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A STATISTICAL APPROACH TO LEAD (PB) MITIGATION OF A SUPPLEMENTARY OF MINERAL IN DRINKING WATER.

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Abstract: Lead (Pb) has been consistently listed as one of the ten chemicals that pose a major threat to public health by the World Health Organization (WHO). Even though the toxic nature of lead has been known since the 20th century, due to its beneficial properties, it is still used in a wide range of products. Openness to lead represents roughly 900,000 passings every year and excessively influences those in low-and center-pay nations (LMIC) because of various reasons like neediness, unhealthiness, and absence of information on the harmful idea of lead. Air, soil, dust, diet, and water are all sources of lead exposure. While aqueous lead exposure is the most frequently examined method of lead exposure in high-income nations, little is known about this method in LMICs. Thus, the point of this study is to show that superior well-being is conceivable by diminishing openness to lead-defiled water via a contextual investigation in Toamasina, Madagascar. Toamasina is a coastal city where centralized piped water is not always affordable or readily available. As a result, the city needs a decentralized self-supply water system that typically consists of a pitcher pump that serves one or a few homes. Leaded components are typically used in the production of these pumps, which can have several negative effects on the health of those who use the water for cooking and drinking. The unique market for hand-driven wells, cultural norms, and a lack of understanding of the health effects of lead on locals all contribute to the complexity. Previous researchers discovered an engineered approach to retrofitting the pumps with non-leaded components.

however, widespread use of the engineered approach was limited.

This study remedied more than 1,000 pumps, tested aqueous lead levels in more than 600 pumps, modeled blood lead levels (BLLs) and their economic impact, tested BLLs in more than 300 children, and created and implemented a social marketing campaign aimed at pump technicians. Aqueous lead levels decreased by a statistically significant amount in both 2018 ($Z = -11,.0001$) and 2020 ($t(35)=3.78, p\ 0.001$); (95 percent CI [6.75,22.42]) corrections. A profit from speculation (return for capital invested) of more noteworthy than 1000-to-1 was assessed in light of the 2018 remediation. However, a comparison of measured and modeled BLLs revealed that the IEUBK model significantly underpredicted BLLs, suggesting that the anticipated ROI is probably an optimistic estimate. Since there is no correlation between a change in BLL and aqueous lead, it is likely that there is an unaccounted-for factor affecting BLLs. However, a statistically significant decrease in measured BLLs was observed ($t(54)= 6.15, p\ \ 0.001$); 95% CI[2.81,5.52]). The social marketing campaign's evaluation revealed a rise in lead-free practice adoption. Additionally, the findings suggest that future research efforts should concentrate on raising awareness among Toamasina residents and pump owners.

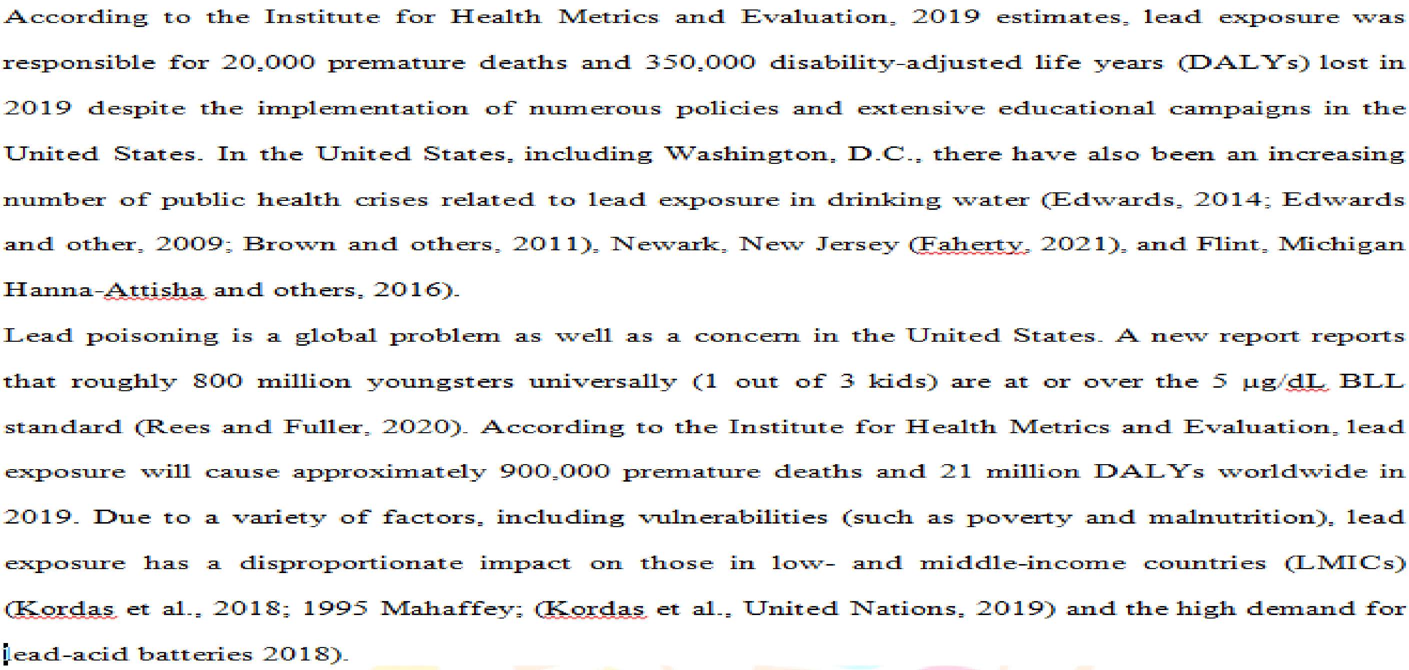
This dissertation demonstrates how improved global health can be achieved by integrating engineering, social marketing, and public health using a convergent research approach. The methodology presented in this dissertation can be adapted to examine additional exposure sources and routes in other locations. Small-scale remediations can have an impact on reducing exposure and protecting public health, and interdisciplinary approaches are required to sustainably address global challenges, according to the presented results.

INTRODUCTION

Motivation

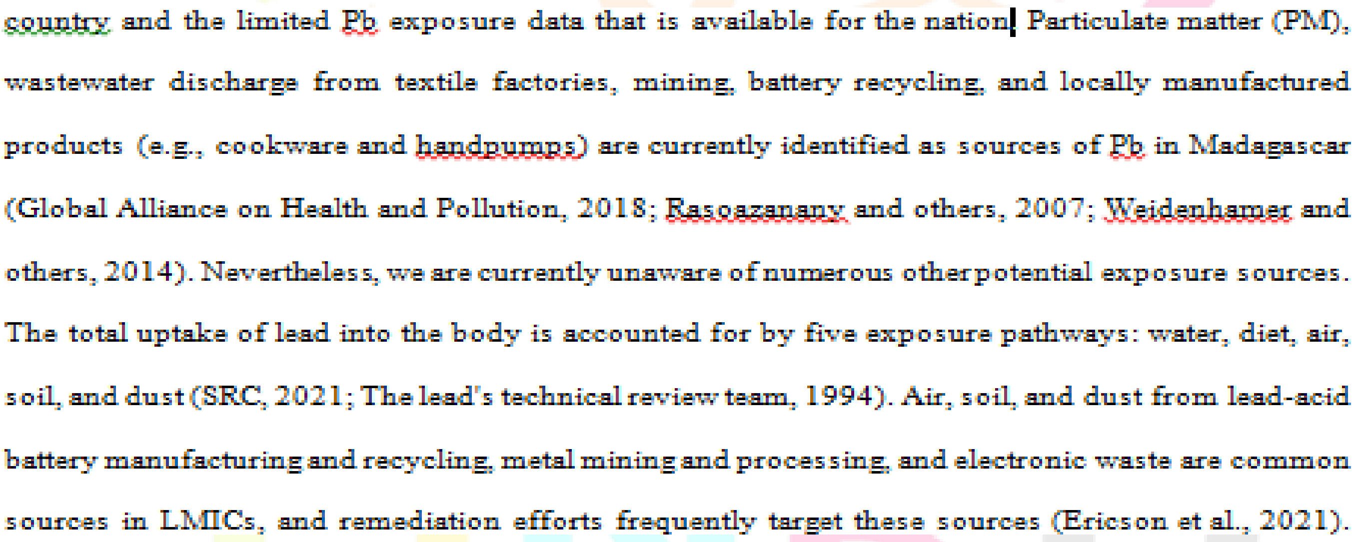
Numerous heavy metals regularly appear on the WHO's list of ten chemicals that pose a major threat to public health (World Health Organization, 2010b; Africa Regional Office of the World Health Organization, 2014). Weighty metals are of concern on account of the numerous unfavorable wellbeing suggestion that emerge because of their harmful nature at expanded portions. The metal lead (Pb) is one of these. In the 20th century, it was discovered that lead, a common naturally occurring element, was toxic to humans (Pedersen, 2016; World Wellbeing Association, 2019a). Low IQ, irritability, forgetfulness, abdominal pain, high blood pressure, heart disease, and decreased fertility are some of the effects of a high blood lead level (BLL) (World Health Organization, 2019a). However, it has been widely used in paints, cosmetics, batteries, gasoline, and pipelines due to its resistance to corrosion and extreme malleability. Leaded gasoline and lead paint have both been phased out in many parts of the world since the toxic nature of lead was discovered.

Numerous laws were enacted in the United States to safeguard people's health from lead-contaminated water: the Lead and Copper Rule of the Safe Drinking Water Act, the Toxic Substance Control Act, the Clean Water Act, and the Lead Contamination Control Act (U.S. Environmental Protection Agency, 2020). Knowledge of the health effects at various exposure levels and the potential for protective measures is constantly being reviewed. The Lead and Copper Rule (LCR) update, which was released in December 2021 and has a compliance deadline of October 2024, is one of the most recent notable changes. (1) A trigger level of 10 g/L is set in the updated LCR based on the 90th percentile of tap water samples, requiring additional planning, monitoring, and treatment requirements (USEPA, 2019). (2) A lead service line (LSL) inventory and replacement plan is required. Although it has been determined that there is no safe level of lead exposure (ACCLPP, 2012; CDC blood lead level reference values were updated in 2021 to move the reference value from 5 g/dL to 3.5 g/dL), 2016 in Health; 2021; National Environmental Health Center 1993 (World Health Organization)

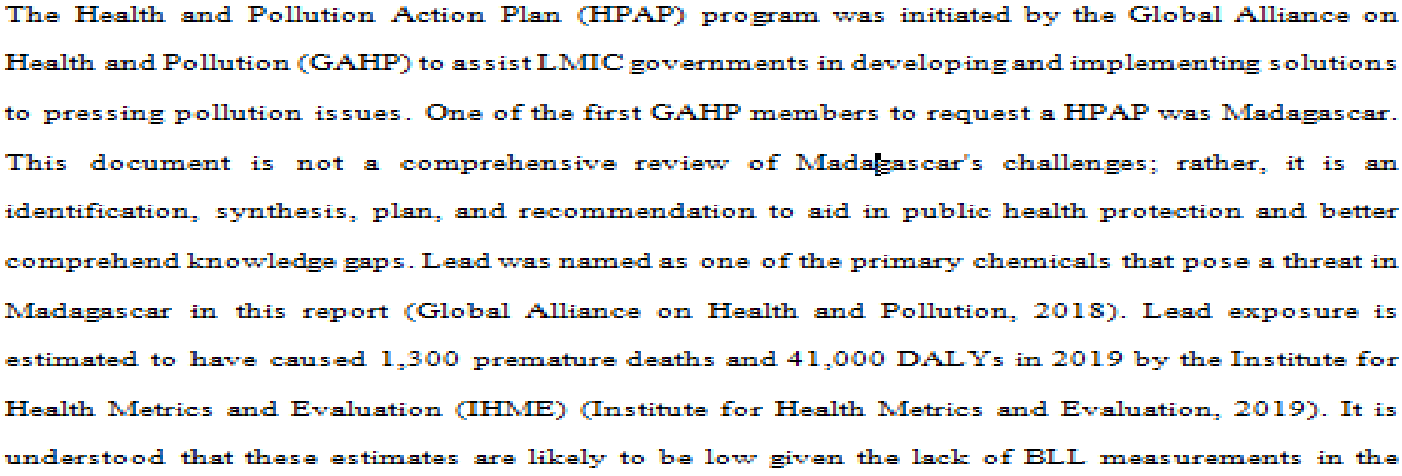


According to the Institute for Health Metrics and Evaluation, 2019 estimates, lead exposure was responsible for 20,000 premature deaths and 350,000 disability-adjusted life years (DALYs) lost in 2019 despite the implementation of numerous policies and extensive educational campaigns in the United States. In the United States, including Washington, D.C., there have also been an increasing number of public health crises related to lead exposure in drinking water (Edwards, 2014; Edwards and other, 2009; Brown and others, 2011), Newark, New Jersey (Faherty, 2021), and Flint, Michigan Hanna-Attisha and others, 2016).

Lead poisoning is a global problem as well as a concern in the United States. A new report reports that roughly 800 million youngsters universally (1 out of 3 kids) are at or over the 5 µg/dL BLL standard (Rees and Fuller, 2020). According to the Institute for Health Metrics and Evaluation, lead exposure will cause approximately 900,000 premature deaths and 21 million DALYs worldwide in 2019. Due to a variety of factors, including vulnerabilities (such as poverty and malnutrition), lead exposure has a disproportionate impact on those in low- and middle-income countries (LMICs) (Kordas et al., 2018; 1995 Mahaffey; (Kordas et al., United Nations, 2019) and the high demand for lead-acid batteries 2018).



country and the limited Pb exposure data that is available for the nation Particulate matter (PM), wastewater discharge from textile factories, mining, battery recycling, and locally manufactured products (e.g., cookware and handpumps) are currently identified as sources of Pb in Madagascar (Global Alliance on Health and Pollution, 2018; Rasoazanany and others, 2007; Weidenhamer and others, 2014). Nevertheless, we are currently unaware of numerous other potential exposure sources. The total uptake of lead into the body is accounted for by five exposure pathways: water, diet, air, soil, and dust (SRC, 2021; The lead's technical review team, 1994). Air, soil, and dust from lead-acid battery manufacturing and recycling, metal mining and processing, and electronic waste are common sources in LMICs, and remediation efforts frequently target these sources (Ericson et al., 2021).



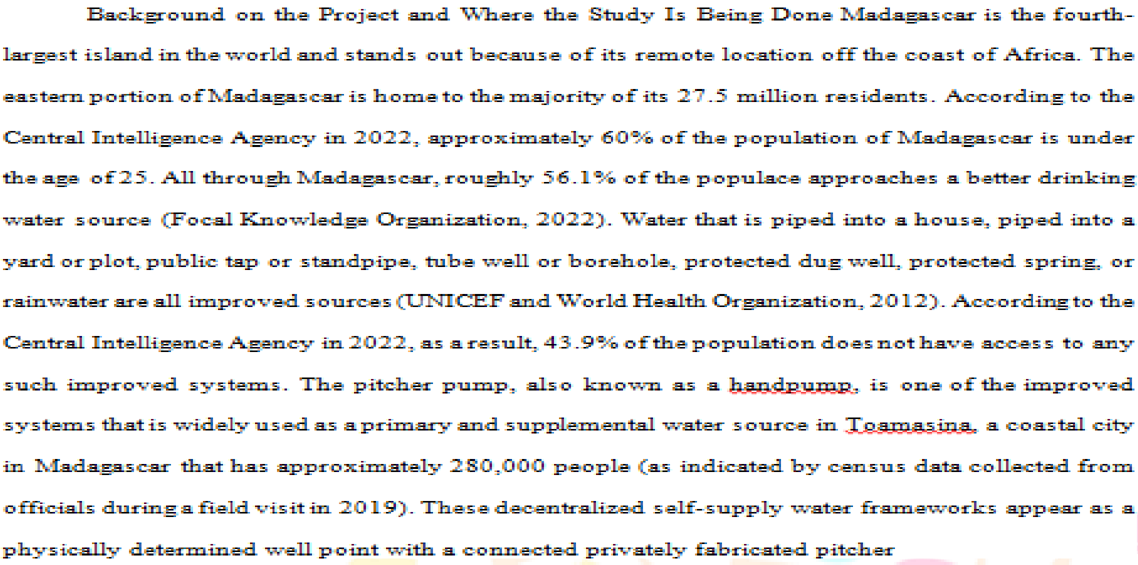
The Health and Pollution Action Plan (HPAP) program was initiated by the Global Alliance on Health and Pollution (GAHP) to assist LMIC governments in developing and implementing solutions to pressing pollution issues. One of the first GAHP members to request a HPAP was Madagascar. This document is not a comprehensive review of Madagascar's challenges; rather, it is an identification, synthesis, plan, and recommendation to aid in public health protection and better comprehend knowledge gaps. Lead was named as one of the primary chemicals that pose a threat in Madagascar in this report (Global Alliance on Health and Pollution, 2018). Lead exposure is estimated to have caused 1,300 premature deaths and 41,000 DALYs in 2019 by the Institute for Health Metrics and Evaluation (IHME) (Institute for Health Metrics and Evaluation, 2019). It is understood that these estimates are likely to be low given the lack of BLL measurements in the

However, LMICs have begun to pay attention to exposure to drinking water and cooking water. According to studies, traditional water systems in sub-Saharan Africa often use lead or lead- containing materials, such as brass, which increase lead concentrations in water (Akers et al., 2020; Fisher et al., 2021). In addition, as the concentration of lead in water increases, the importance of absorption with food also increases, and its share in the total consumption of lead is sometimes up to 50% (Akers et al., 2020). However, there is little research on water and dietary lead exposure in LMICs. For example,

technologies can be used to reduce lead exposure from a specific source (Khalid et al., 2016; Kordas et al., 2018), regulations (Kordas et al., 2018; behavior change (Greene et al., 2019).) UNEP Global Alliance to Eliminate Lead Paint) 2015), as well as combinations of those approaches when the source is found. Corrosion control is one common exposure control method for water lead (Lee et al., 1989), material substitute (also known as LSL) 2008, and point-of-use (POU) water filters (Bosscher et al., 2019). However, all these methods must be combined with education and behavioral interventions, because they are either too expensive, unavailable, or not applicable in LMICs. For example, according to Bosscher et al., POU water filters can effectively reduce lead in drinking water when used correctly. 2019), but estimates show that LMICs do not consistently use POUs (Evans et al., 2011: Fiebelkorn et al., 2012; Sobsey et al., 2008).

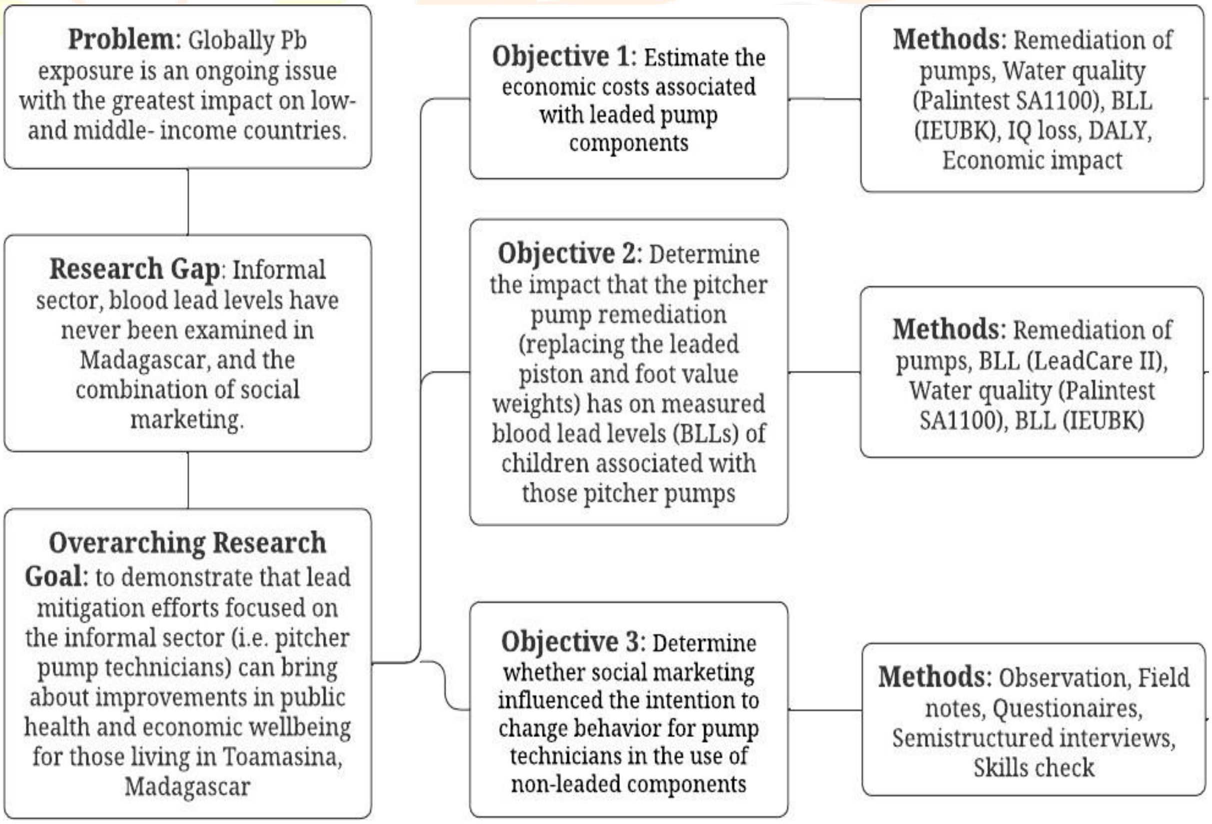
It has been observed that culture, perception, and behavior must be integrated with technological development for sustainable adoption (Mihelcic et al., 2017). Social marketing is one way to increase the adoption of technologies or other mitigation methods such as policy. According to Lee and Kotler (2016), social marketing uses business marketing tools to influence behavior for the benefit of society. Health, environmental protection, and safety and injury prevention are just some of the areas where social marketing has been used (French et al., 2010; 2005, Grier and Bryant; 2016, Lee and Kotler; Wakefield et al., 2010). Of the 32 studies that looked at behaviors or products related to water and sanitation improvement, a large amount of successful behavior change was found (Evans et al.,). However, there are few studies specifically using social marketing in the WASH sector. 2011). Social advertising achieved good results according to the openness of managers. For example, a social marketing campaign in New York had a positive impact on reducing lead exposure by encouraging parents to report peeling paint needed for property maintenance or repair (Greene et al., 2015). To my knowledge, social marketing has not been used to reduce lead exposure in LMICs.

To address water lead exposure from locally manufactured and installed supplemental water systems in Toamasina, Madagascar, this dissertation research uses social marketing as a method to complement technological innovations (e.g., lead-free pump components). This thesis framework can be used to understand and protect public health in other settings, informal sector economies, exposure pathways, and pollutants.



Background on the Project and Where the Study Is Being Done Madagascar is the fourth-largest island in the world and stands out because of its remote location off the coast of Africa. The eastern portion of Madagascar is home to the majority of its 27.5 million residents. According to the Central Intelligence Agency in 2022, approximately 60% of the population of Madagascar is under the age of 25. All through Madagascar, roughly 56.1% of the populace approaches a better drinking water source (Focal Knowledge Organization, 2022). Water that is piped into a house, piped into a yard or plot, public tap or standpipe, tube well or borehole, protected dug well, protected spring, or rainwater are all improved sources (UNICEF and World Health Organization, 2012). According to the Central Intelligence Agency in 2022, as a result, 43.9% of the population does not have access to any such improved systems. The pitcher pump, also known as a handpump, is one of the improved systems that is widely used as a primary and supplemental water source in Toamasina, a coastal city in Madagascar that has approximately 280,000 people (as indicated by census data collected from officials during a field visit in 2019). These decentralized self-supply water frameworks appear as a physically determined well point with a connected privately fabricated pitcher

Table 1.1 Dissertation outline.



Problem: Globally Pb exposure is an ongoing issue with the greatest impact on low- and middle- income countries.

Research Gap: Informal sector, blood lead levels have never been examined in Madagascar, and the combination of social marketing.

Overarching Research Goal: to demonstrate that lead mitigation efforts focused on the informal sector (i.e. pitcher pump technicians) can bring about improvements in public health and economic wellbeing for those living in Toamasina, Madagascar

Objective 1: Estimate the economic costs associated with leaded pump components

Methods: Remediation of pumps, Water quality (Palintest SA1100), BLL (IEUBK), IQ loss, DALY, Economic impact

Objective 2: Determine the impact that the pitcher pump remediation (replacing the leaded piston and foot value weights) has on measured blood lead levels (BLLs) of children associated with those pitcher pumps

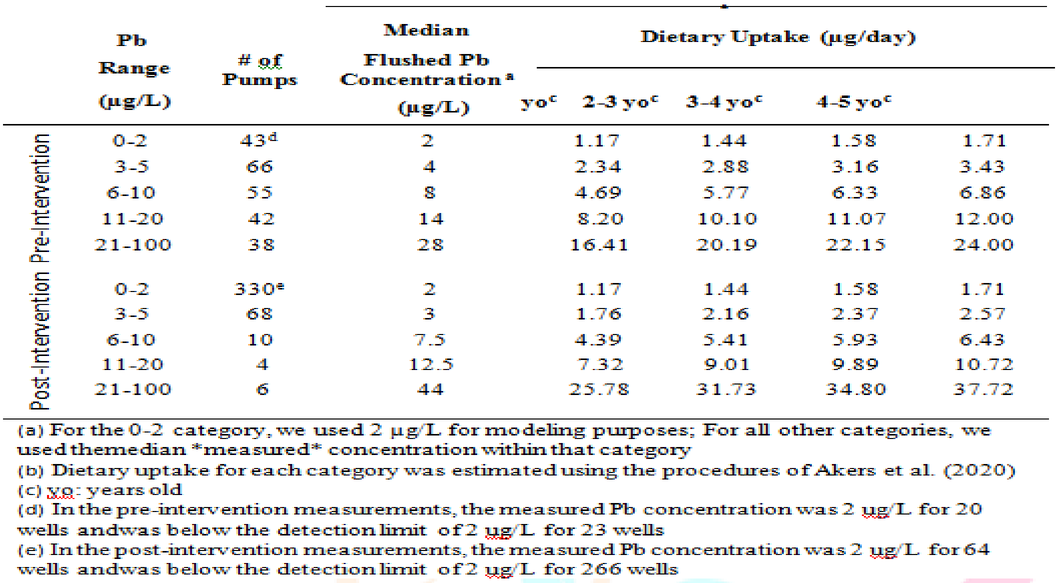
Methods: Remediation of pumps, BLL (LeadCare II), Water quality (Palintest SA1100), BLL (IEUBK)

Objective 3: Determine whether social marketing influenced the intention to change behavior for pump technicians in the use of non-leaded components

Methods: Observation, Field notes, Questionaires, Semistructured interviews, Skills check

According to Landrigan et al., people living in low and middle-income countries (LMICs) are disproportionately affected by pollution on their health and well-being. 2018). Lead (Pb), currently responsible for 1.06 million premature deaths and 2 million disability-adjusted life years (DALYs) annually worldwide, is one of the chemical pollutants that pose multiple health risks (World Health Organization, 2019a). Idiopathic mental retardation (IQ loss), hypertension, coronary heart disease, and stroke are all associated with lead exposure (Rees and Fuller, 2020). According to the World Health Organization (WHO), lead exposure is associated with damage to the developing fetus and neurobehavioral impairment in children at blood lead levels (BLL) as low as 5 g/dL (World Health Organization, 2010a). Unfortunately, according to a recent study (Ericson et al.), approximately 800 million children worldwide (or one in three children) meet or exceed the 5 g/dL BLL standard. 2021; 2020)

(Rees and Fuller). In addition, lead absorption is increased in malnourished children (Mahaffey, 1995). According to a 2019 UN estimate, there are approximately 19 million such children under the age of 5 worldwide, with less than 75% occurring in LMIC countries.



	Pb Range (µg/L)	# of Pumps	Median Flushed Pb Concentration [a] (µg/L)	Dietary Uptake (µg/day)			
				yo[c]	2-3 yo[c]	3-4 yo[c]	4-5 yo[c]
Pre-Intervention	0-2	43[d]	2	1.17	1.44	1.58	1.71
	3-5	66	4	2.34	2.88	3.16	3.43
	6-10	55	8	4.69	5.77	6.33	6.86
	11-20	42	14	8.20	10.10	11.07	12.00
	21-100	38	28	16.41	20.19	22.15	24.00
Post-Intervention	0-2	330[e]	2	1.17	1.44	1.58	1.71
	3-5	68	3	1.76	2.16	2.37	2.57
	6-10	10	7.5	4.39	5.41	5.93	6.43
	11-20	4	12.5	7.32	9.01	9.89	10.72
	21-100	6	44	25.78	31.73	34.80	37.72

(a) For the 0-2 category, we used 2 µg/L for modeling purposes; For all other categories, we used themedian *measured* concentration within that category
(b) Dietary uptake for each category was estimated using the procedures of Akers et al. (2020)
(c) yo: years old
(d) In the pre-intervention measurements, the measured Pb concentration was 2 µg/L for 20 wells andwas below the detection limit of 2 µg/L for 23 wells
(e) In the post-intervention measurements, the measured Pb concentration was 2 µg/L for 64 wells andwas below the detection limit of 2 µg/L for 266 wells

Estimation of IQ Loss and DALYs

It is known that exposure to lead can cause intellectual disabilities, including reduced IQ (Bellinger, 2008; Needleman, 200; J. Schwartz, 199). In addition, childhood lead exposure can affect adult cognitive function and socioeconomic status (Reuben et al., 2017). Therefore, we estimated the reduction in IQ and the resulting disability life years (DALYs) to quantify the health effects of lead exposure among children in Toamasina. Most studies agree that a 10 g/dL increase in BLL results in a loss of approximately 1-IQ points, even though different research groups have proposed different quantitative associations between BLL and IQ decline (Bellinger, 2008; 199, J. Schwartz) based on the findings of Lanphear et al., the following equation was used in this case: 2005 and can be applied to children with BLL levels above 2.g/dL (Lanphear et al., 2005). This combined analysis of seven studies from 2005: one from Mexico, one from Yugoslavia, and one from the United States, Lanphear et al. The results of the 2005 study by Lanphear et al. are often cited and used in several LMIC studies (Attina and Trasande, 2013; Dowling, Ericson, et al., 2018).

IQ loss = 6.2903 log10 (BLL) - 2.3886 (Equation 1) Estimated distributions of BLLs were used to estimate distributions of IQ points lost. This equation has been exploited. To represent the estimated change in the Malagasy child population, the modeled IQ distribution was subtracted from the original IQ distribution with a mean of 100 and a standard deviation of 15. This results in a comparison of three IQ distributions: the "benchmark" level. of intelligence distribution for the population not presented as leaders, the Toamasina intelligence distribution for boys who use water from non-renewable (pre-prayer) siphons, and the intelligence level of room machine youth using reclaimed water. (After transfer) siphons. The DALYs of the Toamasina children can then be estimated using the IQ loss due to lead exposure. DALYs are calculated using years of life lost (YLL) and years lost to disability (YLD). DALYs were assumed to correspond to YLDs because it was assumed that mild intellectual disability should not cause death. YLD is the estimated number of overall cases multiplied by the weight of the injury. As shown in Table 2, lead-related mental impairment has five possible impairment weights, each varying according to the severity of the impairment. The five categories of mental disability are borderline, mild, moderate, severe, and profound.

The number of normal cases is multiplied by the (adjusted) weight of disability in each of the five categories in the total DALY calculation, which is then added to obtain the sum. Estimated DALYs per 1000 children were derived from this.

Table 2.2 Disability weights (DW) for severity levels of intellectual disability

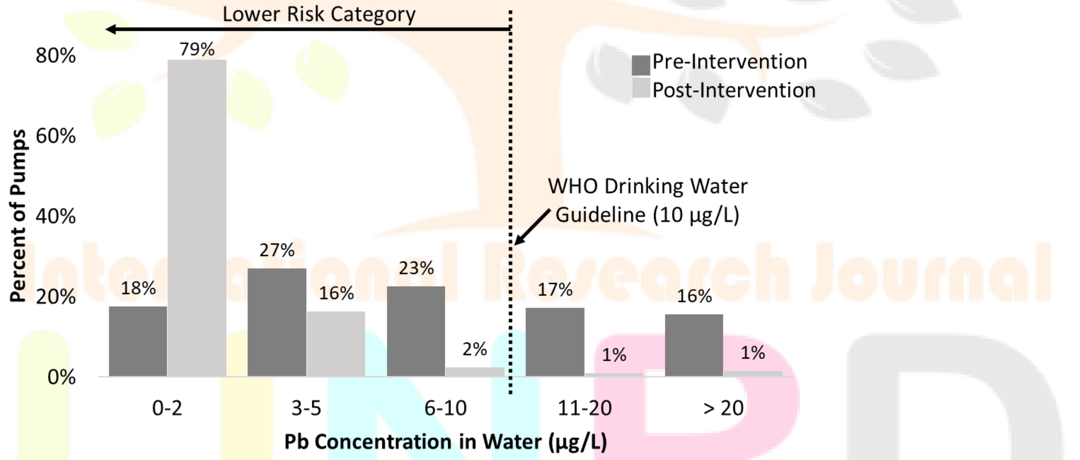
IQ range	Severity of Intellectual Disability	Disability Weight GBD 2016^{a*}	 GHE 2016^{b*}
70-85	Borderline	0.011	0.011
50-69	Mild	0.043	0.127
35-49	Moderate	0.100	0.293
20-34	Severe	0.160	0.383
<20	Profound	0.200	0.444

(a) GBD 2016: Global Burden of Disease 2016 assessment
(b) GHE 2016: Global Health Estimates
*WHO (2018)[52]

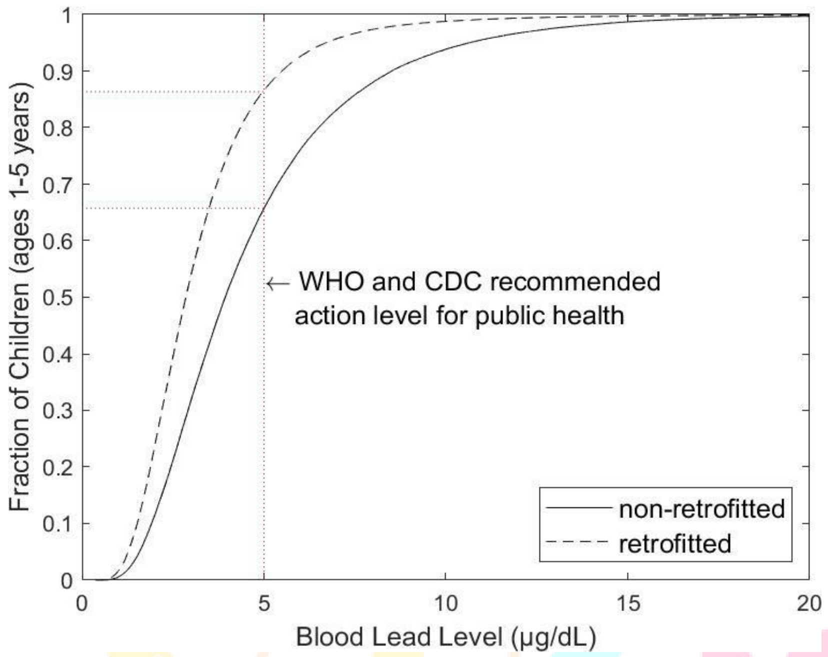
Estimation of Economic Impact

According to Attina & Trasande (2013), intellectual impairment caused by environmental neurotoxins and neurotoxicants results in lost economic productivity, and the economic cost of this productivity loss increases with intellectual impairment severity. Bierkens and others, 2012; Dórea, 2019; 2010 by the United Nations Environment Programmed These costs, which do not consider other societal costs like rising rates of crime or the requirement for special education services, are sometimes referred to as "lost opportunity costs." The approach described by Attina & Trasande (2013) was used to calculate the attributable cost resulting from lead exposure from pump water. (eq.2) The estimations and definitions that follow apply to this equation.

N is the number of children between the ages of one and five who were rehabilitated with the 504 pumps during the intervention. N = 730, as each child benefits in some way from the reduced lead exposure. The environmentally attributable fraction of lead for the first child is shown by EAFi. Based on the assumption that natural processes account for little lead exposure, the EAFi was assumed to be 1.0 for all children in this study (Attina & Trasande, 2013).

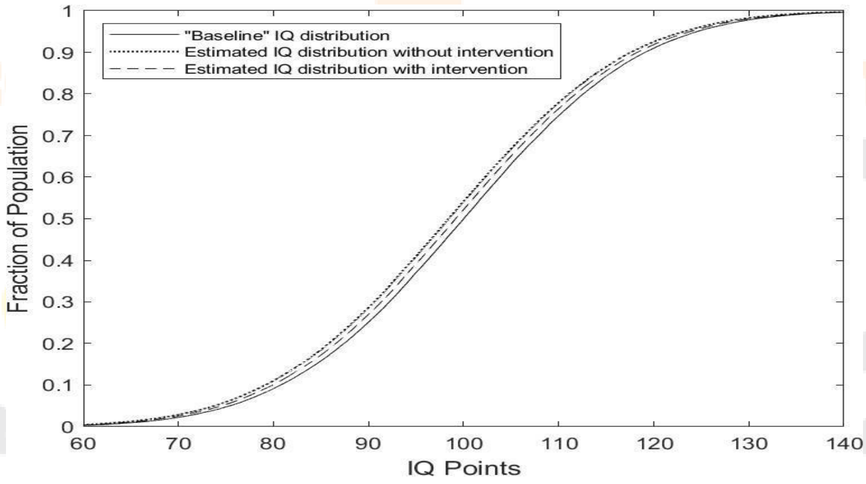


However, because lead has a half-life of one to two months in blood, it is not anticipated that the BLLs will decrease immediately upon the removal of the leaded components from the pump (CDC, 2017).



Estimation of IQ Loss and DALYs

Estimated BLL distributions were used to estimate distributions of IQ in children in Toamasina. Figure 3 shows three estimated IQ distributions. One is a "baseline" IQ distribution with a mean of 100 and a standard deviation of 15, which corresponds to a population of children with no significant lead exposure. The other two IQ distributions shown in this figure correspond to children using non-retrofitted wells (pre-intervention) and children using retrofitted wells (post-intervention); that is, the IQ distributions in Figure 2.3 correspond to the BLL distributions in Figure 2.2. Figure 2.3 shows that, if leaded components are not removed from the pumps, exposure to lead in household water is estimated to decrease the IQ distribution of children in Toamasina by about 2 points on average. That decrement is lowered to about one IQ point as a result of the intervention Based on the ranges of DALYs given above, we estimate that the intervention we performed may save 0.4-1.0 DALYs for the 730 children using the 504 retrofitted pumps. If this number is extrapolated to consider all 9000 pumps that are estimated to be present in Toamasina (MacCarthy et al., 2013), it suggests that removing lead from household pumps may save 8.0-20.0 DALYs for children in Toamasina, based solely on the prevention of IQ loss.



Materials and Methods

Sample Selection and Distribution in This observational pre/post remediation (i.e., replacement of lead pump components with non-leaded pump components) study evaluated aqueous lead concentrations of pumps and BLL measurements of children under six years of age in Toamasina, Madagascar. This assessment is part of a larger project that remediated 500 pumps and assessed the BLLs at baseline for over 300 children in Toamasina before remediation efforts (Champion et al., 2022). Recruitment for the larger project employed a cluster sampling approach and used nine local health clinics across five arrondissements (or city districts) in Toamasina. Families seeking care at the clinic were recruited based on willingness to participate and have a child between six months to six years old. All study protocols were approved by the Biomedical Research Ethics Committee of the Ministry of Public Health of Madagascar and the USF Institutional Review Board (STUDY000143).

Data Collection Methods

Blood Led Level (BLL) Measurements Following parental consent, a 50 µL blood sample was collected from the child's finger by trained medical personnel and analyzed using a Magellan Lead Care II device (North Billerica, MA). The Lead Care II testing instrument is a portable device for testing the amount of lead in whole blood using anodic stripping voltammetry. Our test kits were not affected by the 2021 FDA recall (U.S. Food and Drug Administration, 2021). To limit contamination, the child washed their hands with soap and water and their finger was cleaned with alcohol before sampling. The Lead Care II system displayed measured BLL readings as either a value between3.3 - 65 µg/dL, "Low" if below the lower detection limit of µg/dL, or "High" if above the upper limit of 65 µg/dL. Values below the detection limit were replaced with 2.33 µg/dL in our analysis, calculated as the lower detection limit divided by $\sqrt{2}$, consistent with previous studies (Desai et al., 2021). No values above 65 µg/dL were seen in the study sample.

Aqueous Lead Concentrations in Pumped Water

Following the methodology outlined by Akers et al. (2015), samples were collected both before and following the remediation of the pump. The remediation process consisted of removing and replacing the lead-containing piston and foot valves with non-leaded components. The sampling procedure consisted of wasting 15 L from the pitcher pump system (~1-5 well volumes) and then collecting another 15 L sample for analysis. A 10 mL glass pipette was rinsed using the sample water and a 5 mL aliquot sample was collected to represent a flushed composite sample. Samples were analyzed using a Palin test Scanning Model 1100 Analyzer (SA1100) that measures dissolved lead by the process of anodic stripping voltammetry with a lower limit of detection of 2 µg/L of lead. Readings under the detection limit were put in as 1.41 µg/L for analysis (calculated as the lower detection limit divided by the square root of two (Desai et al., 2021)). Only dissolved lead was measured as part of this study.

Blood Led Level (BLL) Estimations

Blood led levels for children aged one to five years were modeled using Windows version 2, Build 1.66, of the Integrated Exposure Uptake Biokinetic (IEUBK) Model, developed by the U.S. Environmental Protection Agency (United States Environmental Protection Agency, 2021). The model requires inputs for exposure routes related to water, diet, air, soil, and dust and outputs an estimated geometric mean BLL for the specific age range of the child with the given exposure. The IEUBK model is commonly used to estimate lead exposure effects throughout the world (Adeyi & Babalola, 2017; Rees & Fuller, 2020).

Default values were used for air (0.1 µg/m3), soil (200 µg/g), and dust (150 µg/g) exposure as there were no known local lead measurements at the time of the study. Measured aqueous Pb concentrations were used for the water inputs. Dietary uptake values were adjusted using the methodology of Akers et al. (2020) to acknowledge the absorption of lead through commonly eaten starches (e.g., rice) representative of a Malagasy diet (Akers et al., 2020; Buerck et al., 2021). Table 3.1 presents the model inputs used for water and diet. The outputs from IEUBK for each group were then weighted according to the percent of pumps with the given aqueous measurement and used to produce a distribution of predicted BLL values for a population of 1,000,000 children.

Statistical Analysis

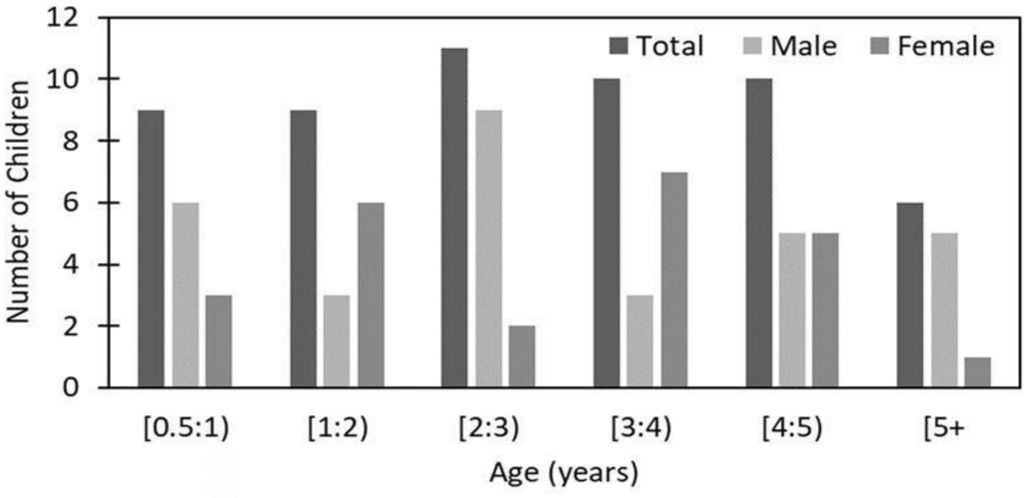
Paired-sample t-tests were conducted to determine if there were significant differences in measured aqueous lead levels and BLLs pre- to post-remediation. Further analysis of paired samples included examining correlations between the aqueous Pb and BLLs via Pearson correlations and regression analysis. Pre-remediation-measured BLLs were also analyzed concerning the modeled Pre-remediation BLLs.

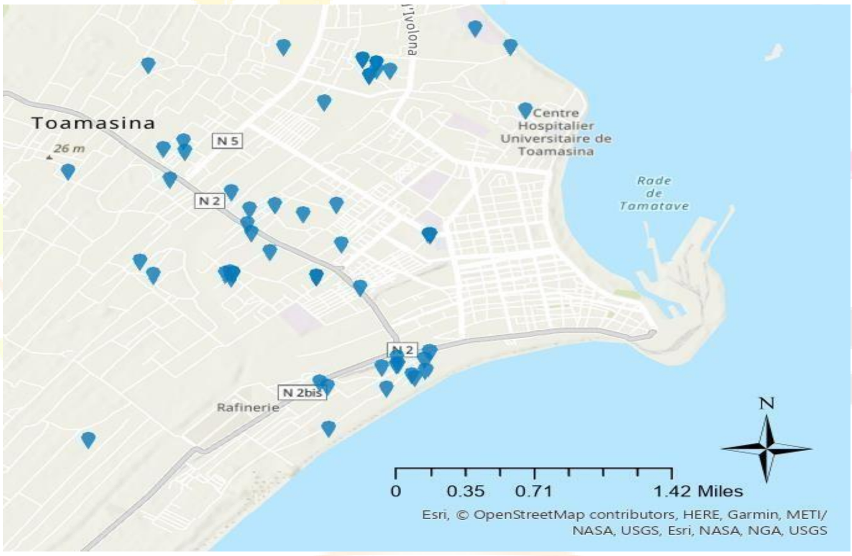
Results and Discussion

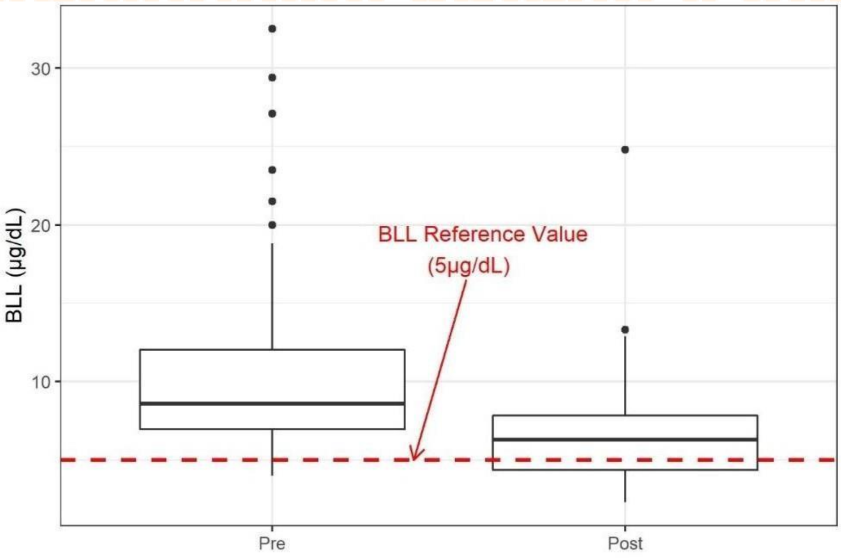
Blood Led Level (BLL) Measurements

For this study, a sample size of 34 paired samples was required, based on a medium effect size of 0.05, 80% power, and 95% confidence interval (Dhand & Khatkar, 2014). In total, this study collected and analyzed paired data (i.e., data collected pre- and post-remediation of the two pump check valves) for 55 children 6 months to 6 years (31 males and 24 females). Further breakdown of the sample population by age, gender, and distribution of the location within Toamasina can be seen in Figures 3.1 and 3.2. BLL readings were taken before the pump remediation, and at least 1 month (37-67 days) post-pump remediation to allow for approximately one half-life of lead in the blood to occur (half-life of blood lead is 1-2 months) (Centers for Disease Control and Prevention, 2017). 96% of the children (n = 53) had BLLs greater than 5 g/dL (the BLL reference value) before the intervention. A paired-sample t-test on the BLL values revealed a significant decrease (t (54) = 6.15, p 0.001), and only 65% of the children (n = 36) had measured BLL over 5 g/dL following the remediation. Pre-remediation levels (mean = 10.85, SD = 6.30) and post-remediation levels (mean = 6.68, SD = 3.70) of measured BLL concentrations (95 percent CI [2.81,5.52]) Figure 3.3 depict a graphical representation of BLLs before and after remediation.

48 children (87 percent) saw a decrease in BLL, ranging from 0.2 to 24.8 g/dL (mean = 4.91 g/dL), while six children saw an average increase of 0.9 g/dL. BLLs will likely decrease further in the future, as the half-life of BLL is estimated to be one to two months and there is an average of 45 days between remediation and the post-BLL test (Centers for Disease Control and Prevention, 2017).







Aqueous Lead Concentrations in Pumped Water 48 pumps were examined before and after the two pump check valves were remedied, and the results were in line with those of the 55 children with paired BLL data. One pump had three children and five pumps had two children, necessitating the examination of seven fewer pumps. Aqueous lead concentrations that were higher than the WHO provisional guideline of 10 g/L were found in 27% (n= 13) of the pumps sampled in this study using the flushed sampling protocol

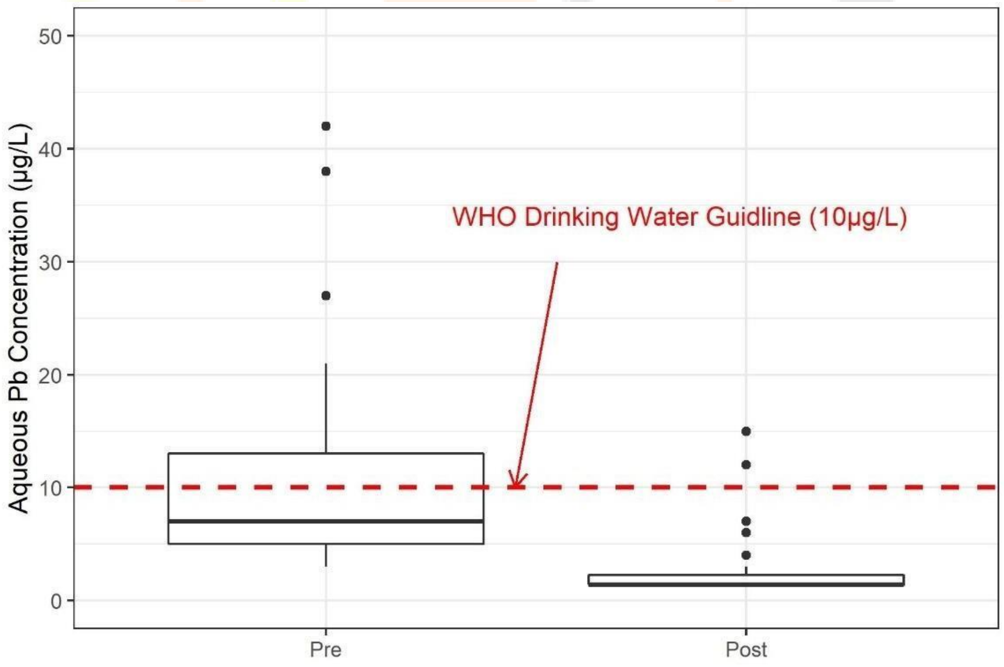
(World Health Organization, 2011). This was higher than the findings of Fisher et al.'s study of aqueous lead in Sub- Saharan Africa (2021), in which 24 out of 261 samples (or 9.2%) exceeded the WHO's provisional guideline. Fisher and others 2021) sampled with a stagnation time of one hour, in contrast to our flushed sampling protocol. As it has been discovered that aqueous lead concentrations follow a logarithmic growth pattern about stagnation time (Lytle et al.,), this difference in protocol speaks even more to the levels of aqueous lead that were measured. 2021).

Like the 2018 campaign, in which 3% of pumps exceeded the provisional guideline following remediation, a small number of pumps continued to exceed it (2/48). However, there was a discernible decrease in the two pumps that measured more than 10 g/L, with one pump experiencing a reduction in the aqueous lead concentration of more than 50%. Figure 3.4 depicts the pump water's aqueous lead concentration before and after lead removal.

12 pumps with an aqueous lead concentration that was either too low or too high to be detected before the remediation was taken out. The detection level remained at or below for all removed pumps. A paired sample t-test was used to determine whether the remediation resulted in a statistically significant difference in the concentration of aqueous lead. Of the remaining 36 pumps, all of them showed a decrease ranging from 1 to 97 g/L. The aqueous lead concentrations at pre-remediation levels (mean = 17.31, SD = 23.97) and post-remediation levels (mean = 2.47, SD = 2.98) differed significantly (t (35) = 3.78, p 0.001); 95% CI [6.75,22.42]).

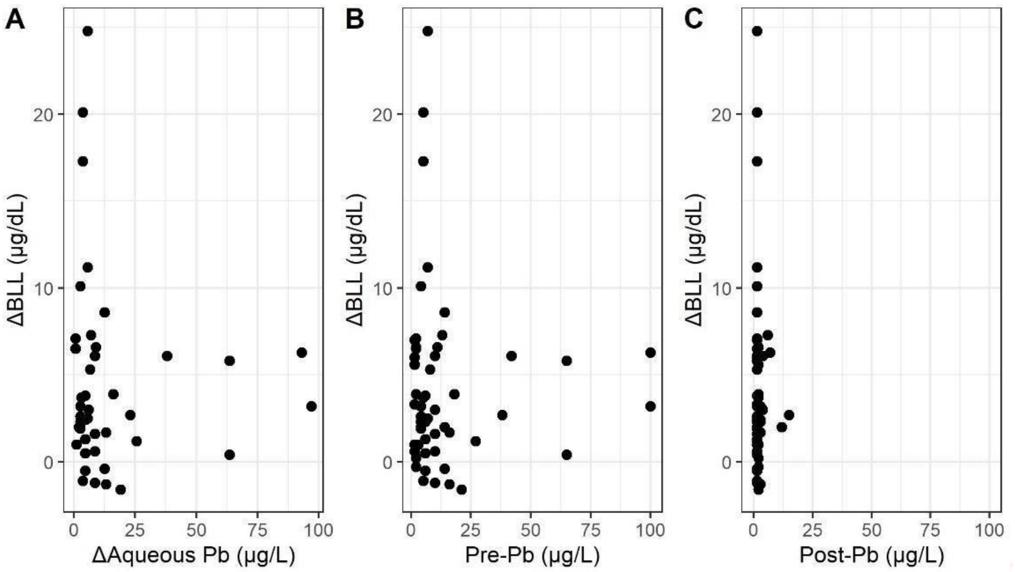
We hypothesize that the lead-tainted valves made the most significant contribution to the lead concentrations in the pitcher pumps. However, after remediation, the most likely cause of elevated lead levels in some pumps is the presence of other lead-containing water system components. Lead solder, for instance, is still used in Madagascar, despite being phased out in numerous other parts of the world (Sandvig et al., 2008). In most groundwater supply systems, the good screen is attached with led solder. Leaded solder has been found to frequently leach into drinking water and, in some instances, significantly increase aqueous lead concentrations (Brown et al., 2011; Lee and others, 1989). However, it has also been discovered that solder lead release decreases over time; therefore, the pump's age and condition may indicate the potential impact of aqueous lead from pump solder (Sandvig et al., 2008). Galvanized steel, brass, and bronze, among other materials used in pump and well screen manufacturing, have the potential to raise aqueous lead concentrations (Clark et al., 2015; Lee and others, 1989; Li and others, 2020; McFadden and others, 2011; Pieper and others, 2019).

Studies have found metal parts are especially liable to add to watery lead levels in both HICs and LMICs (Fisher et al., 2021; 2007 Kimbrough). According to Fisher et al.'s research on West African water systems, systems with brass components were predicted to have 3.8 times more aqueous lead than systems without brass components. 2021).



Statistical Analysis of the Relationship Between Aqueous Lead and BLLs

Nine variables' Pearson correlations were investigated: age, height, weight, pre-aqueous Pb, post-aqueous Pb, BLL, and aqueous Pb before and after BLL. Table 3.2 displays the outcomes. Five variables are found to be statistically significant up to the 0.001 level and to have a high correlation (r 0.6). Age, height, and weight had the strongest correlation. As would be expected for a typical population, these three variables all had strong positive correlations. Both the change in BLL and the pre-BLL level were found to be correlated (r = 0.81, p 0.001) with post-BLL. According to these correlations, participants with a higher starting BLL tended to have a higher BLL change and a higher BLL post-BLL. These correlations do follow expected trends in BLL reduction because a participant's starting BLL is more likely to decrease if it was high. For further comparison, the relationship between change in BLL and aqueous lead concentrations in pumps used for cooking and drinking was graphically examined. Additionally, a review of Figure 3.5 reveals that there is no correlation between changes in BLL and aqueous lead concentrations alone, indicating that additional variables must be controlled for in this analysis. The author knows that the only way the concentration of aqueous lead changed directly during the study; As a result, demographic variables were controlled for using regression analysis.

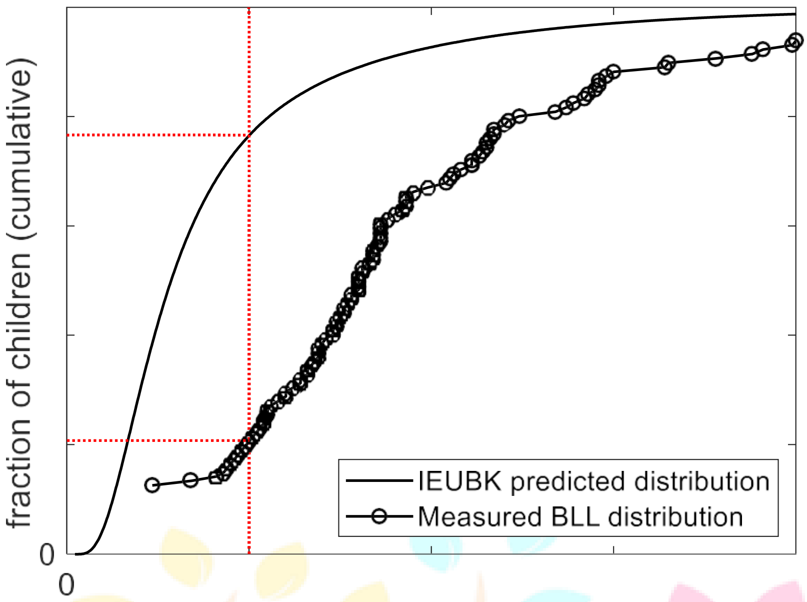


Plot of change BLL concentrations (μg/dL) of children aged six months to six years to decrease in aqueous Pb (n = 45), pre-Pb (n = 55), and post-Pb (n = 55). No statistically significant correlations were found.

Pre-aqueous Pb concentrations were the only independent variable in the first model of the sequential regression approach used here (Table 3.3, Model 1). Pre-aqueous Pb levels were chosen as the first variable because they would be simple to measure across a community and help prioritize remediation efforts. When pre-aqueous Pb levels were the only independent variable, there was no statistical significance, just like there was no correlation in Figure 3.5B. It is important to note, however, that the coefficient's direction is not logical: There is the less (-) change in BLLs as the pre-Pb concentration rises. The inclusion of age, weight, or height was the next logical factor because Pb contamination affects younger people. To control for participant variability, the participants' weights were entered into Model 2; However, once more, there was no statistically significant prediction of BLL changes by either variable. Finally, in Model 3, pre-BLL was entered and accounted for a significant amount of change in BLL [R2=.689, F (3,41) =30.29, p.001], but did not result in statistical significance for pre-remediation Pb levels (Table 3.2). Again, the direction of the relationships is not logical in Model 2. However, in Model 3, the relationships went in a logical direction: a positive relationship with BLLs before remediation, a negative relationship with weight (as weight decreases, changes in BLL increase), and a positive relationship with Pb before remediation. Pre-remediation BLLs can help create a Pb mitigation strategy, but it is more difficult because it would require testing actual BLLs rather than just measuring Pb concentrations at the pump.

There could be several reasons for the inability to predict and correlate: the intricate nature of the blood-lead relationship (such as pre-existing health conditions, intake of calcium and iron, etc.), the limit of approximately one half-life before the post-test, measurements of aqueous lead that do not consider particulate lead, or a small sample size It is necessary to carry out additional analysis to investigate any additional variables that may affect the change in BLL. The time between the pre-BLL test and the BLL test, the occupation of parents, and location are all examples of variables to use.

IEUBK was used to model children aged one to five with a measured BLL and an aqueous Pb concentration before remediation. 123 children between the ages of one and five were looked at. Figure 3.6 depicts the measured and estimated BLL distribution. According to the model, 76% of children would have BLLs below the reference value of 5 g/dL. On the other hand, the fact that only 23% of the measured BLLs were below the reference value suggests that the modeled values significantly underpredict the measured BLLs.



Multiple factors could be to blame for the model's underestimation, including underestimating or omitting crucial lead exposure routes. This alternative community exposure route is highly likely because there is no statistically significant correlation between changes in BLL and Pb concentration before remediation. Since no local lead measurements are known for this region, default values were used in the model for soil, dust, and air. Based on peer-reviewed literature, these default values represent national averages for the United States (SRC, 2021). As regulations and phase-outs of leaded products (such as leaded gasoline) are implemented, the use of these default values may underestimate exposure from soil, dust, and air (Mielke et al., 2019; Rees & Fuller, 2020)) in Madagascar began later, and are less stringent than those in the United States (Champion et al. for more information). 2022)). However, there are no local lead readings in the soil, dust, or air in Toamasina, and many measurements in LMICs were taken at known contaminated sites (such as mining, battery recycling, etc.), The effect of the exposure cannot be independently verified.

Due to exposure through products (such as cookware), parents' occupations (such as mechanic/technician), and diet (such as beans and rice), there is also a risk in Madagascar due to a lack of regulations and understanding of the harmful effects of lead on health (Champion et al., 2022). Persistent lack of healthy sustenance and weakness are additionally common in Madagascar, especially among small kids (Focal Knowledge Organization, 2020; USAID, 2014, 2021). These ailments lessen the calcium and iron in the body, the two contenders to lead take-up, considering expanded lead take-up (Mushak, 1991; The lead's technical review team, 1994). To accurately depict the BLLs of children in Madagascar and other LMICs, it may be necessary to adjust the model's bioavailability and uptake potential values considering the increased prevalence of chronic malnutrition in Madagascar. However, weight is not the only controlling factor that needs to be taken into consideration given the poor output of regression model 2. Stanek and others Similar to this study, 2020) demonstrated that water can be an important lead transport channel. It should be noted that particulate lead was not considered in our study. According to Triantafyllidou (2011), considering particulate lead would likely result in higher aqueous lead levels being measured. This would raise the importance of water and diet pathways. Wilson, 2016 Estimates of the global effects of lead exposure have been made using the IEUBK model (Adeyi & Babalola, 2017; Chantian and others, 2020; Debebe and others, 2020; Zhang et al., 2017). Policy development and implementation have benefited from the results (Delgado-Caballero et al., 2018; 2021; Utembe and Gulumian Wang and others, 2018). When resources to measure children's BLLs are limited or unavailable, the IEUBK model is a useful resource. The current IEUBK model, on the other hand, should not be used to estimate BLLs in LMICs because it may not accurately reflect the unique exposures found in these areas.

Conclusion

By measuring the concentrations of lead in water and blood, this study demonstrates the significance of aqueous lead exposure in LMICs. After the pump remediation, measurements revealed that only 4% of pumps had aqueous lead concentrations above the WHO guideline of 10 g/L—like those recorded on a much larger pump sample size in previous studies (Chapter 2). After the leaded components were removed, measured BLLs showed a statistically significant decrease (t (54) = 6.15, p 0.001) However, there were no correlations between BLL and aqueous lead concentrations that were statistically significant. The IEUBK model underpredicts BLLs, according to an examination of modeled and measured BLLs. Model updates are required to consider the factors that are found in LMICs, as shown by the disparities between measured and modeled BLLs. Lead exposure can be significantly reduced through small-scale remediation, particularly through water in LMICs. Additionally, similar remediation efforts to this one has demonstrated a return on investment of approximately $4000 per dollar invested (Buerck et al., 2021). Aqueous lead exposure has the potential to generate positive health benefits through small-scale and economically feasible remediation efforts, despite not being a common lead source addressed in LMICs.

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