopment process will also generate an increased sense of ownership and assure that the new function is in line with local demands (5, 6).

However, managing public participation in sensitive environmental projects is not easy. One case study experienced that it is important to make sure that different community groups and representatives are equally involved, as some groups may be well organized but not necessarily represent all perspectives within the community (20). Another experience related to potential misperceptions in the community regarding the contamination and its effects, which e.g. affected the sales of local agricultural products (17) or caused a preference for removing all contamination when technically the best solution was to immobilize and cover the contaminated site (6, 20).

Reflecting these challenges, various interviewees stated that it is of utmost importance for local governments to be transparent at all times and provide clear, consistent and trustworthy information on the level of contamination and the remediation process (16, 6, 17, 20). In this context, it is important that local authorities publish adequate and evidence-based information on site-specific pollution levels and whether they are a reason for concern or not (16). If such transparency has not been the case in the past, it should not come as a surprise that especially environmental groups tend to mistrust local communication and decision-making (20). To avoid potential mistrust in official communications, one solution could be to collaborate directly with independent scientists and/or national institutions and have them deliver findings and guidance information directly to local residents (17). The adoption of structured communication plans (aiming to understand the severity of possible health impacts, the most affected groups, and the roles played by stakeholders) can also support transparency (17).

Finally, one case study suggested that the lack of appropriate public participation may generate increasing mistrust in local authorities and their decision-making, and that it takes long to regain the trust of the local community (20). It is therefore necessary for local authorities to walk the talk and inform transparently about contamination levels and remediation plans. Respective examples are provided in Box 5.

Box 5: Practice examples on community participation and outreach

- The city of Biancavilla (Italy) collaborated with national health institutions to inform local residents about the contamination-related risks and the required action steps. National institutions also helped to avoid potential stigmatization of agricultural products from the area (17).

- For the remediation of a waste site in a nature resort close to Amsterdam (Netherlands), local residents feared regional tourism and gentrification effects if the site was developed into a nature park attracting external visitors. They successfully pushed for a redevelopment plan tailored to local needs (6).

- Civil society organizations and citizen groups have an increasing relevance, and been able to influence political decision-making on the new functions of converted sites in various case studies. In Rutherglen (UK)(5), Mojkovac (Montenegro)(12) and Durham (UK)(23), local citizens opted for open and natural spaces.

3.3.6 Defining the role and mandate of public authorities

Local or regional governments play a crucial role in managing the identification, remediation and redevelopment of contaminated sites within their jurisdiction area. Irrespective of the ownership of the site, local authorities are the decision-makers for a wide range of relevant actions, such as the implementation of legal frameworks, the enforcement of environmental measures, the control of remediation measures, or the decision on future site functions and establishment of redevelopment plans. In addition, local authorities would need to manage the interests of various stakeholders in that process, including the coordination of public participation activities. Summarizing the expert interview input, the following experiences can be highlighted:

(1) Local / regional authorities have the mandate to request compliance with environmental standards and regulations, and therefore own most relevant decision-making powers. On the other hand, this mandate makes local governments responsible for the outcome of site remediation and redevelopment, and requires them to provide certain skills and capacities.
(2) Local / regional government departments are the counterparts for all legal and procedural aspects of the remediation and redevelopment process. Given the complexity of such projects, local authorities therefore have significant influence on the efficiency of formal procedures and the issuance of approvals.
(3) Public authorities need to be a role model in open and transparent communication that earns the trust of the local community.

Local or regional authorities are tasked with the enforcement of national laws on local level and therefore have many mechanisms to manage contamination and initiate remediation – be it to assure environmental safety, health protection, or simply the application of legal procedures (14). In some cases, remediation and redevelopment may be done to remove direct health threats (17), to establish new site functions (14, 16, 29), or to simply clean the site, rather than enabling new infrastructural redevelopments (6, 23). However, public authorities may themselves be very interested in and committed to such remediation processes, as it helps them to define future functions on sites that can complement and/or further diversify current functions and infrastructures, and enables urban development based on land recycling rather than the use of other land resources and natural areas (16, 29). On the other hand, a lack of redevelopment and investment opportunities (e.g. depending on the limitations or location of the site) could also become an obstacle to remediation, as local politicians may wonder whether it is worthwhile to invest local budget) (6). Brownfield sites with low economic value are especially disadvantaged as they are no priority for action from a social or urban context, and if the contamination level is low, they are also no environmental priority – leading to local sites of deterioration across communities (23). The interviewed experts also noted that the scope for action by public authorities is very much depending on the legislative framework – if no detailed standards are set, it is difficult for local governments to enforce pollution thresholds (12).

In any case, the expert interviews also show a clear need to apply the legal frameworks to existing sites where contamination may occur, or to site closures and site sales where the magnitude of contamination can be checked (14). This would enable early identification of contamination and avoid longer time lags as shown by many of the 28 case studies discussed in the section 3.2. In this context, the relevance of small sites (e.g. former dry cleaners or gas stations) that may not be immediately considered as "problem sites" is to be highlighted, especially as they often are located in mixed-use urban areas and a residential follow-up function is often the case.

Local and regional governments oversee all formal processes related to the assessment and remediation of contamination. However, the administrative processes are highly compartmentalised as they involve different departments and touch upon different regulatory frameworks, the overall process can therefore be slow and ineffective even if there is general support to a project (see section 3.3.2 on legal frameworks)(20, 23). The large amount of bureaucracy is especially a problem for smaller site projects that are no municipal priorities and do not attract investors (23). Public authorities may therefore consider to establish structures to harmonize and better coordinate these independent processes (see also section 3.3.1 on a common vision), which could range from a case manager for each site or project to formal entities specialized in contaminated site management (5, 14, 16, 20).

The establishment of specialized bodies (or programmes / initiatives) to deal with contaminated sites would also help to tackle the challenge that public authorities often face in relation to the skills and capacities required for managing contaminated sites and their remediation (5, 12, 16, 17, 20). Such specialized agencies could also be considered at higher spatial levels, covering different municipalities (5) as well as being established at regional (14, 16) or national (17) scale and benefiting from the resulting accumulation of expertise in managing contamination and remediation. Generally, cooperation of experts at national, regional and local level could also help to ensure capacity building and increase environmental health literacy (17). In addition, the relevance of having access to qualified external experts and consultancies was mentioned (also see section 3.3.3), as these actors provide a specific skill set that many - and especially smaller - municipalities cannot provide (17, 20).

Finally, many expert interviews have highlighted the need for public authorities to communicate in a responsible and transparent way, using evidence-based information (17). This may be specifically relevant for contamination cases, as the sensitivity of the local population may be very high (14, 17). The expert interviews also highlighted that the way of handling these issues is crucial for a local government to be trusted, and that a failure to recognize this may require a very long time to regain the trust (6, 20). This is especially true if the contaminated site has been under public control and/or there is a public perception to local authorities have not duly executed their mandate for environmental protection measures (6).

Box 6 below shows some examples of how local / regional authorities can play their role in redeveloping contaminated sites.

Box 6: Examples of local or regional authority action to support redevelopment projects

- In Frankfurt (Germany), a former industrial site was redeveloped to host residential areas. Being aware of the site history and acknowledging the mandate to protect the residents, the competent regional authority assured a quick follow-up when public concerns arose that could potentially be associated with the former contamination (e.g. investigations into a cluster of health symptoms in day care settings etc.) (14).

- The Flanders region in Belgium has established a public waste agency specializing on remediation of contaminated sites. The regional agency acts on behalf of local authorities, which often do not have the required expertise (16). A public entity constituted of the local and the regional governments was created in Barcelona (Spain) to manage the development of the respective urban master plan, with responsibilities including the remediation and redevelopment of contaminated sites (20).

- Residents of Biancavilla (Italy) were afraid that the local quarry was not only going to be used to deposit contaminated material from the local infrastructure, but may also be used as a storage site contaminants from other Italian regions and therefore increase local exposure. Local authorities provided immediate clarification that this will not happen and acted transparently to enforce this commitment (17).

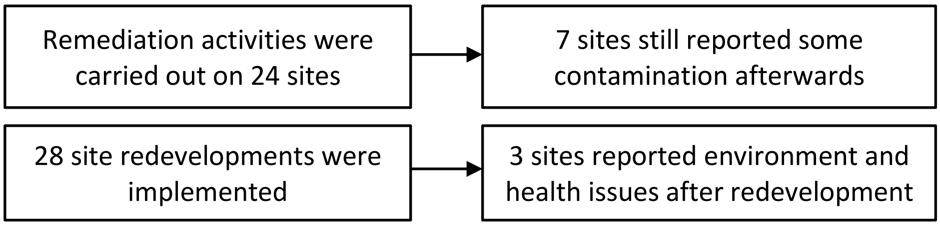
4. Discussion and conclusion

4.1 Case study collection

Following our call, 28 contributions were submitted presenting case studies on redeveloping contaminated sites across WHO Europe. Case studies were originated from 15 different countries, and varied largely in terms of geographic scale, site history and previous and new functions. Respondents indicated that redevelopment projects were overwhelmingly seen as successful, with beneficial health and well-being impacts and positive changes in the physical environment.

Despite successful project implementations, the complex site legacy likely complicated the redevelopment process and affected project timelines and costs. Soil and groundwater were almost always contaminated, and case study contributors reported several groups of contaminants present at the same site. There was a significant time span between site closure and start of remediation/redevelopment, which had potentially multiple impacts on the process. First, many sites were closed in the 80s or earlier, when environmental standards and remediation requirements were less strong and site clean-up was maybe less effective. Second, early closure might be linked to lack of appropriate documentations or records on the site history, levels and composition of contaminants. All these – and further unexplored factors – likely lead to discovering unexpected contamination after remediation and redevelopment, which happened for seven case studies after remediation and still three case studies after redevelopment (*Fig. 21*).

Figure 21: Number of contaminated sites by procedure



This shows that, although case studies have been taking measures to mitigate the contamination, unexpected contaminations and risks may still remain - highlighting the need for (a) proper site investigations before remediation, and (b) continued monitoring after the redevelopment. For the latter, time frame and frequency of measurements must be planned early in the process. This is particularly relevant if the new functions are human centred and tailored to the needs of the population, such as residential or recreation areas.

Despite the clear relevance of health aspects, health authorities were in less than half of the case studies included in the redevelopment (*Fig. 7*), and health monitoring was rarely conducted after the redevelopment (*Fig. 19*). Although health and environmental assessments took place in almost all cases, this should not be conducted as a check box exercise.

Another key result was the importance of public participation for the overall success of the conversion process. In order to increase the project acceptance, especially with regards to the follow up use of the sites, the local communities and residents should be considered from the initiation of the project. It is crucial to provide trustworthy and evidence-based information on the overall project, including contamination, remediation techniques and redevelopment works. Moreover, involving communities and local stakeholders in the planning and implementation process, eventually in the decision-making, should be further enhanced in the future, as being a key factor for successful project implementation.

Finally, two main limitations related to case study collection through survey mode should be acknowledged. First, as reported earlier, site closures were often several decades ago and sufficient documentation on contamination and conversion was not always available, likely affecting the responses throughout the survey. Second, even if the case study presented a recent redevelopment project, only few case study contributors were involved in the entire project, from its initiation until making it accessible to the public. These limitations likely contributed to a considerable amount of “Don’t know” answers and might have led to recall bias.

4.2 Expert interviews

The semi-structured expert interviews provided additional insights into the project processes and the challenges faced by local conversion projects. Although each case study had a unique context, various patterns and commonalities could be identified - such as the challenging diversity of legal frameworks and actors involved, or the impact of timelines and archiving site records. The interviews also showed the need for all involved actors to agree on a common objective, and to adequately facilitate the site conditions and conversion process to the local and affected communities.

The expert interviews thereby reflected several of the issues identified by analysis of the 28 case studies, but enabled a more detailed understanding of the nature of these issues, their origin and the different ways of being dealt with. This is especially valid when looking at the common challenges of such projects, which seem to be very much affected by the large number of actors, regulations and frameworks and therefore restrict the ability of local authorities to act in a consistent way when coordinating risk assessment, remediation and redevelopment of contaminated sites. This diversity of legal and procedural frameworks, potentially combined with different leads and focal points within the municipality, can have significant impacts on the project implementation and – if not managed – may lead to internal conflicts. However, at the same time, detailed legal frameworks, regulation and standards are required to enable public authorities to have a solid basis for action and decision-making vis a vis other stakeholders.

Next to the challenge of managing the involvement of different sectors and entities, local decision-making is often affected by a lack of information and evidence on the site status on the one hand, and a high level of public interest and sensitivity on the other. This makes the redevelopment of contaminated sites a very difficult management and coordination tasks for local authorities, which may be unable to meet all the logistical, technical and procedural requirements with internal capacities (see section 3.2). It is therefore important for local authorities to have access to accredited and competent external service providers.

A list of frequently mentioned "lessons learned" from the expert interviews is provided below, structured by the six general themes identified during the interview analysis (Table 2).

Table 2: Lessons learned on contaminated site remediation and redevelopment

Shared vision	• Bring stakeholders together early in the planning phase and agree on the redevelopment objectives • Establish cooperation with site owners and investors
Legal frameworks and their implementation	• National government to provide standards and criteria to be enforced/requested by local authorities (and possibly, national action plans on contaminated sites) • Provide regulatory stability as a precondition for any type of investment into remediation projects and technologies (for both public and private actors) • Assure that legal frameworks enable local governments to carry out environmental investigations when sites are closed or sold • Explicitly put the legal responsibility for contamination (and associated impacts and remediation) on the entity that caused the pollution, and include rules for managing possible legal conflicts with polluters
Technical aspects of contamination assessment, remediation and monitoring	• Carry out solid risk assessments before starting remediation and redevelopment activities • Include a budget buffer for unexpected contamination and respective changes to remediation and redevelopment plans • Involve different actors and stakeholders in compiling background information on the site • Environmental authorities need to ensure that adequate technologies for safe site remediation and redevelopment are implemented • Health authorities and respective experts need to be involved in contaminated site projects at an early stage

Impact of timelines	• Prepare for closure of contaminated sites and pre-plan future functions and redevelopments early • Act quickly on abandoned sites and avoid longer time periods of stagnation (and implement interim site management during periods of non-action) • Assess environmental contamination after site closure and in relation to land sales to make the polluter accountable • Ensure that records on contaminated sites are archived properly (in digitalized format); potentially contaminated sites may also be covered
Community involvement and participation	• Provide transparent and evidence-based communication on the site status (and associated environmental or health threats), remediation procedures, and its future functions • Involve local citizens and community groups in defining the future site functions
Role of local authorities	• Assure protection of environment and local population at all times throughout the process and request respective data and assessments • Establish specialized public entities dealing with contaminated sites and coordinating projects in harmonized way (possibly at higher jurisdiction level with other local authorities or stakeholders) • Provide a focal point or case manager overseeing site-specific project work across different departments • Be accountable for political decisions made • Provide training and capacity building to local staff and support cooperation of experts at national, regional and local level • Act quick on public concerns regarding environmental safety and health impacts

In summary, the expert interviews indicate that it is most important for local authorities to be aware of the influential role they have when working on the redevelopment of contaminated areas, and to understand that timely and effective enforcement of the existing legal frameworks and consistent and transparent coordination and management is one of the keys for a successful site redevelopment.

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Annex 1: List of case studies and follow-up interviews

#	Contributor	Case Study	Location	Affiliation	Short description	Site closure	Follow-up interview
1	Dorte Harrekild	anonymous	Denmark	Ramboll *(Private company, organisation or consultancy)*	An old landfill/waste site in a larger Danish city was remediated and turned into a residential housing area. The site investigation found immobile contamination in soil (lead, PAHs, oil products, metals) as well as production of methane gas in the soil due to deposited household waste.	1986	No
2	anonymous	anonymous	Albania	Research institute/ university	A landfill site near Tirana, Albania, which affected the surrounding environment mainly by burning waste and creating high level emissions (dioxins and furan), has been refunctioned for other purposes including industry and some housing and recreation.	2008	No
3	Paul Nathanail	The Avenue	Chesterfield, United Kingdom (England)	LQM *(Private company, organisation or consultancy)*	An industrial area in Chesterfield, UK, was transformed into residential areas with nearby commercial and recreational areas. Detected contaminants included PAHs, asbestos and aromatic hydrocarbons.	1992	No
4	Robynne Sutcliffe, Nadine Gerner, Mario Sommerhaeuser	Lake Phoenix	Dortmund, Germany	Emschergenossenschaft *(Local or regional authority)*	An abandoned industrial area (contaminated by heavy metals and PAHs) in Dortmund, Germany was developed into a multipurpose lake (Lake Phoenix) surrounded by residential areas. Moved soil was used to model embankment areas and terraces for housing.	2001	No
5	Kirstie Ogilvie, Lynne Valentine, Alison Brown	Cuningar Loop Woodland Park	Rutherglen, United Kingdom (Scotland)	South Lanarkshire Council / Clyde gateway *(Local or regional authority)*	A 15 hectare loop surrounded by the River Clyde in Glasgow, UK, had become the biggest expanse of derelict land in the area after being used for mining, quarrying and an unlicensed landfill site (affected by lead, other heavy metals and PAHs). The regeneration of Cuningar Loop has created an urban green space for residents and visitors.	1978	Yes
6	Frank van Hage	Volgermeer-polder	Amsterdam, Netherlands	Municipality of Amsterdam *(Local or regional authority)*	A former chemical waste disposal site in Amsterdam, Netherlands produced high dioxin levels and contamination with chlorinated hydrocarbons. Remediation included gas drainage, foil, water layer and clean soil. The site is now a recreational area and a natural reserve.	1980	Yes
7	Marta Rodrigues	Park of Nations	Lisbon, Portugal	Directorate General for Territory *(Public agency/ state agency)*	In 1994, 340 hectares, along 4 kilometres riverfront in Lisbon, Portugal has started to be transformed and renewed. Heavy industries, associated with a contamination by oil products and aromatic hydrocarbons, gave place to a modern neighbourhood, characterized by a modern mix-use urban structure.	1993	No

8	Phil Hartley	Byker City Farm	Newcastle upon Tyne, United Kingdom (England)	Newcastle City Council *(Local or regional authority)*	The site in Newcastle, UK was an urban farm used for education purposes growing vegetable crops and animal husbandry. Former lead works contaminated the soil, together with arsenic and other heavy metals. Remediation included excavation of soils and importation of clean capping layers. The site is now the Ouseburn City Farm, with recreational function.	1965	No
9	anonymous	Former landfill transformed into greenspace in Helsinki	Helsinki, Finland	*Public agency/ state agency*	A landfill in Helsinki, Finland that was closed in 1962 but still used illegally as a waste dump. In 1970, a housing area was built on the site and in the 1990s hazardous substances were detected (oil products, chlorinated hydrocarbons, PAHs). The housing areas were demolished and turned into a recreational area.	1962	No
10	Annette Haselhoff	anonymous	Netherlands	Tauw bv *(Private company, organisation or consultancy)*	Former gas, garage and cotton factories in Haarlem, Netherlands contaminated soil and groundwater with arsenic, other heavy metals, oil products and cyanide. Remediation took place in the now built up residential area.	1920	No
11	Anastasia Kentepozidou	Recycling Park	Agii Anargiri Kamatero, Greece	Municipality of Agii Anargiri Kamatero *(Local or regional authority)*	An old warehouse and construction unit in Agii Anargiri Kamatero, Greece, which was the source of much environmental pollution by e.g. oil products, was remediated and turned into the "Recycling and Environmental Education Park".	2000	No
12	Borko Bajic	Remediation and Re-cultivation of the Mojkovac Lead and Zinc Tailings Mine	Mojkovac, Montenegro	Institute of Public Health Montenegro (Public agency/ state agency)	Remains of the "Brskovo" lead and zinc mine in Mojkovac, Montenegro were remediated and transformed into green spaces for recreational purposes. Contamination included lead, mercury and other heavy metals.	1991	Yes
13	Peter Storey	Markham Vale North	Derbyshire, United Kingdom (England)	Derbyshire County Council *(Local or regional authority)*	The former Seymour Colliery and coal stocking grounds in Derbyshire, UK (contaminated by heavy metals and PAHs) were remediated and regenerated with the objective to provide new employment opportunities and deliver environmental improvements enabling outdoor recreational use.	1994	No
14	Thomas Ormond, Dirk Krebs	Former site of Vereinigte Deutsche Metallwerke	Frankfurt am Main, Germany	Regierungspräsidium Darmstadt *(Local or regional authority)*	Metal production site and a former landfill in Frankfurt, Germany resulted in contamination of soil and groundwater with chlorinated hydrocarbons as well as heavy metals or PAHs. Since the remediation, the site is used as a residential and commercial area.	1982	Yes
15	Donald Payne	Kirkland Steelworks Methil	Methil, United Kingdom (Scotland)	Fife Council *(Local or regional authority)*	This site in Methil, UK beside the River Leven was a spinning mill from the 1780s, which later operated its own gasworks for lighting and still later manufactured cyanide. The site was redeveloped as a housing area after remediation of contamination by lead, PAHs and asbestos.	1990	No

16	Eddy Wille	Schotte	Aalst, Belgium	Flemish Government *(Public agency/ state agency)*	Due to the chromium tannery process at this site in Aalst, Belgium, chromium salts and acids ended up in the soil, further contaminants included asbestos and oil products. In 2016, the whole site was remediated and a multifunctional sports complex of more than 25.000 m² was realized.	1997	Yes
17	Pietro Comba, Biagio M. Bruni, Daniela Marsili	Biancavilla and the quarry	Biancavilla, Italy	Istituto Superiore di Sanità *(Public agency/ state agency)*	A quarry in Biancavilla, a small town in Italy, was remediated due to an observed excess mortality of pleural mesothelioma. Amphibolic fibres were detected in the mined material that was also used for building houses and urban infrastructure. Redevelopment included the opening of a mineralogical park.	1999	Yes
18	anonymous	anonymous	Netherlands	*Local or regional authority*	Former waste dump and place of incineration of chemicals, which has been turned into a park and outdoor recreation area close to a new city district. The major contaminants included heavy metals and chlorinated as well as aromatic hydrocarbons.	1972	No
19	anonymous	anonymous	Italy	*Local or regional authority*	Within a harbour area, soil conditions were characterized and remediated to redevelop a better-quality dock area.	2008	No
20	Consol Perez Cruz	Arids Catalonia	Barcelona, Spain	Consorci Urbanistic del Centre Direccional de Cerdanyola *(Local or regional authority)*	Arids Catalonia was an old clay quarry exploited in the 70's, and later filled with construction debris including asbestos. Contamination also included oil products and lead. The site is now reforested and new paths have been created for public use, incorporating the area to the Parc de l'Alba green corridor.	2006	Yes
21	Chris van de Meene	Griftpark	Utrecht, Netherlands	Municipality of Utrecht *(Local or regional authority)*	Former gas manufacturing site in the middle of a highly populated area in Utrecht, Netherlands. The site was contaminated by oil products and hydrocarbons (coal tar, BTEXN) up to 40 m depth, threatening the aquifer for drinking water. The sites new function is outdoor recreation and cultural and community space.	1960	No
22	Federico Del Gaia	Remediation of a logistic park	Sansepolcro, Italy	MAST *(Private company, organisation or consultancy)*	The site in Sansepolcro, Italy is still in use by a trucking company and located within a logistical park with various industrial services. On-site remediation technology was used to remediate local contamination and leakages (e.g. oil products and aromatic hydrocarbons), and protect an adjacent green area from potential vapour emissions.	2015	No
23	Karen Johnson	ROBUST (Regeneration Of Brownfield Using Sustainable Technologies)	Easington Colliery, United Kingdom (England)	University of Durham *(Research institute/ university)*	The site at Easington Colliery, UK was remediated in 2014. It is of low value economically and was marginally contaminated with lead, arsenic and PAHs. The site was remediated as part of an interdisciplinary research project which aimed at community-led regeneration and established an outdoor recreational space.	1979	Yes

24	anonymous	Flugfeld Böblingen/Sindelfingen	Böblingen and Sindelfingen, Germany	*Local or regional authority*	Due to decades of military use of the site in Böblingen, explosive ordnance and soil contamination affected the site after military use ended in the early 90s. A soil remediation concept was established (contamination by chlorinated and aromatic hydrocarbons) and implemented to redevelop the site into residential, commercial and recreational functions.	1992	No
25	Inge De Vrieze	De Krook	Ghent, Belgium	OVAM - Public Waste Agency Flanders *(Public agency/ state agency)*	Formerly, textile factories and a Gas Plant were located at this site in Ghent, Belgium. In the 20th century there was a garage workshop, a sports hall and a residential area. Contaminated soils (aromatic hydrocarbons and PAHs) were remediated. A monumental building (De Krook) has been built, which houses the city library and the University of Ghent.	1900	No
26	Amanda Sterkenburg	Söderkaj site	Halmstad, Sweden	REGENESIS *(Private company, organisation or consultancy)*	At this site in Halmstad, Sweden historical activities including fisheries, metal plating, dry cleaning and maritime industries, have led to chlorinated solvent contamination and PAHs in groundwater. After remediation, the construction of 330 apartments was realized.	2009	No
27	Morar Cezar	The former military areas in the city of Oradea	Oradea, Romania	University of Oradea *(Research institute/ university)*	Former military structures in Oradea, Romania, were redesigned for innovative economic, educational and cultural purposes following the remediation of heavy metal contamination in soil, surface water and aquifers.	2000	No
28	Tinatin Doolotkeldeiva	anonymous	Kyrgyzstan	Kyrgyz-Turkish Manas University *(Research institute/ university)*	Unusable storage facilities of hazardous chemicals in Kyrgyzstan lead to contamination by chlorinated hydrocarbons and PAHs. Two variants of biodegradation experiments were conducted, serving as an example for alternative soil cleaning methods and establishing new recreational functions.	1985	No
	EXPERT INTERVIEW ONLY						
29	Andrea Hoeber	---	North Rhine-Westphalia, Germany	Regionalverband Ruhr *(Public agency/ state agency)*	The regional agency coordinates a municipality network on redeveloping coal mining areas, taking the opportunity to prospectively plan the conversion of mining sites before they actually close their operations.		Yes

ANNEX 2: RATINGS OF WIDER URBAN IMPACTS OF REDEVELOPMENT

	Strongly disagree (1)	Disagree (2)	Undecided (3)	Agree (4)	Strongly agree (5)	Don't know	Mean
The redevelopment project is overwhelmingly seen as successful by the public.	0	4	1	2	17	4	**4.3**
Social and economic aspects							
The redevelopment led to gentrification.	0	8	6	4	4	6	**3.2**
The redevelopment increased rents and property values in the area.	1	1	4	11	7	4	**3.9**
Further investments, renovations and beautification projects followed the redevelopment in the neighbourhood.	0	1	1	10	13	3	**4.4**
The project created new job opportunities after redevelopment.	0	4	0	10	9	5	**4.0**
Crime rates decreased in the area.	1	1	5	4	1	16	**3.3**
The project created spaces for social interaction and exchange.	1	2	3	4	15	3	**4.2**
Vulnerable and disadvantaged residents in the surrounding communities benefitted from the project.	0	2	9	5	8	4	3.8
Subtotal							**3.8**
Physical environment							
There is more green space available for recreation.	0	2	2	10	14	0	**4.3**
Public transportation improved in the area.	0	5	5	6	5	7	**3.5**
There is less waste and rubbish in the surrounding area.	0	2	4	10	9	3	**4.0**
The project improved access to recreation and cultural activities.	0	1	5	6	14	2	**4.3**
Subtotal							**4.0**
Health and well-being							
The redevelopment led to increased physical activity in the neighbourhood.	0	1	3	6	13	5	**4.3**
The well-being of the neighbouring communities increased.	0	0	3	10	12	3	**4.4**
The project improved the quality of life for residents.	0	0	2	11	15	0	**4.5**
Subtotal							**4.4**

A review of impact assessments related to remediation and further re-use of contaminated sites[1]

This review report outlines current practices of impact assessment (IA) processes on the redevelopment of (formerly) contaminated sites in residential contexts. The focus is on processes leading to public consent decisions that aim at identifying, assessing and mitigating negative environmental and health (and possibly equity) effects and at enhancing positive outcomes. A case study approach is taken. Scopus and Google searches, an expert survey and a WHO case study collection on redeveloping contaminated sites were used in order to identify case examples from current practices for three types of IAs; Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA) and Health Impact Assessment (HIA). Nine such cases from five countries (Germany, Portugal, Spain, The Netherlands and the UK) are introduced and reviewed. At times other assessment were found in association with those; these are also mentioned and discussed. Further information was obtained on some of the cases from key individuals involved in their preparation. Environmental and health risks of contaminated sites are usually covered in risk assessments (RAs; e.g. human health risk assessments – HHRA – and environmental risk assessments – ERA) when seeking to obtain remediation permits or licenses, for example, in order to operate mobile plants for the treatment of soils and contaminated substances. Only in one of the cases reviewed did associated RAs include the future use of a site (Parc de l'Alba, Barcelona, Spain). SEA considers contaminated sites in the preparation of e.g. local land use or urban and master development plans within or next to existing residential areas with a focus on future use, EIA is applied in major development projects on formerly contaminated sites, at times also considering the remediation phase, frequently outside existing residential areas. Participatory HIA processes are currently applied only in the context of planning for future use of remediated sites. Only one of the reviewed IAs was found to have some short-term monitoring provisions for a formerly contaminated site. The default assumption by those dealing with future use is therefore usually that following remediation, sites are safe once they are remediated.

[1] The authors of this paper would like to thank Tara Muthoora (University of Liverpool, United Kingdom), and Julia Nowacki and Matthias Braubach (WHO European Centre for Environment and Health) for comments and further input on earlier report drafts.

INTRODUCTION – EIA, SEA, HIA AND RA AND CONTAMINATED SITES

Contaminated sites are "areas having hosted or being affected by human activities which have produced environmental contamination of soil, surface or groundwater, air, or food-chain, resulting or being able to result in human health impact" (Martuzzi et al, 2014). Contamination can be of different origin. It can be caused by industrial or military usage, by agricultural or other processes. If not fully and effectively remediated, conversion of contaminated sites can pose health risks, either to those living or using functions on the sites or to people living close to remediated sites.

ENVIRONMENTAL IMPACT ASSESSMENT

Conducting Environmental impact Assessment (EIA) for major development projects is currently a legal requirement in all European countries. In the EU, the EIA Directive (2014/52/EU of the European Parliament and of the Council of 16 April 2014, amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment) is transposed in all EU member states. Its Annex III 1. (g) states that 'the risks to human health (for example due to water contamination or air pollution)' are to be considered when taking a decision on whether or not to conduct an EIA. Whilst EIA appears to be only very rarely used in the context of the initial remediation of a contaminated site (where risk assessments frequently come into play), it is routinely applied to assess the potential environmental impacts of major development projects, including those on or next to formerly contaminated sites.

EIA requirements in most countries focus on establishing an assessment procedure, which is conducted next and / or in parallel to a project planning process with the aim of obtaining development consent. Typically, the procedural stages covered include:

- Screening; i.e. deciding on the need to conduct EIA, usually based on checklists defining those developments that require EIA (based on their size and scale of a project) or based on case-by-case screening, where the sensitivity of the environment is considered);
- Scoping; i.e. deciding on the scope of EIA, based on expected significant effects, including spatial and temporal coverage, as well as environmental aspects and alternatives to be considered; scoping usually includes stakeholder consultation and participation;
- Analysis and evaluation of effects of different alternatives;
- Suggestions for how to avoid, reduce or otherwise mitigate significant negative environmental impacts of the different alternatives considered;
- Production of an EIA report, which is usually the basis for public participation;
- Decision making, taking the results of the EIA into account;
- Follow-up and monitoring; checking whether predicted impacts are in line with what is observed and whether mitigation measures are implemented.

It is important to note that EIA is currently applied to (very) big projects only. In the UK, EIA is only required for residential developments of over 5 ha (NB: this means that only 8 of the 28 cases identified by Baranyi et al, 2020 would have potentially come with an EIA). Whilst thresholds can be lower in other countries, there are similar issues with regards to many developments not being covered by EIA (Fischer, 2007). In most countries, over 99% of projects requiring planning permission will not involve the preparation of EIA. However, by far most of those projects would be very small scale, including e.g. loft conversions or new garages. All projects with expected significant negative environmental impacts usually involve EIA.

STRATEGIC ENVIRONMENTAL ASSESSMENT

Strategic Environmental Assessment (SEA) is applied throughout Europe to spatial and sectoral (transport, energy, waste and other) plans and programmes and at times policies. In the EU, the SEA Directive (2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment) established SEA requirements for the 27 EU member states. Plans and programmes to be assessed can include areas of contamination. It can reasonably be expected that those sites would be flagged in SEA and surveys would be needed in order to establish existing risks emanating from sites and potential implications for future use. Furthermore, through SEA suggestions can be made on what future development may be compatible with the specific characteristics of a site. In addition to the SEA Directive, further requirements for SEA are formulated by the Protocol on SEA to the UNECE Convention on EIA in a Trans-boundary context (Espoo Convention). This is an international agreement which provides for legal obligations and a procedural framework for the implementation of SEA in countries that are Parties to it. Importantly, the SEA Protocol applies to all plan and programme (and potentially policy) assessment practices of the Parties, and not just when transboundary issues are at stake. As of February 2020, the Protocol had 33 Parties, including the European Union. Importantly in the context of this review report, whenever referring to environmental impacts, the protocol adds 'including health' (see e.g. UNECE, 2020).

In most systems, SEA is approached through procedural requirements, similar to those for EIA introduced above. However, it has been suggested that seeing SEA as a procedure with a focus on negative impacts only is likely to seriously restrict its usefulness and effectiveness (Fischer, 2006). It has been argued that instead, SEA should be approached as a framework, where different assessment tasks, alternatives and issues are allocated to different decision tiers, including strategies / visions, policies, plans and programmes, and which is tiered with project EIA. More recently this framework idea has been included in national and international guidelines (see e.g. IAEA, 2018; Bundesministerium für Verkehr, 2018; UNECE, 2020). An associated concept of 'selection logic', which also considers the administrative level and sector of SEA application, has been discussed by Fischer and González (2020).

HEALTH IMPACT ASSESSMENT

With regards to HIA, whilst there are formal requirements in some countries and nations (e.g. Czechia, Andalusia in Spain and the United Kingdom), currently its application is usually either voluntary or based on specific regional or local requirements (see e.g. Fischer and Muthoora, 2019). Many countries and international organizations recommend the use of HIA when significant health effects could potentially arise from policies, plans, programmes or projects (see e.g. https://www.who.int/health-topics/health-impact-assessment#tab=tab_1). This review was commissioned due to concerns about potential health effects of formerly contaminated sites on residential areas, either nearby or on on-site. In this context, HIA could play an important role.

Similar to EIA and SEA, HIA is usually approached as a process when the intention is an application of a comprehensive assessment (there are also checklist based 'rapid' approaches; e.g. NHS London Healthy Urban Development Unit 2017). However, HIA does not normally mention a need to consider alternatives. In practice, HIA is not following the impact driven approach routinely used in EIA and SEA (here with a focus on significant negative impacts).

Rather, it is looking to support positive outcomes, applying a problem-driven approach, where human health is to be promoted. Whilst EIA and SEA tend to quantify impacts wherever possible, HIA often uses a qualitative approach. In this context, HIA can adopt the role of guidance, enhancing communication and awareness amongst stakeholders (Fischer et al, 2018). Also, and importantly, HIA is frequently applied after a plan has been prepared, rather than within or in parallel to it, providing suggestions for how positive outcomes can be enhanced (Fischer and Muthoora, 2020). This is why the procedural stage 'decision making' is usually missing in HIA guidelines. Furthermore, whilst health (including well-being) is only one of many aspects in EIA and SEA, it is at the heart of HIA.

RISK ASSESSMENT

A different type of IA which is of key importance for the remediation of contaminated sites is risk assessment (RA, including e.g. Human Health Risk Assessments – HHRAs and Environmental Risk Assessments ERAs). It is routinely used within the context of obtaining remediation permits or certificates, for example to operate mobile plants for the treatment of soils and contaminated substances. Furthermore, it can be used to assess potential impacts of follow-up development with the aim to establish whether there may be any human health and environmental risks and, if necessary, to propose the remediation for a specific future use. Whilst RAs can inform SEAs, EIAs and HIAs, they are not usually aimed at assessing impacts of follow-up development on formerly contaminated sites. Opposite to the other IA tools introduced above, RA is understood as a scientific process, applied to obtain a permit or licence. Most commonly, it is focusing on either human health (HHRA) or environment (ERA). In this context, RA is said to follow a number of steps, usually including an identification of hazards and an estimation of who might be harmed and how. Furthermore, RA includes an evaluation of the risk and a decision on precautionary measures. Finally, findings should be recorded, implemented and reviewed (Rausand, 2013). According to the US EPA (2020), HHRA consists of the following four steps:

1. Hazard Identification; aiming at examining 'whether a stressor [e.g. a contaminant] has the potential to cause harm to humans and/or ecological systems, and if so, under what circumstances'
2. Dose-Response Assessment; examining 'the numerical relationship between exposure and effects'
3. Exposure assessment; examining 'what is known about the frequency, timing, and levels of contact with a stressor [e.g. the contaminant]'
4. Risk characterisation; examining 'how well the data support conclusions about the nature and extent of the risk from exposure to environmental stressors'.

A further in-depth description of RA in the context of contaminated sites is being worked on as a forthcoming supplement to this review focusing on impact assessments.

METHODOLOGY

Based on a review of real-life examples, this review report aims at reflecting on how potential health effects of planned follow-up use of (formerly) contaminated sites is considered in different types of IAs leading to public consent decisions on the redevelopment of those sites in residential contexts. The main focus is therefore on health impact assessment (HIA), environmental impact assessment (EIA) and strategic environmental assessment (SEA). We also aim at exploring when and how reference is made to risk assessments (RAs), used in the (earlier) remediation of the sites in HIA, SEA and EIA.

There are three main objectives of the review. These include the establishment of whether SEA, EIA and HIA are used to:

- Identify a need for remediation of contaminated sites, influence and/or modify remediation,
- assess and / or evaluate remediation measures,
- identify continued or new environmental and/or health risks after and / or despite the remediation in follow-up development.

The conclusions will refer back to these objectives. The methodology used consist of five main stages. In this context, three pathways were followed in order to identify IA examples for the follow-up development of (formerly) contaminated sites. Furthermore, two stages focused on the review and the interpretation of results. The five parts are organised as follows:

(1) Scopus and Google searches

- A Scopus (the largest abstract and citation database of peer-reviewed literature: scientific journals, books and conference proceedings) search was conducted, using the terms 'contaminated sites' / 'brownfield' / 'redevelopment' / 'contaminant' and 'environmental impact assessment' / 'strategic environmental assessment' / health impact assessment'.
- A Google search was conducted, using the terms "Impact Assessment" AND "contaminated sites" / "conversion of contaminated sites" on google.com.

(2) IA expert survey

- IA experts were contacted and information was requested from them on any IA practice cases they were aware of and which revolve around contaminated sites' remediation, as follows; (a) making a call on 'IAIA connect' (the members' communication platform of the International Association for Impact Assessment – IAIA; www.iaia.org) for experts to name possible IA examples for the development of formerly contaminated sites or to refer to experts who may be able to name cases; and (b) establishing direct contact with IA experts in order to identify suitable IA cases.

(3) WHO Case Study Collection

- To screen those case studies gathered through the WHO's background report 'Redeveloping contaminated sites: Good practice and lessons learned' (Baranyi et al, 2020) that were found to have included IA for possible inclusion in the review.

(4) Review of Identified Cases

- Reviewing a number of EIA, SEA and HIA cases thus identified, using the following review categories (adapted from the project terms of reference):
  - Project name
  - Year IA was prepared
  - No of pages
  - Project content
  - Sources/references
  - What is the site which is being assessed / what is the contamination problem?
  - Purpose
  - Approach
  - What environmental & health impacts are observed with regards to contamination
  - What type of redevelopment had been assigned to new development on the site
  - which possible future impacts had been taken into consideration during the planning phase of the new development / through the IA with regards to health
  - Recommendations of the IA in relation to health effects to improve the project,

    - Evidence for recommendations being taken up
    - Implementation evidence
- Providing observations on the basis of the review results and drawing conclusions with regards to the project's objectives.

(5) Interpretation of results
- Discussing results during an online WHO meeting on redevelopment of contaminated sites, held from 28 to 30 September and 5 October 2020
- Conducting interviews with key individuals involved in some of the IA cases reviewed.

SCOPUS AND GOOGLE SEARCHES FOR REAL IA CASES THAT ARE SUITABLE FOR REVIEW

Scopus and Google.com searches were conducted beginning of September 2020. Results are subsequently introduced.

SCOPUS SEARCH

Thirteen documents were identified on Scopus when searching for "Health Impact Assessment" AND "Contaminated Sites". All of these focus on technical methods and data needs for remediation, therefore taken a risk assessment angle of view. None make any reference to HIA studies carried out in the context of conversions of contaminated sites.

A total of 176 documents were identified when searching "Environmental Impact Assessment" AND "Contaminated Sites". However, none of them made any reference to cases involving the participatory decision support tool EIA. Instead, many of the documents referred to studies into e.g. what type of pollution is present in contaminated sites and wider ecotoxicological questions. Furthermore, the suitability of techniques such as Life-cycle assessment (LCA) and cost-benefit analysis (CBA) are discussed. Risk assessment techniques and technologies for remediating contaminated soils (e.g. phytoremediation) receive some attention, along with the possibility to apply specific techniques, including e.g. GIS. Finally, tracing of species and biomarkers with regards to contaminated sites are discussed.

No documents were identified on Scopus when running the search "Strategic Environmental Assessment" AND "Contaminated Sites". Whilst nine documents were identified when changing the second search term to "contamination", none of them provided any practice examples.

GOOGLE SEARCH

Google searches for "impact assessment" and "contamination" / "contaminated sites" resulted in several 1,000 of hits. A wide range of issues and topics are covered in those. A main focus is on environmental risk assessment of contaminated sites, with particular attention given to contaminated land reports and remediation experiences of specific sectors. Here, an important area of application is clearly nuclear site remediation. Many consultancies present their services, advertising, for example, land contamination surveys. However, whenever specific projects are mentioned, then the focus is on developments following on from remediation. Therefore, an underlying assumption in practice appears to be that whilst development happens on sites that were contaminated, remediation has made those sites safe and there are no further risks. In this context, an important message provided is that that developers need to ensure that all contaminated sites are remedied before new development is considered[1]. Furthermore, a number of hits are connected with activities of development banks and international organizations, including in particular the World Bank and the WHO.

What is very clearly emerging from the Google search is that many countries have regulations and guidelines in place for approaching remediation of contaminated sites, with a particular focus on risk assessment techniques. Furthermore, local and regional authorities have remediation strategies and guidelines in place. Two examples include Tower Hamlets (2013), a Borough in London which has released a 'Strategy for identification of contaminated land' and Norfolk County Council (undated) which has released Technical Guidance on the 'Development on Land Affected by Contamination'[2]. Also, health risks of brownfield (i.e. potentially contaminated) land are discussed on various sites. However, these tend to focus on risks to people living next to non-remediated sites and not on people living on formerly contaminated sites.

Examples for where the preparation of IAs was explicitly mentioned in the context of contaminated sites include road bypasses and other transport projects. However, and importantly, most of the contaminated site examples that were identified received no mentioning of EIA, SEA or HIA[3]. Overall, the Google search resulted in two cases being identified that were suitable for review, i.e. for which the necessary documentation could be obtained after going to the respective authorities' websites. These two examples are included in the sample of reviewed IAs below.

Based on feedback received from participants of the online 'WHO meeting on redevelopment of contaminated sites' from 28 to 30 September and 5 October 2020, limitations of the google search approach taken are acknowledged. These limitations revolve mainly around conducting the search in English only. In this context, participants stated that similar searches in Spanish (e.g. 'Evaluación Ambiental Estratégica, sitios contaminados'), German (e.g. 'Umweltbericht, kontaminierte Fläche') and other languages would likely result in many more hits. This was confirmed when doing such surveys in October 2020, at a time when results of the reviews were interpreted. A recommendation for future research is therefore to not just rely on English when looking for suitable case examples.

IA EXPERTS' SURVEY

The 'call for expert knowledge' made on the IAIA Connect website resulted in responses from various individuals who were able to name experts who had worked on contaminated sites and IA. One reference was to a researcher who had led the 'HIA working group' in the Industrially Contaminated Sites and Health Network (ICSHNET), which was a COST action (IS1408), supported by the EC Horizon 2020 programme and which was active from 2015 to 2017. This Action resulted in a special issue of the Journal 'Epidemiologia & Prevenzione' (2018, 5+6) on 'Environmental Health Challenges from Industrial Contamination' (https://www.epiprev.it/materiali/suppl/2018/COST/Suppl_COST_WEB.pdf). However, the papers included in this special issue all focus on risk assessment techniques, with no examples of real life HIAs or SEAs and EIAs applied to the further development of those sites being mentioned or discussed.

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[1] This is an indication that remediation is undertaken before the specific type of follow-up use is defined. This raises some concerns, as different uses of land react differently to any potentially remaining risks.
[2] Most local councils in the UK have these strategies and guidelines in place
[3] There can be different reasons for this, which may also include confidentiality

A number of experts were directly contacted and included experts from Austria, Germany, The Netherlands, Denmark, Sweden, Portugal, the UK and Spain. This resulted in the identification of various other experts who were also approached. This chain led to a total of about 30 experts who were able to share their knowledge on IAs and contaminated sites. Five of the nine IAs subsequently reviewed were thus identified.

Some examples for remediation focused on the stage before an EIA, SEA or HIA was started. These were mostly associated with risk assessments. Depending on e.g. the size of the contaminated site, this is routine practice. An example is a former landfill site near the river Mersey in Liverpool, the so-called area Garden Festival Site. Around 1,500 homes are supposed to be built here and remediation of the site (with a top layer of soils and materials of up to 5 meters being cleaned) started before any Master Plan/ EIA is being published (https://www.placenorthwest.co.uk/news/ liverpools-festival-gardens-gathers-speed/), presumably on the basis of a remediation permit granted, based on a risk assessment being conducted.

WHO CASE STUDY COLLECTION

The WHO (Regional Office for Europe) compiled a set of case studies on 'Redeveloping contaminated sites: Good practice and lessons learned' (Annex 5 to this project report). Background information on the 28 identified case studies on contaminated site redevelopment established that 12 of the cases came with EIAs and 7 with HIAs. All HIAs were connected with cases that also had EIAs prepared. Whilst 6 of the 12 cases that came with EIA provided links to some further web-based information, only two provided for some direct links to documentation prepared for remediation activities (Fife in Scotland and Barcelona in Catalonia). However, only the latter provided access to associated impact assessments (including SEA, HIA and other IAs for the Parc de 'Alba-Barcelona') and is included in the subsequent review. Furthermore, for one case an additional web survey identified IA documentation and this case is also used (Avenue Development Chesterfield). The other 5 cases provided links to some useful background information. However, it is not clear whether any associated IA documentation is publicly available for them and associated subsequent web searches did not result in the identification of any.

In addition to the case study collection produced for this project on redeveloping contaminated sites, the WHO has a collection of other relevant research reports and published papers at their disposal. This led to the identification of an HIA for 'Land Remediation Options' for a Site of a former Phurnacite Factory in Wales (Lester et al, 2003). However, up until now, this site has neither been remediated nor developed, even though development for residential purposes has been discussed. Therefore, it does not provide for a suitable case to be reviewed.

EIA/SEA/HIA REVIEWS

A total of 9 IAs were identified through the Scopus and Google searches, expert survey and WHO background report, as was explained above. All IAs were prepared over the last 7 years. Table 1 provides an overview of the cases and Table 2 presents detailed review results.

Table 1: Overview of nine reviewed EIAs/SEAs/HIAs

Type and name of Impact Assessment	Purpose and former use / pollution source	Distance to residential area	Identified through	New use
EIA Wiener Neustadt und Weikersdorf am Steinfelde, Austria.	Remediation of aluminium dross landfill	About 500m	Direct expert contact	Forestry, hunting, recreational
SEA Bebauungsplan / building plan Pioneer Kaserne, Hanau, Germany	Redevelopment of former barracks 'Pioneer Kaserne'; contamination through petrol station, chemical laundry and potentially weapons / unexploded bombs	On residential area	Direct expert contact	Residential area
HIA of the Northumberland Local Plan, UK (**SEA** was also done)	Aiming to ensure healthy future development, including the need for treating contaminated sites	On residential area	Literature Review	Various uses; mainly residential and services
HIA Avenue Development, Chesterfield, UK (**EIA** was also done)	Follow up to the Avenue Remediation and Landscaping Project which remediated nearly 100 ha of former coking works' waste	Next to other residential areas	WHO case study report	Residential, services and recreational (park)
SEA (SA) of the Submission Draft Liverpool Local Plan, UK (**HIA** was also done)	Aiming to ensure healthy future development, including the need for treating contaminated sites (over 3,000 ha in total)	On residential area	Literature Review	Various uses; mainly residential and services
EIA of extension of A7/A8 motorways, Purmerend and Zaandam, The NL	Asbestos and hydrocarbons from service station. Residential areas nearby	About 100m	Direct expert contact	Rush-hour relieve road near residential areas
SEA, Parc de l'Alba, Barcelona, Spain; **HHRA** and **HIA** also conducted	Redevelopment of 340 ha, 10% of which affected by old clay pits convert in old landfills and former industrial activities: brick factories, asphalts factory and sale aggregates	In between 2 suburban towns	WHO case study report	technological, residential, recreational and natural areas
EIA, Matinha Quarter, Lisbon, Portugal	Redevelopment of 8bha of former gas production/processing site	Right next to other residential areas	Direct expert contact	Residential, commercial, a new church
EIA, re-cultivation of salt stock, Wathlingen, Germany	Re-cultivation of salt stock, including household landfill; over 25 ha and over 80 m high.	About 400m	Direct expert contact	Recreational

Table 2: Review of nine EIAs/SEAs/HIAs with regards to how contaminated sites and health are considered

Project name	**EIA for remediation of aluminium dross landfill in Wiener Neustadt und Weikersdorf am Steinfelde, Austria.**	**SEA of the redevelopment of former barracks 'Pioneer Kaserne', City of Hanau, Germany (Bebauungsplan / building plan)**	**HIA of the Northumberland Local Plan, UK**
Year IA was prepared	2013	2019	2018
No of pages	Only an online non-technical summary was available.	191	48
Project content	Remediation of site of 46,000 m2; closest residential area is 500m away.	Redevelopment of 51 ha (510,000 m2) of former barracks into a green residential area	Northumberland County Council Local (Development) Plan; about 5,000 km2 and population of 320,000
Sources/references	https://www.altlasten.gv.at/atlas/verzeichnis/Niederoesterreich/Niederoesterreich-N6.html https://www.yumpu.com/de/document/view/51721198/bescheid	https://hanau.de/mam/aktuelles/bauleitplaeneimbeteiligungsverfahren/05_umweltbericht.pdf	https://www.northumberland.gov.uk/NorthumberlandCountyCouncil/media/Planning-and-Building/planning%20policy/Local%20Plan/Health-Impact-Assessment-LP-Publication-Draft-v1-1.pdf
What is the site which is being assessed / what is the contamination problem?	A former gravel pit which was subsequently (1974-1990) filled with aluminium dross; there are harmful emission into air and groundwater contamination potential. Next to the former pit is a new gravel pit.	Used as barracks for 70 years, mostly by the US army until 2008. The area has some underground pollution with regards to mineral oils (petrol stations, garages), and chlorine hydrocarbons due to two former (chemical) laundry facilities. Weapons and unexploded bombs are suspected, too.	Testing health consequences of local plan which has a pollution and land quality objective (POL1) 'Unstable and contaminated land'
Purpose	Precautionary remediation; avoid possible future damage	Site to be used as residential development; remediation required	Establishing possible contamination problems of future development sites early
Approach	Pro-active	Pro-active	Reactive, establishing effects on baseline
What environmental and health impacts are observed with regards to contamination	There are emissions into air (methane, CO2, ammoniac, hydrogen) and water (Ammonium, Nitrate, Alkali metals und Chloride) and a high contamination potential of ground water has been established. The recontamination requires the installation of various devises and a rerouting of an existing road along with some other measures.	Underground contamination which is affecting underground water	Development on brownfield sites is expected to have positive impacts, as remediation of contaminated sites will occur that would otherwise remain contaminated. For development of greenfield sites it is stated that 'Positive effects will come from development being located outside of unstable or contaminated land areas or mitigating impacts from such land.'

What type of redevelopment had been assigned to the new development on the site	Remediation of a site which is within a ground water protection area; reclaiming of material and reforestation are anticipated (wider area is used for forestry and recreational purposes).	At various locations soils and underground material will be removed and / or cleaned in order to redevelop the area for residential purposes.	Numerous brownfield sites to be converted into housing and other usages.
Which possible future impacts had been taken into consideration during the planning phase of the new development / through the IA	The project (remediation) was triggered because of potential health impact of water decontamination. Health impacts were assessed for the construction period, in particular potential harmful air emissions. No potentially significant health effects are predicted through emissions into air during construction.	The SEA considers human health next to a number of other environmental aspects. Next to underground contamination, noise emissions are also considered as the area is located next to a busy main road. Noise barriers are anticipated. Other aspects include vibrations, odour, bio-climate, recreation. A separate ground renovation plan is also prepared.	Development on uncontaminated sites positive for human health. – Development on formerly contaminated sites also positive overall, due to Wation requirement.
Recommendations of the IA in relation to health effects to improve the project,	Dust emissions during construction are to be reduced, in particular with regards to any potential negative impacts on construction workers.	Various noise protection measures (noise barrier, glazing). No contamination remaining after removal of contaminated soils and underground. Micro-climatic measures are suggested, including greening of roofs and removal of sealed areas. The area is to be connected to the cycle lane network of Hanau and a cycle lane will run through the development; external ecological development measures are planned to offset negative environmental impacts	'Mitigation is built into the policies in this chapter. Developments are required to limit the amount of pollution they produce to a minimum. If a development proposal would produce unacceptable levels of pollution, it would not be permitted.'
evidence for recommendations being taken up	Activities have started, taking mitigation measures into account	To be built	Implementation of local plan outstanding
Implementation evidence	Remediation activities started	Not yet	Not yet.

Project name	**HIA of Avenue Development - The Avenue Remediation & Landscaping Project, Chesterfield, UK**	**SA (SEA) incorporating Equalities Impact Assessment (EqIA) and HIA of the Submission Draft Liverpool Local Plan, UK**	**EIA of extension of A7 and A8 motorways (additional lanes for rush-hour traffic) near Purmerend and Zaandam, The Netherlands**
Year IA was prepared	2016 (EIA was conducted in 2006)	2018	2014
No of pages	93	138	71
Project content	The former Avenue Coking Works at Wingerworth near Chesterfield (ended in 1992) is one of the most contaminated sites in Europe (nearly 100 ha), and is thought to be the UK's biggest and most complex remediation project (at a cost of £172M). Facility included a waste tip and settlement lagoons for the disposal of hazardous solid and liquid wastes. Nearly 500 new homes are now planned on the site next to a primary school, playing pitches, employment land and about 73 hectares of country park.	A sustainability appraisal (SA), which includes an HIA for the draft Liverpool Local (development) Plan -LP (i.e. for an area of nearly 500,000 people and of 112km2). The aim is to prepare the city for future population and economic growth	This project is about adding an extra lane to a motorway for a stretch of about 10 km. The motorway borders a Natura 2,000 area and the extension will touch small areas of contaminated soil. Residential areas are nearby
Sources/references	https://www.derbyshire.gov.uk/site-elements/documents/pdf/council/have-your-say/consultation-search/consultation-search-index/rapid-health-impact-of-the-avenue-development.pdf	http://consult.liverpool.gov.uk/portal/slp_jan_2018/slp_jan_2018?tab=files	http://www.commissiemer.nl/docs/mer/p28/p2899/a2899ts.pdf (advice of Dutch EA Commission)
What is the site which is being assessed / what is the contamination problem?	Follow up development to a formerly contaminated site which was decontaminated (a remediation strategy was conducted earlier); large amounts of hydrocarbons, asbestos, cyanide and arsenic contaminated a 98ha site, (around 200 football pitches).	Past industrial activity has left 3,023 ha of potentially contaminated land. Some of this brownfield land is supposed to be used for development. 14 residential and 20 employment sites are on potentially contaminated brownfield land.	There are small pockets of contamination next to the motorway (asbestos and hydrocarbons / service station). Existing residential areas are nearby the motorway (at certain points less than 100m).
Purpose	'Healthy' re-use of a remediated site	Raising awareness for contaminated sites	Avoid contamination of groundwater and wider environmental damage
Approach	Pro-active, Rapid-HIA	Reactive (assessing impacts of given options)	Reactive (one preferred option is compared with existing situation)

What environmental & health impacts are observed with regards to contamination	HIA does not focus on former contamination, as the site has been remediated. HIA considers environmental and socio-economic determinants.	Potential contamination of groundwater; if contaminated sites were not remediated	Potential additional nitrate pollution
What type of redevelopment had been assigned to the new development on the site	Prior to the development ideas and the HIA, since 2009 ecological, landscape and soil-forming processes of floodplain restoration, woodland and meadow creation have taken place.	Residential and employment sites to be developed on contaminated land (after remediation).	An additional lane to an existing motorway.
Which possible future impacts had been taken into consideration during the planning phase of the new development / through the IA with regards to health	The HIA focused on the following topics: 1. Housing quality and design; 2. Access to healthcare services and other social infrastructure; 3. Access to open space and nature; 4. Air quality, noise and neighbourhood amenity; 5. Accessibility and active travel; 6. Crime reduction and community safety; 7. Access to healthy food; 8. Access to work and training; 9. Social cohesion and lifetime; neighbourhoods; 10. Minimising the use of resources; 11. Climate change.	The SA focuses on (a) biodiversity; (b) population; (c) human health; (d) fauna; (e) flora; (f) soil; (g) water; (h) air; (i) climatic factors; (j) material assets; (k) cultural heritage, including architectural and archaeological heritage; (l) landscape; and (m) the interrelationship between the issues referred to in sub-paragraphs (a) to (l). Individual major development sites are assessed, also with regards to potential contamination.	Transport safety, noise, air quality, transport of dangerous goods, nature / ecology, landscape /archaeology / cultural history, soil, water. There is an additional separate study 'background report soil' (40 pages)
Recommendations of the IA in relation to health effects to improve the project,	Recommendations on all 11 topics introduced above. The earlier EIA was ass-ociated with an environmental masterplan which included detailed monitoring of air quality, water and ecological and biodiversity impacts during reclamation.	An overall positive effect on health is identified in relation to potential health effects associated with the legacy of contaminated land. This includes policy support for development and remediation of contaminated land.	Noise reducing asphalt; contaminated soil will be remediated. Awareness and care taken of Natura 2000 sites.
Evidence for recommendations being taken up	The assumption is that recommendations are taken up; accountable bodies and 'leads' are identified for recommendations	Local plan policy is to be followed by developers	The realisation of mitigation measures is said to be secured.
Implementation evidence	Not yet	Not yet. Past experiences show that whilst not all proposed action is implemented, some is not mentioned in the local plan but is taken forward. [4]	Not yet

[4] For example, a major site (festival gardens) not considered in the LP is currently prepared for residential development (1,500 new homes). This is a former landfill site and is currently remediated (about 5 to 6 m of soil and underground material; no EIA)

Project name	**SEA of Parc de l'Alba-Barcelona and HIA plus earlier & Human Health Risk Assessment (HHRA), Spain**	**EIA of the redevelopment of the Matinha quarter, Lisbon, Portugal**	**EIA of the re-cultivation of the salt stock near Wathlingen, Germany**
Year IA was prepared	Master Plan started 2006, with 3 revisions, latest in progress (finalising license incl. SEA)	2019	2017
No of pages	SEA: over 1000 pages with 70-page summary document HIA: 65	Considering all studies included in the EIA, several 100s of pages. NTS has 15 pages.	241 pages
Project content	Redevelopment of 340 ha, 10% of which are/were affected by old clay pits convert in old landfills and former industrial activities, for technological and residential uses as well as a high-quality urban park in the metropolitan area of Barcelona. Redevelopment activities started around 2006.	Just over 8 ha of development of a former gas production/processing site, including residential and business area and the construction of a new church.	Re-cultivation of a salt stock (94% rock salt), including a household landfill site. Covers a total area of just over 25 ha and 11.5 M m3. The salt stock is over 80 m high. The stock will be covered with construction waste and an associated recycling plant will be built next to the stock and run for about 16 years.
Sources/references	https://www.parcdelalba.cat/biblioteca/arxius//aridscat//Sustainable_Brownfields_Restaurations_ParcdelAlba_Aquaconsoil_Nicole.pdf; https://www.parcdelalba.cat/biblioteca/items/2646_A/01_Informe_Salut.pdf	https://participa.pt/pt/consulta/loteamento-da-matinha	https://nibis.lbeg.de/LBEGVeroeffentlichungen/Planfeststellungsverfahren/Kali%20und%20Salz%20-%20Abdeckung%20Halde%20Niedersachsen/
What is the site which is being assessed / what is the contamination problem?	Several sites with various types of contamination (hazardous waste, hydrocarbons, asbestos). There are gas emissions from the subsoil area.	This is a former gas production/ processing site (1944 to 1999) with numerous contaminations issues (hydrocarbons, acidic substances and others).	The salt stock consists of tailings from potassium and ancillary salt mining which happened between 1910-1997. Parts of the stock served as household landfill (1957-1975). Salty water from the stock drains into a local stream. Residential areas are located less than 400 m from the stock.
Purpose	'Healthy' re-use of a remediated site	'Healthy' re-use of a remediated site	Ensuring activities are not damaging.
Approach	Pro-active	Reactive, looking at a planned development	Reactive, looking at existing ideas
What environmental and health impacts are observed with regards to contamination	For each contaminated site, HHRAs assessed compatibility with planned use and proposed remediation, if necessary. SEA looked at contamination problems. HIA assessed strategic action "Recovery	A 17-page annex (4.5) deals with health effects, focusing on remediation risks, air quality & noise impacts. Other areas (future use) include jobs and social cohesion, access issues, green areas,	Main areas covered include water draining from the stock into a local stream (Fuhse), soils and also dust, noise and other emissions from the construction activities, including the running of the recycling plant

	of land from former landfills and degraded areas" on environmental and socio-economic health determinants. It pro-actively looked at how to enhance health benefits from redevelopment.	transport modes and light; all presented with regards to potential health effects. A **remediation plan** from 2018 provides a detailed description (180 pages) on how decontamination is to be done	up to 2045 and about 100 truck loads of construction waste each day.
What type of redev-elopment had been assigned to new dev-elopment on the site	Residential, economic development areas and green infrastructure / urban parks.	Residential and economic activities next to a church	Ultimately, a re-cultivation is planned. The salt stock will be covered with recycled construction waste up to 2045 and the hill thus obtained will be planted.
Which possible future impacts had been taken into consideration during the planning phase of the new development / through the IA with regards to health	SEA assesses all the potential impacts related to the construction and management of development, including the remediation. In HIA environmental, social and economic impacts are taken into account, divided into 5 major groups and 16 determinants of health; density, street connectivity, land-use mix, landscape and traffic; various actions of the plan are assessed with regards to those groups and determinants. Contaminated sites are also considered.	The EIA is looking at a range of potential impacts, including those connected with construction, remediation and noise and air pollution. Generally speaking, remediation is assessed to have positive impacts, including health as the focus is on the end-product (i.e. the remediated site). The EIA does not assess remaining risks, as the assumption is that the site is safe after remediation. Furthermore, noise pollution from construction and transport (railway) is identified as a negative effect along with transport congestion.	The EIA is looking at effects of all environmental aspects mentioned in the European EIA Directive. Three options for grading off salt from the stock are compared and rail/road options for delivery of construction waste. Main impacts are associated with the re-cultivation activities over more than 20 years, rather than contamination related. Groundwater was found to be of a poor chemical quality. However, this was agriculture related. With regards to human health, recreational areas, dust and noise were considered, but no significance was established.
Recommendations of the IA in relation to health effects to improve the project,	SEA focuses on the restauration of land not compatible with use as an open space. SEA and HIA consider compatibility of envisaged uses (Urban plan). Environmental monitoring of the degraded areas is ongoing. This will have to be validated by relevant authorities.	Recommendations include setting up noise barriers. Also, a slight rerouting of a major road next to the development is recommended along with the introduction of parking spaces for residents. Monitoring measures are proposed with regards to e.g. potential water pollution.	There is a nature protection area next to the salt stock. Mitigation and compensation measures are suggested for this during construction. There is no mitigation anticipated for human health.
evidence for recommendations being taken up	Too early to tell	Too early to tell.	Too early to tell
Implementation evidence	Parts of Master Plan have started being developed, including Àrids Cataluña	Not yet.	Not yet.

EXPERT FEEDBACK

This section summarises expert feedback received on an earlier draft version of this review report. This was obtained from:

(a) Discussions during an online WHO meeting on the redevelopment of contaminated sites, held from 28 to 30 September and 5 October 2020.
(b) Interviews with key individuals involved in some of the IA cases reviewed, conducted in the last week of October 2020.

With regards to (a), 'comments obtained from the WHO workshop participants', most were of a generic nature, with a few also focusing on specific report aspects. An important generic message arising from the discussion is that IA should be approached as a framework, rather than a one-off process, integrating different IA instruments applied at different decision tiers (policies, plans, programmes, projects) and administrative levels (e.g. national, regional and local). Its usefulness is connected with an ability to co-ordinate different activities and issues that are of relevance for the development of formerly contaminated sites. In this context, a challenge of existing practices is that they frequently neglect the wider context of a particular site, focusing on contamination only, rather than on establishing how the site fits into the overall development within e.g. a town or neighbourhood. Whilst legal frameworks for different types of IAs exist in most countries, they are often covering larger sites only. This was seen to be problematic, as smaller sites would frequently not be associated with a requirement to assess impacts and / or risks. Also, different types of IAs were not always integrated well. In this context, a problem was the integration of those IA tools used in decision consent procedures (e.g. SEA and EIA) and those prepared with the purpose of obtaining permits / licenses (e.g. risk assessments). Informing and involving experts and the general public was seen as a key function of IA. Connecting human health data with information on contamination and de-contamination was seen as particularly important when monitoring sites.

With regards to (b), 'interviews with key individuals involved in the reviewed IA cases', a particular issue arising is a sensitivity towards presenting projects that may be considered controversial by some. This is why comments are presented here in a generic way only, without associating them with specific IA cases. Interviews were conducted with four individuals representing four of the IAs reviewed. Two issues emerging from the discussion are perceived to be of particular importance with regards to the potential usefulness of IA, namely its aptitude to co-ordinate different actions and to function as a platform for public debate and involvement. With regards to the former, co-ordination of different issues and activities means IA can help making a particular site compatible with future uses and to establish where conflict may arise, including any potential health impacts, identified in either HIA or any of the other IA tools. This requires taking the overall context of a site into account, including characteristics of the town or neighbourhood within which a site is located. On the latter, on many occasions it is through IA that the public is informed and being enabled to get involved in decision making on formerly contaminated sites and it is here that IA plays a key role. It is also suggested that existing requirements tend to be sufficient for an effective application of IA instruments when dealing with contaminated sites. However, there was concern that these were not always used according to what is possible or desirable. Finally, and in the absence of any other platforms for public debate of future use of (formerly) contaminated sites it is suggested that EIA and SEA could be used by interest groups that are e.g. against a particular type of development. As HIA tends to be non-statutory, it wasn't explicitly mentioned during interviews[5]. In this context, they can hide the real reason for their involvement and use the associated process to e.g. delay a decision. This was observed by other authors in different situations of application, as well (McKillop and Brown, 1999). Whilst this is an issue of concern, IA on its own cannot resolve this. It requires e.g. the legislator to become active and provide for the necessary space to have an open public debate on development. In this context, timing is of particular importance. Only if applied early will IA be capable of pro-actively informing decision making on the development of formerly contaminated sites.

DISCUSSION

Starting the discussion, it is important to stress that the professional literature is currently quiet on contaminated sites and the application of EIA, SEA and HIA and that that all findings presented here are based on the primary research carried out to inform this review report. Furthermore, establishing and getting access to suitable case studies is difficult and even experts have problems naming examples for review (at least in English; as was discussed earlier, this may be less of an issue in other language contexts). In addition, even if assessments can be identified, they may either not be publicly accessible or be considered highly sensitive. There are therefore limitations with regards to the scope of this review report.

Environmental Impact Assessment (EIA), Strategic Environmental Assessment (SEA) and Health Impact Assessments (HIA) were found to be used in different situations of follow-up development projects in the context of public consent decisions on the redevelopment of (formerly) contaminated sites. Furthermore, when seeking to obtain e.g. remediation permits and licenses, land contamination surveys and risk assessments (RAs) were also applied.

When RA is applied, in most countries there are guidelines and standards available for how to deal with different contaminants. The focus of RA therefore is on the cause of the contamination and on how to remediate in order for sites to meet acceptable standards. RAs include Human Health Risk Assessments (HHRAs) and Environmental Risk Assessments (ERAs). Connections with follow-up usage are only rarely made and an important assumption is that a site is safe following remediation.

With regards to the coverage in the nine IA cases reviewed in this background paper, three key stages in the remediation of a contaminated site are observed;
Stage (1): Establishing that a site is potentially contaminated and whether there should be remediation;
Stage (2): Preparation and implementation of remediation / remediation, once a decision has been made that a particular site requires it (usually following the identification, evaluation and selection of feasible remediation options through RA), on one occasion taking into account the new use.
Stage (3): Planning and implementing follow-up development once a site has been remediated.

[5] However, Fischer et al (forthcoming) report on one community-led project HIA in England, which was conducted via a neighbourhood planning process and the project proposal ended up being rejected, in part because of predicted negative health impacts.

Only one of the IAs reviewed covered all three stages,[6]:

1. **EIA** Wiener Neustadt und Weikersdorf am Steinfelde, Austria: Stages (2) and (3)
2. **SEA** Bebauungsplan / building plan Pioneer Kaserne, Hanau, Germany: stages (2) and (3)
3. **HIA** of the Northumberland Local Plan, UK: stage (1) (SEA/SA also prepared)
4. **HIA** Avenue Development, Chesterfield, UK: stage (3) (EIA also prepared; furthermore, a remediation strategy was prepared earlier for stage (2))
5. **SEA** (**SA**) and **HIA** of the Submission Draft Liverpool Local Plan, UK: stage (1)
6. **EIA** of extension of A7/A8 motorways, Purmerend and Zaandam, The Netherlands: stages (2) and (3)
7. **SEA**, Parc de l'Alba, Barcelona, Spain: prepared in 2006, 2014 and 2020 for three stages of master plan development; a human health risk assessment – **HHRAs** were also prepared earlier and an **HIA** for the master plan: stages (1), (2) and (3)
8. **EIA**, Matinha Quarter, Lisbon, Portugal: stage (3) (a separate remediation plan, which was attached to the EIA was prepared earlier for stage (2)[7]
9. **EIA**, re-cultivation of salt stock, Wathlingen, Germany: stages (2) and (3)

With regards to remediation of sites involving project EIA, only for those where the future anticipated use was recreational (forest or park development) and road construction (i.e. IAs 1., 6. and 9) *outside existing residential areas* were stages (2) and (3) found to be approached in a combined manner. No EIA was found to be conducted on an existing residential area. Depending on the administrative level at which SEA was prepared, it either aimed at stage (1) (i.e. municipal level local plan IAs 3. and 5.) or at stages (2) and (3) (i.e. for the building plan 2., which is prepared at the neighbourhood level). Project level EIA and HIA for residential development only covered stage (3). Here, remediation strategies or environmental / health risk assessments focused on the remediation stage (2). Depending on where HIA was allocated (i.e. within the context of a municipal spatial / land use plan or EIA) its approach followed the same logic. The approach taken by SEA is either to recommend avoiding contaminated sites or to advise on land contamination surveys/RAs, and if needed, remediation of sites earmarked for development. It is also possible that any or all of these assessments (site investigations/land contamination surveys/RAs) inform SEA of a spatial / land use plan, i.e. they are prepared before SEA. There are, therefore different ways of progressing. Generally speaking, RAs (e.g. human health risk assessments and environmental risk assessments) were conducted when seeking to obtain e.g. remediation permits to operate mobile plants for the treatment of soils and contaminated substances. Table 3 summarises these findings. It is important to stress that this Table is not attempted to show an 'ideal' framework. Rather, it is meant to explain current practices, as found in the 9 IAs.

[6] What is presented here is based on the documentation obtained. Whilst it is possible that other assessments were conducted at a different stage, there was no mentioning of this in the assessment documents reviewed.
[7] The EIA provided for short term monitoring (quality of the soils after the removal of the contaminants, air quality during the remediation works) and monitoring in the operational phase during the first year after the completion of the buildings, focusing on 1) ground water quality and 2) indoor air quality of the basement (parking) of the buildings.

Table 3: IAs applied at different stages of remediation

Purpose / Remediation stage	Residential (+ commercial and often recreational)	Recreational only (next to residential areas)	
Stage 1 (identification of problem)	Screening of site / pre-studies Land contamination surveys) **SEA** (large scale[1]; considering	(e.g. site investigations and anticipated future use) / **HIA**	Communication/Consultation
Stage 2 (remediation)	Risk Assessments (RA)	EIA (including RA) or if EIA is not required potentially only **RA** (combined for stages 2 and 3)	Communication/Consultation
Stage 3 (post remediation development)	**SEA** (small scale[2]) or **EIA** / **HIA**		Communication/Consultation
Stage 4 (Post development)	Follow-up defined in	SEA, EIA and HIA	Communication/Consultation

[1]for e.g. spatial / local land use / development plans
[2]for e.g. Master or Building Plans
SEA; EIA: possibility for the public to participate

Importantly, in the context of this review report, HIAs were not conducted within the context of remediation/ remediation activities when the ultimate purpose was residential and other associated developments. In this context, human health risk assessment (HHRA) was used[8]. In all situations where HIA was applied, this was covering environmental as well as socio-economic determinants of health and was focusing on future use of a site. SEAs and EIAs usually focused on bio-physical determinants of health only. The exception was the one case were SEA was applied within the context of sustainability appraisal (SA) and where HIA was also applied in parallel (i.e. the Liverpool Local Plan). Here, biophysical and socio-economic determinants of health along with well-being were considered. However, it is not clear whether this ultimately led to trading off the 'weaker' bio-physical determinants, as has been observed to happen frequently in SA practice (Therivel and Fischer, 2012).

Only one of the cases that involved stage (3) IAs (i.e. post remediation development) covered potentially remaining risks after a site was remediated, namely case 8. 'Matinha Quarter', Lisbon. The approach taken was very short term, though, and included a provision for some monitoring with regards to (a) the quality of soils after the removal of the contaminants as well as (b) air quality during the remediation works. Furthermore, it included provisions to monitor air and water quality during the operational phase in the first year after the completion of the buildings. An assumption taken by most IAs conducted at stage (3) therefore usually appears to be that the site is safe after remediation. Whilst certain monitoring requirements, in particular for biophysical aspects, are included in all IAs, an important question arising is whether provisions to monitor e.g. soil, groundwater and air quality should always be established. Further generation of evidence and debate on this are required.

With regards to the observations made here, it needs to be stressed that EIA is applied to big projects only. This means there is a need to look into whether the issue of remaining risks is

[8] As explained earlier, HHRA provides for estimates of the nature and probability of adverse health effects of humans exposed to chemicals in contaminated environments

dealt with differently in developments involving EIA from those that do not require preparation of EIA.

CONCLUSIONS

The conclusions provide responses to each of the objectives stated in the introduction of this background report, as follows:

Does SEA/EIA/HIA Identify a need for remediation of contaminated sites, influence and/or modify remediation?

Based on the evidence obtained from the nine cases this can be answered with a 'yes'. The need for remediation is currently established through SEA, as well as through HIA when this is applied next to SEA. Furthermore, in the context of identifying a need for remediation, site investigations and land contamination surveys play a key role.

Does SEA/EIA/HIA assess and evaluate remediation?

Again, this can be answered with a yes. This was observed to happen when EIA was applied to sites outside existing residential areas. Furthermore, one SEA also assessed compatibility of planned use with remediated sites. Follow-up use was assessed through HIA and if required (based on the size of the development), also by EIA. Remediation is routinely assessed through RA, either HHRA and / or ERA.

Does SEA/EIA/HIA identify continued or new environmental and/or health risks after and despite the remediation?

Only one case provided any evidence for this to happen in current practice, which is the only case were residential development was planned right on top of former contamination (all others had residential areas planned next to it). However, the monitoring outlook was very short, covering one year only. This does not suggest it may not be important to do so. However, currently SEAs/EIAs/HIAs do not appear to usually take remaining potential health risks into account after remediation. Whilst these are the findings derived from reviewing existing practices, it is important to elaborate on whether observations are in line with what we want to see or whether practice needs to improve.

With regards to the perceived benefits provided by IA to the development of (formerly) contaminated sites, two issues are found to be of particular importance. First of all, through functioning as a framework (rather than a one-off process), IA can help to co-ordinate different actions, activities and issues. This can support making sites compatible with anticipated future use and can also help to establish future use. Secondly, on many occasions IA provides for the only platform currently available for public debate on the future use of a (formerly) contaminates site, providing it with a key role in democratic public decision making.

Finally, it is important to state that this review report is covering unexplored and new ground and is providing new insights into practices that to date have not been discussed in the professional literature. There are currently no published studies on how EIA, SEA and HIA are applied in contaminated site remediation and follow-up development. This report is therefore a first step towards developing a better understanding for how IAs are currently used and where practice needs to or should be improved.

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