Identifying Lead Components in Uganda's Water Infrastructure Supply: A Supply Chain Mapping and Intervention-Identifying Analysis

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Abstract

Lead (Pb) exposure through drinking water causes a substantive preventable disease burden. The primary source of Pb in drinking water is through Pb-containing infrastructure, including leaded-brass fittings, galvanized iron/steel pipes, and some plastics. As the source of Pb through drinking water is widely known, its prevention through a supply chain intervention is possible. This is true in Uganda, where the use of potentially Pb-containing handpumps and piped drinking water infrastructure has been previously documented. As Uganda has signed the Global Lead-Free Water Pledge and appears to import Pb-containing materials, an evaluation of its supply chains for drinking water infrastructure may identify points of future intervention. We used an established desk-based methodology to produce Supply Chain Maps (SCMs) of major infrastructure components, including handpumps, submersible pumps, and pipes. We collected information from drinking water infrastructure vendors, installers, manufacturers, and relevant press statements through searches from October 2024 to April 2025. We identified a diverse set of handpump manufacturers (n=25) in South Asia, from which evidence indicates that Pb-containing galvanized iron/steel infrastructure is entering Uganda. We found a smaller set of firms responsible for producing handpumps and submersible mechanized pumps (n=8), for which materials are advertised as Pb-free stainless steel. However, this claim lacks third-party validation in many cases. If true, this indicates the existence of available Pb-free alternatives, suggesting that future installation of Pb-containing materials can be avoided. We did not find evidence of a domestic manufacturing base for handpumps in Uganda, suggesting that the import process may be a critical control point for Pb elimination. There was limited information about the pipes and fittings used in drinking water systems, as the processes governing this infrastructure are decentralized and appear to lack an online presence. We present the potential for leveraging the outputs of SCMs to inform other tools, like the Hazards Analysis and Critical Control Points (HACCP) framework for protecting national drinking water supply chains, and the Water Safety Plan (WSP) tool for ensuring Pb-free local water systems. From the findings of the Uganda SCM, we identified potential intervention points to be further evaluated through HACCP and WSP frameworks. This study demonstrates that even in the absence of direct material testing, supply chain structures can identify plausible entry points and controls for toxic materials in drinking water infrastructure.

Introduction

Lead (Pb) is a toxic metal that causes severe and irreversible harm to human health (1–5). Childhood exposure to Pb is particularly harmful, causing lifelong cognitive and developmental impairment (6–9). Exposure to Pb is also linked to cardiovascular disease (10) and cancer (11). The World Health Organization has noted that there is no safe level of exposure to Pb (12). Lead exposure occurs through drinking water, resulting from the leaching of Pb-containing materials in water systems (13–15). Common Pb-containing materials used in drinking water infrastructure include leaded brass, galvanized steel (GS, sometimes interchangeably referred to as galvanized iron), and leaded solders (13,14,16–20). Common types of drinking water infrastructure include utility/municipal piped systems, public standpipes, motorized/mechanized boreholes, and handpumps. Each of these may include brass, GS, and/or leaded solders that can leach Pb into drinking water. In utility systems, otherwise “clean” drinking water lines may have brass valves and fittings (20,21) or galvanized pipes. Small-scale piped infrastructure, such as public standpipes or mechanized systems, may use a combination of Pb-free components below ground with Pb-containing brass taps (13). Pb-containing fixtures may also be used in premise plumbing for homes with household connections(22). Prevalent handpump models used globally may contain GI/GS and brass materials that come into contact with drinking water, both above- and below-ground (23). 200 million people in Sub-Saharan Africa (SSA) depend on handpumps for drinking water access (24), indicating that the use of Pb-containing materials in this infrastructure and supply chain may contribute towards a broad baseline of Pb exposure. There has been an expansion in the use of mechanized systems to replace handpumps (25,26). The use of Pb-containing materials in supply chains for mechanized systems is not well characterized.

Lead is often intentionally added to materials to improve the manufacturing process. Brass, a metal alloy of copper and zinc, is widely used in valves, fittings, and other components in handpumps and piped systems; Pb is added to brass to increase ductility and machinability (17,19) and enhance the seal of threaded joints (27). Galvanized coatings for GI and GS are produced by hot-dip galvanization, which involves immersing an iron or steel component in a molten zinc bath (18). Pb is introduced into molten zinc by deliberate addition for the commercial benefits it confers on the galvanizer (28,29). However, Pb in a galvanizing coating has been shown to increase corrosion rates in saline or other aggressive waters (29–31). The use of Pb as a stabilizer in polyvinyl chloride (PVC) and unplasticized PVC (uPVC) piping poses an additional risk of Pb contamination in water through leaching (32). Lead contamination of drinking water is well documented in high-income countries, where Pb-containing infrastructure has been installed over centuries (33–35). The risk of Pb contamination is also a concern in low- and middle-income countries (LMICs). More LMIC data are needed to understand the pathways by which contamination occurs and can be prevented.

Uganda may provide an example of opportunities to prevent the installation of Pb-containing materials in new and expanding drinking water supply systems for the LMIC context. The government of Uganda is actively expanding the country’s water infrastructure (36); the 1995 Constitution of Uganda establishes the right to “clean and safe water” as a fundamental right (37). Through integrated management plans for its water sector, Uganda’s Ministry of Water and Environment (MWE) has increased the share of consumers with access to an improved water source from 61.4% to 84.2% between 2000 and 2022 (38). According to the WHO/UNICEF Joint Monitoring Programme for Water Supply, Sanitation, and Hygiene (JMP), most rural residents (67.9%) use non-piped improved drinking water sources. In comparison, most urban residents (52.5%) drink water from piped sources (38). The government of Uganda has made expanding the reach of safe, accessible piped drinking water one of its official objectives (39). While hand pumps reached 67% of Uganda’s population in 2021, the government has sought to move towards solar-mechanized and piped sources (40). Despite this progress, Uganda’s potable water infrastructure faces structural problems related to its composition and corrosion.

Uganda's existing infrastructure, especially systems built during the 1980s through the early 2000s, relies heavily on deep borehole handpumps. Between 2021 and 2022, over 50% of handpump riser pipes in Ugandan boreholes and shallow wells were composed of GI (40). Common handpump models widely installed in sub-Saharan Africa also specify brass valves and galvanized steel (GS) components (41), and there is evidence of Pb-contamination in such components, as well as in other plumbing products and infrastructure in other settings within Sub-Saharan Africa (15). Thus, there is cause for concern that leaded products may be entering Uganda and being installed in water supply infrastructure. However, the empirical extent to which Pb-containing vs nonleaded materials are being marketed and installed in Ugandan water supplies has not been well characterized. Such evaluations are instrumental to preventing lead exposure from drinking water and are enabled by robust supply chain mapping.

Supply chain mapping (SCM) is a key tool for public health practitioners to identify the sources and flows of materials. It requires the evaluation of material sources, value addition through manufacturing or transformation, and their final destinations (42,43). This includes documentation of the producers of raw materials, manufacturers, wholesalers, vendors, and end-users of a finished product. The final set of actors and processes is integrated into a unified supply chain map. SCM has not been applied to evaluate the flow of materials related to the global drinking water supply. Regarding lead contamination in drinking water components, SCM can identify points of leverage to prevent and remediate Pb contamination. These points of leverage can be passed from an SCM to safety-oriented tools like the Hazards Analysis and Critical Control Points (HACCP) framework and then Water Safety Plans (WSPs) for countries and communities to address Pb in drinking water. Both tools require a "flow diagram of the complete process" and a "water supply map," respectively, to identify potential risks and controls to protect consumers (44,45). The supply chain maps produced as part of this study may serve as a key process flow diagram, providing the first step in a broader quality assurance process to reduce Pb in drinking water through tools like HACCP and WSPs. Therefore, an analysis of Pb use in water infrastructure through supply chain mapping can help Uganda's stakeholders adopt a proactive regulatory stance to prevent future contamination. An assessment of Pb-related leaching from a supply chain perspective will be an asset for understanding the entry, dispersion, and endpoints of lead in the Ugandan water supply. We therefore aim to apply a desk-based SCM approach to understand how the Ugandan drinking water sector may involve Pb-containing and Pb-free materials. We aim to achieve this through a desk-based analysis, with results validated by local subject matter experts, to determine whether this low-cost mapping tool may be useful in limiting the flow of Pb-containing infrastructure for drinking water in Uganda. These findings can be used as entry points to addressing Pb through the HACCP framework and WSPs throughout the country.

Methods

The supply chain mapping process used in this study follows that recommended by Gardner et al. (43). Namely, the authors conducted an initial rapid literature review to understand key search terms and expert stakeholders; developed a search strategy; collected publicly available data; and validated results through expert consultation and stakeholder review.

Supply Chain Mapping Search Strategy

We began by conducting a brief literature review of the types of infrastructure used for drinking water in Uganda, which is summarized in the S1 Appendix. This generated a set of system types (India Mark handpumps, Solar-mechanized systems, etc.) and components (riser pipes, ¼" valves, etc.) for which we searched.

We used an internet-based search strategy to obtain information about key firms in Uganda's manufacturing supply chain with the following process: (1) Web Search: Using a list of key terms (Table 1), we conducted a web search on Google Chrome with default settings, using the first five pages of Google search results to find firms. We define a firm as a unique legal entity operating within a single country, irrespective of its role(s) in the chain. For example, an entity that acts as a manufacturer and a vendor in Uganda would be considered one "firm." In contrast, the same company operating in Kenya would be considered a separate "firm." A single node represents a case where a firm operated as multiple actors, such as a manufacturer/vendor or a purchaser/reseller. (2) Online Marketplace Search: Using a list of key products generated as an output from the literature review in S1 Text, we conducted an online marketplace search on Alibaba, Jiji Uganda, and IndiaMart to find specific manufacturers and vendors of water infrastructure components. Where necessary, we contacted manufacturers and vendors to collect catalogs of available products. (3) Economic Data Collection: Using databases such as Statista, the government of Uganda's Water Atlas, the United Nations Joint Monitoring Programme, and other databases provided by nonprofit organizations like the International Zinc and Lead Working Group, we collected generalized data on the sources and economic volume of raw materials and goods. We collected all data through iterative searches from October 2024 through April 2025. We were unable to use a VPN to search as if from Uganda.

Table 1. *Key terms used for reviewing firms in Uganda online.*

Key Terms		
"Uganda water pump suppliers"	"Ugandan drinking water pipe manufacturers"	"India Mark 2 hand pump parts producers"
"Ugandan hand pump manufacturers"	"Galvanized steel pipes Uganda"	"Uganda modified hand pump parts producers"
"Ugandan hand pump distributors"	"Brass drinking water suppliers Uganda"	"Uganda hand pump installation"
"Ugandan hand pump vendors"	"PVC pipe suppliers Uganda"	"Drinking water NGOs Uganda"
"Engineering firms drinking water Uganda"	"Borehole drilling Uganda"	

Data Synthesis and Interpretation

A mapping approach is crucial for developing any framework for understanding the entry points of Pb into Uganda's markets and the water supply. Gardner & Cooper define a process map as a representation of a single production process for internal use, with a high level of detail (43). Supply chain maps should show the whole network of processes in a generalized way that is easy for outsiders to understand. For this study, we created detailed process maps for the most important individual components (India Mark hand pumps, mechanized solar-powered pumps, or supply pipes). We combined them into a supply chain map that sacrifices specificity for comprehensiveness. Developing these outputs followed guidelines from the National Institute of Standards and Technology (NIST) and previous work (42,46,47). We conducted a pilot evaluation of the initial two steps of the HACCP framework, listing potential hazards and determining critical control points, respectively, using the SCM outputs as a basis for analysis.

Data screening and inclusion

We included data points for which there was sufficient evidence that a product was in the supply chain. Where a link was explicitly stated, such as a manufacturer's use of a specific raw material supplier or a vendor's listing of a manufacturer, such data was always included. Similarly, where online marketplaces based in Uganda listed a product as available, it was included in the supply chain. In more ambiguous cases, such as when a product was listed on a foreign marketplace, we consulted the vendor or manufacturer listed to confirm its availability in Uganda before inclusion in the supply chain. All manufacturers and vendors of pump infrastructure who responded noted either the ability to ship to Uganda or a regional distributor in East Africa. Non-responsive manufacturers and vendors were excluded from the final supply chain. Where links between a vendor and a purchaser appear possible but cannot be confirmed, we have included them as dotted lines.

Expert Validation

To understand gaps in our SCM results and potential intervention points, we followed a semi-structured consultation process, in which research team members, local officials, and experts in Uganda, the US, and other contexts were consulted. We presented the results of the SCM desk review to Ugandan stakeholders involved in the procurement process for drinking water infrastructure for iterative feedback. The first results were presented to one major vendor and one major purchaser/installer of drinking water infrastructure in Uganda in October and November 2025, respectively. We presented results to three government officials familiar with drinking water infrastructure during a group interview in March 2026. We finalized validation through an interview with an additional importer/vendor in April 2026. The finalized SCM and resulting HACCP-informed recommendations were based on the stakeholder input.

Results

Rapid Literature Review

There is widespread use of the India Mark models of handpumps in rural drinking water in Uganda (23,40). This includes a Uganda-modified model, which is highly prevalent. The use of Pb-containing materials in these systems is shown in the S1 Appendix. It indicates that many handpump components in contact with drinking water may contain Pb, based on manufacturer's material sheets (41). There is growing use of submersible pumps (25,26), often advertised as stainless steel, which, by definition, excludes Pb from the manufacturing process. Distribution pipes are made of various materials, including GI/GS, PVC, uPVC, and High-Density Polypropylene (HDPE).

The primary sources of Pb in Uganda's drinking water were lead additives used in galvanization, brass alloying, and uPVC polymerization. Most of the materials used in galvanizing drinking water infrastructure are sourced from just a few companies that dominate worldwide production of raw zinc and Pb. For example, around 80% of India's primary zinc market share is held by a single integrated zinc producer, Hindustan Zinc Limited, which operates primarily in Rajasthan (48). The primary use of this zinc in India was for galvanizing Indian products, including the bodies, tanks, and spouts of India Mark handpumps, among other models. This galvanizing process relies on the hot-dip galvanizing of steel or iron components, typically conducted by manufacturers. Globally, over 50% of zinc mining end use is for galvanization, linking the raw materials stage to the manufacturing process. Tracing the flow of zinc used for the galvanization of drinking water components may reveal where Pb additives enter the supply chain.

Additional findings from the rapid literature search are available in S1 Appendix.

Conceptual Model

We developed a series of process maps, outlined in Fig 1 below. Each process map step was then integrated with the others to develop a series of high-level supply chain maps. The geographic summaries of these supply chain maps are grouped by product type (hand pumps, solar/mechanized pumps, and pipes) and are discussed below. Our search strategy identified 142 total unique firms, which were synthesized into these maps.

Fig 1. Schema for process maps used for the investigation; synthesizing several such process maps will produce a supply chain map.

Handpumps and Solar/Mechanized Pumps

The geography of firms involved in pump manufacturing was mapped in Fig 2. The sequential procedure and analogous map for handpumps, from manufacturing to purchase, export, and installation, are illustrated in the S1 Appendix. Together, these maps captured the results of the desk-based review as they related to technologies of groundwater extraction that may be Pb-contaminated or Pb-free. There was a distinct geographic distribution of firms involved in pipe manufacturing, as shown in Fig 3. The distribution of government funders was mapped alongside a broader distribution of funding identities (S1 Appendix). Together, the content of these maps was simplified and integrated into a complete supply-chain map of potentially Pb-containing water infrastructure (S1 Appendix).

Fig 2. Geographic Supply Chain Map of Handpumps and Solar or Mechanized Pumps for final use in Uganda (note: illustrative, not exhaustive). Dots represent manufacturing hubs, with a larger dot representing two actors in a setting.

Of the total firms evaluated (n=142), we identified a total of (n=25) handpump manufacturers, of which 24 were based in India. The remaining non-manufacturing firms in the supply chain include raw material extractors, component and product vendors, implementers, and funding agencies, summarized in Tables C and D in S1 Appendix. Numerous firms (n = 16) were in the northern states of Gujarat, Uttar Pradesh, and Maharashtra, and in the national capital territory of Delhi, with others headquartered in industrial cities in the south, such as Coimbatore and Hyderabad (Fig 2). In particular, the India Mark II & III hand pumps were primarily exported by Indian manufacturers. Based on manufacturer catalogs and conversations with wholesale distributors, the catalog-reported material selection includes GI or GS, often with brass fittings, were the default option for purchase. A subset of manufacturers (n=3) offered stainless steel models upon request. It is unclear what percentage of the market this Pb-free alternative comprises in terms of units sold.

The identified flow of pumps corresponds to import-export data, indicating that in 2021, the value of Indian-origin handpumps imported into Uganda surpassed USD 2.5 million (49). The wide range of prices listed online per pump (spanning multiple orders of magnitude, not accounting for potential bulk-ordering pricing) makes it difficult to estimate the number of imported units. Indian firms were also prominent in producing the Uganda 3 Modified (U3M) handpump. Most firms provided specifications and listed themselves as export-certified; however, these specifications were not particularly informative due to a lack of material specificity (with few third-party material certifications) and terminological confusion (using terms such as galvanized iron, galvanized steel, and steel interchangeably). The lack of clarity about the specific materials used means that, through a desk review, no certified Pb-free components can be identified for handpumps in the Ugandan supply chain. While most firms were concentrated in India, one manufacturer was identified in Kenya. Individual hand pump parts, such as check valves and rising mains, were often manufactured and distributed by hand pump and mechanized pump manufacturers. However, many informal parts and pump manufacturers are likely not captured by the online-based search process outlined in this paper.

The supply chain for solar and mechanized pumps is distinct from that of handpumps. Solar and mechanized pump manufacturing firms (n=8) were headquartered primarily in Europe, although a diffuse network of manufactories was also identified in western India. Important solar pump manufacturers included firms headquartered in Denmark and Germany, which were explicitly identified as the pump technologies used in several of the evaluated projects (Fig 2). These companies maintain lists of verified distributors, but additional unlisted distributor firms were discovered through the search methodology. This may indicate that either a set of submersible pumps is being resold or “knock-off” products are being marketed as coming from a reputable manufacturer. A domestic solar and mechanized pump manufacturer in India was also identified, which exhibited a clearly identifiable relationship with a specific vendor from production to distribution in Uganda. Of the marketed solar and mechanized pumps, the use of stainless steel in their components is commonly advertised. If these reports are accurate, this would indicate a Pb-free alternative to existing drinking water infrastructure in Uganda, suggesting that the practices that lead to the installation of toxic Pb in drinking water infrastructure are potentially avoidable.

Pipes and Fittings

We identified that PCV and uPVC pipes were manufactured by both international and domestic firms (Fig 3). Plastic components are useful only as replacement parts for the Afridev pump; however, they are also advertised for use in conveyance within mechanized systems. Many pipes sold by leading Ugandan corporations were listed on decentralized market platforms such as Jiji Uganda. Furthermore, Ugandan pipe manufacturers listed specific firms with which they worked to install pipes. However, upstream raw material- vinyl chloride production- was challenging to identify. Even less specific was the composition of manufactured plastic, which often had few specifications beyond company statements that it conformed to standards set by Ugandan bureaus. Several firms in India, as well as one in China, also produced GS pipes; however, the quality of zinc galvanizing and Pb content was unclear in these cases. We found evidence of GS pipe manufacturing from a handful of firms within Uganda. We did not find GI/GS pipes sold in sufficiently large diameters to suggest their use in water main lines. However, smaller galvanized pipes and brass taps may be used in smaller distribution lines. Further synthesis of process maps for handpumps and submersible pumps, and the overall conceptual supply chain map of Uganda's drinking water infrastructure, are available in S1 Appendix.

Fig 3. Geographic Supply Chain Map of Pipes for final use in drinking water infrastructure in Uganda (note: illustrative, not exhaustive). Dots represent manufacturing hubs, with a larger dot representing two actors in a setting.

Potential intervention points

The simplest point of intervention to prevent contamination is often the source. For Uganda's drinking water infrastructure, this would require a coordinated effort with external actors and foreign governments. A potential opportunity would be collaboration with regulators in South Asia, particularly in the Western Indian states of Maharashtra and Gujarat, to ensure that products intended for use in potable water systems comply with international standards for non-leaded products, such as NSF-372 restrictions on Pb content (50). This could include verifying both the raw materials used and the finished products manufactured by such manufacturers. The Indian Bureau of Standards may be able to play a key role in developing such regulations. While this is true of many handpump manufacturers, there are upstream actors for almost all components, spread globally. Initiatives through the distributors of raw materials and major galvanized goods manufacturers may likewise be avenues for an actor to restrict Pb contamination from centralized processes.

The next step in the supply chain is at the point of entry into the continent. An area of potential intervention involves leveraging the concentration of imports through Kenya's Mombasa Port. Because this port is a vital conduit for sea-based transit of products from South Asia to East Africa, the East African Community (EAC) could play a vital role in maintaining water quality. A possible agreement on unified standards for water infrastructure imports and implementation of a system for testing and quality control at Mombasa's Port could prevent future installation of Pb-containing infrastructure.

Continuing through the supply chain, the next opportunity for intervention is at the entry of goods via land crossings through the towns of Busia and Malaba. These points are already the preeminent entry routes through which goods, particularly in container and tanker trucks, enter Uganda from Kenya. This suggests that inspection or certification of goods crossing through this point may build on existing regulatory infrastructure. There is an existing, multilateral EAC institution with a permanent secretariat whose job it is to maintain smooth trade at these points: the Northern Transit and Transport Coordination Authority (NTTCA). However, one aspect to consider is that border-crossing times are already significant at Malaba, averaging more than 9 hours (51). While the EAC has taken steps to decongest this crossing (52), any regulation should again be weighed against the risk of creating incentives for unregulated border crossings into Uganda to deliver products.

In proposing policy interventions aiming to reduce the quantity of Pb-containing components entering Uganda's water infrastructure through the supply chain, it is important to note that the government of Uganda has already devolved regulatory authority in this regard to the National Environmental Management Authority (NEMA). Under the National Environmental Act of 2019, Article 74 allocates to the authority the power to "prohibit the manufacture, import, export, or use of...lead" in products (53). Furthermore, the Act mandates that the Authority provide Pb-free alternatives. This forms a legal basis for the proposed intervention areas detailed below.

Our synthesis of supply chain maps for Uganda's water infrastructure identified two types of processes that will affect potential interventions. "Concentrated" processes were closely integrated within a particular geographic or economic sphere, or otherwise dependent on one or a few firms. The primary concentrated processes were the hand pump manufacturing process centered in India, and Uganda's domestic pipe manufacturing industry. "Distributed" processes were multinational, decentralized, and not beholden to a few dominant firms; they often took place offline, making them invisible to Internet-based methodologies. Pump and pipe acquisitions through domestic Ugandan vendors and project development by charitable NGOs operating through Ugandan affiliates were key examples of these low-visibility processes. Several potential intervention points for preventing Pb in the Ugandan drinking water infrastructure supply chain were identified. These are summarized in Table 2 below.

A more dispersed but potentially fruitful point at which to apply a policy intervention is the education of registered firms in Uganda itself, informed by the set of implementers from the SCM. The Ugandan government additionally maintains a list of drilled boreholes on the Ministry of Water and

Environment's information portal. By reaching out to the registered firms responsible for installing pumps at these sites, the Ugandan government can connect purchasers with manufacturing firms that do not produce Pb-containing components. For full effect, this education campaign would need to reach the entire water sector of Uganda, and can be achieved through collaboration with firms and implementers to identify key gaps and potential means to ensure Pb-free water systems.

Table 2: SCM-identified (and HACCP-informed) interventions of Ugandan Drinking Water Infrastructure for Lead prevention

Supply Chain Stage	Potential Intervention	Justification and Notes
Raw Materials	Material evaluation to ensure the use of non-leaded alloys and polymers	Most applicable to plastic production.
Manufacturing	Verification of input materials by the manufacturer of value-added plumbing products	Due to a lack of material certification observed, manufacturers of non-leaded products can ensure conformity of finished products to international standards (e.g., NSF 372 (50), NSF 61 (54), etc.) through 3rd party evaluators
	Verification by a third-party certifier of conformity for finished goods	
Manufacturers/ Vendors	Pre-shipment verification	Given the concentration of handpump manufacturing and export in India, exporters/importers of non-leaded products can obtain and include a traceable third-party conformity verification for each lot before shipment. This verification is typically issued at the manufacturing stage. For goods manufactured abroad, this will require bilateral collaboration.
	Evaluation at Borders	Most products produced in South and East Asia are imported through the port of Mombasa, Kenya and the land border crossing at Busia, Uganda. This presents opportunities for an import-based evaluation.
	Procurement specification with traceable verification	End-users can ensure procurement documents specify non-leaded products

Manufacturers/ Vendors/ Implementers		and cite applicable international standards.
	Product branding with traceable verification	There is no universally accepted notation for Pb-free components in the Ugandan drinking water supply chain. Collaboration with manufacturers and vendors through a certification process may help identify Pb-free alternatives.
	Product acceptance	End-users can spot-test a random subset of examples of each non-leaded product type received before acceptance and document results in a traceable manner.
Implementers	Product confirmation	Installers can review product specifications and documentation to confirm that lot numbers match traceable documentation of suitable conformity verifications, and to ensure that all installed parts match the specified descriptions.
	Replacement and refurbishments	Operators can ensure that replacement parts and materials meet the same non-leaded specifications as those in procurement and installation standards.
Policy for Exposure Reduction	Restrictions on the selection of components; Requirements for verification of materials before installation; Clarification on responsibility for ensuring Pb-free status on materials	The national government of Uganda has a potential role in every step of the supply chain of its drinking water infrastructure.

Discussion

We found substantial evidence that the predominant models of handpumps imported for use in Uganda use Pb-containing materials based on the Supply chain map. A primary entry point for these Pb-containing handpumps appears to be their import from manufacturers centered in India, one of three “concentrated” processes found in the SCM. All identified concentrated processes occur outside of

Uganda. On the one hand, this limits Uganda's ability to enforce interventions upstream of Pb contamination of the water supply. However, the supply chain analysis suggests points where economic input/output was concentrated. First, there was a corporate concentration of Indian hand pumps' raw zinc and Pb input under the Hindustan Zinc corporation. However, this zinc itself is not Pb-containing. Instead, it presents an opportunity for mapping downstream users of zinc for galvanizing by regulators. Second, there is a concentration of regulatory power for the approval of hand pumps under the Indian Bureau of Standards. Based on the available online information, almost all hand pump products sold in Uganda were manufactured in India. The import of handpump components presents the final observed concentrated process, and would potentially require collaboration with the government of Kenya to implement changes at the port of Mombasa. The Government of Uganda's strategies for reducing the impact of these Pb-containing handpumps and similar infrastructure will therefore depend on collaboration with a broad set of international stakeholders.

Importation of other goods, such as brass and PCV, is a more "distributed" process. Uganda relies primarily on external imports of vinyl chloride, which could be regulated via import controls. However, the polymerization and additive processes, during which Pb is most likely introduced, occur in Uganda. This process is less controlled, and its distribution is essentially via informal vending networks like Jiji Uganda. However, one interesting point for potential intervention in the plastics supply chain is at the capital goods stage; machines for polymerizing and extruding solid polyvinyl chloride are, from these findings, imported mainly from a few specialized firms geographically dispersed across West Asia, India, China, and Europe (Fig 3). Copper-brass was the most challenging entry point to investigate. Products from these materials were primarily spare parts, such as brass taps, check valves, and connecting joints. Understanding that many of the vendors and manufacturers of such parts are likely invisible to a desk-based methodology, tracking copper-brass-related Pb contamination is a formidable challenge. Brass fittings, valves, and taps can present a significantly underappreciated contribution to Pb in drinking water. Brass may be used as a subcomponent in larger products like pumps, making its tracking and control logistically difficult. Accurate material specification sheets with 3rd-party verification of sub-components would be necessary to confirm the Pb-free status of any products.

Implications for Lead Exposure

Our study identified risk pathways but did not measure the specific Pb concentrations or quantify the prevalence of Pb-containing materials in existing infrastructure in Uganda. Such a process would depend on access to additional procurement records to estimate the transfer of Pb into Uganda through drinking water infrastructure. Instead, our results rely on prior literature to understand the public health implications of a Pb-containing supply chain. Work from the Rural Water Supply Network (RWSN) in 2015 identified the predominance of India Mark II, India Mark III, and Uganda-Modified India Mark III handpumps in Uganda (23). Our work found that all handpump vendors used GI/GS and brass as the default material selections, with stainless steel available only upon special request and subject to additional manufacturing specifications. If historic procurement practices mirror the catalog defaults of brass and GI/GS, we expect that the majority of already-installed systems likely had a similar material profile, suggesting widespread use of Pb-containing materials in handpump infrastructure. This finding is reinforced by Roy et al., who identified a widespread use of Pb-containing infrastructure in drinking water handpumps in Ghana (13) and by Rezek et al., who noted the propensity of GI/GS and brass materials to leach Pb at levels of concern (14). This suggests that there may be a Pb burden from already-installed rural drinking water infrastructure through ingestion.

A growing trend in Uganda appears to be the use of submersible, often solar-powered, mechanized pump systems. Many online posts by implementers note the installation of new solar-powered drinking water pumps. One reason for this may be the growth of financial incentives for solar-powered water pumps, such as discounts up to 60% (26). However, the existence of a Pb-free alternative, with stainless-steel submersible pumps marketed in Uganda, implies that future infrastructure may avoid unnecessary Pb exposures. As noted by Roy et al., however, even this infrastructure requires both material verification and downstream use of Pb-free materials, such as stainless steel or polished nickel taps or faucets (13). These materials were unfortunately difficult to evaluate from a desk-based survey and would require field measurements to determine their prevalence and availability in markets.

While rural infrastructure can be characterized, urban infrastructure is dominated by a handful of utilities and lacks publicly available procurement guidelines. They likely use a different selection of larger pumps and pipes in main distribution lines, which were not captured with our search strategy. Their use of Pb-free components in public standpipes and end-user infrastructure is unclear. While not indicative of actual supply chains, one major utility has an image of a public standpipe using both a galvanized riser pipe and a brass tap on its homepage as of June 2026. If this design is prevalent in urban standpipe settings, a broader segment of the population may be exposed to leaching drinking water.

The infrastructure supply chain serving Uganda's drinking water sector is not unique – the same water infrastructure is used across all rural Sub-Saharan Africa (23). As such, the flow of Pb-containing infrastructure through the import and installation of brass and galvanized materials may be generalizable to contexts beyond Uganda. This was true in rural Ghana, where Pb-containing materials were common in drinking water systems (13). The use of similar drinking water infrastructure in Sub-Saharan Africa suggests that results may be most applicable in these rural settings. Globally, Pb exposure through drinking water may represent a baseline public health challenge, with a 2025 systematic review by Fisher et al. finding that roughly one in three drinking water samples in low- and middle-income countries contained Pb above the WHO guideline value of 10 µg/L. Similar occurrences of Pb-containing infrastructure being installed for drinking water consumption may be playing out globally.

The SCM evaluation presents actionable steps for preventing Pb contamination of drinking water through infrastructure selection and verification. To ensure the elimination of Pb in new systems, an actor needs to (1) select stainless steel or other Pb-free alternatives where Pb-containing products are available, (2) establish a 3rd-party method of verifying the Pb-free status of products and sub-components, (3) build regulations (or internal policies for organizations) to set a target for conformity, and (4) monitor and continue to verify the future use of Pb-free infrastructure in all settings. For communities and implementers, these actions can be wrapped into the WSP framework to prevent future contamination events if infrastructure selection is correctly identified as a potential hazardous event.

Global collaboration is needed to fully address Pb-containing drinking water infrastructure. Handpump manufacturers are linked to upstream suppliers of raw materials. As they receive raw materials and sub-components from other firms, they may be blind to the Pb-containing nature of aspects of their products. While larger firms may be able to conduct material verification of all incoming materials and components, smaller competitors may not be able to validate the Pb content from external sources. Collaboration among material and component suppliers, governments, regulatory bodies, academia, and manufacturers may enable broader verification and deployment of Pb-free infrastructure.

Opportunities for SCM integration into HACCP and WSP for Pb prevention

The use of desk-based SCM offers an easy entry point for Pb prevention in drinking water by integrating it into the HACCP framework and WSPs. Both HACCP and WSPs involve the process of mapping the distribution of drinking water, the potential for its contamination, and opportunities for either prevention or treatment (55). The WSP process is specific to a single water network, whereas the HACCP framework is capable of a broader application to the entire conceptual system of drinking water delivery. The HACCP framework not only identifies hazards but also identifies potential critical control points and verifies the impact of the controls (44). The application of HACCP under the scope of the national drinking water delivery system would enable the evaluation of all drinking water infrastructure inputs, whereas WSPs would govern downstream, individual networks. These two tools can therefore be applied to two aspects of protecting drinking water safety through infrastructure selection, as represented by Fig 4 below. The SCM process can therefore act under two distinct functions: (A) A hazard discovery tool of where Pb-containing materials enter the drinking water system conceptually, which actors are responsible, and which products are most at risk; and (B) An intervention targeting tool, used to identify where the fewest actors control material flows, where verification activities may be most efficient, and where regulations or specifications may have the greatest effect. The integration of SCM with national-level HACCP and localized WSPs may ensure the prevention of Pb-containing materials for drinking water infrastructure. The WSP outlines steps to improve water quality and ensure public health through evaluations of water systems (45). Step 2 of the WSP recommends a log of materials in contact with drinking water, at which point components made of GI, GS, or brass may be excluded to better integrate Pb into the WSP framework. The risks from Pb, including those arising from the installation of new infrastructure or uncertified replacement parts, may also be emphasized in Step 3, in which the WSP committee identifies and assesses existing and potential future hazards. Both HACCP and WSP should use verification tools to further ensure that potential hazards are eliminated from drinking water infrastructure.

Fig 4. Conceptual model for how Supply Chain Mapping can be applied to the Hazards Analysis and Critical Control Points (HACCP) framework and the Water Safety Planning (WSP) tool

Limitations

The analysis had key limitations—the first dealt with the broad scale at which most processes had to be examined. By necessity, the SCM begins with an expansive view of raw material extraction before narrowing in on individual firms and components. Besides some implied connections, there is an inability to link mining outputs to specific galvanizing companies and downstream manufacturers. This information would help Ugandan stakeholders gain additional policy instruments to verify material quality and to work directly with producers. Similarly, while we could identify manufacturers, wholesalers, and implementers, the specific contracts between firms were neither available nor publicized. Thus, the next step will be to understand and map the specific flows between firms. The next step will be a complete evaluation incorporating data from interviews and on-the-ground data collection from Uganda. While traceability is a benefit for full supply chain mapping, conformity verification can be applied without this data.

The second limitation concerns the opacity of Uganda's water industry. Funding from, and projects completed by, foreign NGOs (incorporated under diverse legal systems) may be underreported. Financial partners could support the procurement and installation of Pb-free infrastructure through restrictions on material selection for their implementers. Domestic Ugandan firms, particularly local spare parts vendors that can informally change hands without an online catalog, are invisible to this analysis. This is likely the largest limitation of this study. This is most relevant to urban drinking water infrastructure, where utility installers typically do not publicly disclose information about specific vendors and manufacturers for sourcing components. Therefore, on-the-ground interviews will be key for the internal validation of the study's conclusions.

Finally, at a broad level, the methodology is limited by internet access bias. While higher-priced infrastructure, such as handpumps and submersible pumps, is documented as sold through online vendors, lower-priced infrastructure, such as valves, fittings, taps, and pipes, is difficult to evaluate. A complete supply chain analysis would therefore require an evaluation of the components available at local (physical) markets where such items are likely to be purchased. There was a potential for English-language bias in the search methodology. While English is the lingua franca for global marketplaces, we may have underrepresented some South, Southeast, and East Asian manufacturers and distributors of materials during the search process.

Future Work

Based on the information provided in this exploratory study, the project has several potential directions for future work. To fill the SCM, further mapping of upstream suppliers would identify additional intervention points, though this would require information from manufacturers. With respect to Ugandan infrastructure, an initial step would be to conduct a material evaluation using X-ray fluorescence, as demonstrated by Roy et al. (13), to validate the presence of Pb-containing materials and Pb-free alternatives. More focus is needed on the decentralized processes, such as the manufacturing and distribution of brass and pipe infrastructure. Additionally, by matching confirmed bids for pump installation to the observed boreholes in Uganda (tracked by Uganda's Ministry of Water and the Environment), a more thorough accounting of potential sites of Pb contamination can be developed. This would shift the sector mapping from broad, generalized categories to more specific ones, allowing Ugandan authorities to target remedial activities in specific geographic areas. Creating a cost index that compares the prices of the hand pumps identified here with those of solar and mechanized pumps with lower lead content may help determine the costs of a Pb-free transition. Finally, by tying these two projects to the sector map developed here, Ugandan authorities and funding agencies may be able to target expenditures to help transition firms to Pb-free pump systems and, through regulation, track the movement of potentially Pb-containing materials from outside the country. These two policy tools will be critical to Uganda's ability to meet lead safety in its drinking water. Additionally, the integration of SCM, HACCP, and WSPs may ensure that national-level activities to prevent Pb-containing infrastructure are implemented in local drinking water systems.

Conclusions

Ultimately, this exploratory study aimed to develop a sector and supply chain map that provides information on potentially Pb-containing components in Uganda's water infrastructure. Our novel proposed integration of SCM, HACCP, and WSP for the contamination of drinking water infrastructure by Pb-containing materials identified the need for international and sectoral collaboration to reduce future Pb exposures. We have identified contamination of the Uganda water system supply chain by Pb-containing parts through hand pumps and the process-level integration of Pb into common products. The presence of apparently Pb-free solar and mechanized pumps indicates that the installation of Pb-containing infrastructure may be entirely preventable, pending verification. There is still potential risk from smaller brass components not captured by the internet-based search. Global supply chains for drinking water infrastructure may share similar characteristics, facilitating the import and installation of Pb-containing materials. Given global efforts to expand drinking water access, the water sector faces reputational risk if it allows the preventable contamination of water through the continued installation of Pb-containing materials. There remain opportunities for regulation, enforcement, conformity verification, and sector collaboration to establish Pb-free drinking water at a global level.

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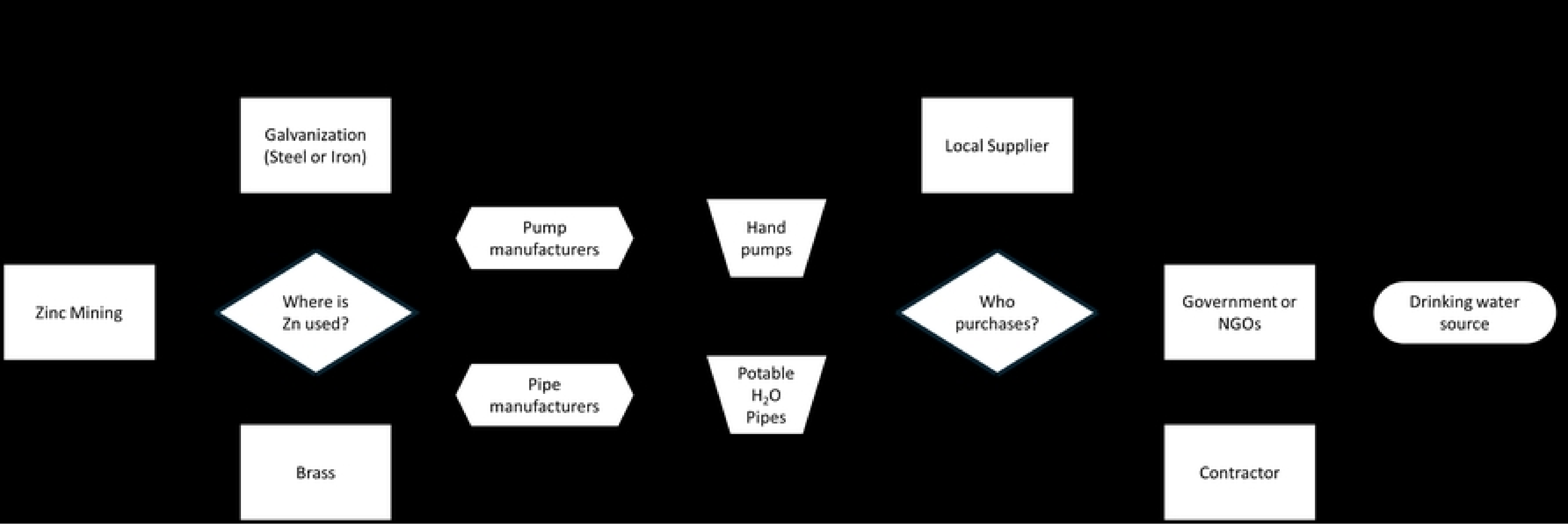

Zinc Mining
Galvanization (Steel or Iron)
Where is Zn used?
Brass
Pump manufacturers
Pipe manufacturers
Hand pumps
Potable H2O Pipes
Local Supplier
Who purchases?
Government or NGOs
Contractor
Drinking water source

Fig 1

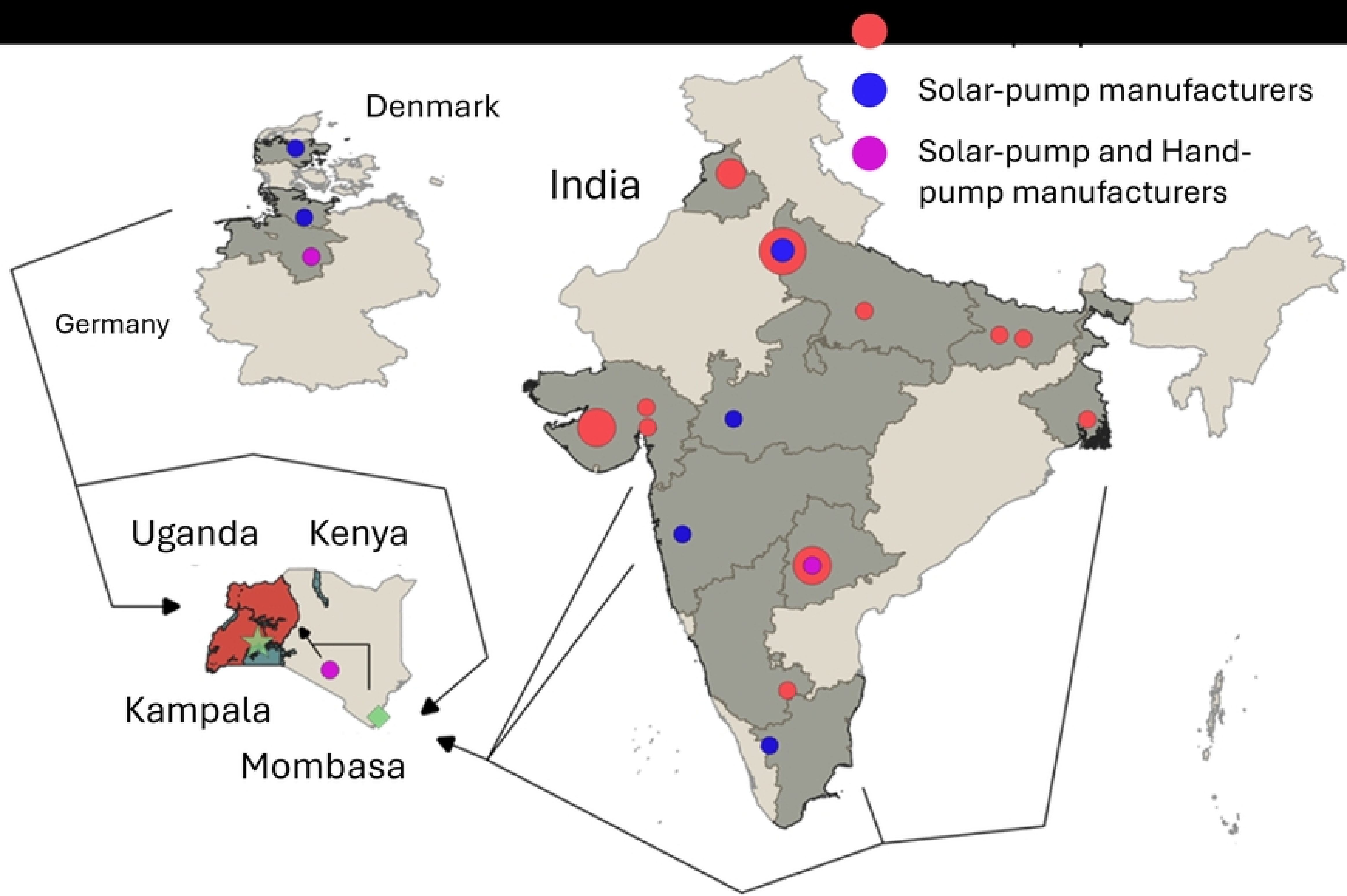
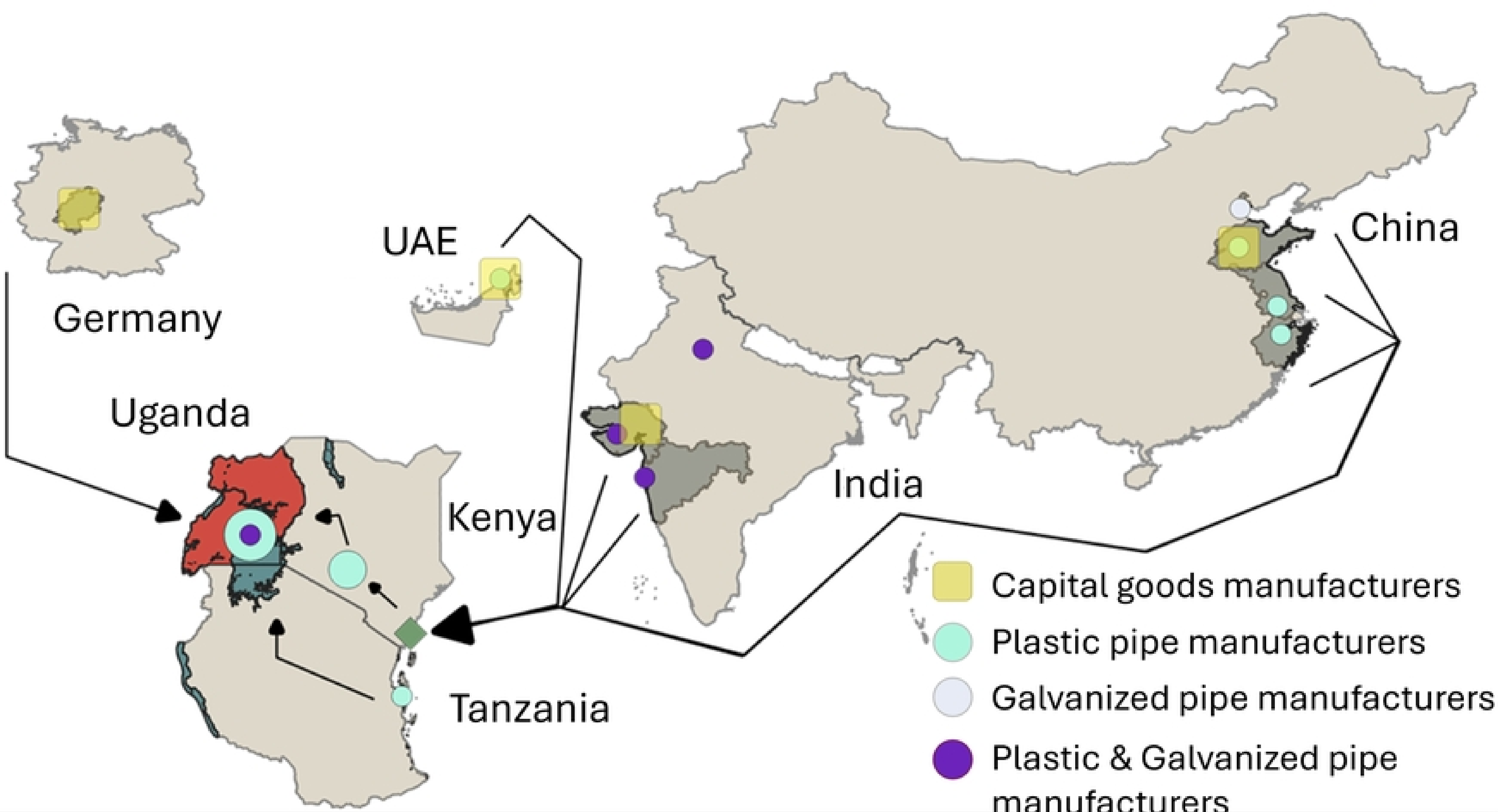

[redacted]
Solar-pump manufacturers
Solar-pump and Hand-pump manufacturers
Denmark
Germany
India
Uganda
Kenya
Kampala
Mombasa

Fig 2



Germany
UAE
China
Uganda
Kenya
India
Tanzania
Capital goods manufacturers
Plastic pipe manufacturers
Galvanized pipe manufacturers
Plastic & Galvanized pipe manufacturers

Fig 3

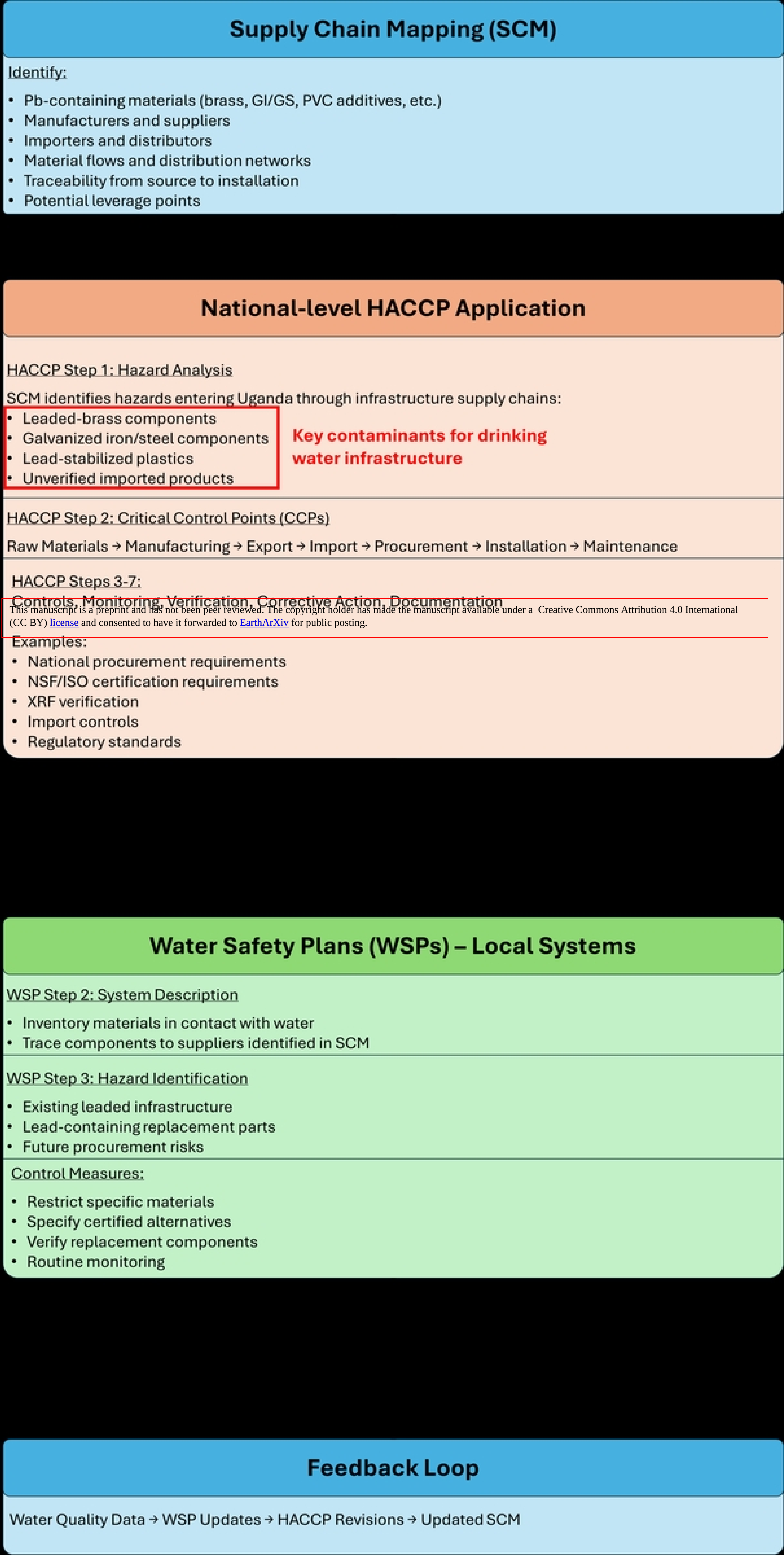

Supply Chain Mapping (SCM)
Identify:
• Pb-containing materials (brass, GI/GS, PVC additives, etc.)
• Manufacturers and suppliers
• Importers and distributors
• Material flows and distribution networks
• Traceability from source to installation
• Potential leverage points
National-level HACCP Application
HACCP Step 1: Hazard Analysis
SCM identifies hazards entering Uganda through infrastructure supply chains:
• Leaded-brass components
• Galvanized iron/steel components
• Lead-stabilized plastics
• Unverified imported products
Key contaminants for drinking water infrastructure
HACCP Step 2: Critical Control Points (CCPs)
Raw Materials → Manufacturing → Export → Import → Procurement → Installation → Maintenance
HACCP Steps 3-7:
Controls, Monitoring, Verification, Corrective Action, Documentation
Examples:
• National procurement requirements
• NSF/ISO certification requirements
• XRF verification
• Import controls
• Regulatory standards
Water Safety Plans (WSPs) – Local Systems
WSP Step 2: System Description
• Inventory materials in contact with water
• Trace components to suppliers identified in SCM
WSP Step 3: Hazard Identification
• Existing leaded infrastructure
• Lead-containing replacement parts
• Future procurement risks
Control Measures:
• Restrict specific materials
• Specify certified alternatives
• Verify replacement components
• Routine monitoring
Feedback Loop
Water Quality Data → WSP Updates → HACCP Revisions → Updated SCM

Fig 4