Toolkit on Remediation of Informal Used Lead-Acid Battery Recycling Sites to Reduce Lead Exposure

December 2022

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ACRONYMS

BLL	Blood Lead Level
CSM	Conceptual Site Model
DSA	Detailed Site Assessment
HEPA	High Efficiency Particular Air Filter
IRB	Institutional Review Board
ISS	Initial Site Screening
PSA	Preliminary Site Assessment
TSIP	Toxic Site Identification Program
TSP	Triple Super Phosphate
ULAB	Used Lead-Acid Battery
WHO	World Health Organization
XRF	X-Ray Florescence Analyzer

1 INTRODUCTION

The Lead Remediation Toolkit is designed to act as a resource for the Government of Bangladesh, non-governmental organizations, and environmental engineers for assessing and mitigating risks associated with lead contamination in populated areas, with a focus on informal used lead-acid batteries (ULAB) recycling operations.

The document provides approaches to evaluate lead impacted sites, assess potential impacts to affected populations, and mitigate exposure to lead impacted materials such as soil and dust. A remediation designed by Pure Earth and Tauw and implemented in 2022 in the community of Mirzapur, Tangail, is included as a model for other potential risk mitigation projects.

This document is intended to be used as guidance only, as each ULAB recycling operation and its impacts on the environment are site-specific. As such, environmental and health impacts evaluated, as well as potential risk mitigation options, must be evaluated for each site. In addition, those working in lead contaminated areas should be appropriately trained and employ health and safety protocols that are beyond the scope of this guidance document.

1.1 Dangers of Lead Exposure

Lead (Pb) is a naturally occurring heavy metal with a range of industrial applications, but it has been long recognized as a hazard to human health, particularly among children.

Lead can enter the body through a range of exposure pathways, including ingestion (e.g. contaminated dust, water, food stuffs) and inhalation. With regard to inhalation, lead vapors from combustion sources quickly condense and accumulate in nearby area soils, thereby presenting an exposure risk only to those in close proximity to a lead smelter during operation. The predominant pathway of human lead exposure is incidental ingestion of contaminated dust. As most inhaled lead dust particles are too large to penetrate the lungs they migrate via the mucociliary elevator to the esophagus and are then ingested. In children about 50% of ingested lead is absorbed into the blood. Once there, it mimics calcium ion, thereby facilitating its passage across the blood brain barrier and impeding brain growth (ATSDR, 2007).

Exposure to lead has well documented neurotoxic effects on children's developing brains, including impaired cognitive development resulting in lower intellectual quotient (IQ). Increases in blood lead levels as low as 0.1-1.0 µg/dL in children are associated with the loss of one IQ point (Budtz-Jørgensen et al., 2013). Elevated blood lead levels in children have been associated with behavioral disorders, attention deficits, impulsivity and hyperactivity, anemia, hypertension, renal impairment, immunotoxicity, and toxicity to the reproductive organs, as well as depression and anxiety (WHO, 2022; US Environmental Protection Agency, 2013).

There is no known safe blood lead concentration. The World Health Organization (WHO) uses a reference for blood lead levels (BLL) of 5 µg/dL and the US CDC now uses 3.5 µg/dL, though much lower concentrations have been shown to result in lifelong neurological impairment (WHO, 2022; Budtz-Jørgensen et al., 2013; Centers for Disease Control and Prevention, 2017). Near poorly controlled or informal ULAB processing sites, BLLs often exceed 30 µg/dL (Daniell et al., 2015; Haefliger et al., 2009). A maximum BLL of 47.5 µg/dL was recorded at a ULAB site in Kathgora, Savar, Bangladesh, prior to risk reduction activities (Chowdhury et al., 2021). Similarly, a maximum BLL of 47.1 µg/dL was reported among children in the ULAB-impacted community of Mirzapur (unpublished data).

1.2 Lead Pollution in Bangladesh

The best available evidence suggests that exposure to lead is taking a dramatic toll on public health and economic development in Bangladesh. Lead is a known neurological and cardiovascular toxicant with long-term health and developmental impacts, particularly to children. Lead exposure affects children’s cognitive, social and behavioral skills and undermines their potential to enjoy healthy, productive lives.

According to the 2019 Global Burden of Disease analysis by the Institute for Health Metrics and Evaluation (IHME 2019), lead exposures are estimated to cause 70% of the developmental intellectual disability in Bangladesh and result in the loss of 690,000 years of healthy life each year across the population. Nearly 31,000 deaths were attributed to exposure to lead exposure—3.6% of all deaths nationally—making Bangladesh one of the most severely lead-impacted countries in the world (IHME, 2019).

The health impacts from lead exposure have not declined in Bangladesh over the past 30 years, and deaths attributed to lead have actually increased substantially (IHME, 2019).

Leaded gasoline was a significant historical source of lead exposure, and residual contamination from this use remains common globally. Bangladesh instituted a ban on leaded gasoline in 1999. Around the same time, cities in Bangladesh also saw rapid conversion of vehicles to run on natural gas as it was a cheaper alternative fuel. Analyses of air and dust samples indicate that lead concentrations remain correlated with heavy traffic areas and industrial activities (Begum and Biswas, 2008; Rahman et al., 2019). High lead concentration in industrial air samples have been traced to clusters of cottage industries that include battery recycling operations of the informal sector (Woo et al., 2018). Despite the gains in reducing lead exposure following the phase out of leaded gasoline, the large proportion of children with elevated blood lead levels described above indicates a significant ongoing threat.

The informal processing of used lead-acid batteries is a major source contributing to lead exposures in Bangladesh and is described in more detail below.

1.3 Informal ULAB Recycling as a Source

Lead-acid batteries consist of pairs of lead plates separated by an insulator (or separator) resting in an electrolyte solution (often sulfuric acid) in a plastic enclosure. Over time, batteries lose their capacity as sulfates and oxides form on the exterior of the lead plates, reducing their conductivity. However, the lead plates inside are still valuable as the lead can be recycled, generally into new batteries. In Bangladesh, demand for lead-acid batteries is driven by growing numbers of vehicles, motorcycles, and electric rickshaws (easy bikes), as well as the increasing use in solar power systems. Typically, lead-acid batteries used in Bangladesh have a usable life of about two years, after which they must be recycled.

While Bangladesh does have industrial operations for recycling ULABs, the capacity of battery manufacturers and dedicated recyclers in the formal sector does not match the volume of ULABs generated. Informal recyclers have proliferated in the country engaging in illegal smelting activities. It is estimated that there are about 1,100 informal and illegal ULAB recycling units across the country, putting more than one million local community members living near these sites at risk (World Bank, 2018). The decentralized nature of the informal economy poses regulatory challenges which have implications for environmental quality and health.

The informal recycling of ULABs creates highly localized contamination hotspots and severe risks to children that live, play, or go to school near active or abandoned informal recycling sites. Lead dust is released on site through the breaking and smelting of battery components. Because lead is quite heavy, fumes and airborne dust generally precipitate and fall back to the ground within several hundred meters of the source.

More than 250 individual recycling sites have been identified and assessed by Pure Earth under the Toxic Sites Identification Program (TSIP) from 2011 to the present in conjunction with the University of Dhaka and with engagement with several Bangladesh government agencies.

Investigations at informal sites by local Pure Earth staff indicate that site operations included breaking open ULABs, draining out sulfuric acid, removing lead plates, and processing other internal battery components and the plastic battery carcasses. Site operations also include the uncontrolled smelting of the lead battery components in open pits with no pollution controls. The smelting operations can cause extensive lead contamination of the surrounding surficial soil and leaf litter through atmospheric deposition. These operations leave behind residual battery component wastes (e.g., separators and battery cases), concrete processing pads containing the smelting pits and highly contaminated soil not only in the area of operations, but in the surrounding area. Contaminated site remediation projects conducted by Pure Earth have shown that lead released during informal recycling is generally confined to the top 2 cm of local surface soils outside of the immediate smelting area. Lead-contaminated waste left behind from these operations can contribute to elevated environmental lead levels, putting local residents, particularly children, at risk.

The predominant exposure pathway at a ULAB recycling site is incidental ingestion of contaminated soil and dust. The ingestion of soil and dust as an exposure pathway for lead and other environmental contaminants has been documented among Bangladeshi children (Kwong et al., 2019). This occurs via hand-to-mouth activity, mouthing objects, and, among the youngest children, directly ingesting soil. Kwong et al. also found that soil consumption in a rural Bangladeshi setting was substantially higher than existing estimates for children in high-income countries. As most inhaled lead dust particles are too large to penetrate the lungs, they are cleared from the lungs and then ingested. In addition, children often engage in hand-to-mouth behaviors, and play in and around waste due to proximity to these sites, thereby ingesting whatever lead dust they have on their hands. A further possibility for lead exposure is the use of lead contaminated leaf litter in open fires.

Figure 1. Manual disassembly of lead-acid batteries.

Figure 2. Concrete processing pad with lead smelting pit at Mirzapur site.

2 STRATEGIES TO REDUCE LEAD IMPACTS ON PUBLIC HEALTH

Without interventions, lead released to the environment through informal ULAB recycling and other industrial activities will remain a hazard, as lead does not naturally dissipate or degrade. A successful risk reduction strategy to address the public health effects of lead pollution includes, but is not limited to, engineered action such as waste excavation and disposal.

There is no safe way to recycle lead in an informal setting. If the release of lead to the environment is unabated and unsafe practices continue, a cleanup program will not have a lasting benefit.

Therefore, policy work is necessary in parallel to site-specific risk reduction efforts. Policy interventions are required to draw batteries into the formal sector and greater enforcement and oversight is needed to ensure the formal sector is operating in an environmentally sound manner. Simply shutting down informal recyclers will likely lead to them shifting their operations to a new site, spreading the problem to additional communities. In August 2021, Pure Earth, DoE and other stakeholders collaborated on the development of a Lead Roadmap, which lays out systemic and national-level approaches to address lead pollution challenges.

Recommended elements for environmental lead risk reduction strategies include:

- Working with industry to reduce or control pollution releases
- **Education and community involvement**
- **Engineered actions/interventions**
- **Home cleaning**
- **Pre- and post-project monitoring**

This guidance document will focus on the four elements in bold, and the information is particularly relevant for "legacy" sites, where the polluting activities are no longer taking place.

In the case of the highlighted project at Mirzapur, the informal recyclers had already ceased their activities in the area as a result of action by the community, before the remediation was designed and implemented.

3 SITE SELECTION AND PLANNING

3.1 Identifying and Assessing Sites of Concern

Identifying sites of concern, such as former ULAB recycling operations, can be conducted jointly with the Department of Environment, other relevant government agencies, community leaders, health departments and local teams. The purpose of this exercise is to identify potential sites for further investigation and to initially gather information about each potential site and the surrounding area (e.g., nature and timing of operations, nature of potential contaminant(s), environmental setting, potentially affected populations). This information is intended to help evaluate the need for additional investigative work and prioritize such work. For example, further investigation of a former ULAB recycling site adjacent to a primary school may be prioritized over a similar site which is in an industrial area.

- *Documentation Produced: List of potentially contaminated sites*

3.2 Initial Site Screening (ISS)

Once a site has been identified and selected for assessment work, an Initial Site Screening (ISS) may be completed. Pure Earth has developed and implemented an ISS protocol as part of its Toxic Site Identification Program, which can be replicated or adapted for specific needs. View the TSIP ISS Protocol. As part of the ISS, locally contracted and trained consultants are used to collect initial environmental samples, take photos, and collect pertinent information regarding site history and environmental setting. This work is again done in concert with government agencies, community leaders, health departments and local teams to the maximum extent possible.

The nature of environmental impacts from former ULAB recycling operations concerns heavy metals, predominantly lead. Lead in soil may be analyzed in commercial testing laboratories or in the field using portable instrumentation such as an X-Ray fluorescence (XRF) instrument. The use of a portable XRF in the field gives the investigator the essential ability to measure metals concentrations in real time, inform the investigation as the site assessment progresses, and ultimately to map out the degree and extent of metallic impacts while still in the field.

The goal of the ISS is to gain an initial understanding of the breadth and magnitude of environmental impacts at a potentially contaminated site, noting that a more detailed site assessment would be completed where warranted to further inform the investigator of potential remedial alternatives. With that in mind, samples should be analyzed along a grid with points on the order of approximately 3 to 10 meters apart during the ISS. The spacing of individual points is of course site-specific, and based on the source characterization and setting, and can be adjusted in the field based on real-time findings using the XRF, available timing and resources, and site constraints (e.g., buildings, wetlands). Efforts should be made to gain entry to private yards (residential, commercial, and industrial) if safe to do so, though not at the expense of missing a larger number of points elsewhere. Again, the purpose of the ISS is to rapidly characterize the area as a whole, not to develop estimates of quantities of impacted materials or to characterize individual plots. Note that in general, all sampling is done on the surface; the depth of contamination is not an object in the ISS. The key objective is to determine the rough areal extent of contamination – what area should be further investigated and what is the boundary of this area, the number of receptors, and people that may be impacted by the contamination in this area.

- *Documentation Produced: ISS entered in the TSIP database*

3.3 Preliminary Site Assessment (PSA)

Based on the results of the ISS, sites with a confirmed human exposure risk may be prioritized for a Preliminary Site Assessment (PSA). View the PSA Guidance Document. As part of the PSA, additional information is collected on the degree and extent of contamination, primarily through additional assessment of surface soils. Materially, the most significant distinction between an ISS and a PSA at a ULAB site is the number of samples taken, with an ISS typically consisting of <50 measurements, and a PSA consisting of >50 measurements. Thus in practice, an ISS could be expanded during initial assessment if human health exposure is confirmed. Also, some investigation of the depth of contamination may be part of the PSA to gain an initial understanding of the vertical extent of contamination at various representative locations (e.g., in the area used for ULAB recycling; area of disposal of ULAB wastes; areas impacted by atmospheric deposition.

In general, a trained XRF operator can analyze 100 to 250 points of soil in a day, depending on site conditions, access, and weather (the work can be tiring and less productive in hot humid weather.) In this way, approximately 60,000 m^2 (250 meters by 250 meters) can be assessed in a day for sites with minimal logistical constraints. XRF readings are collected by taking measurements with the instrument at ground surface for the PSA, with the reading itself collected within less than 1 minute. Sampling results should be recorded on paper with a unique sample identifier, the latitude and longitude of the sampling location (typically to 5 decimal places), and a brief site description (e.g., address; rear (easterly) yard of smelter; school play area: heavily vegetated). A rough field map can be created showing testing locations and XRF results to help guide the field investigation in real time. Latitude and longitude should be identified with a handheld GPS unit operated by an additional person. Recording information on both paper and in the electronic memory of the equipment creates necessary redundancy. In the event that data are lost or confusion arises about specific points, the paper documentation can be consulted for clarification. This system also allows for key information to be noted about locations that can later serve as a reference. This sampling should continue until the entire area has been assessed. The area can be defined as the extent of contamination above natural background levels for a particular element such as lead. However, the extent of contamination above a risk-based cleanup threshold (e.g., the US EPA's 400 ppm level for lead) is typically more pertinent for evaluating the target area for a potential risk mitigation project. A key objective of the PSA sampling is to determine the approximate boundaries of the contamination above such a risk-based threshold.

The data collected during the PSA (i.e., lead concentrations and locations) should be immediately transferred on to a map and shared with key stakeholders. Freely available software from Google or QGIS are adequate. The map should be clear and easy to understand, using color-coded points to indicate the severity of contamination (see Figure 3 and Figure 4). Such geographic representations create a basis for discussion regarding the severity and extent of the problem. At this point, possible interventions should be discussed at a cursory level only. By sharing the map with key stakeholders in this way a sense of trust and transparency is fostered. This can facilitate access to private yards for the detailed assessment at a later time.

View the Mirzapur PSA Document.

- *Documentation Produced: PSA*

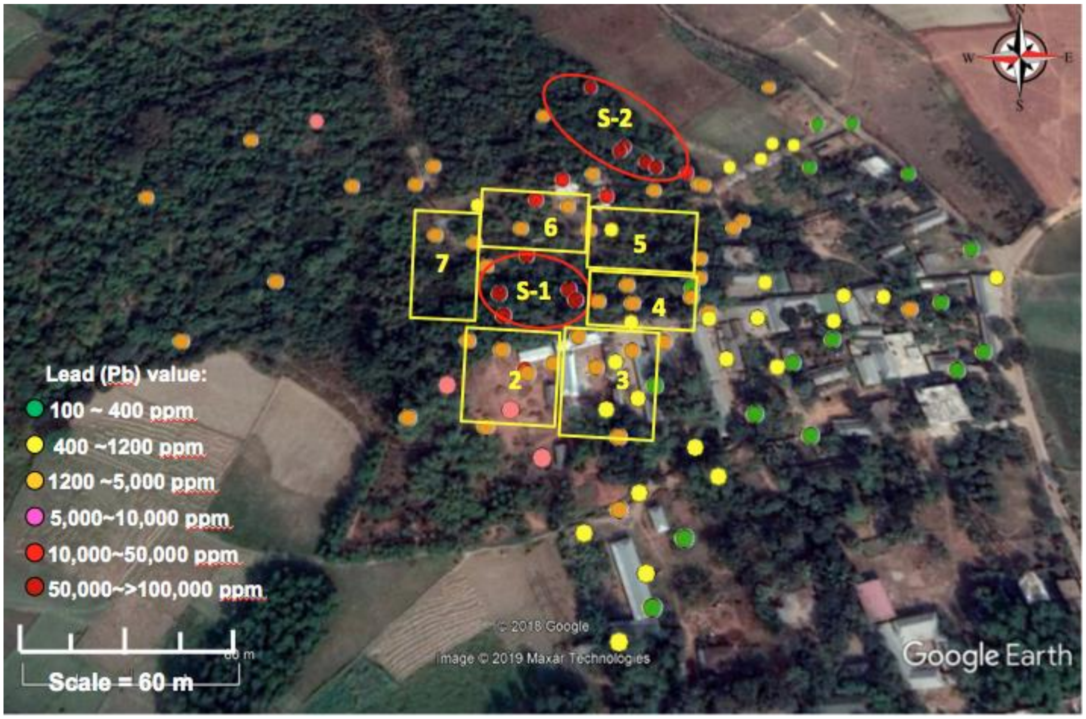

Figure 3. Site map of Mirzapur with sectors outlined and numbered with lead levels from the PSA.

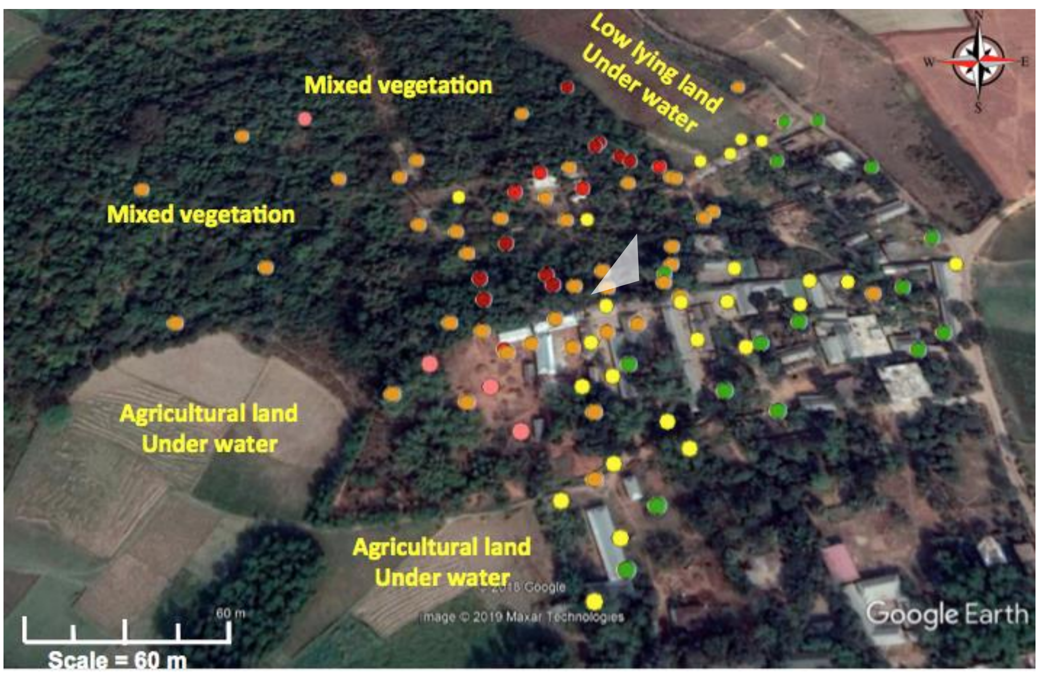

Figure 4. Site map with lead levels and local topography from Mirzapur PSA.

3.4 Risk Evaluation and Prioritization of Sites for Further Action

During this stage, program implementers review the need and feasibility of risk reduction at each assessed site and generate a shortlist of sites for Detailed Site Assessments and possible remediation or risk mitigation projects, as detailed below. The factors used to prioritize sites for further work may depend on the goals and budget of the implementer, but typically include: relative risk to public health, size and vulnerability of the population at risk, suitability of the site for remediation actions, potential costs, and current and future use of the site.

- *Documentation Produced: Shortlist of Sites for Detailed Site Assessments*

3.5 Detailed Site Assessment

The goal of the detailed site assessment (DSA) is to fully characterize the degree and extent of the lead impacts at high priority sites selected for further evaluation based on the findings of the ISS and PSA. As part of the DSA, additional site-specific information is collected in order to effectively evaluate potential risks of the environmental impacts as well as potential remedial options to mitigate exposure pathways. The methodologies employed for the DSA are largely the same as those employed for the PSA. However, more focus is placed on those locations where some type of remedial action is likely warranted. A key difference between the DSA and PSA is that, where off-site disposal of contaminated soil or materials is a viable risk reduction alternative, the DSA will develop good estimates of the quantity of contaminated soil or materials that should be disposed. This generally means accurate depth profiling of contamination, as discussed later.

The DSA process is governed by a site-specific Conceptual Site Model (CSM). The CSM for a given site considers the type of contaminant, how it entered the environment, how it may have migrated and/or transformed in the environment, and considers potential exposure pathways. The CSM can be a very useful tool for not only guiding the investigation, but also devising effective remedial options to appropriately mitigate exposure to the given contaminant distribution. A CSM for a typical ULAB recycling operation may incorporate the following: The main contaminant (i.e., lead) may enter the environment through lead-impacted sulfuric acid drained onto the open ground, through distribution of lead-impacted detritus (e.g., battery carcasses, separators, lead oxides, connectors), fugitive dust created during battery breaking and handling, and waste materials generated during smelting. The lead impacts associated with the above are generally near the surface and relatively close to the area where the processing took place. However, contamination may be deeper where lead contaminated waste has been disposed of in piles, pits, ditches, etc. Also, contaminated solids that have been disturbed through activities such as gardening or building construction may show contamination at some depth. Further, smelting is sometimes done in shallow (approximately 1 m deep) pits, resulting in deeper impacts.

Importantly, atmospheric deposition associated with smelting can lead to widespread impacts, not infrequently several hundred meters or more from the smelting operation source, although such deposition is generally very surficial (<2 cm), particularly in downwind areas relative to smelting operations, unless the soil has been disturbed. Once in the environment, lead is typically strongly adsorbed to soil particles, particularly more organic rich soils, and is relatively immobile and recalcitrant in the environment. Lead adsorbed to soil may be mobilized and re-deposited through erosional processes in certain environments – for this reason storm runoff drainage routes are often a focus of investigation during the DSA. As noted earlier, the primary exposure pathways are from surficial lead-impacted soil, contact with lead impacted waste materials and dust, and ingestion of the same particularly with hand to mouth contact in children.

A less obvious transport and exposure route includes “take-home” exposure from workers during active ULAB recycling operations. Workers can carry very significant contamination home on their clothing and shoes, resulting in houses becoming contaminated with lead – floors, walls, furniture, mattresses, etc. Other examples of the “take home” pathway include children playing in lead-impacted dirt and then coming home, or use of lead-impacted battery carcasses to carry water or as planters or stools. This “take-home” pathway needs evaluation during the DSA, as it leads to decisions about which houses need to be cleaned as part of risk reduction measures.

Again, the CSM from a typical ULAB recycling operation can help guide the investigation (e.g., where to look for the worst contamination) and help devise effective mitigation techniques depending on the actual contaminant distribution and considering potential exposure pathways. A CSM is not something that is set in stone, but something that is revised continually throughout the investigative process as one gains an understanding based on interviews, site history, site setting and concentration data.

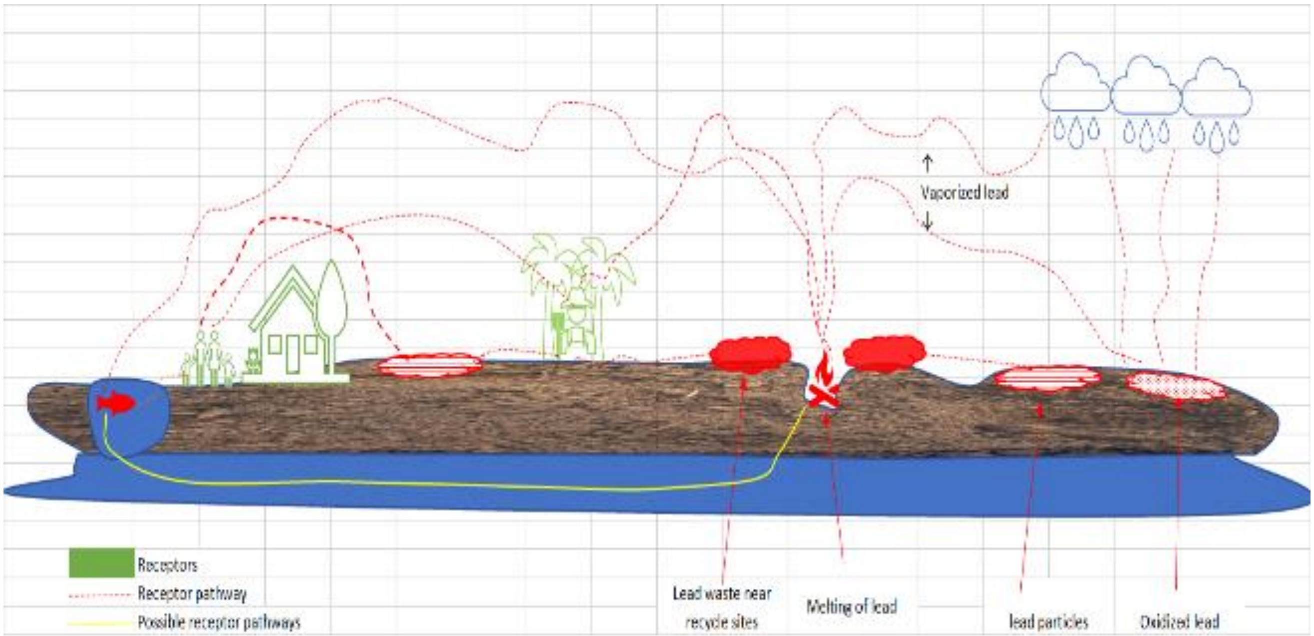

Figure 5. Health risk conceptual site model of a lead recycling site.

The more detailed assessment during the DSA should be focused on the source areas with the highest degree of impacts identified during the ISS. Sample spacing should be on the order of 1 to 3 meters apart in these source areas and in areas with particularly vulnerable receptors (e.g., schools and playing yards) with elevated concentrations. The DSA work needs to focus on both the source area and receptor areas, including individual yards and homes. The spacing of the sampling locations may increase distal to the source area when contaminant levels decrease and concentrations become more homogeneous. Sampling should be completed in all directions away from the source areas until concentrations have consistently dropped below 400 mg/kg of lead, or the site-specific threshold. The data from the DSA should be on area specific maps drawn to scale and containing details of the area (e.g. presence of pavement, degree of vegetation, accessibility) that would be pertinent to evaluating potential remedial alternatives. An understanding of the precise area(s), i.e. square meters, that need to be mitigated should be defined during the DSA.

Figure 6. Lead concentrations in surficial soil and leaf matter from Mirzapur DSA.

As part of the DSA, an effort should be made to evaluate the depth profile of the contaminant distribution at representative areas in the source area and areas distal to the source area as guided by the CSM. The depth of lead impacted soil may inform the viability of certain remedial options. For example, the depth of contamination in areas subject to atmospheric deposition distal from the source area may only be 1 cm or less in a widespread area, allowing for hand scraping and subsequent handling of such soil in a more concentrated area. Alternatively, the depth of contaminated soil may be on the order of a meter or more in the source area, suggesting machine excavation or covering with clean soil in a much smaller area might be a more viable approach to mitigate exposure. This level of detail is necessary in the DSA in order to evaluate appropriate alternatives.

Table 1. Concentrations (ppm) of lead with depth within fixed 1m^2 from Mirzapur DSA.

Depth	Point 1	Point 2	Point 3	Point 4	Point 5	Mixed Sample 1	Mixed Sample 2	Mixed Sample 3
0 – 1 cm	20,000	7,725	6,944	5,571	11,600	22,800	13,200	19,100
1 – 3 cm	81,900	7,876	14,600	12,500	64,600	41,800	58,100	75,700
3 – 7 cm	35,600	57,300	86,400	160,000	86,700	8,882	3,684	5,801
7 – 9 cm	371	321	265	70	3830	80	23	90
> 9 cm	69	19	330	180	140			

In addition to depth profiling of the contamination, soil samples should be collected from approximately 2 to 5% of the sampled locations for later laboratory testing to confirm the accuracy of the XRF instrument. Generally, there is very good correlation between XRF and laboratory results for total lead concentrations. However, false positives of XRF readings for certain elements (e.g., arsenic and cadmium) in the presence of elevated lead concentrations have been confirmed with laboratory testing. Care should be taken to collect the same soil samples for laboratory testing as was evaluated by the XRF instrument. Samples should be first collected in a plastic bag and mixed well prior to taking at least three XRF measurements for all metals of concern. This well mixed sample should then be submitted for laboratory analysis for total metals for comparison to the XRF measurements. Samples should be collected that represent the range of concentrations detected during the ISS and PSA.

Lead oxides are generally considered to be relatively insoluble. However, leaching tests of soil samples for several legacy ULAB sites in Bangladesh and elsewhere have shown leachable lead at concentrations significantly exceeding international drinking water standards. As such, lead contaminated soil at such sites does represent a threat to shallow drinking water. In addition, the question of potential water contamination is nearly always raised by the community or other stakeholders after they are informed about the contamination. The DSA must evaluate this potential exposure route. The source of the local water supply(s) should be ascertained during the DSA along with any information about well construction and usage. The wells should be geolocated and mapped with a unique well designation assigned to each. Samples of any active wells in the contaminated areas (particularly any shallow wells) as well as the water supply (if different) should be collected and analyzed by a laboratory for total lead.

Contaminated foodstuffs are also a potential exposure route at legacy ULAB recycling sites. Contaminated foodstuffs include unwashed leafy green vegetables that have lead dust or have absorbed lead from soil, or chickens that have adsorbed lead by eating in contaminated areas. These potential exposure routes should be addressed as part of a DSA.

Qualified technical experts should work with government and key stakeholders to select a risk management approach after considering the following factors: risk reduction effectiveness, sustainability, cost, community acceptance, technical/logistical issues, speed, regulatory compliance, internationally accepted practices, and environmental impacts of the approach. An Alternatives Evaluation Matrix should be developed to aid comparison of alternatives. The most appropriate risk reduction alternative is selected in the next stage in view of all factors with input from governments and key stakeholders. The alternatives considered should include a “no action” alternative.

Interventions can be focused on any or all of the components of the toxic contamination problem; elimination of the source (such as waste removal or elimination of use of a toxic substance in a process); control of migration routes (such as installation of pollution control equipment or covering waste piles); elimination of exposure routes (such as covering or paving contaminated areas; providing clean drinking water sources); or reducing the number of people living in contaminated areas (such as by fencing off disposal sites). It is useful to determine where interventions are feasible and how they should be prioritized. It is very common to recommend different risk reduction approaches for different areas at a contaminated site. For example, a risk reduction program might include off-site disposal of concentration wastes with high lead content, covering of contaminated yards, paving some contaminated high use areas, and cleaning of contaminated houses. Thus the alternative evaluation may include sub-evaluations for differing areas at a site, which are then consolidated to present a larger alternative evaluation for the entire site.

Please refer to Appendix A for the Alternative Matrix from Mirzapur as an example. View the complete Mirzapur DSA document.

- *Documentation Produced: DSA*

3.6 Design Risk Reduction Project

Based on the Alternatives Evaluation Matrix, a design for risk reduction measures should be developed that is sufficient to conduct detailed estimates and issue tenders for work. The product should include specifications and quantity estimates for required materials; drawings showing locations and types of work to be done; estimates of labor and equipment requirements; measures for community protection and plans to minimize environmental impacts during the work; as well as a health and safety plan for workers; and quality control requirements. Post-work or long-term care measures are also defined. Environmental impacts should also be identified either through a formal Environmental

Impact Assessment or on the absence of resources, their identification in the Alternatives Matrix.

Because ULAB contamination is primarily a dust and soil exposure risk, that will be the focus of the remediation activities described in this guidance document.

View the Mirzapur Risk Reduction Project Plan Project Plan.

- *Documentation Produced: Risk Reduction Implementation Plan*

3.7 Obtain or Allocate Funds, Get Approvals & Select Contractors

An evaluation of applicable laws should be conducted as part of the design process. Be aware of any permitting or approval requirements. Blood testing will likely require approval. This should be addressed as part of an ethical review from an Institutional Review Board (IRB).

Based on the project design, a number of tenders will need to be developed. Each should include an evaluation matrix and minimum qualification for contractors.

- *Documentation Produced: Minimum qualifications for contractors; Tenders and evaluation matrix; Approvals*

4 EDUCATION AND COMMUNITY INVOLVEMENT

Community education and involvement are critical to the success of a remediation program. If the community does not understand the health impacts of pollution or if people fear that environmental programs will threaten their ability to make a living, they will not support it. Universally, families want to protect their children and their health, and if the message is delivered by trusted members of the community, it can be successful. Health screening such as blood lead level screening in children should be a part of this effort; and it is typically conducted before and after completion of remediation. This information helps assess the extent of the health problem and the effectiveness of steps taken.

Stakeholder and community involvement should be made a priority during all phases of the investigation and during evaluation of various remedial and risk mitigation options, with their input incorporated into the Alternatives Matrix included in the DSA.

A community education campaign should always be conducted prior to commencing project work. This typically consists of presentations and discussions in community-wide forums. Materials should be developed by local partners in consultation with experts, and the education sessions should be led by local partners and government officials to assure appropriate language, content, and communications appropriate for the community (who often have limited formal education). The campaign should be designed to ensure that the community knows of hazards and project work plans and to gain community support for the project.

A well-constructed community education program is essential to any project. The program should be designed specifically for the relevant community. Easy to understand literature should be produced and distributed in the local language and featuring homes, neighborhoods, and residents which look similar to those of the project. Photographs of foreign homes will not have resonance with community members. Materials and programs should be designed accordingly.

Please refer to Appendix B for materials from Mirzapur.

Community education campaigns should be comprehensive, explaining the need for and rationale of the project. Nutrition, livelihood adjustments, and home cleaning should all be addressed. High attendance rates at community education workshops are essential.

The stakeholder group involves representation from community leaders, local NGOs, and regulators. Representatives from schools, health clinics, churches/ mosques/ temples, industry, and other key stakeholders should be encouraged. Representatives from the most local government unit should always be included, such a local ward or district leaders, mayors for small towns. Importantly, a stakeholder group can be too large, resulting in inconsistent attendance or lack of a sense of ownership.

- *Documentation Produced: Pamphlets and educational materials; Attendance sheets*

Figure 7. Coordination meeting on implementing the Mirzapur lead remediation program at DoE.

5 REMEDIATION OR RISK MITIGATION ACTIONS

Metals such as lead to not break down over time and present a long term environmental and human health risk unless appropriately addressed. Remediation and/or risk mitigation actions can be effective in reducing exposure to lead at contaminated sites. In order to properly evaluate various remediation and/or risk mitigation options, sufficient information on the extent and degree of contamination; an understanding of the exposure routes; human and environmental impacts; potential costs; community acceptance; and feasibility; and long term sustainability as determined through completion of a Detailed Site Assessment.

Remediation actions for lead contamination generally include removal and disposal of residual battery wastes and contaminated soil at an off-site, appropriately permitted facility, in addition to addressing any other exposure routes such as contaminated groundwater, impacted homes, and impacted foodstuffs. Risk mitigation actions for lead contamination generally include reducing exposure to contaminated media (soil, foodstuffs, etc.) using engineered and institutional controls. These may include construction of an on-site secure disposal area for soil and wastes; restricting site access through fencing; capping contaminated soil (e.g., with clean soil, pavement or bricks); house cleaning to reducing exposure to dust as warranted; restrictions on water usage and/or consumption of contaminated vegetables, etc. Generally, risk mitigation does not represent a permanent solution to the contamination issue, and a long term monitoring and maintenance program must be incorporated to ensure the sustainability of the selected option(s).

5.1 Contaminated Soil

For ULAB sites in Bangladesh, in-situ (on-site) risk mitigation approaches have been found to more feasible than ex-situ (off-site) alternatives due to transportation costs and the unavailability of appropriately permitted facilities in Bangladesh to accept residual battery wastes and contaminated soil for incineration, treatment and/or disposal. Therefore, this guidance document will focus on in-situ options.

5.1.1 Scraping

Lead contamination from ULAB sites typically does not penetrate deep into the soil, although the depth of contamination may be affected by erosion and redeposition, construction or other earth moving projects, and/or burial. The exact depth of the contamination should be characterized during the Detailed Site Assessment by determining at what depth XRF readings are consistently below a given risk-based cleanup threshold such as 400 ppm.

At sites in Bangladesh assessed by Pure Earth and the University of Dhaka, the depth of contamination has typically been found to be less than 10 cm in areas close to the smelting pits, and less than 1 to 2 cm in areas of the site away from the smelting pits. Leaf litter on the ground surface can also have high levels of lead.

Scraping can be a cost effective way of removing such relatively shallow contaminated soil. Such scraping may be done using manual labor and hand tools such as hoes and wheelbarrows. Scraping also allows mature shrubs and trees to remain in place. Clean soil may be placed over areas that were scraped to protect remaining vegetation and support new vegetation growth. The depth of scaping should be monitored using an XRF to determine when soil above the risk-based cleanup threshold has been sufficiently removed.

One benefit of this method is its low cost. Typically, this work can be carried out by local laborers with limited training. The majority of the work can be completed with hand tools and manual labor. The workers should be supplied with hand tools such as shovels, rakes, wheelbarrows, and hoes. Dump trucks or excavators can be engaged as needed for transporting soil.

See Section 5.3 for information on how to manage scraped soil and leaf litter.

Figure 8. Workers removing surface layer of contaminated soil.

Figure 9. Spreading of clean soil in scraped house yards.

5.1.2 Capping

An alternative to scraping is to cap existing contamination with clean soil, concrete, or other materials. Capping mitigates exposure to the contaminated soil by the community and reduces the spread of lead-containing soil as dust. Contaminated roads may be covered with gravel, concrete, or asphalt. Residential areas can be capped with pavers, concrete, brick, or a range of other materials. Capping may be most appropriate where the thickness of soil does not permit scraping or due to other logistical concerns.

Capping with clean soil is typically an affordable option. This involves the use of a geotextile layer, covered by at least 30 cm of compacted clean soil (Ericson et al., 2018). The geo-textile is a permeable fabric layer intended to act as a visual barrier only. The geotextile inhibits soil blending ensuring that the first 30 cm of soil remains clean and uncontaminated. In the event that residents dig into the cap, the presence of contaminated soil is immediately signaled by the geotextile. The barrier can also be augmented by durable and perforated polyethylene fencing (> 10 mil) to discourage disruption of soils beneath the barrier.

Soil capping requires forward thinking about sustainability. This approach should not be selected if it is likely that the soil will be disturbed to a greater depth than the covering. Such disturbance can be a result of gardening, agriculture (e.g., plowing) or construction of foundations. Another key concern is erosion; heavy rain can quickly disrupt cover soil, which can limit this approach on sloped areas or areas frequented by heavy rains. At the least, firm compaction of cover soil and provision for storm drainage must be provided. Finally, this approach may not be suitable in flood plains as floods can quickly wash away or disrupt cover soils.

5.1.3 Soil amendments

Additional soil amendments can be considered to reduce the leachability and bioavailability of lead. Literature shows that phosphate (a major component in most commercially available agricultural fertilizers) is able to immobilize lead in soils by formation of sparingly soluble lead minerals like pyromorphite. Phosphate can be added in different forms, but addition in the form of the fertilizer triple super phosphate (TSP) is feasible because this fertilizer is available in Bangladesh. This fertilizer contains about 19.65% P as calcium phosphate.

Once contaminated soil has been consolidated in a stockpile, through scraping for instance, the TSP can be incorporated before the material is placed in a disposal area. Once filled, a geotextile marker layer should be placed atop the amended soil, and the pit brought to meet surrounding grade with at least 1 m of clean soil. The sequence of excavation, amendment, and burial in each of the pits is shown in Figure 11.

While this specific application of phosphate for ULAB-affected areas is still being researched and assessed, an example of the calculations needed to determine the quantity of TSP to add are included below:

- A stoichiometric ratio of 2 mol P versus 1 mol Pb should be sufficient.
- An estimated density of soil of 1.6 metric ton/m^3 can be used.
- Determine an estimate of the volume of the stockpile of contaminated soil that is being disposed of.
- Determine an estimate the average concentration of lead in the soil using at least 10 dispersed XRF measurements of the well mixed stockpile.

In the case of the Mirzapur project, one of the stockpiles contained an average of 6,000 mg/kg Pb, indicating that 2 mol P/mol pb x 28.99 mmol Pb/kg soil = 57.98 mmol P/kg would have to be added, which equals 9.1 g triple super phosphate / kg soil. The estimated volume of the stockpile was 450 m^3 soil, which is equivalent to 720 metric tons at a density of 1.6 metric tons/m^3. For this amount of soil, 720 metric tons x 9.1 g TSP/metric ton = 6,552 kg of TSP fertilizer was needed (6.6 tons) to amend the soil in the stockpile prior to burial.

5.2 Contaminated Waste

Informal ULAB recycling leaves behind large quantities of lead-contaminated battery wastes, including plastic separators, plastic battery cases, plastic sacks, and paper (Figure 10). These materials typically have high concentrations of lead and should be isolated from the community. Depending on the volume of waste, it can be incorporated into in situ disposal plans, or arrangements must be made with established landfills. It may be possible that formal recycling industries can process the waste to recover lead.

In the case of Mirzapur, multiple options for incineration of the waste at industrial facilities were explored, but ultimately the material was brought to a municipal solid waste landfill for disposal, as shown in Figure 12.

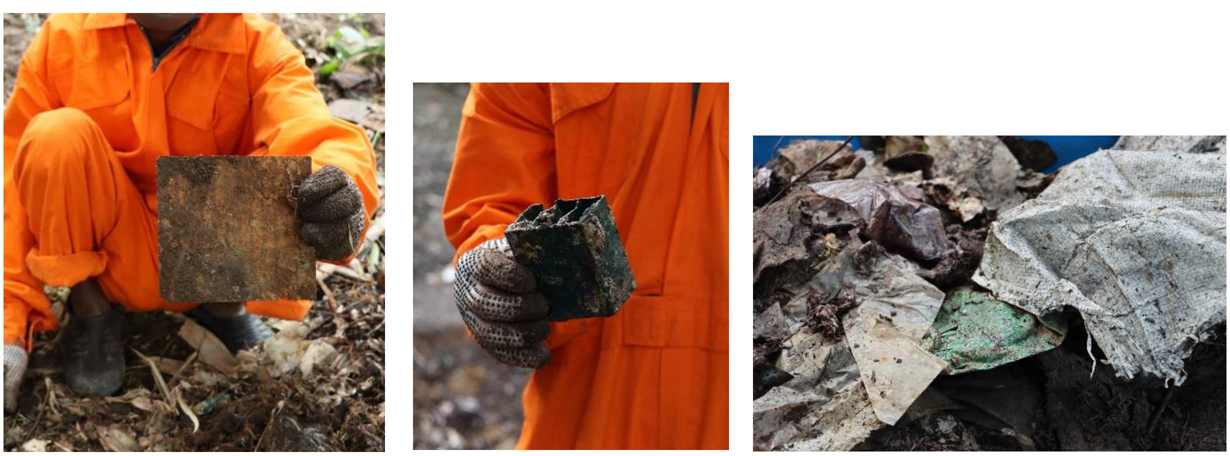

Figure 10. Different types of battery waste found at ULAB recycling sites.

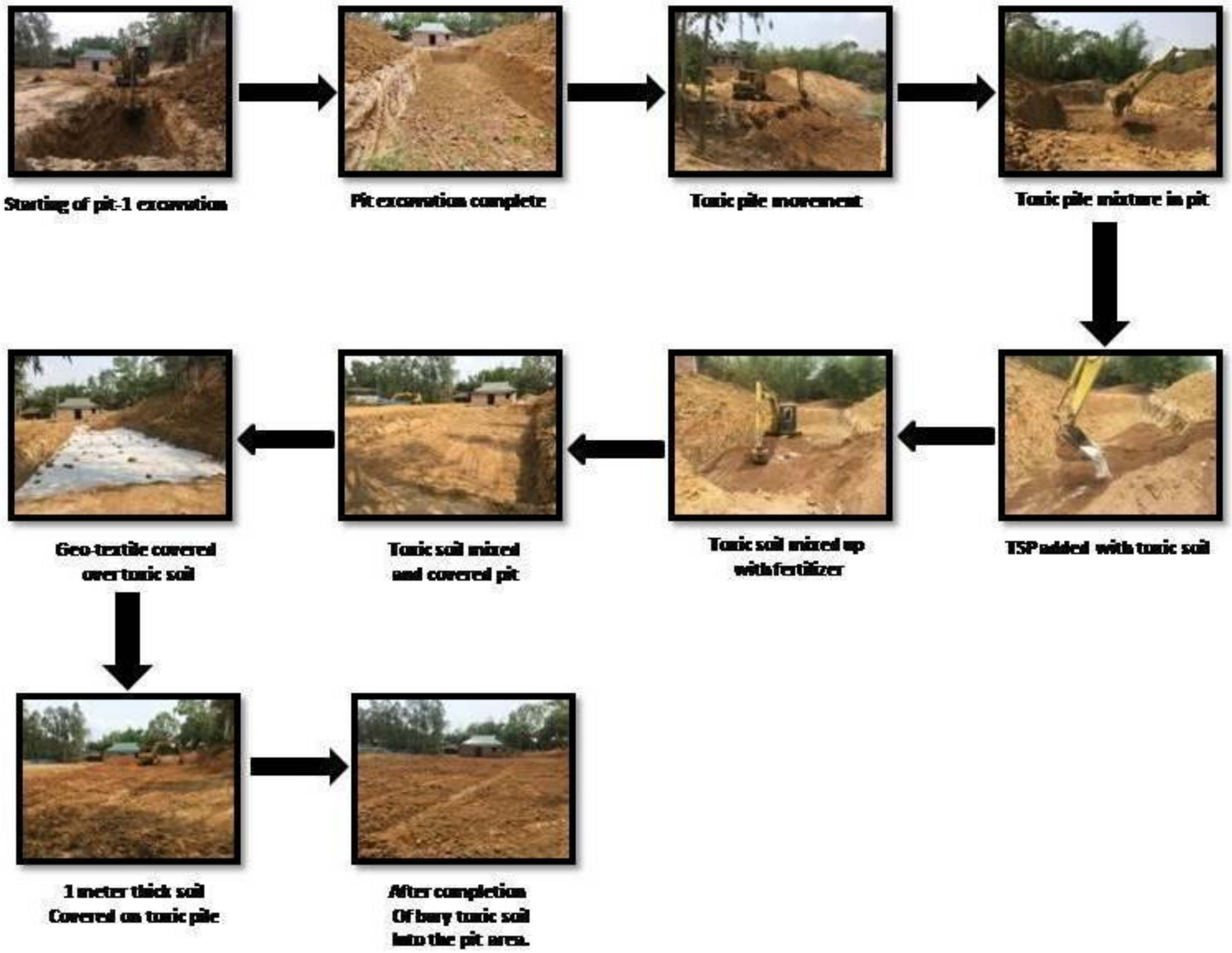

Figure 11. Process of mixing TSP with soil and burying in a disposal pit with geotextile layer.

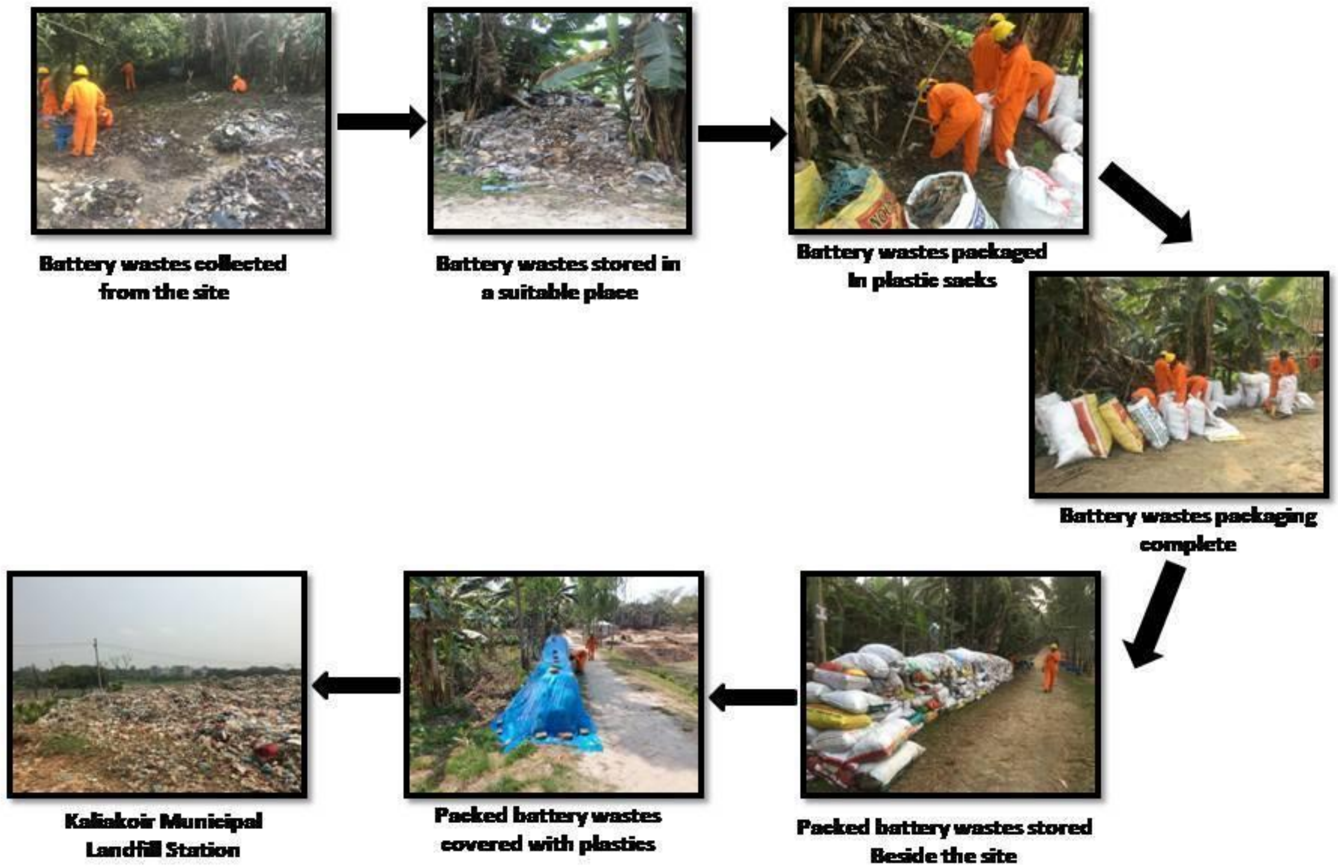

Figure 12. Battery waste collection, package, storage, and transportation to a municipal solid waste landfill.

5.3 Disposal

In Bangladesh, a limiting factor for engineered environmental cleanups is a lack of secure landfill capacity or other treatment or disposal methods to handle waste and contaminated soil. Construction of a project-specific disposal area to contain wastes may be necessary. Such disposal areas need to be located away from the general public, designed to protect surface and groundwater, and resistant to being disturbed or uncovered.

Project-specific disposal areas have been constructed as part of a 2017-2018 Pure Earth demonstration program for a lead-acid battery recycling site in Kathgora, Bangladesh, as well as the 2022 project at Mirzapur. In both cases, a pit was dug to isolate the contaminated soil. In the case of Kathgora, the location of the disposal area was a site where a building was about to be constructed. This reduced the chance that the material would be excavated in the future.

The contaminated soil should be covered with a geotextile liner and at least one meter of topsoil. An excavator is likely required to dig the pit, mix in any soil amendments, and recover the pit. Clean soil excavated to create the disposal pit can be used as clean fill for capping or covering scraped areas.

At Mirzapur, the concrete pads used for the smelting pits were also crushed and incorporated into the disposal area.

6 CLEANING INTERIORS

Following the engineered remediation activities, home interiors (including walls and floors) and furniture should be cleaned thoroughly to remove remaining lead dust.

The following steps should be taken:

1) Remove all materials from inside the home and vacuuming the area with a HEPA vacuum (HEPA: High Efficiency Particulate Air filter. HEPA filters can remove fine dust particulates greater than 0.3 microns in diameter with 99.97% efficiency.).
2) Wet washing and scrubbing with a detergent solution to dislodge lead dust, followed by a clean water rinse and wet vacuuming to removal all water.
3) A final HEPA vacuuming after all surfaces have dried.
4) Hard furniture (wood, plastic) should be cleaned by hand with soap and water. Removable covers should be washed with soap and water. Soft furniture with covers that cannot be removed should be cleaned by vacuum as much as possible, then covered with a plastic and new fabric cover. Mattresses are often a key concern as they can take in lead dust and hold it indefinitely, and of course

exposures can be high because children sleep on them. Where possible, mattresses in contaminated houses should be removed and replaced, with the removed mattresses being securely disposed, and if necessary, destroyed by cutting.

5) Furniture and other personal items will be moved back into the rooms after the items and room has been cleaned. All hallways and central areas should then be cleaned thoroughly following the same process above.

Figure 13. Photos of house cleaning.

7 PROJECT MONITORING

7.1 Blood Testing

Potential impacts to populations living and working in the area of present and/or former ULAB operations are generally evaluated through sampling and testing blood samples from potentially impacted adults and children. Such blood testing work may help assess the human health impacts of lead exposure and may dictate medical intervention in extreme cases. However, collection and testing of blood samples is invasive and can be conducted only by appropriately trained medical personnel. Institutional Review Board (IRB) approval is required during the design phase and before starting. Bio-monitoring programs must include an approval process from the monitoring participant or their parent, communication to them about what is being done and why, and a plan to respond to high lead levels found in blood – what will the participant or parent be told and what further action will be taken.

It important to know that reduction in blood lead levels through medical intervention (e.g., chelation therapy) may be short-lived if the impacted individual is returned to the same setting and re-exposed to lead-impacted media. Thus, collection and testing of blood samples is not recommended as part of an initial environmental assessment that is done long before risk reduction measures are taken (and lead emission sources controlled). This wait/pause should be implemented *unless* the need is readily apparent for extreme cases. Such human testing is recommended once the degree and extent of the environmental impacts are better understood, and ideally once a plan is in place to mitigate future exposure to the affected community. Absent environmental intervention, it is very unlikely blood lead levels at these sites will decline (Nussbaumer-Streit et al., 2016).

Biological samples can both form a component of a community education program and help measure the results of a project. Blood tests can be carried out with a Leadcare II analyzer, which is field-based and cost effective. Laboratory methods can also be used if the appropriate equipment and trained staff are available. Elevated results should be communicated to the subject by a medical professional and paper documentation should be given that provides both the sample result and a context for interpreting that result.

Biological samples should be focused on children <6 years where possible, but may include children up to 7 or 8 years old where there is a need to get a good sample size or to increase community acceptance. Contact information and other relevant details should be collected and whenever possible, the same children should be sampled before and after the intervention to gage the effectiveness of the intervention.

Figure 14. icddr,b collecting blood samples in Mirzapur.

7.2 Treatment for Children with High Lead Levels

The most effective method for reducing blood lead concentrations is to remove the exposure in the long term, and therefore project resources should be focused on mitigating exposures.

If a child (≤ 10 years) is found to have a very high blood lead level (≥ 45 μg/dL), the World Health Organization (WHO) recommends chelation therapy. Please refer to the [WHO Guideline for clinical management of exposure to lead].

7.3 Health and Safety during Remediation

Risk reduction and management measures should be implemented by contractors under the oversight of local staff and qualified technical experts. A third-party quality control and assurance officer should be contracted to monitor the projects and ensure designs are appropriately followed. The quality of work is assured with ongoing assessment and environmental sampling.

There should be a clear and enforced health and safety plan for workers involved in the project implementation. All workers must be trained in health and safety requirements. Regular monitoring of health and safety measures is essential, with significant repercussions to workers or contractors who fail to adhere to required health and safety measures. In some cases, such as prolonged projects at contaminated sites, blood lead level monitoring of workers may be made mandatory.

Measures should be taken to protect the community members and keep them informed about health and safety measures during the work. These measures may include fences around work areas; signs about the work, schedule of work, pamphlets about health and safety measures; covering of excavated contaminated materials; carefully selected access routes for heavy vehicles; measures to monitor and clean up spilled contaminated material, etc. The community should know who is in charge of the project and be able to contact the on-site project manager about any concerns.

7.4 Post-Work Monitoring and Evaluation

After the project's completion, qualified experts and local staff should determine the success of risk management measures. This is to be done, where possible, by health improvement outcomes, notably including bio-monitoring where feasible. Community members and other stakeholders should be interviewed to determine their views about the project. The project work and results should be documented in a thorough project report, which should be made available to appropriate government departments as well as project funders. The report should include discussion of any difficulties, deviations from designs or plans, delays, incidents, or problems, as well as key learning from the project. Responsibility for the project report should be borne by the project manager.

View the Mirzapur Project Completion Report.

- *Documentation Produced: Final Report*

7.5 Long Term Site Care and Management

Given the typically financial resource-poor environments in which projects are executed, risk reduction alternatives that require no or minimal on-going operation and maintenance requirements should be selected where possible. Operations and Maintenance (O&M) costs should be included as a parameter, estimated and evaluated in the Alternatives Matrix. These costs should be estimated for a period of at least 5 years. Once this is done, a fund should be set aside to cover the total O&M costs for the period. Responsibility for on-going O&M should be clearly identified in the project plan and approved by the appropriate government department. Often, on-going O&M becomes a responsibility of local governments and in this case, assurances must be obtained that the government is willing and able to assume this responsibility for maintenance.

In addition, the project should be monitored, and the site should be periodically assessed for a period of at least five years following the completion of the project. Where re-contamination has occurred and it is feasible to address within existing O&M budgets, additional work should be conducted. In the event that recontamination has occurred and it is not feasible to address it under existing budgets, efforts should be made to identify additional resources.

- *Documentation Produced: Long-Term Site Care and Management Plan; Annual site report for at least 5 years*

8 ANTICIPATED COSTS FOR REMEDIATION PROGRAMS

The components and price of remediation programs will vary depending on the specifics of the contaminated site. A list of anticipated cost categories is presented in Table 2 based on remediation projects in Bangladesh in the towns of Kathgora and Mirzapur.

The anticipated duration of the typical remediation program would be twelve to eighteen months, with the engineered actions and hygiene programs requiring three to six months.

There are non-government organizations, United Nations offices (such as the UN Environment Programme, UN Development Programme, and the UN Industrial Development Organization), multilateral organizations (such as development banks) and government organizations (such as the European Commission and US Agency for International Development) that may be able to provide guidance and support to Bangladesh in developing a strategy for pursuing remediation of polluted sites. The World Health Organization has many published resources that describe the health impacts of pollutants and can help Bangladesh government officials in developing communication and education tools for the public and for industry.

Table 2. Anticipated cost categories for a risk reduction program in a community impacted by lead pollution.

Remediation actions
Equipment for excavation and waste hauling and construction
Materials and supplies including clean soil, bricks for paving, hand tools, and personal protective equipment
On-site staff and laborers
Accommodation, meals, transportation, and other support services for laborers
Communication and Community Engagement
Communication materials
Community events
Health Impact Assessment
Pre- and post-remediation blood screening supplies and/or lab costs
Technical support staff

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APPENDIX A: EXAMPLE ALTERNATIVE MATRIX

Surface Soil Alternatives	Risk reduction effectivene ss	Sustain-ability	Logistical feasibility	Community acceptance	Schedule	Environmental impact	Anticipated costs
A. Scrape and bury	Moderate – mitigates exposure but not leachability	High	Feasible	High	Short	Low – exposure of large area removing top soil	Moderate – manual labor and heavy equipment rental
B. Mix surface with deeper soil	Moderate – contaminat ion diluted but still potentially leachable	High	Feasible – with adequate mixing / sufficient dilution	High	Short	Moderate – may have increased erosion from disturbing top soil layer	Moderate – heavy equipment purchase/rental
C. (A) w/ phosphate	High – addresses exposure and leachability	High	Feasible	High	Short	Low – phosphate confined to pit	Cost of (A) + cost of phosphorus
D. (B) w/ phosphate	High – addresses exposure and leachability	High	Feasible	High	Short	Moderate to high – potential impact to surface water from erosion	Cost of (B) + cost of phosphorus

APPENDIX B: EDUCATION AND COMMUNICATION MATERIALS

Information, education and communication materials on childhood lead poisoning and infographics on remediation work.