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Functionality and water quality of Elephant pumps: Implications for sustainable drinking water supplies in rural Malawi

Rochelle Holm [a,*], Robert Stroud [b,1], Golden Msilimba [a], Simeon Gwayi [a]

[a] *Centre of Excellence in Water and Sanitation, Mzuzu University, P/B 201, Mzuzu 2, Malawi*
[b] *Pump Aid, Development House, 56-64 Leonard Street, London EC2A 4LT, United Kingdom*

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ABSTRACT

In 2013, our team performed a program evaluation of the sustainability and water quality of 338 Elephant Pumps in Malawi. The team tested the water quality, evaluated the pump functionality and investigated the community's satisfaction. The water in most samples (68%) conformed to the Malawi Government drinking water standard for *Escherichia coli*. Likewise, the nitrate concentrations were within both the Malawi Government and the WHO established standards. The functionality of the Elephant Pumps was 78% (producing water), which is comparable to the functionality rate of hand pumps in Sub-Saharan Africa, which is posited as 64%. Pumps that are working well tend to have the lowest (significantly) *E. coli* contamination levels. The majority of the households use the water for common household activities; however, water was also used for irrigation and commercial purposes in a limited number of cases. Ninety one percent of the respondents reported that they were very satisfied with the pump design. Although most Elephant Pumps produce water that conforms to the standards by the Malawi Government and with above average functionality, no perfect pump design exists. The performance of Elephant Pumps can still be improved through better training of area mechanics and community pump caretakers, and the availability of improved networks for spare parts.

1. Introduction

An estimated 663 million people are still without access to improved sources of drinking water (UNICEF and World Health Organization, 2015). In 2000, the United Nations proposed a Millennium Development Goal with respect to water quality of halving "the proportion of the population without sustainable access to safe drinking water and basic sanitation" by 2015 (United Nations, 2015). Fortunately, Malawi has met the Millennium Development Goals for improved drinking water sources (UNICEF and World Health Organization, 2015). However, diarrheal diseases, often associated with unsafe drinking water and poor sanitation, remain a leading cause of mortality in children under five in Malawi with over 3000 children dying per year (World Health Organization). The study reported herein is an extension and comparison of other research projects focused on rural Malawian groundwater quality (British Geological Survey; Taylor et al., 2012; Pritchard et al., 2007; Pritchard et al., 2008; Wanda et al., 2011; Kanyerere et al., 2012).

To address the gap in knowledge for provision of a safe rural water supply, this study evaluated the functionality and water quality parameters (total coliform, *Escherichia coli*, nitrate, total hardness, total alkalinity, pH, free chlorine and total chlorine) in shallow wells with Elephant Pumps (Fig. 1) installed by Pump Aid in Malawi. This study has three goals: 1) to survey 338 Elephant Pumps, including the oldest pumps, to identify possible sources of contamination and to develop solutions to ensure the pumps are providing safe drinking water, 2) to examine pump functionality rates and downtime along with user satisfaction, and 3) to propose recommendations for implementing and improving safe rural water supply.

2. Materials and methods

For 6 weeks, a field team covered five districts and surveyed 338 Elephant Pumps (Fig. 2). During this time, the team tested the water quality, evaluated the pump functionality, investigated community satisfaction, and made any necessary repairs to the pumps.

The sampling strategy aimed to select a representative number of pumps from 2843 pumps that were installed (at the time of the

* Corresponding author.
E-mail addresses: rochelle@rochelleholm.com (R. Holm), robtstroud_uk@yahoo.co.uk (R. Stroud), msilimba@yahoo.co.uk (G. Msilimba), smgwayi@gmail.com (S. Gwayi).
[1] Current Address: 1 Deepwell Drive, Camberley, Surrey GU15 2HF, United Kingdom.

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Fig. 1. Elephant Pump, Malawi.

study) by Pump Aid in Malawi; therefore, the results could be used to draw conclusions on a countrywide basis. Three hundred thirty eight pumps across the country were selected with respect to physiographic area (113 in the highland/escarpment, 183 in the plateau, and 42 in the wetland). The oldest pumps, installed in 2008 and 2009, were purposely chosen within each zone. Whether a pump was functional or non-functional was unknown at the time of study selection, although it was determined based on the field visit. A pump was classified as functional if water for sampling could be collected and drinking water was available to the users on the day of the site visit.

After testing the survey tools, the data collection team used a standardized questionnaire relying on both observations and focus group discussions with the members of the water user committee and community using the water.

Water quality analysis included total coliform, *E. coli*, nitrate, total hardness, total alkalinity, pH, free chlorine and total chlorine. Of the 338 pumps studied, 285 were functional and available for water quality sampling. In the sampling procedure, water was pumped from the Elephant Pump to purge stagnant water prior to sample collection. To capture a sample representative of drinking water conditions, the sample was collected directly from the outlet of the pump into two Whirl-Pak® bags containing a sodium thiosulfate as a preservative (Nasco, Fort Atkinson, Wisconsin). The samples were transported to a field lab for analysis the same day. The water samples were not filtered prior to analysis. For the microbial analysis, new disposable Petri plates, pipettes, and funnels were used once. The forceps were flame sterilized, and the vacuum unit was wiped with alcohol and flamed before each new water sample was analyzed. Total coliforms and *E. coli* were analyzed simultaneously using a Hach m-ColiBlue24® (Hach Company, Loveland, Colorado) membrane filtration method in duplicate. Visible colonies were counted under 10–15X magnification. For chemical analyzes, the equipment was triple rinsed with sample water prior to analysis. Nitrate was detected and quantified using a Hach Nitrate Test Kit Model NI – 11 (Hach Company, Loveland, Colorado). The limit of detection is 1 mg/l, which is less than a tenth of the WHO guideline, therefore providing adequate sensitivity (World Health Organization). The total hardness, total alkalinity, pH, free chlorine, and total chlorine in the samples were monitored in duplicate with Hach, Aquachek 5 in 1 Water Quality Test Strips (Hach Company, Loveland, Colorado). The chemical assays were also performed in duplicate, and the average results are reported.

The data were analyzed using statistical software, SPSS version 16, and Microsoft Excel. The data were summarized in terms of means, medians, frequencies, and percentages, as represented in tables. In terms of inferential statistics, a one-sample *t*-test was used to evaluate whether the mean for microbial parameters (*E. coli* and total coliform counts) and chemical parameters (nitrate, hardness and pH) in the water were significantly different from the Malawi Government (Malawi Bureau of Standards, 2005a, 2005b) and WHO (World Health Organization) standards. A Chi-square test showed the relationship between the visible pathways for contamination and *E. coli* levels. The statistical analyzes were conducted at the 95% confidence interval.

Field data were collected from February to May 2013 during the rainy season. Previous studies have shown that microbiological contamination exceeding standards in Malawi was more prevalent during the rainy season (Pritchard et al., 2007, 2008). This is also supported by the earlier study from shallow wells and boreholes in rural areas during the dry and rainy season by Taylor et al. (2012), which found higher fecal contamination during the rainy season. A study limitation was that for the study under Taylor et al. (2012) data on well chlorination was not available.

3. Results and discussion

3.1. Functionality

A majority of the pumps (69%) were reported as functioning well (good yield and easily to be pumped by users), whereas 9% were functioning badly (low water yield or difficult to pump) but were still producing water, and 22% were not functioning. The non-functioning wells were spread throughout the country and were not localized to a geographic district. The percentage (78%) of pumps producing water was compared with the hand pump functionality rate in Sub-Saharan Africa, which was posited as 64% based on data from 20 countries (Rural Water Supply Network). The yield of most of the pumps (minimum 0.14 l/s; maximum 1.33 l/s) met the established government minimum of 0.25 l/sec (Malawi Bureau of Standards, 2005a).

The functioning of hand pumps may be related to how long the pump has been working combined with the ability of the community to make repairs. Pumps reported as having low water yield or difficult to pump water by users (9%) may be attributed to mechanical pump malfunctions, initial site selection, or groundwater levels. Pump malfunction was primarily reported as the result of parts of the pump wearing out, and lack of access to spare parts. In the current study, 69% of the Elephant Pumps had broken down within their lifetime (ca. 6–7 years). The major causes of mechanical malfunction were due to a cut rope (61.8%, $n=215$) and rope slippage (18%, $n=63$). Other lesser causes noted included a broken pole and problems with the pipe. The downtime of the pump was often only for a short period, and only 30% of the pumps were reported to be out of order for over a week without being repaired. Community members provided a number of reasons for not repairing the pumps which were not functioning or functioning poorly. Data gathered using open-ended questions provided the feedback that a lack of spare parts was the most frequent (73.3%) reason for not repairing the pumps.

However, 87% of repairs were considered 'easy' by the local community members, including pump committee members, area mechanics, and other local skilled personnel. The skills to repair pumps are provided verbally through demonstrations by Pump Aid during the installation. An analysis of the cost of the pump repair revealed that 16% of the communities paid for the repairs, and costs ranged from MK250–MK6000 (0.38 £ to 9.10 £/USD$0.54 to USD$12.95). The majority of the repairs cost between MK500 and MK2000 (0.76 £ to 3.03 £/USD$1.08 to USD$4.31). Nonetheless, these pump functionality results compliment findings in the Democratic Republic of Congo that the availability of spare parts is only a portion of hand pump sustainability, which requires