Civil Engineering

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ice | proceedings

Proceedings of the Institution of Civil Engineers
http://dx.doi.org/10.1680/jcien.15.00034
Paper 1500034
Received 22/07/2015 Accepted 11/01/2016
Keywords: public health/rehabilitation, reclamation & renovation/waste management and disposal

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Institution of Civil Engineers
publishing

Protecting communities by remediating polluted sites worldwide

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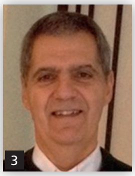

Millions of people worldwide are suffering health risks as a result of living near highly contaminated sites including abandoned industrial and mining sites, and polluting artisanal areas. More than 3000 sites across 50 developing countries have been identified. Nearly 100 million people are at risk at just these sites. The main impact falls on people in low- and middle-income countries, with children being particularly vulnerable. Interventions have been implemented at about 100 of these sites, with significant success in reducing impacts. This paper aims to draw the attention of practising engineers to the scale and impacts of the problem and to encourage expanded efforts to implement cost-effective solutions. Tackling contaminated sites is part of broader efforts under the umbrella of the Global Alliance on Health and Pollution to reduce environmental pollution, which is one of the largest contributors to the burden of disease worldwide. Clean-up is required but prevention of pollution must also be a high priority.

1. Character and scale of the problem

Site identification and initial investigation of contaminated sites worldwide over the past decade have demonstrated that toxic substances from industry and mining activities are affecting the health of hundreds of millions of people in low- and middle-income countries. Field studies have identified heavy metals, pesticides, solvents, radionuclides and other toxic substances at dangerous levels at thousands of sites. Health analysis at about 400 sites in Asia (discussed below) has shown that more than 8 million people are exposed to risks at just these sites.

Addressing the problems is not a question of confronting 'international polluters' – it is the challenge of working with local communities and their governments, at many levels, to find practical and affordable ways forward. Many of the problems are tied to subsistence or informal industries, and therefore the interventions must focus on financial and social aspects as much as purely technical ones. Practical interventions have been found to mitigate these toxic exposures while protecting livelihoods, although the scale of the problem is such that it is going to take considerable amounts of effort, resources and time to achieve large improvements (Figure 1).

Figure 1. Investigating waste lead dump in the Dominican Republic

Work on reducing the damage from these contaminated sites was initiated about a decade ago by the Blacksmith Institute, a relatively small not-for-profit organisation with the vision of 'a clean planet for our children' and local representation in a dozen countries. (The Blacksmith Institute is based in

New York and also operates as Blacksmith Initiative in the UK and Europe and as Pure Earth in the USA. For convenience, the broad name 'Blacksmith' is used in the text.) Practical actions to help communities deal with contamination began about 14 years ago working with local non-government organisations and community activists in India, Russia and several countries in Africa. It rapidly became clear that the 'isolated' problems that were being addressed were representative of much more widespread challenges. However, as each individual problem was local, there was little recognition at state or national level of the aggregate scale of the problem.

Efforts to scale up the funding being applied to contaminated sites in lesser developed countries suffered from the low visibility of the issue as a whole. Individual managers at aid and development institutions were often supportive but stressed the need to quantify the problem and to put it in the context of other development challenges. Subsequently, Blacksmith developed a standardised approach for collecting and recording data on sites across all of its operations. This approach was further refined and standardised into a Toxic Site Identification Programme with funding from the EU, the World Bank, the Asian Development Bank and Green Cross Switzerland.

At the same time, efforts were increased to identify and implement practical interventions at a number of sites, in order to reduce the impacts and to demonstrate the practicality of achieving improvements at relatively low cost.

2. Toxic site identification programme

There was a clear need for a trustworthy database of contaminated sites, especially in countries where interventions were under consideration. One of the first major efforts was in India with support from the Asian Development Bank, during which more than 70 known sites were reviewed and about half these were assessed in the field (Blacksmith Institute, 2007). The results, with recommended priorities, were provided to the state and central governments and became inputs to a national remediation programme. Following this, several donors began to support a standardised and wider-ranging approach, which became the toxic site identification programme.

The toxic site identification programme is structured to identify and screen contaminated sites in low- and middle-income countries where public health is at risk, particularly from toxic and persistent contaminants such as heavy metals and organic chemicals. The programme is not intended to be a comprehensive inventory but to understand the scope of the problem. The main targets are sites where there is believed to be a serious level of soil contamination, often with associated groundwater pollution. A particular emphasis is on so-called 'legacy' or 'orphan' sites, where there is no responsible party that can be held to account.

Ongoing processing or manufacturing activities are typically excluded from the investigations, because these should be under the oversight of the relevant environmental authorities. Similarly, air emissions and water discharges are best managed by regulatory action and are not included in toxic site identification programme data collection. However, it has emerged that a major but often unacknowledged source of contamination is from informal or small-scale activities. There is an increasing number of sites being identified where activities such as lead recycling, artisanal mining and others are a danger to the people involved and a serious but poorly recognised risk to surrounding communities and the environment.

> More than 3100 potentially contaminated sites have been recorded and about 2200 have been visited and screened

The toxic site identification programme utilises a network of national investigators to visit and document hazardous waste sites (Ericson *et al*., 2013). Over the period since the toxic site identification programme was established, more than 500 national investigators and government officials have been trained and have carried out screening on local sites. These investigators are usually from local technical institutions or agencies and are trained in the identification of sites and the implementation of a standardised rapid assessment tool called the initial site screening protocol. The initial site screening records major elements of a contaminated site, including key pollutants, human exposure pathways, the estimated population at risk and sampling results. After quality control checks, the results of the investigations and the relevant database are provided to government agencies.

To date, more than 3100 potentially contaminated sites have been recorded in the database (Figure 2), and about 2200 of these have been visited and screened. Internal toxic site identification programme estimates are that these sites alone represent a potential health risk to an estimated more than 80 million poor people, with heavy metals such as lead, mercury and chromium being the most prevalent toxicants. However, this obviously represents only a fraction of the overall total and current efforts at extrapolating from the limited data set estimate that the number of potentially exposed people is in excess of 200 million (Ericson, forthcoming).

The quality of data in the database varies and it includes information that remains to be confirmed or expanded; therefore the full database is not made publically available. The relevant data are shared with national agencies and release of information on sites is the prerogative of the legally responsible agency.

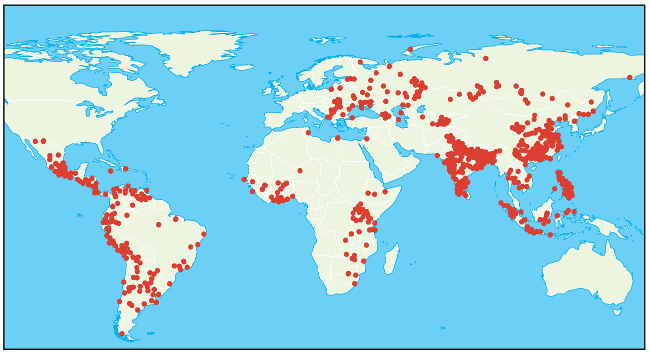

Figure 2. Toxic sites identified worldwide

3. Site ranking and impacts

The variety in type and scale of the contaminated sites requires ways to characterise and compare them. Information in the database, although consistent across all the sites as far as possible, is limited in scope and the range of sites and conditions are varied. Therefore a simple and robust methodology for comparison was needed.

The ranking methodology, known as the Blacksmith index, was developed following the basic structure of the hazard ranking system created for the United States Environmental Protection Agency (USEPA, 1992) and used with only limited changes for several decades.

The Blacksmith index has the same general structure as the hazard ranking system, with the key components of pollutant, pathway and population, but it does not address ecological risks and requires much less data (Figure 3). It is calculated for each site from the initial site screening data and allows simple and rapid calculation of comparative risks (Caravanos *et al.*, 2014). The approach provides reliable order of magnitude precision and is reported as a number in the range 1–10.

4. Growing evidence on health risk

Many of the substances found at the contaminated sites are known to have some potential impacts on human health. However, there are very limited substantive data on the overall health impacts of contaminated sites, individually or collectively.

The basic indicator of health status, across all types of diseases and risks, is the 'burden of disease'. This approach was developed by researchers at the World Health Organization (WHO) and was subsequently reported in a series of papers presenting comparative data on the global burden of disease (e.g. Ezzati *et al.*, 2004; Global Burden of Disease Study 2013 Collaborators, 2013). Estimates of the burden of disease are expressed in the metric of 'disability-adjusted life years', which allows for morbidity and mortality that results from diseases, injuries or other health states.

Estimation of disability-adjusted life years is a complex process, with a range of uncertainties, and not all health states and risks are included in WHO reports, although coverage has been expanding in recent years. Until recently, there had not been any detailed estimates of the death and disability attributable to toxic waste sites and the corresponding overall burden of disease.

The first detailed peer-reviewed estimates of the health impacts from toxic sites used toxic site identification programme data from 373 sites in India, Indonesia and the Philippines to generate disability-adjusted life year figures (Chatham-Stephens *et al.*, 2013). Extrapolating from the toxic site identification programme data it was concluded that more than 8.5 million people were at risk from industrial pollutants at these sites. The exposure was estimated to result in about 830 000 disability-adjusted life years in 2010. This number is comparable in scale to the burden of disease in those countries from outdoor air pollution or from malaria, illustrating the remarkably high health impacts associated with the toxic sites.

Figure 3. Soil testing using portable X-ray fluorescence

More recent work reinforces the broad finding that the health impacts of pollution are considerably more serious than generally realised (WHO, 2014a, 2014b).

5. Global Alliance on Health and Pollution

There have been increasing efforts to identify and address contaminated sites and there is a growing understanding of the impacts of various types of pollution. These efforts are increasingly driven by country governments, supported by development agencies and multilateral banks. The Blacksmith Institute has played a central role in promoting coordination of such efforts, a process that has recently become more structured through the establishment of the Global Alliance for Health and Pollution (GAHP).

GAHP is a collaborative body that facilitates the provision of technical and financial resources to governments and communities to reduce the impacts of pollution on health in low- and middle-income countries (GAHP, 2014). It works to raise awareness and provide technical support, as well as being a forum for countries and their supporters to identify priorities and to share experiences.

6. Making a difference on the ground: example projects

Data collection and analysis of information are critical activities to establish the global urgency of addressing contaminated sites. At the same time, Blacksmith's emphasis has always been on 'shovels in the ground': implementing practical on-site actions to address directly the most immediate threats. Support – financial and technical – continues to be provided to partners in-country to identify, structure and implement projects. Since 2002, about 100 projects specifically targeted at reducing the impacts of toxic sites have been supported. Many of these are relatively small, limited by the funds available. More recent projects have benefitted from this learning and have produced cost-effective outcomes on a wide range of contaminated sites.

The choice of project and the approach to the problems have been driven by a small number of core concepts (Table 1). The most basic point is that there must be serious buy-in from the local community for action. Often there is a local champion who has been agitating for an intervention to deal with a problem. With the help of this person, a stakeholder group is brought together to discuss the extent of the problem, identify opportunities and generate broader local involvement. The commitment of the local community to assist actively in an intervention is essential.

Often there are very limited initial resources to bring to the intervention and therefore there is a need to target cost-effective initial actions. The focus is on reducing or eliminating health risks and these first activities may include community awareness and advice, together with containment or isolation of the worst sources. Where risks are high, there is a need to use the available resources to start the process while additional resources (local or external) are being found.

Blacksmith projects aim to bring the best science and an understanding of the latest technology, through a broad-based technical advisory group, who have been extremely helpful over the years. At the same time, simple approaches are often the most appropriate for physical interventions when technical skills and equipment may be very limited. It is important to find the right blend of high-tech and traditional for each case.

Examples of projects in which practical experience has been applied are set out in the following subsections.

6.1 Dong Mai, Vietnam (2013–2015)

In this village of about 300 houses, the main economic activity has been informal small-scale recycling of used lead–acid batteries, often carried out in the yards of individual homes. The blood of local children shows very high levels of lead (Daniell *et al*., 2015; Noguchi *et al*., 2014) and the local government re-located much of the recycling activity to an industrial area on the outskirts of the village. However, the studies demonstrated that even after the main activities had been moved, soil lead levels remained high in many areas of the village (see Figure 4) and many children still had lead burdens well above levels of concern.

The broad extent of soil lead throughout the village created a challenge in remediation design, which was discussed at length with the villagers and their leadership who were deeply involved throughout. The broad ‘road map’ adopted, given the resources that could be applied, was based on targeting the most acute areas initially and on encouraging subsequent further action by community members, at the household level, through education and demonstration.

The priorities for physical intervention were 42 homes with the highest lead levels in the houses and yards, and also several stretches of road in the village, which showed high lead levels. The community campaign addressed the importance of eliminating any remaining furtive home smelting, cleaning of properties to reduce exposure at home, and improved hygiene practices to prevent workers at the new plant bringing lead dust back to their homes (Figure 5).

Under the project 39 home interiors were cleaned by project staff, using a protocol that had been developed on earlier projects and that stressed appropriate personal protective equipment and effective techniques. These cleanings also served as demonstrations for community members who later successfully carried out cleaning of many of their own homes. To deal with risks in the yards of homes, the contaminated areas were covered with a geotextile layer (on a sand base) and then 200 mm of new material, either sand, clean soil or concrete, depending on the uses of the areas. The alternative of removing the contaminated soil to landfill would have been prohibitively costly, disruptive and would have generated new risks during transit. Research and advice from the GAHP technical advisory group showed that this type of soil capping is an accepted methodology for many regulatory agencies and was appropriate in these circumstances.

A separate risk was posed by workers returning home from the industrial area. To address this, a changing room was constructed with equal cost sharing from the smelter owner. The changing room has hot water showers, toilets and lockers, among other amenities.

Following this externally supported project, community members and district authorities pooled resources to continue the

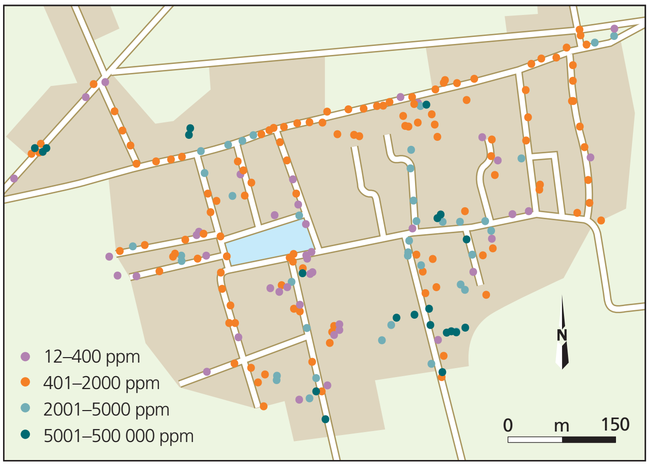

Figure 4. Soil lead monitoring results in Vietnam village

Figure 5. Stakeholder meeting in Vietnam

Gold processing releases large quantities of mercury vapour to the surroundings, causing health impacts in the local community and impacting on the global environment

remediation, including paving three of the most affected roads within the village, which will significantly reduce dust generation and ongoing community exposure, and remediating an additional approximately 70 homes to date.

As a result of the interventions, blood lead levels have already shown major reductions. A forthcoming paper by the research team will report on blood lead level changes in 200 children who were tested before and again after the first (externally funded) interventions. The results are still being analysed but initial indications are that significant reductions were achieved over this period, with particular improvements seen for individuals who initially had the highest, most dangerous levels. These reductions are gratifying but given the chronic nature of exposure and the severity of the body burden, it may take several years for levels to return to acceptable values, such as the US Centers for Disease Control and Prevention reference value of 5 mg/dl (CDC, 2015). However, paving of the roads, increased awareness and a focus on hygiene and other physical improvements are expected to result in further significant declines over time.

6.2 Central Kalimantan, Indonesia (2009–ongoing)

The agreement in 2013 of the Minamata Convention on Mercury has brought more international attention to the health and environment problems of mercury (UNEP, 2015). Efforts have been underway for several decades to reduce and eventually eliminate the use of mercury in artisanal and small-scale gold mining (e.g. Veiga and Baker, 2004).

The Kalimantan project has been working closely with Yayasan Tambuhak Sinta, a well-established local non-government organisation, to tackle the problems in a group of gold mining villages. The approximately 5000 miners were adding large quantities of mercury during gold processing to produce a gold-rich ball of 'amalgam', from which the gold can be extracted by burning off the mercury. However, the process releases large quantities of mercury vapour to the surroundings, causing health impacts in the local community and adding to the impacts on the global environment. Mercury can be highly toxic and inhalation of mercury vapour is one of the highest risk pathways (ATSDR, 1999). Estimates from the project were that about 50 t of mercury per year are released from this area.

The project team focused on improving mercury recovery from the amalgam burning stage, which usually happened in gold shops in each village, run by wealthier individuals – the gold 'bosses'. A basic technology for recovering mercury is the 'retort', which has been in use in different forms for many decades, and which captures and condenses mercury vapour to be recovered, thus reducing exposure of the workers and the local community. The project tested and refined a number of different retorts and settled on a basic design that can process 1 kg of amalgam at a time. Following implementation of this and further discussions with the bosses, a large-scale retort was developed, capable of processing 30 kg per day of amalgam, and four of these were installed in larger gold shops (Figure 6).

Monitoring of the effectiveness of 29 smaller retorts and the four large retorts indicated that collectively they captured and allowed the recycling of nearly 3 t of mercury in 2009 (internal reports). This greatly reduces the release of toxic mercury vapours and the mercury exposures of people in the villages, although direct measurement of the body burden of mercury and related health effects is not practical in remote mining villages. Recycling also brings a significant economic benefit. The replacement cost of 3 t of mercury was, at that time, about US$200 000. As the miners pay for the mercury used, this recovery represents a major return of capital to the miners, although the details of how this value is shared are not clear.

Nevertheless, there are still large quantities of mercury being released to the environment in the grinding and separation stages of mining. In the project area, a particularly inefficient technology known as 'whole ore amalgam' is used. Technologies exist to process gold without mercury or alternatively with much lower losses of mercury. However, these are sometimes inefficient in gold recovery, may not be suitable for some ores, and require changes to traditional methods in an industry that has very little time or resources to experiment. There are a number of international groups with experience in artisanal and small-scale gold mining, which are working under the Global Mercury Partnership to identify and bring about the adoption of mercury-free or low-mercury technologies in mining areas worldwide. The variety of social, economic and geological conditions in which artisanal and small-scale gold mining takes place is a major challenge in reducing worldwide mercury releases.

6.3 Horlivka, Ukraine (2010–2014)

This was an unusual and ultimately successful remediation at an abandoned chemical manufacturing plant, but sadly the benefit has been lost in the chaos and carnage in eastern Ukraine. The site, identified by local officials, was a plant where military products

Figure 6. Testing large mercury retort in Indonesia

had been manufactured before the withdrawal of Soviet forces and where toxic chemicals were left dumped around the plant (Figure 7). The most hazardous of the uncontained chemicals was mononitrochlorobenzene (MNCB), which is believed to have been used in trinitrotoluene (TNT) manufacturing but which can also be a component of nerve gas. The problems became compounded when former staff at the plant identified process equipment where TNT still remained.

In 2010, efforts began to build a coalition of donors and stakeholders to fund, design and implement a project to deal with an estimated 2000 t of MNCB and to extract an estimated 30 t of TNT from the plant. The worst-case scenario was a massive TNT explosion, which could have spread the toxic MNCB across the centre of the city of about quarter of a million population. It was a complex operation described as dealing with a 'toxic site on top of a bomb', as summarised vividly by the project manager (McCartor, 2014). Eventually, the MNCB was collected and repackaged for disposal off-site in an approved incinerator. The TNT was carefully removed from the process pipework and tanks, which required cautious dismantling of dilapidated buildings, and was also packaged and sent for incineration.

The project succeeded in its aims not least because it was conceived and driven from the bottom up, and because it was possible to bring together diverse collaborators from private, public and non-profit sectors. The project eliminated a very high-risk situation, which was a major concern for the local area. However, this progress has been entirely overtaken by the armed conflict in this region, which has put paid to earlier plans to address other problems at the site.

7. Broad project approach

The basic finding of the projects described in the previous section and other practical projects is that it is possible to achieve progress in dealing with serious contamination and saving lives in nearly every situation, even if in some cases it may take time and repeated efforts to make substantial progress.

Figure 7. Toxic spillages in Ukraine

It is possible to achieve progress in dealing with serious contamination and saving lives in nearly every situation, even if it may take time and repeated efforts to be substantial

The technical elements are often relatively straightforward; the challenges include agreeing on the scope, selecting the technical approaches, and ensuring that the institutional and regulatory aspects are handled early and effectively. Projects follow standard requirements including environmental review and sound site safety and management procedures, although the details are tailored to the local requirements and resources. Overall project principles that have evolved and continue to be refined are summarised in Table 1.

One key issue faced in the implementation of many remediation projects is whether on-site options are feasible and if an off-site alternative is practical. Many of the contaminants addressed are metals (such as lead) or other persistent organic chemicals, which do not readily break down or transform in the environment, and therefore some form of stabilisation or encapsulation may be required (Figure 8). Some form of controlled burial is often an attractive technical approach. Discussions with regulatory authorities at several project sites identified a fundamental issue related to disposal: whether material such as that from a lead remediation project has be taken to a specialised so-called 'sub-title C' hazardous waste landfill, following US practice. Sub-title C refers to the section in US Resource Conservation and Recovery Act legislation, which sets out the stringent requirements for a landfill that accepts 'hazardous waste'. Very few such facilities exist in low- and middle-income countries.

A review of international regulation and practice was carried out with the help of GAHP technical advisors. The conclusions were that international practice allowed relatively homogeneous and well characterised waste (such as that from lead remediation) to be managed in a specifically designed 'mono-landfill' and that full sub-title C technical requirements did not necessarily apply (GAHP, 2014)). Recently, a lead clean-up project near Bogur in Indonesia included such a 'mono-cell' constructed as a separate cell at a regional landfill, with the explicit approval of both local and national authorities, drawing in part on the findings of the review.

8. Scaling up to deal with the challenges

Concerted effort by national governments, with significant international assistance, will be required over several decades to come to grips with even just the worst sites identified so far. Work is ongoing with several governments to encourage and assist them to develop national plans to address toxic pollution, either for specific issues or more comprehensively. Outputs from

Practical operational principle	Description
Focus on health	Priority is placed on situations with a clear health risk and a defined population in the pathway of exposure to toxic pollution. Other projects may be supported where there are more general health risks and broad local support.
Ensure local ownership	Strong local ownership of a proposed intervention, demonstrated by commitment of effort and resources, is seen as confirmation that the problem is really a local priority and so can justify external support.
Polluter pays where possible	Clearly the responsible parties should remedy the problems wherever possible. However, proceeding with urgent interventions should not be held hostage to legal battles. In some cases, relevant parties may be persuaded to support clean-up without admitting liability.
Start with the most urgent steps	Efforts to deal with the most urgent problems should be initiated even if the full long-term planning has not been finalised. Such steps typically revolve around stopping and/or containing the movement of pollutants. They should be accompanied by establishing the process and planning for the long term. Necessary immediate interventions should not be delayed while details of the ultimate solution are being examined.
Strengthen local implementation capacity	Local institutions and groups are crucial in tackling priority problems and in achieving sustainability of pollution control efforts. Lack of experience and skills in technical aspects and in project management should be deliberately addressed through guided 'action learning' in the initial phases of dealing with the problem. Ad hoc stakeholder groups should be encouraged to coordinate or even integrate with existing institutions where this can bring stability and support for long-term efforts.
Combine excellent science and robust technology	Health and pollution issues can be complex. A clear understanding of underlying issues and process is important to identify the relevant approaches. However, simple and robust technology is often appropriate for first stage interventions, especially where the results are not sensitive to small variations.
Adjust to evolving circumstances	Pollution and health problems are often not clearly defined. Initial interventions are made on the basis of best available information but flexibility must be maintained to respond to further data, often obtained during the implementation of initial works, which can require changes in the planned intervention. It is often impractical to expect to define the details of the necessary works before some site works are started, particularly where soil contamination is involved. Monitoring in parallel with implementation can be an effective way to determine the extent of the work.
Prevent recontamination	The benefits of clean-up must not be lost through recontamination or continuation of pollution. Control of any active sources of pollution must be an essential part of a remediation programme.
Preparation of a road map	Every project is based on these broad principles. Ideally, the early stage of a project includes the preparation of a 'road map' setting out the steps that need to be taken to remove the most immediate risk and also outlining the process for longer-term remediation, as needed. In practice, after discussion with stakeholders the project team usually proposes a set of actions that are discussed with the relevant local authorities, and then modified and implemented as agreed.

Table 1. Principles underlying interventions

Figure 8. Dumped pesticide repackaging in Somaliland

such a process should include a commitment by the parties to specific actions in the short term together with the identification of resources available and required, and agreement to move forward on initial implementation actions such as pilot projects. National programmes of one kind or another have been developed in India, China, Mexico, Indonesia and other countries. In terms of putting together the specifics of a national remediation programme, the World Bank has recently provided guidance (Kovalick and Montgomery, 2014) and there is also a guidance note on remediation on the GAHP website.

Financing is obviously a fundamental challenge in reducing the number of sites that remain to be addressed. The polluter pays principle is universally accepted, but its application often faces difficulties including the lack of a legally responsible party or a genuine inability of the party to provide funds. Consequently, the main challenge is often to find financing for site remediation while minimising the public contribution required. When public funding has to be found, this is inevitably in competition with other public priorities, and so a strong case needs to be made showing that dealing with this kind of pollution has economic benefits in terms of health, productivity and land use, and can also generate local political support.

The polluter pays principle is universally accepted, but its application often faces difficulties, including the lack of a legally responsible party or a genuine inability of the party to provide funds

9. Growing recognition of pollution and its impacts

Work in recent years has documented and drawn international attention to the scale of the problems of pollution of all kinds. Under the broad umbrella of GAHP, composite figures are being compiled to assess the overall impacts of the major types of pollution – outdoor and indoor air pollution, water pollution and soil contamination. These have traditionally been addressed in isolation, but using figures published by WHO and others it can be shown that environmental pollution, broadly considered, is actually the leading risk factor for death in low- and middle-income countries (Landrigan and Fuller, 2014, 2015). Figure 9, compiled by GAHP, shows the contribution of pollution to the major causes of death globally.

Experience in industrialised countries has shown that pollution is preventable, although it takes effort and time. Prevention of pollution must be a high priority for governments in low- and middle-income countries, because it is much more cost-effective than clean-up, even if better regulation and enforcement are a challenge to implement. The high human and economic costs of pollution are too often not taken properly into account in policy making or in the international development agenda. Death by pollution is not inevitable but more action (and resources) need to be targeted at the key problems.

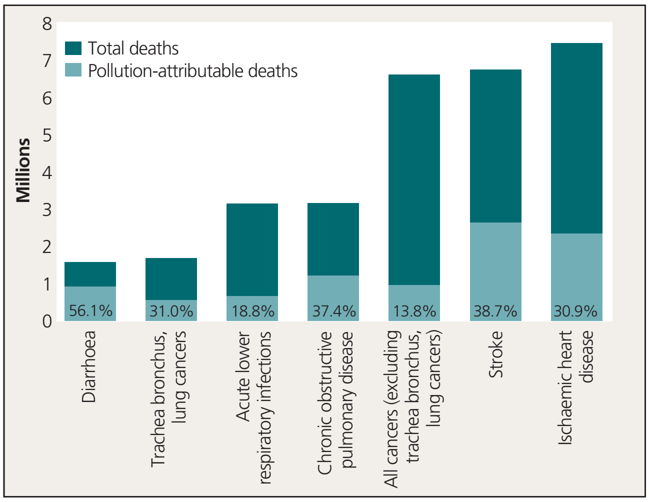

Figure 9. Leading causes of death and portion caused by pollution in 2012

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