Final Project Report Submitted to: Water Charities

Reducing Lead Exposure by Replacement of Lead-Containing Hand Pump Components in Tamatave, Madagascar

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Project Goal. The goal of this project supported by Water Charities is to reduce lead (Pb) concentrations below World Health Organization (WHO) guidelines in water supplied by locally-manufactured hand pumps in Tamatave, Madagascar. This goal was met by the following objectives:

(1) Perform surveys of pump owners and manufacturers to ensure there is no disruption to the local hand pump market by the small subsidies provided in the project.
(2) Replace Pb pump components for 500 pumps in Tamatave.
(3) Develop a training program for local manufacturers of hand pumps so they replace Pb components with locally manufactured unleaded components and develop education materials for the local population to teach about the dangers and prevention of lead exposure.
(4) Perform detailed water quality analysis on a subset of pump water samples to determine what groundwater and infrastructure properties might influence Pb concentration.

Highlights (Indicators of Project Success)

Indicator of Project Success	**Value**
Number of pumps with replaced Pb valve components (foot and/or piston valve)	504
Total number of beneficiaries	6,247
Number of children under 6 years old benefitting from retrofitted pumps	1,109
Percent of pumps/wells tested (*after intervention*) with Pb concentrations below the WHO guideline of 10 μg/L (N=418)	98%
Percent of pumps/wells that had Pb concentrations of ≤ 5 μg/L (*after intervention*) (initial percent was 45%) (N=418)	95%
Percent of pumps/wells that had Pb concentration of ≤ 2 μg/L (*after intervention*) (N=418)	80%
Percent of pumps/wells with Pb concentration reduced below detectable levels (<2 μg/L) (*after intervention*)(N=418)	65%
Percent of children (age 1-5) who possess an action blood lead level of ≥ 5 μg/dl *(after the intervention*) (initial percent was 35%)	14%
Number of local manufacturers trained in the construction of unleaded hand pumps.	12 [1]
Number of local manufacturers who participated with our team in replacing Pb check valve components with Fe components.	4

[1] A total of 7 manufacturers received training in both leadless check valve and well screen construction, 2 manufacturers in only leadless check valve construction, and 3 manufacturers that already used leadless check valves were trained in leadless well screen construction.

What this Intervention means for a Child's Blood Level

Figure 1 shows estimated blood levels (using the IEUBK blood level model)[2] for Malagasy children ages 1-5 before and after the intervention (i.e., replacement of up to two Pb containing valves in a handpump). Based on our experiences, our model assumes the two primary exposure routes are drinking contaminated water or consuming starches (e.g., rice) cooked in lead contaminated water.

The World Health Organization (WHO) states that "lead is associated with neurobehavioral damage at blood levels of 5 µg/dl or lower." 5 µg/dl is the U.S. Centers for Disease Control and Prevention (CDC) recommended action level. In adults, lead levels above 5 µg/dl may result in higher blood pressure which can lead to cardiovascular disease.

Our modeling of children blood levels shows our intervention moves 21% of exposed children below the CDC action level of ≥ 5 µg/dl. Another way to say this is prior to the intervention 35% of exposed children had a blood lead level greater than the CDC action level and after the intervention only 14% of exposed children possessed elevated blood lead levels.

Note that our modeling assumes individuals only drink and cook with flushed water. We know from surveys however that in the morning about one-quarter of pump users do not flush their pumps before pumping the first bucket of water in the morning and also consume their pump water. Additionally, people generally do not flush their pumps before drawing water during the day so pumps without a lot of users may be unused for multiple hours in the day and have longer contact times with lead components. Thus, exposure to lead may be greater than we have modeled and our intervention may thus be more important than our data suggests for reducing lead exposure.

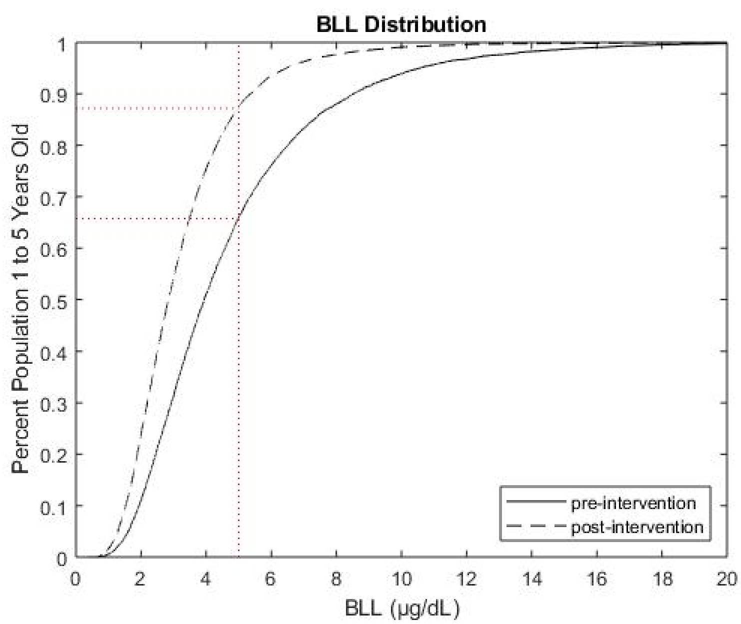


Figure 1: Distribution of Modeled Blood Lead Levels (µg/dL) of Children Aged 1-5 in our Study Area before and after the intervention. No blood lead level is considered safe; however, the CDC states the action level for blood lead levels in children is 5 µg/dL.

[2] The Integrated Exposure Uptake Biokinetic (IEUBK) Model is developed and maintained by U.S. EPA. It is the primary tool to estimate blood lead concentrations in children exposed to environmental lead.

Pb Water Quality Results before and after the Intervention

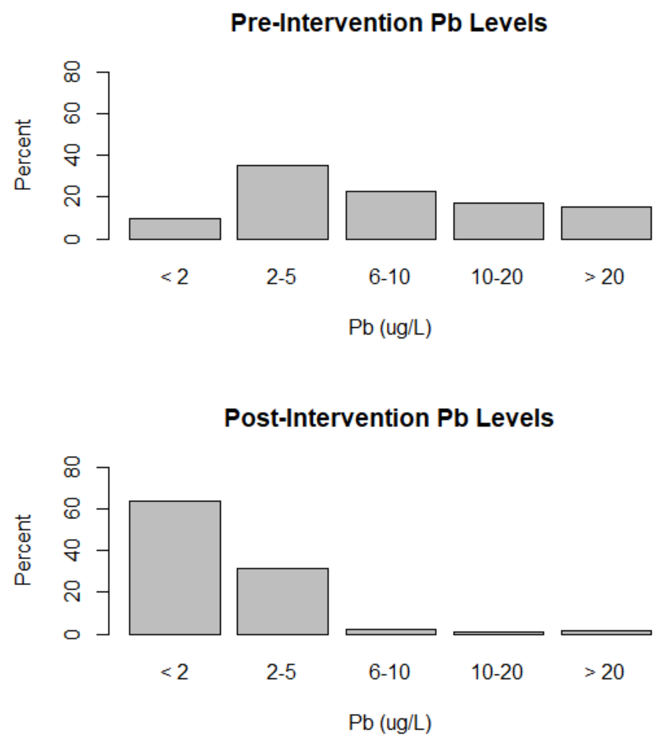


Figure 2: Percent of total wells tested for pre- and post-intervention lead (Pb) water levels.

The World WHO drinking water guideline for Pb is 10 µg/L. Prior to the intervention, the Pb from first withdrawal samples showed highest values of > 100 µg/L and after flushing there were still some concentrations measured as > 100 µg/L. After the intervention 98% of pumps/wells tested had Pb concentrations below the WHO guideline of 10 µg/L.

Analysis of samples obtained during pre-intervention (top graph, N=244) showed that 109 out of 244 wells (45%) measured < 5 µg/L (lower health risk), while post-intervention (lower graph, N=418) 398 out of 418 wells (95%) fell in that range. Another positive outcome of the intervention was that 80% of post-intervention samples showed lead concentrations of ≤ 2 µg/L.

1) Surveys to determine the impact of pump subsidy prior to this larger intervention

The goal of the first activity was to monitor and assess if subsidies of previously replacing lead components in hand pumps is not harming the existing market. This was addressed by completing a survey of 45 well owners whose pumps had previously had all the lead removed in an unrelated project performed by our group. Surveys were administered by a team of trained Malagasy professionals.

Main Objectives:

(1) Did households retain Fe check valves?
(2) Did households retain leadless well screens?

(3) Identify why households either retained a leadless pump or reverted back to lead components? Identify any benefits consumers might have on the improved product and/or what are barriers in retaining a leadless system?
(4) What do households believe may influence decision making regarding switch to Fe weighted check valves with or without a subsidy?

Results showed that 13 of the 45 pumps had some form of lead reintroduced into the pump (primarily in the piston valve but in some cases the foot valve or well screen also). Out of those 13 pumps 12 of them had a local technician perform repairs (for one pump it was unknown whether a technician or the owner had performed the repair). This indicates a need for technician involvement in the education process and sustainability of the intervention.

The surveys also indicated that education of the adverse health effects of lead components that originate from doctors or health clinics and are transferred to pump users would be most influential for empowering owners to request non-lead adaptations of their pumps. Results also indicated that the Fokotany (*i.e.*, neighborhood) president is a trusted person in the community that is looked to for advice. It is also important to note that owners repaired their pump, either by themselves or by hiring a technician, even after receiving a subsidized repair which suggests that a one-time subsidy may not be harmful to this hand pump market.

2) Pre-intervention Survey for 500 well owners

The goal of the second activity was to determine the best strategy to remove lead from pitcher pumps and keep the lead from returning. This survey was performed with a subset of 50 well owners from the 500 owners identified for the Pb replacement with three main objectives.

Main objectives:
(1) Determine what may encourage change to using unleaded pumps.
(2) Determine barriers to changing to using unleaded pumps.
(3) Determine if subsidized valve replacements will be a harmful disincentive to adoption of unleaded pumps outside of the program.

This survey included an educational component about the adverse health effects of lead and gathered respondents' thoughts on general topics about lead and their pumps. This survey suggested that Malagasy communities are unaware of the adverse health effects that lead has and are skeptical of the intervention. This was evident by responses such as "am I already sick?" and thinking that "lead is what makes the pump work". The survey also suggested that the subsidies will not be a disincentive to the owners switching the pump themselves, but will provide them with the means (education and parts) to make the adaption of the improved technology sooner. When asked how they think those that do not get a subsidy from the program would react, there was a mixture of responses. These responses ranged from many indicating they do not think there would be any issue to those that did not get the subsidy might feel sad, jealous, or discriminated against. This wide range indicates that it is important to have information that can be shared when neighbors are feeling left out or have questions about the project they know who to be sent to and how to get their pump adapted even without the subsidy. Throughout the intervention project field staff also noted many theories that they had heard due to the knowledge gaps including that the project was a governmental scheme (there was elections coming up during the time period of the intervention) and that the team just wanted to collect all the lead for themselves to sell later.

3) Perform Pump Intervention by Replacing Lead Valve Components for 500 pumps

We replaced Pb-based valve components in 504 pumps with Fe valve components over 3 months (there are 2 check valves per pump that typically have lead; a piston and foot valve). The replacement was performed by local Malagasy technicians hired by our team and monitored by our Malagasy and U.S. project management team.

Our team first met with officials at government ministries for public health and water as well as government administrators at the district and neighborhood levels to introduce the proposed project to the proper authorities in Tamatave. We selected 6 neighborhoods to work in. Within these neighborhoods we identified 500 household pumps to repair, introduced the project to the households, and made a point of contact for each pump. We established agreement terms outlining household permission and detailed the type and limits of the intervention, quality of the intervention, checklist outlining the condition of the pump before the intervention, and responsibilities of each partner. There were also quality assurance guidelines for the repairs developed for the manufacturers that required we ensure pumps functioned properly after the intervention.

A household education plan was developed for lead contamination and pump functions and adaptations. In this education we emphasized the pump water quality would be improved but informed the pump user the water would still not be potable (due to microbial contamination). This education module was delivered to the pump owners and, if available, other people such as other family members and renters living on the property. Additionally, programs on the radio were aired briefly to further educate people in Tamatave about the health issues with lead in hand pumps.

4) Train Manufacturers on Unleaded Hand Pump Construction

The formal training of manufacturers took place over a two day period. The curriculum for the training included health education about water quality and lead, talk about the expectations for the technicians and key points about interacting with households in the program, theoretical and practical sessions on the construction of leadless check valves and well screens, and a practical session were in-use hand pumps had lead removed from them. All manufacturers were expected to construct a leadless check valve and leadless well screen during the training. In summary, a total of 12 manufacturers from 10 different workshops were trained in unleaded hand pump construction techniques between the formal and informal trainings during this project.

During the first day of the workshop, 5 technicians that represented 4 different hand pump manufacture workshops participated. On the second day two additional technicians joined the training making a total of 7 technicians representing a total of 5 manufacture workshops. This initial number was below the targeted 10 technicians that were invited to the training; the technicians that did not arrive said that they either had a job that they needed to do during that time or in one case a technician did not arrive because he was injured. Additional technicians were later trained in the construction of unleaded hand pumps in other, smaller, informal training which allowed us to meet our target of 10 technicians (see below).

The manufacturers were engaged and interested throughout the entire training. Many of them asked good questions during the theoretical technical sessions and were also engaged in the practical, hand-on construction sessions. All the technicians seemed convinced that there were health issues with using lead and no one questioned whether using lead was a health issue. By the end of the training, all the technicians stated that they did not have any issues with constructing leadless hand pumps.

In addition to the formal training other technicians received training on construction of unleaded hand pumps. Two technicians that did not attend the formal training received a training focused only on using leadless check valves because it was thought that they would participate in pump adaptations. They later could not participate in pump adaptations because they had found other, full-time work. Three technicians that did not attend the training but were hired to work with the program and were already using leadless check valves also received training on making leadless well screens. Two of them constructed a new leadless well screen and one was involved in a repair of a pump with a leadless well screen.

5) Perform detailed water quality analysis on a subset of pump water samples to determine what environmental and infrastructure properties might influence Pb concentration.

Water quality analysis was performed on a subset of 244 out of the 500 pumps before the intervention to remove lead components from hand pumps. 418 pumps were tested for Pb in water after the intervention. We flushed the wells approximately 15 L before collecting pre- and post-intervention water samples. This volume equates to several volumes of water inside the well casing.

Overall water quality analysis consisted of testing for lead, pH, conductivity, total dissolved solids (TDS), temperature, and observational notes. This provided a baseline and an understanding of the water before the adaptation. Results showed a range of pH from 5.7 to 7.9, conductivity from 58 to 1,820 μS/cm, TDS from 30 to 1,080 ppm, an average temperature of 26°C, and lead concentrations ranging from less than 2 μg/L (detection level) to more than 100 μg/L.

More in-depth water quality testing was performed on a subset of 30 wells that we are studying to determine lead leaching mechanisms and also what regions of groundwater are more susceptible to lead leaching. This will inform us for scaling up our intervention. This included additional testing of: Nitrate (NO_3), Nitrite (NO_2), Iron (Fe), Manganese (Mn), Fluoride (F), Sulfate (SO_4), Chloride (Cl), Total alkalinity (HCO_3), Calcium hardness (Ca), Ammonia (NH_3), Arsenic (As), Lead (Pb) (first withdrawal in the morning and after purging), and *Enterococcus*. We have also been measuring the surface area of coatings we observed on the replaced lead components.

From the results of these tests the ratio of nitrate and nitrite to their guideline values were calculated, the chloride-sulfate mass ratio, and the Langelier saturation index. From this in-depth water analysis there are a few things that stand out: elevated NO_3 (up to 212 mg-NO_3/L) and NO_2 (up to 1.3 mg-NO_2/L) (WHO Guidelines are 50 mg NO_3^-/L and 3 mg NO_2^-/L). Also, 22 of the wells showed *Enterococcus* counts of >0 CFU/100 mL.

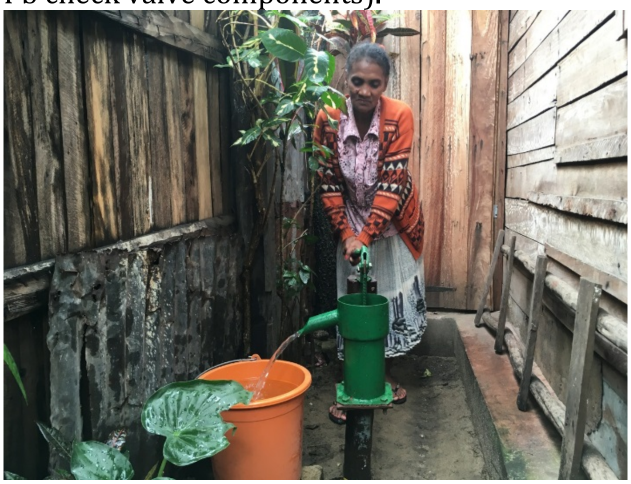
6) Project monitoring and quality control

There was post-intervention monitoring that included quality checks of repairs with household visits and correcting any repair issues as soon as possible after the visit, along with post-intervention water quality test for Pb. We corrected all follow up issues with pump functionality after our intervention took place.

The methodology we used for sampling involved flushing 15 liters of water from the wells before sampling. Therefore, the concentration of lead is lower than what is obtained from a first grab of water from a pump. The reason for sampling after a first flush was so we would obtain water concentrations more representative of all pumps with similar contact-time with their lead components (*i.e.*, because of large sample size some pumps were sampled in morning, some later in the afternoon).

Photos to Share

The project did a preliminary pump adaption at this woman's house. Here, she is using the pump after adaption (replacing Pb check valve components).



An inside look at the pump.

New lead-less parts being installed into the pump by local manufacturer.

New foot valf3 parts: The two check valves consists of leather and an iron weight to replace lead weight.

Some of the Malagasy team reviewing survey results.

Pump manufacturer Nary making an adaptation of piston valve with Fe components.

Second photo of pump manufacturer Nary making an adaptation of valve with Fe components.

Another photo of our local project team reviewing survey results.

Project team reviewing survey results.

A pump before adaptation showing lead components in piston and foot valves.

Pump manufacturer Nary and USF research engineer Michal Usowicz adapting pump while beneficiary watches (Michal was part of our International Development Engineering graduate program and can speak Malagasy).

Pump parts for sale: leather is on the top row.

Another pump prior to adaptation.

Nary works on pump along with USF research engineer Michal.

Close-up view of piston valve.

Another pump that is being rehabilitated

Example of lead weight used for check valve that was replaced during the intervention.

Nary working on pump

Team badges are used to identify project members when they visit households.

Our laboratory technician Bakoly reading results from *Enterococcus* test.

Setting up for testing physico-chemical parameters using photometer.