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Unsubsidised Self-Supply in Eastern Madagascar

Michael F. MacCarthy

Dept. of Civil & Environmental Engineering, University of South Florida, Tampa, Florida, USA; mmaccarthy@mail.usf.edu

Jonathan E. Annis

WASHplus, CARE International, Washington, DC, USA; jonathanannis@care.org

James R. Mihelcic

Dept. of Civil & Environmental Engineering, University of South Florida, Tampa, Florida, USA; jm41@usf.edu

ABSTRACT: Self-supply is widely reported across various contexts, filling gaps left by other forms of water supply provision. This study assesses mature and unsubsidised Self-supply markets in an urban context in Madagascar. Locally manufactured drilling and pumping technologies are widely provided by the local private sector, enabling households to access shallow groundwater. The market for Pitcher Pump systems (suction pumps fitted onto hand-driven boreholes) has developed over several decades, reaching a level of maturity and scale. In the eastern port city of Tamatave, 9000 of these systems are estimated to be in use and Self-supply constitutes a primary domestic water source for the majority of the city's 280,000 inhabitants. The market is supplied by more than 50 small businesses that manufacture and install the systems at lower cost (US$35-100) than a connection to the piped water supply system. Mixed methods are used to assess the performance of the Pitcher Pump system and the characteristics of the market. Discussion includes a description of the manufacturing process and sales network that supply Pitcher Pump systems, environmental health concerns related to water quality, pump performance, and system management. In a context where urban piped water supplies are unlikely to be accessible to all anytime soon, recommendations are made for further research and potential technology developments to improve the performance of Self-supply.

KEYWORDS: Low-cost technologies, sub-Saharan Africa, handpump, manual drilling, groundwater, lead (Pb), water supply, private sector

INTRODUCTION

Self-supply – to develop private family or neighbourhood (i.e. small group) water supply systems through own investment – typically relies on low-cost technologies to either extract shallow groundwater or collect rainwater. Some types of household water supply technologies include: 1) family wells (which can be either hand-dug or drilled), 2) water-lifting devices (which can range from being as simple as a bucket attached to a rope, to manually operated, electric or fuel-powered pumps), and 3) rainwater collection set-ups. Self-supply may also include household water treatment, which is commonly done through boiling, filtration or disinfection.

Self-supply is driven by households' interest to access an affordable and convenient water supply, independent of public investment in hardware. It is an alternative, and oftentimes more convenient option to using an improved communal water-point (a protected well, tap stand, or household connection from a piped water supply system), or an alternative to dependence on unprotected sources such as surface water. The willingness of households to bear the full costs of water supply comes with a strong sense of ownership in the developed infrastructure. This, and other attributes of Self-supply systems (e.g. non-donor-driven, building on local knowledge and practices, etc), have been reported to lead to such supplies being more sustainable than other options (Sutton, 2004).

Poor water quality and its associated health risks are commonly the main concerns about Self-supply (Sutton, 2009). This issue is much more complex than simply comparing the water quality of household and communal sources at the point of collection. Households may use water from multiple sources for different purposes, contaminate water between source and point of consumption, and treat water at household level by filtering or boiling. Furthermore, if Self-supply often delivers water supplies that are more accessible, convenient and reliable than alternative options (e.g. communal water supplies), the potential negative health effects of sub-standard water quality may be offset by potential positive health effects related to increased water usage. Previous studies have shown a link between increased domestic water usage and improved health, and that improvements resulting in the use of increased quantities of water have a larger impact on the burden of disease than improvements to water quality at the source (Esrey et al., 1985; Howard and Bartram, 2003).

While much of the literature on Self-supply has been focused on rural areas, Self-supply is also a common phenomenon in many peri-urban and urban communities. It is found where populations are either unserved, intermittently served, or where households cannot afford, or do not see value in, the communal water supply service. For example, a recent study in southwest Nigeria showed hand-dug wells to be very common in areas of a city unserved by community water supply systems (Oluwasanya et al., 2011). Using statistics from Demographic and Health Surveys, Gronwall et al. (2010) estimated that 269 million people in urban areas of 43 surveyed countries in sub-Saharan Africa, South and Southeast Asia, and Latin America (including the Caribbean) rely directly on Self-supply wells as their principal drinking water source.

In eastern Madagascar, there is a well-developed market for the locally manufactured Pitcher Pump. This paper presents the findings of a study investigating this form of water supply and market, believed to be the first in-depth assessment of this type of system in Madagascar. It focuses on the port city of Tamatave (also commonly called Toamasina) and the nearby town of Foulpointe to assess the performance of Pitcher Pump systems (including delivered water quality), user acceptability of the technology, and sustainability of the market. The objectives of the research were specifically to: 1) assess user experience and associated water quality of locally manufactured household groundwater supply systems prevalent in eastern Madagascar and 2) assess local manufacturing practices and sales of these systems.

BACKGROUND

Water supply in Madagascar

According to the most recent Joint Monitoring Program (JMP) update, coverage of improved drinking water sources in Madagascar in 2011 was estimated to be 78% in urban areas and 34% in rural areas (JMP, 2013). JIRAMA, the national parastatal water and electric company, manages piped schemes that supply water to 65 urban municipalities. However, JIRAMA is plagued by operational inefficiencies and lacks the capacity to upgrade aging infrastructure. JIRAMA's poor performance is partly attributed to high operating costs, uneconomically low water rates, and affordability issues among target customers (USAID, 2010).

In rural areas, coverage numbers remain stubbornly low and considerable challenges persist in maintaining existing coverage and extending water supply services to the remaining majority of rural dwellers. Rural water supply systems have been commonly implemented using community water-management models, with questionable long-term sustainability rates. For example, a 2006 study reported that over 90% of donor-funded water projects in the Ikongo District in south-eastern

Madagascar failed to develop or implement adequate financial management schemes to collect money from community members for routine maintenance and purchase of spare parts (Annis, 2006).

There is scope for alternatives in both urban and rural water supply. Piped water supply systems managed by public-private partnerships in rural communities have shown recent potential to be a more sustainable water delivery model (Annis and Razafinjato, 2012). Household investment in Self-supply continues to fill other gaps in service provision in both urban and rural areas.

Self-supply in Madagascar

Traditional Self-supply practices in Madagascar include the development of household wells and, to a more limited extent, household rainwater harvesting systems. Household hand-dug wells (typically with rope-and-bucket systems) are common in many areas of the high plateau region in the central part of the country. In coastal areas with shallow water table depths and sandy soils, manually drilled wells and suction pump systems – the focus of this study – are common at the household level. This type of low-cost system was reportedly first introduced to eastern Madagascar over 50 years ago by a French expatriate working for the national electricity company.

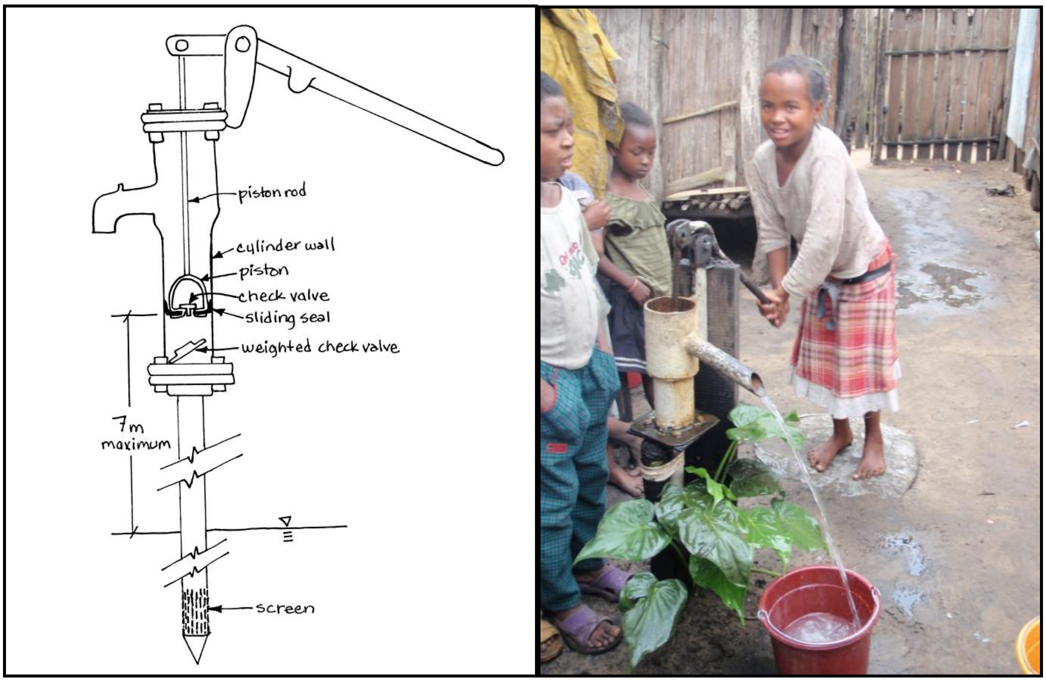
Over the past two decades, numerous other types of low-cost groundwater supply technologies have been introduced in various parts of the island, including two types of handpumps appropriate for household and small community use, and amenable to local manufacture. The Rope Pump was first introduced in Madagascar in 2000 by the national non-governmental organisation Taratra (with support from the Swiss organisation SKAT), and later by other international organisations (Daw, 2004). The Canzee Pump was initially introduced by the international organisation MedAir during disaster relief efforts following a hurricane in 2004, and a commercial market for this pump was later developed by Bushproof, a national company founded during that same period (Mol et al., 2005). In the case of the Rope Pump, which is now manufactured by several local workshops throughout the island, a small private market for these pumps has developed for household and community water supply. The market for the Canzee Pump in Madagascar has been restricted almost exclusively to donor-supported community water supply projects. Several manual drilling techniques have also been introduced to Madagascar over the past decade, including hand-augering introduced by an FAO project (Naugle, 2006), jetting by MedAir, rota-sludge drilling by the Practica Foundation, and hybrid percussion-jetting-rotation manual drilling by Bushproof. While each of these technologies has played a role in increasing access to groundwater in parts of rural Madagascar, none of them have achieved scale in an unsubsidised Self-supply market.

Pitcher Pump systems in Madagascar

The Pitcher Pump system (locally called *Pompe Tany*, combining the French word for pump with the Malagasy word for ground) consists of a small-diameter well fitted with a suction pump. Wells are drilled up to a depth of 12 metres. Figure 1 (a) shows a diagram of the Pitcher Pump system components while Figure 1 (b) shows a locally constructed Pitcher Pump in use in Tamatave.

As shown in Figure 1 (a), the Pitcher Pump has two check valves that are weighted (one on the lower end of the pump head, and a second one on a piston that attaches to the pump handle via a rod) and the pump is installed directly on a drilled well. The check valves are usually made of leather and weighted with lead (Pb). The well is installed by manually boring (coring) down to near the water table, then hammering into the ground a permanent galvanised iron casing pipe that includes a well screen and a pointed drill bit (well-point) at its lower end.

Figure 1. (a) Diagram of Pitcher Pump system (reprinted from Mihelcic et al., 2009, with permission of Linda D. Phillips). (b) Pitcher Pump in use in Tamatave, Madagascar.



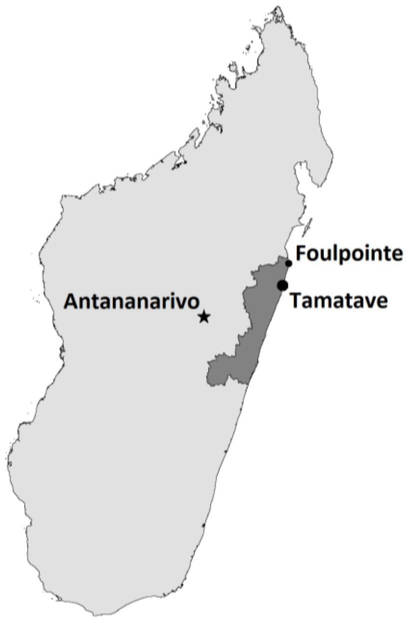
RESEARCH METHODOLOGY

Data related to Pitcher Pump systems were collected in the city of Tamatave (estimated population of 280,000) and the nearby town of Foulpointe (estimated population of 15,000) in the Atsinanana Region of eastern Madagascar (see Figure 2). Primary field data were gathered over a four-week period in August-September 2011, and a local research assistant gathered additional data in 2012 and early-2013.

The field research made use of mixed methods, consisting primarily of a quantitative survey of households that owned Pitcher Pump systems, semi-structured interviews with pump manufacturers, inspection/observation of household water and sanitation infrastructure, and testing of water quality. Supplementary methods consisted of focus group interviews with owners of Pitcher Pump systems and observation of installation of Pitcher Pump systems. Prior to the actual collection of field data, the research objectives and a summary of the field data collection plans were submitted to the Institutional Review Board (IRB) of the University of South Florida (USF), who determined that it was not considered to be human-subjects research under the purview of IRB.

Household visits consisting of a household survey, water/sanitation infrastructure inspection, and water testing were conducted in three neighbourhoods of Tamatave, and in the town of Foulpointe. These areas were chosen based on information from key informants indicating there would be significant numbers of Pitcher Pump systems operational in each area. Households visited within each neighbourhood were identified using 'snowball sampling'. This technique was chosen due to the lack of any available records to locate wells that are often hidden behind walls and within courtyards. A first household in the neighbourhood with a Pitcher Pump system was identified by the researchers, either through visually observing the Pitcher Pump from the road/path, or through talking to local residents of the area. At the end of the first household visit, the surveyed participant was asked if she/he could identify locations of other Pitcher Pump systems in the neighbourhood, which were then visited by the field research team and included in the research sample. In cases where many systems existed in a small area, the field research team made efforts to distribute the sampling of households throughout the neighbourhood.

Figure 2. Map of Madagascar showing field research sites of Tamatave and Foulpointe, in the Atsinanana Region (highlighted).



Household surveys

The 53 surveyed owner-users of Pitcher Pump systems included adult female (32) and male (21) respondents. Survey questions focused on the following aspects of household water supply: 1) basics of water and sanitation infrastructure/technologies used by the household, including length of time the households had used the infrastructure and how it was obtained (e.g. self-financing, subsidy through a local grant or project, with microfinance, etc), 2) water usage by the household, and 3) maintenance, repair, or performance issues.

Observation/Inspection

Water supply and sanitation infrastructure were visually inspected at all surveyed households. Installed pumps were tested to confirm their state of operation. A sanitary survey of the area was performed, focusing on the area immediately around the pump head, and estimating its distance to the household latrine. The flow rates of ten Pitcher Pump systems in one neighbourhood were also tested, representing a range of depths and pump attributes (pump head design, well diameter, etc).

Five local manufacturers were shadowed during construction of Pitcher Pump system components, to gain an understanding of construction techniques and materials used. Additionally, the research team observed the installation of three Pitcher Pump systems.

Water-quality testing

Water-quality tests were performed on 51 Pitcher Pump systems to determine the basic microbiological and chemical characteristics of the water delivered. For comparative purposes, the same water-quality tests were run on samples taken from JIRAMA tap stands in each neighbourhood visited in Tamatave, and a sample was taken from a community hand-dug well in Foulpointe. All water-quality testing was done in mid-August 2011, a time that generally coincides with the beginning of the driest period of the year (FAO, 2006). This period can be considered to be relatively favourable for microbiological water quality, compared to wetter periods of the year when there would be increased likelihood of contamination of well water from surface water run-off and shallower water-table levels.

Sampled water was collected and analysed using portable field kits for thermotolerant coliforms, nitrates, nitrites, arsenic, alkalinity, and pH. Palintest® colorimetric methods were used to detect the presence of nitrate, nitrite and alkalinity, while the Palintest® VisuPass method was utilised to detect the presence of arsenic. An Oxfam Delagua portable water-testing kit was used to measure faecal coliforms in water samples through the membrane filtration technique. *Escherichia coli* and thermotolerant coliforms are a subset of the total coliform group that can ferment lactose at higher temperatures (WHO, 2011).

Ten water samples collected from a subset of the surveyed Pitcher Pump systems were also analysed for lead (Pb). These water samples were collected in plastic bottles and tested in a laboratory at USF. From each of the sample bottles 5 millilitres (ml) were drawn with a syringe and filtered with a 0.2-µm filter into ten separate 10 ml glass containers. All filtered samples were acidified with 2 drops of 70% nitric acid to ensure a constant matrix between standards and samples, as well as to dissolve any particulate lead in solution. The acidified samples were left undisturbed for two days and then analysed on an Atomic Absorption Spectrophotometer (Varian model AA240Z) for lead (Pb) concentration.

Semi-structured interviews

Semi-structured interviews were also a primary tool used for data gathering. Sixteen such interviews were completed with various local water-supply and development stakeholders in eastern Madagascar, including: 1) technicians involved in the construction, installation, and/or repair of Pitcher Pump systems, 2) agents involved in the promotion of water, sanitation, hygiene and/or health, and 3) a government water-supply representative.

Interviews with Pitcher Pump system manufacturers/technicians yielded an understanding of practices related to both Pitcher Pump system manufacturing/installation and marketing/sales of the systems. Interviews with other stakeholders provided background on the water-supply context of the study area.

Focus groups

Three focus group interviews with Pitcher Pump system owners were organised as a supplementary methodological strategy to better understand owner-user management of Pitcher Pump systems, as well as to gain further insight into user appreciation of the Pitcher Pump technology. A focus group was held in each of the three surveyed neighbourhoods of Tamatave.

Data collection

Most of the collection of field data was carried out by a team of three researchers comprising the primary field researcher – a USF water-supply specialist (civil engineer); a USF environmental health specialist; and a Malagasy research assistant experienced in the collection of social science research data. Additional collection of data in 2012 and early-2013 was coordinated by the primary field researcher and carried out by the local research assistant.

Table 1. Core data collection: quantities of household visits and semi-structured interviews performed in each location.

Location	No. of household visits (including survey and inspection of water infrastructure)	No. of semi-structured interviews
Tamatave (City)		15
– Mangarivotra South	18	
– Analankinina	20	
– Ambalakisoa	10	
Foulpointe (a small town)	5	1
Total	53	16

RESULTS AND DISCUSSION

Extent of use, well reliability and pump attributes

According to the 2006 census carried out by the National Institute of Statistics of Madagascar (INSTAT), 60% of the population of Tamatave used Pitcher Pump systems (INSTAT, 2006). In 2009, INSTAT estimated the population of Tamatave as 232,568 (INSTAT, 2009). Considering this population estimate, the 60% usage of Pitcher Pump Systems, and assuming 5% annual population growth, there could be approximately 170,000 people in Tamatave using Pitcher Pump systems in 2013. Considering the average number of users per pump to be 19 (based on collected data showing an average of 4.6 households using a single pump, with an average of 4.2 persons per household in Tamatave as reported by INSTAT), around 9000 Pitcher Pump systems were estimated to be in use throughout the city.

Pitcher Pump systems are also commonly used in other areas along the East and South Coast of Madagascar. One such area, Foulpointe, was included in this field research, and several others have been confirmed during follow-up studies in 2012 and 2013. A conservative estimation of the number of Pitcher Pump systems installed in Madagascar outside of Tamatave is a few thousands. Combined with the estimated number of systems in Tamatave, the authors estimate that there are currently over 12,000 Pitcher Pump systems in use in Madagascar.

Of 53 households surveyed, 50 households (94%) reported that their Pitcher Pump wells provided water throughout the entire year. The other three households (6%) said that their Pitcher Pump wells provided water for 10-11 months per year. Households and manufacturers reported that if a well does not provide water, the casing can be removed and an additional length of pipe added to it, to allow it to be installed deeper in the ground, so that it could still provide water during seasonal low water-table levels.

Analysis of focus group interviews of owners of Pitcher Pump systems showed that the attributes pump owners found important were: 1) low purchase cost and low running (i.e. operation and maintenance) costs, 2) reliability compared to either a piped water supply system or a community well, and 3) convenience, i.e. ease of access and proximity of their system to the homestead compared to community water points.

In Tamatave, Pitcher Pump systems operate in many neighbourhoods served by the JIRAMA-managed public water supply system. Here, there are commonly multiple houses built on one parcel of land (compound). Generally, a landowner who lives on the property will purchase a Pitcher Pump system for use by the entire compound. During household interviews numerous pump owners stated that they would prefer to have a household connection to the piped water network, if not for the prohibitively high connection costs and water tariffs. Focus group participants also expressed a preference to have a household connection if it was available at a similar price to a Pitcher Pump system. As of 2013, the minimum cost for installation of a household connection was reported to be approximately US$215. There are an estimated 10,000 household connections in Tamatave. Owners also frequently mentioned that Pitcher Pump systems were more reliable, as the utility water supply was often interrupted for several hours at a time. Additionally, Pitcher Pump systems were reported to be preferable to getting water from distant communal tap stands.

The researchers observed that numerous non-surveyed compounds with a household piped water connection also had a Pitcher Pump system. The extent to which Self-supply and piped supply might compete with or complement each other is an important question. Self-provision likely leads to lower per capita consumption from the piped system, and may potentially cause the utility company to increase water tariffs to compensate for the lost revenue as volumes supplied decline. Alternatively, Self-supply may equally supply volumes of water that are additional to, or are not supplied by, the piped system. Pitcher Pump systems in Tamatave appear to be filling a void created by the inability of the utility to provide desired service levels at an affordable price to potential customers in its catchment area. It is questionable if JIRAMA is capable of providing sufficient water and service levels to the entire population of Tamatave in the near future. In this context, Pitcher Pump systems offer an affordable, reliable and necessary domestic water supply option in the short term.

This highlights the need for regulation of both piped systems and Self-supply in urban and peri-urban situations, so as to complement long-term urban planning efforts to extend the customer base of piped water schemes. Such is the case in southwest Nigeria, where groundwater systems are not permitted in some areas that have access to a piped water supply system (Oluwasanya et al., 2011). There is no such regulation in Tamatave, and some government offices themselves use Pitcher Pump systems.

Local construction, installation and system costs

Pitcher Pump systems were estimated to be built by more than 50 separate local small businesses in Tamatave. These fall into three categories: 1) welding workshops that manufacture and install Pitcher Pump systems as their principal activity or one of their primary activities (reported range of 12-30 systems sold per month), 2) welding workshops that fabricate and install Pitcher Pump systems as a secondary activity (these workshops commonly focus on other activities such as the construction of steel gates or repair of cars, bicycles and rickshaws; 4-12 systems sold per month), and 3) technicians/artisans who construct and install Pitcher Pump systems as a primary activity, but get the welding work done by a workshop (1-16 systems sold per month). Included in this third category are pump repair technicians who may occasionally also build Pitcher Pump systems.

Installation of Pitcher Pump systems (well drilling/installation, pump attachment) typically takes 1-4 hours on site, and is largely dependent on drilling depth and soils encountered (drilling through silt or clay layers takes longer than drilling through sand). When household Pitcher Pump systems were inspected it was found that any form of well-head protection was rare. Of the Pitcher Pump systems inspected during household visits, less than 4% (2 out of 53) had a sanitary apron (seal) at ground level around the well casing. One household in Foulpointe reported plans to install a concrete apron around their Pitcher Pump well within the next year.

The costs of a Pitcher Pump system were determined primarily from semi-structured interviews with local manufacturers in Tamatave (and one in Foulpointe), and household surveys were used to confirm the range of prices. Complete Pitcher Pump systems are commonly sold in Tamatave and Foulpointe at unsubsidised prices of US$35-100. This price includes system construction and installation, with the variance in cost largely dependent on well depth. The price of the Pitcher Pump itself is typically US$15-25, with well components and installation costing an additional US$5-7 per metre of depth (minimum 4 metres). Manufacturers generally make a profit of US$15-25 per Pitcher Pump system. All households surveyed (53 out of 53) reported paying the full purchase price of their Pitcher Pump system themselves, i.e. without subsidy.

Nearly half the number of Pitcher Pump system owners surveyed (49%; 26 out of 53) reported that they would have significant repairs/upgrades done to their systems over the next year. This included planning to purchase a new Pitcher Pump system (23%; 12 out of 53); well casing pipe addition or replacement (9%; 5 out of 53); and replacement of a pump head (4%; 2 out of 53). Of the Pitcher Pump system owners surveyed, 8% (4 out of 53) reported plans to install a household connection from the JIRAMA system within the next year. Despite an available adaptation to the Pitcher Pump system that allows water to be pumped to an elevated storage container (adding an estimated cost of US$80-150 to the price of a system, not including storage apparatus), none of the surveyed households mentioned any intention to make this investment within the next year.

Pump performance and system management

The performance of Pitcher Pump systems varied considerably and was related to: installed well depth; condition of the valves (if the leather seals in the valves are not sealing properly the pump needs to be primed at the start of use); and the material within the piston column of the pump head (e.g. mild steel, stainless steel, or PVC). Of 52 pumps tested during household visits, 12% (6 pumps) required priming by adding water through the top of the piston valve in order to function. Testing of pumping rates (single pumping subject – healthy adult female (29 years old, 50 kg)) from ten Pitcher Pumps showed a range from 4 litres/minute to 11 litres/minute.

Replacement of the leather pump valves was reported to be the most common maintenance/repair needed. Depending on the use of the pump, as well as the piston column material (that the piston valve makes contact with), this maintenance may need to be done as often as every few months. Other less frequent minor maintenance/repairs include replacement of the well screen, cleaning of the well pipe due to sand infiltration, and minor work to the pump head (e.g. replacing a nut and bolt, or the handle). All of these repairs are most commonly performed by local technicians (as reported by 75% of surveyed households, 40 out of 53) for total costs generally of US$2-6 for replacement of a leather valve. Some respondents (25%, 13 out of 53) reported doing at least some maintenance/repairs themselves. Other reported major repairs/changes to Pitcher Pump systems consisted of replacing the pump head and lengthening the well pipe (to deepen the well), done by local technicians/manufacturers.

Focus group data showed that, typically, Pitcher Pump system owners had general management rules for the use of their systems. The owner typically paid the entire cost of the system herself/himself, but maintenance and repair costs were commonly divided among all families using the system. Many owners said that activities such as washing clothes, bathing or cooking are not allowed within a radius of a couple of meters from the pump. Most owners explained that users who live within the compound where the Pitcher Pump system is located are allowed access at any time, night or day, while users outside the compound would be permitted to access it usually during the day (generally under the same conditions as other users, i.e. sharing maintenance and repair costs with other families). Public tap stands and private water vendors selling water from the piped network are open 8-10 hours/day, 6-7 days/week.

Water quality and household water treatment

Table 2 shows the distribution of faecal coliform counts in tested Pitcher Pump systems in Tamatave and Foulpointe. Faecal coliforms were detected above the WHO guideline of zero faecal coliforms/ 100 ml in 73% (37 of 51) of the Pitcher Pump samples tested. Some 55% (28 of 51) of the Pitcher Pump systems showed faecal contamination of between 0 and 10 coliforms/100 ml of water, which is considered low-risk. Five systems were severely contaminated with greater than 100 faecal coliforms/100 ml. Of the 23 households where Pitcher Pump system water samples showed greater than 10 faecal coliforms/100 ml, 16 households reported they drank water from their Pitcher Pump, and 13 of these 16 households reported treating their water by chlorination and/ or boiling prior to consumption. Pitcher Pump systems where the drilled well was reported to have been installed at a depth of more than 7 metres showed relatively little contamination (all showing either no growth or 1-10 faecal coliforms/100 ml). However, ongoing research commissioned after this study is apparently showing other wells in Tamatave with installed depths of more than 7 metres to have considerable microbiological contamination. The collected data did not show a correlation between microbiological water quality and the distance of the Pitcher Pump system from a latrine. Single water samples taken from JIRAMA tap stands in each of the three surveyed neighbourhoods of Tamatave showed no contamination (i.e. no thermotolerant coliform growth). A sample from a community well in Foulpointe was highly contaminated (thermotolerant coliforms were 'too numerous to count').

Table 2. Microbiological water quality of Pitcher Pump systems.

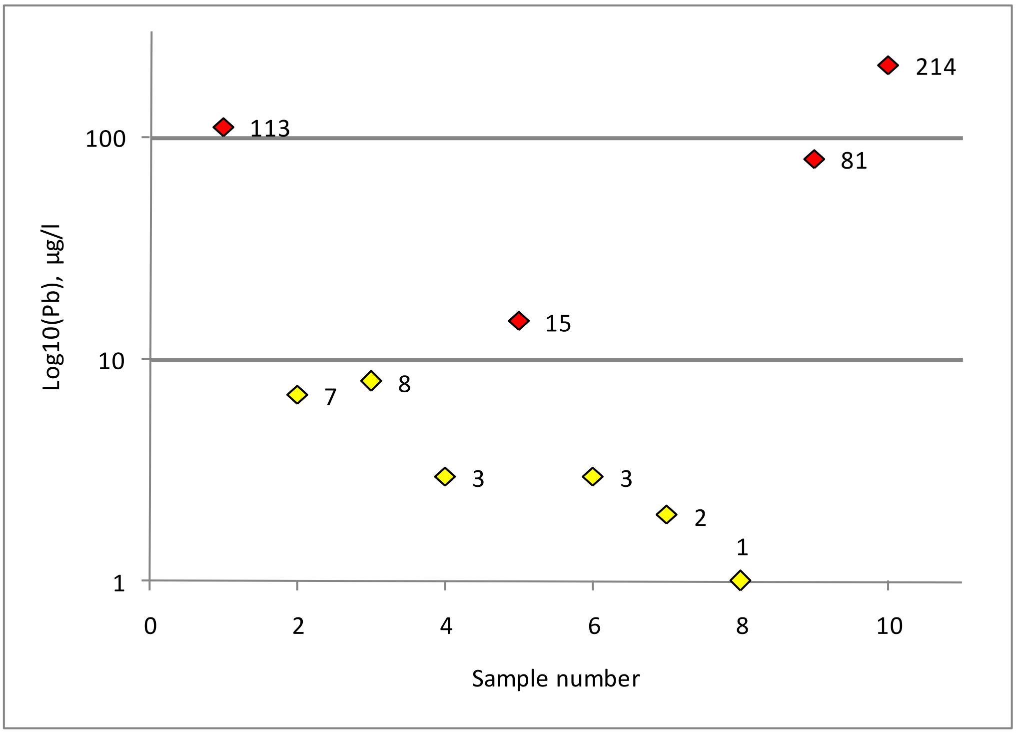
Location	No. of Pitcher Pump systems sampled	Measured thermotolerant coliforms (per 100 ml)			
		No growth	1-10	11-100	Greater than 100
Tamatave (city)					
- Mangarivotra South	17	3	2	10	2
- Analankinina	19	2	7	8	2
- Ambalakisoa	10	8	2	0	0
Foulpointe (a small town)	5	1	3	0	1
Total	51	14	14	18	5
Pitcher Pump systems sampled (%)		27	27	35	10

Nitrate was detected in all water samples. The nitrate concentrations ranged from 4.4 to 35 mg NO_3^-/l (average concentration = 23; standard deviation = 12), while nitrite was detected in four of the nine samples tested, though typical concentrations ranged from 0.1 to 0.2 mg NO_2^-/l. All these nitrogen samples are below WHO guidelines (50 mg NO_3^-/l and 3 mg NO_2^-/l) but suggest some impact on the groundwater supply by anthropogenic activities associated with waste disposal.

Each of the ten water samples tested for lead (Pb) was obtained from households that reported consuming water from their Pitcher Pump systems. All ten samples showed the presence of lead, including four samples that had lead levels higher than the WHO guideline of 10 µg/l (WHO, 2011). These four samples had Pb concentrations of 15, 31, 118, and 215 µg/l. The range of Pb concentrations in the tested samples is shown in Figure 3.

According to WHO, exposure to lead is related to numerous health issues, including neurological issues, cardiovascular disease and issues with fertility and pregnancy (WHO, 2011). The presence of lead in water extracted from Pitcher Pump systems may be due to a combination of three sources: 1) weights used to hold down the two leather valves, 2) brass well screens, and 3) solder used to attach the well screens to the galvanised iron well casing. USF is currently performing additional in-depth research on these three possible pathways of lead contamination from Pitcher Pump systems in Tamatave.

Figure 3. Lead (Pb) concentrations of 10 sampled Pitcher Pump systems in Tamatave and Foulpointe. The WHO guideline is 10 µg/l of lead.



In terms of other water-quality parameters, pH values were determined to be less than 6.8, the limits of the testing meter (follow-up testing in Tamatave has shown pH values in the 6.1-6.9 range). Alkalinity typically ranged from 150 to 250 mg/L $CaCO_3$. Arsenic was not detected in any of the 51 Pitcher Pump system samples (detection level of 10 µg/l).

Regarding the local perception of quality of water delivered from their Pitcher Pump systems, focus group discussions revealed that a small number of owners insisted the water from their systems was potable (and of no risk to their health) without any treatment, while the great majority understood that the water from their systems was likely contaminated, yet said they commonly drink it without treating it. A minority of focus group participants reported the water from Pitcher Pump systems to be not of potable quality and reported either treating the water (through boiling) prior to drinking, or collecting drinking water from an alternative source.

Among surveyed households, 75% of households (40 of 53) reported that they drink water from their Pitcher Pump system. Of these, several (15%, 6 of 40) reported treating water with a chlorination product ('*Sur Eau*', marketed in Madagascar by the NGO PSI) prior to drinking, and 58% (23 of 40) reported boiling water prior to drinking, including two households that reported both boiling and treating the water with chlorine prior to consumption. It is also common practice in Madagascar to drink boiled rice water after each meal (*Ranon'ampango* in Malagasy – made from adding water to a pot with leftover cooked rice in it, and heating/boiling it). It is believed that this traditional practice is why the local population is open to boiling water (though it may also have led to over-reporting of the habitual practice of properly boiling water in household surveys). Table 3 shows reported drinking water treatment practices among surveyed households.

Table 3. Reported water treatment practices of Pitcher Pump users.

Location	No. of house-holds	Reported data from household surveys							
		Drink water from Pitcher Pump systems		Pitcher Pump drinking water treatment method					
				Boiling		Chlorination		None	
		No.	%	No.	%	No.	%	No.	%
Tamatave (city)									
– Mangarivotra South	18	15	83	8	53	1	7	6	40
– Analankinina	20	12	60	8	67	5	42	1	8
– Ambalakisoa	10	9	90	4	44	0	0	5	55
Foulpointe (a small town)	5	4	80	3	75	0	0	1	25
Total	53	40	75	23	58	6	15	13	33

Potential improvements and further research

Potential options for 'technology improvements' that focus on improving water quality include:

1. Adaptations to Pitcher Pump system components:
   a) Elimination of lead-containing pump components. An ongoing study is identifying specific pathways of lead contamination from Pitcher Pump systems, and is considering the technical and social feasibility of using non-lead alternatives for each of the current Pitcher Pump system components that contain lead (e.g. using iron in place of lead for weights on pump valves).
   b) Installation of well-head protection. Installation of a concrete sanitary apron (or, at minimum, a clay apron) to provide a sanitary seal needed to prevent microbiological (faecal) contamination from entering the well alongside the casing.
   c) Possible increased well-installation depth. A separate study is being done to determine the change in water quality at different depths subject to the same environmental conditions.
2. Boiling of water prior to drinking. Many surveyed owners reported that they boiled water from their Pitcher Pump systems prior to consumption. Follow-up research is exploring local practices for making rice water – to determine if the water is sufficiently heated to allow for effective treatment of microbiological contamination, to find out if users later add non-boiled (and untreated) water for cooling down, etc.
3. Household rainwater harvesting for drinking water. Most (90%) of the households surveyed in Tamatave had houses with corrugated metal roofing, which is a very suitable surface for rainwater catchment, and several examples were seen of households practising rainwater harvesting in basic forms (capturing rainfall off their roofs in buckets or larger containers, usually without any gutter system). Tamatave has an average annual rainfall of over 3000 mm, including 9 months with an average of at least 200 mm of rain, and a minimal average monthly reported rainfall of around 120 mm (FAO, 2006). Considering this rainfall amount and the common existence of corrugated metal roofs on houses in Tamatave, low-cost rainwater harvesting technologies could be further explored as a possible household drinking water supply option. This is particularly important for health improvements, as a previous study found that addition of water storage of as little as 400 litres integrated with household rainwater

harvesting could reduce the diarrhoeal disease burden (measured as disability adjusted life years) by as much as 25% (Fry et al., 2010). Rainwater harvesting would also eliminate the nitrogen and lead contamination concerns uncovered in this study.

4. Regulation of the Pitcher Pump system market. This could include quality control support to technicians/manufacturers for construction and installation of Pitcher Pump systems (e.g. minimum standards to reduce health risks from lead contamination, improve microbiological well quality, etc), research of the potential for better complementarity between the JIRAMA system and Self-supply, an environmental awareness campaign to educate users on the risks of using Pitcher Pump systems for drinking water, and monitoring the water quality of Pitcher Pump systems by local stakeholders.

The price of accessing water using Pitcher Pump systems in Tamatave is US$35-100 (initial cost) plus small running costs for maintenance and repairs. While changes in prices for potential improvements are to be determined through further research (e.g. evaluating well-water quality vs. depth, impact of sanitary aprons on water quality, etc), the aim should be to keep costs low while improving the Pitcher Pump system product.

The Self-supply market for Pitcher Pump systems in eastern Madagascar is well-developed. The research has shown there to be an established market for improving access to water for households in the study area at unsubsidised prices that are affordable for most landowners. The existing Pitcher Pump market should be further explored, to determine possibilities to build on existing capacities and practices to design low-cost Self-supply groundwater markets using drilling and pumping technologies which can be used in more diverse hydrogeological conditions, i.e. to drill to deeper depths and through harder soils, and to pump water from deeper depths. The ability to adapt the market to areas where water tables are deeper and soils are harder would be of great value to many areas of Madagascar.

Given the market success of the current Pitcher Pump systems in Tamatave, resistance to change could be expected if the benefits of proposed improvements are not well understood by consumers or Pitcher Pump manufacturers. This resistance could be in the form of unwillingness of consumers to invest in hardware improvements or to implement behavioural change(s) necessary to ensure consumption of water of a good quality. Resistance could also come from manufacturers and installation technicians, who may not be willing (or may be hesitant) to adopt changes to system construction and installation. The relative complexity of the Self-supply context in Tamatave makes further market research important, as the well-established market could be disrupted if changes are not well-designed/implemented.

CONCLUSION

Pitcher Pump systems are widely used in the research area of Tamatave and Foulpointe in eastern Madagascar and are shown to provide reliable and convenient access to water at a low cost relative to household connections to the piped water system. The Pitcher Pump market in the research area is unsubsidised, with system owners paying 100% of the initial cost. This market is believed to be the most significant documented example of an unsubsidised household handpump market in sub-Saharan Africa. Owners commonly share maintenance and repair costs with their tenants and/or neighbours. System maintenance is done by local technicians or family members, with more significant repairs undertaken by local technicians or manufacturers.

There are, however, concerns with the quality of water supplied through these systems (i.e. its suitability for drinking), specifically microbiological and lead contamination. Only 55% of wells sampled provided water associated with low-risk of microbial contamination for household systems, and four out of a small sample of ten wells contained lead in excess of safe limits. The market is also unregulated, neglected even, and there are several potential entry points for enhancements to current

Pitcher Pump system construction and installation practices that could improve the quality of water delivered.

Results of this study are being shared with USAID and local government officials responsible for urban water supply and public health. Complementary research is ongoing to assess the cause of the lead contamination and make recommendations to mitigate exposure. Follow-up efforts in urban Tamatave seek to support WASH stakeholders and local government officials to increase regulation of the Self-supply market and address issues of quality of water delivered by Pitcher Pumps, including the important issue of lead contamination. Further research is needed to determine potential improvements to Pitcher Pump systems, to understand how to create synergies between the Pitcher Pump market and community piped water system, as well as to determine the feasibility of household water treatment and rainwater harvesting Self-supply options to improve access to drinking water.

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