Sustainable Water Services Delivery Project Report

October 2013

WSA
Developing Sustainable Solutions for Africa
UNC WATER INSTITUTE
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This document was prepared by Water and Sanitation for Africa (WSA) in partnership with The Water Institute at UNC as part of the WaSH MEL project, funded by The Conrad N. Hilton Foundation.

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About WSA

As a Pan African Inter-governmental Agency, Water and Sanitation for Africa complements regional efforts by providing continental leadership in the development of innovative and sustainable approaches, evidence-based policy advice, and advocacy services in the provision of water, sanitation and hygiene services in Africa. Previously known as the African Regional Centre for Water and Sanitation (CREPA), WSA has, since 1988, been developing innovative approaches and technologies in the water, sanitation and hygiene (WASH) sector. Currently, WSA seeks to apply its years of experience to provide the necessary technical advice on continental issues and expert services in WASH.

About The Water Institute

The Water Institute at UNC provides international academic leadership at the nexus of water, health and development.

Through ***research,*** we tackle knowledge gaps that impede effective action on important WaSH and health issues. We respond to the information needs of our partners, act early on emerging issues, and proactively identify knowledge gaps. By developing local initiatives and international ***teaching and learning*** partnerships, we deliver innovative, relevant and highly-accessible training programs that will strengthen the next generation's capacity with the knowledge and experience to solve water and sanitation challenges. By identifying or developing, synthesizing and distributing relevant and up-to-date ***information*** on WaSH, we support effective policy making and decision-taking that protects health and improves human development worldwide, as well as predicting and helping to prevent emerging risks. Through ***networking and developing partnerships***, we bring together individuals and institutions from diverse disciplines and sectors, enabling them to work together to solve the most critical global issues in water and health.

We support WaSH sector organizations to significantly enhance the impact, sustainability and scalability of their programs.

The vision of The Water Institute at UNC is to bring together individuals and institutions from diverse disciplines and sectors and empower them to work together to solve the most critical global issues in water, sanitation, hygiene and health.

About the Conrad N. Hilton Foundation

The Conrad N. Hilton Foundation is a family foundation established in 1944 by the man who started Hilton Hotels. The Hilton Foundation provides funds to nonprofit organizations working to improve the lives of disadvantaged and vulnerable people throughout the world. The Foundation works to improve the well-being of the ultra-poor in targeted developing countries through its Strategy for Sustainable Water Access. This strategy emphasizes interventions for expanding sustainable access to safe water, strengthening the enabling environment for WaSH interventions in target countries, and disseminating relevant sector-wide knowledge.

About the Authors

Michael Fisher

Mike Fisher joined the Water Institute in 2012. His current work with the Institute focuses on leveraging monitoring, learning, and evaluation to maximize the impact of water, sanitation, and hygiene (WaSH) interventions. His research and fieldwork experiences have included work on developing, implementing, and evaluating technologies for low-cost water treatment and safe water access. This work has spanned rural and urban developing country settings on four continents.

Hannah Leker

Hannah began working with the Water Institute in June of 2013, joining the Institute as a part of the Knowledge Management staff. She will be working widely with various projects within the Water Institute to identify, characterize, distribute and share lessons learned and insights from ongoing international water and sanitation projects. She completed her undergraduate studies at the UNC School of Public Health, graduating with a Bachelor of Science in Public Health in the area of Environmental Health Science.

Destina Samani

Destina Samani is the Resident Representative of Water and Sanitation for Africa (WSA) in Ghana, a role she has held since June 2011. She is responsible for the overall coordination and management of WSA activities in Ghana, including research, capacity development, field implementation of sustainable WASH solutions, policy work with governments, and building local partnerships in the West Africa region. Prior to joining WSA, she was the Officer in charge of WaterAid Ghana's field office in Tamale, overseeing all of WaterAid's work in the three Northern Regions of Ghana, and doubled as the WaterAid lead for the establishment of WaterAid's Liberia Country Programme, as well as serving as and the focal person for Equity and inclusion for Ghana. Ms. Samani has over 11 years of experience in community development work.

Patrick Apoya

Patrick Apoya is currently the Director of the Africa Sanitation Think Tank, an Initiative of the Pan African Inter Governmental Organization, Water and Sanitation for Africa (WSA). Patrick Apoya has over 18 years' experience in development work, specializing in health, water, sanitation and hygiene. He has experience managing community-based programs at the grassroots level in Ghana, as well as coordinating civil society policy advocacy efforts at the National and international levels. He has served as Board member of Pan African and Global Civil Society Networks, and an Advisory member of the Fresh Water Action Network (Global). He is the immediate past Executive Secretary of the Ghana Coalition of NGOs in Water and Sanitation.

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Abbreviations, Acronyms and Names

HF	Conrad N. Hilton Foundation
ES	Evaluation Specialist
CWSA	Ghana Community Water and Sanitation Agency
GoG	Government of Ghana
M&E	Monitoring and Evaluation
MEL	Monitoring, Evaluation & Learning
NC	North Carolina
NGO	Non-Government Organization
ODF	Open Defecation Free
TS	Technical Support
UNC	The University of North Carolina – Chapel Hill
VLC	Virtual Learning Center
WV	World Vision
WaSH	Water Sanitation and Hygiene
WI	Water Institute
WSA	Water and Sanitation for Africa
WSMT	Water and Sanitation Management Team

Executive Summary

Safe drinking water and basic sanitation are critical to human health and development, yet over 750 million people lack access to safe drinking water from an improved source, many of these in sub-Saharan Africa. Since the 1990s, The Conrad N. Hilton Foundation has invested in expanding access to safe drinking water in West Africa, largely through partnership with non-governmental organizations (NGO) to install thousands of boreholes with handpumps in underserved rural communities. Sustainability is a key objective of the Hilton Foundation's safe water work, but independent studies have found that 30-50% of boreholes with handpumps in rural sub-Saharan Africa may not be functional at any given time.

In order to assess the sustainability of Hilton-funded systems with respect to functionality, water safety, and level of service, the Hilton Foundation partnered with Water and Sanitation for Africa (WSA), an African NGO that was not involved in implementing earlier Hilton projects, to conduct a follow-up assessment of 1500 water points in 520 communities in the Greater Afram Plains (GAP) region of Ghana. WSA conducted this work in partnership with Water for People, a US-based NGO with a novel mobile data collection platform call FLOW (field-level operations watch). WSA also partnered with local Ghanaian universities and government agencies, as well as international consultants, to develop and administer surveys and to conduct testing of boreholes and water quality samples.

The results of this collaborative Safe Water Service Delivery (SWSD) assessment showed that approximately **80% of the water points surveyed were functional** at the time of the study. System functionality varied with system age, management structure, and the presence or absence of a user fee. Specifically, the functionality of older water points decreased by 2% per year of age, while systems collecting a tariff were 40% more likely to be functional than those without a tariff, after controlling for other factors. **Systems with an identifiable management team more than twice as likely to be functional** as those with no identifiable management structure. The presence of an identifiable management team was found to be the factor most strongly correlated with the sustainability of community water points in the Greater Afram Plains. Additional factors correlated with functionality were the reported difficulty of pumping water from a given handpump, the region in which the system was located, and the number of users per system. Finally, India Mk II, Afridev, and Nira pumps appearing to perform slightly better than Vergnet pumps, although these results were not statistically significant at the 95% confidence level.

For nonfunctional systems, users reported a range of reasons that the system had not been repaired, but **cost was by far the most commonly cited reason**. In addition, users reported that approximately half of all water points had failed within the past year, and multiple failures of a single system within the previous year were common. These results suggest that water point failure is a common occurrence, and functionality is highly dependent on the presence of an active management team with the ability to oversee routine maintenance and repairs.

Water quality samples were collected from 46 of the 1509 water points visited, and *E. coli* concentrations were reported for 38 wells. This sample size was too small to draw conclusions about water quality in the GAP region. Preliminary data suggest that water from many, but not all boreholes was in compliance with World Health Organization (WHO) guidelines for *E. coli* and several chemical parameters at the time of the visit, but additional monitoring is needed to make meaningful statements about water safety in the GAP.

Finally, it should be noted that the average number of people reportedly using water points in the study area was 115, as compared to the 300 people typically assumed by government and NGOs to be using each water point in Ghana. Thus, current beneficiary calculation methods may not provide sufficiently accurate estimates of user numbers, and more accurate methods should be explored.

The results of this study suggest that while borehole functionality in GAP is far higher than in much of sub-Saharan Africa, and water points constructed by World Vision appear to be particularly sustainable over time, implementers may be able to further improve the percentage of water points that are functioning at any given time by regularly monitoring the presence of functional management teams and by quickly rehabilitating or reconstituting management teams that cease to collect tariffs and actively manage the community's water points. In addition, implementers may benefit from using pumping difficulty as an early warning sign for mechanical and hydrogeological difficulties, while conducting regular water quality monitoring to detect and address microbiological impairment of water sources. The Water Institute will continue to work with WSA and WaSH implementers to develop recommendations for ongoing monitoring and implementation best practices for improving sustainable safe water access in GAP and beyond.

1. Introduction

Access to safe drinking water and sanitation are critical to human health and development [1,2]. Lack of continuous access to adequate quantities of safe drinking water can contribute to increased burdens of morbidity and mortality, particularly among children under the age of five [3-5]. The world has already achieved the drinking water component of target 7C of the Millennium Development Goals, halving the proportion of people without access to safe drinking water. However, over 750 million people still lack access to an improved source of drinking water [2]. Expanding coverage to unserved individuals while working to retain recent gains in safe water access is a critical development goal for the coming decades.

National governments, non-governmental organizations (NGOs) and international donors are working hard to expand access to safe drinking water in countries with low coverage rates. This work poses distinct challenges in rural and urban areas. One organization that has been extremely active in promoting rural safe water access in sub-Saharan West Africa is the Conrad N. Hilton Foundation, which has supported major NGOs in their efforts to deliver safe water to countries with low coverage rates. To date, the Hilton Foundation and its partners have provided safe drinking water to thousands of communities in Ghana, Mali, Niger, and Burkina Faso through its partnerships with NGO implementers.

The value of expanding safe water access in rural West Africa is clear. However, this challenge consists not only of providing service to those lacking improved drinking water facilities, but also of ensuring that those with service continue to enjoy its benefits. The sustainability of safe drinking water sources is therefore a critical issue for governments, NGOs, and donors. However, water point sustainability has received far less attention than water source construction in both national and international efforts to expand safe water access. As a result, new water point construction continues at a rapid pace, while old water points frequently deteriorate and cease to function reliably. One recent study suggests that at any given time, one third of rural water supplies in sub-Saharan Africa are nonfunctional [6], while borehole functionality in some countries may be even lower [7,8]. Furthermore, many functional rural water points may produce drinking water that is unsafe due to chemical or microbiological contamination [9].

Water point sustainability depends on multiple factors. If a water point is properly constructed and well maintained by an active supervisory entity with access to sufficient funds, it can continue to function for decades, and even be replaced when it eventually fails. If a water point is regularly monitored and inspected, the safety of the water it produces can likewise be ensured. When water points fail, this failure can be due to several factors, including technical factors such as faulty construction or inadequate maintenance, hydro geological factors such as changing water tables or borehole collapse, financial factors such as insufficient funds for maintenance and repairs, or social factors, such as the lack of a designated management entity to oversee the management of the facility. Often, these factors can be closely intertwined, so that social problems lead to financial ones, and financial shortfalls precipitate technical failures. Meanwhile, contamination of water points can occur at any time for a number of different reasons. While effective construction and management can make a water point less vulnerable to contamination, only regular monitoring and testing can ensure that the system continues to provide safe drinking water to users.

In response to findings of widespread rural waterpoint failure in sub-Saharan Africa, the Hilton Foundation sought to investigate the current status of water points in West Africa whose construction it had funded in the past two decades. Specifically, The Hilton Foundation sought to assess water points in the Greater Afram Plains (GAP) area of Ghana constructed by World Vision since the early 1990s. To do this, they partnered with Water and Sanitation for Africa (WSA, formerly CREPA) and Water For People (WfP) to conduct a Sustainable Water Services Delivery (SWSD) study. Through this collaboration, Water For People refined its field-level operations watch (FLOW) mobile data collection tool; a software package that uses mobile phones running the Android operating system to collect GPS coordinates, water point functionality data, and household survey data, and automatically upload these to a cloud server from which the data can be aggregated and viewed using an online dashboard. During the course of the project, the development of the FLOW tool was taken over by Akvo, an NGO that specializes in information technology solutions for the WaSH sector.

WSA developed a set of waterpoint, household, and WaSH management committee (Watsan) surveys and trained 100 local enumerators in the administration of these surveys using the FLOW 1.0 mobile data collection tool. The enumerators then sought to conduct an exhaustive sample of approximately 1000 Hilton-funded water points and WaSH committees in the Afram Plains area, as well as a representative sample of households in the communities in which Hilton-funded water points were located. Since many of these communities also contained water points funded by the government of Ghana (GoG) and other donors, a number of non-Hilton water points were also studied.

A large volume of data was collected, and WSA conducted preliminary analysis of these data with the help of its consultants, presenting the initial findings at a regional workshop in Tamale, Ghana in March of 2013. The Water Institute at UNC (WI) is currently collaborating with WSA to assist with further analysis of the data collected during the SWSD project. The results presented here include detailed analyses of the data collected during the course of the SWSD project, as well as a discussion of the implications of these findings for future safe water service delivery by donors and NGOs in rural West Africa.

2. Methods

2.1. Sample

Communities were selected based on a list of 1000 borehole implementation sites in the Greater Afram Plains (GAP) provided by World Vision's Ghana Rural Water Project (GRWP), which maintains detailed records of all water points installed in the country. While the intention was to capture an exhaustive sample of Hilton-funded water points in the GAP, a number of systems were inaccessible due to road and weather conditions or could not be located based on the information provided, and these systems were not sampled. The final sample included more than 900 of the original Hilton-funded water points in 570 communities, making the results representative of Hilton-Funded systems in the Greater Afram Plains. Water points constructed by other funders that were present in the 570 communities visited were also sampled. While this convenience sample included approximately half of the estimated number of settlements in the GAP, it was neither an exhaustive nor a random sample with respect to non-Hilton funded water points, and the results may not be representative of non-Hilton funded systems in the region. As a result, this study design does not allow quantitative comparisons between Hilton-funded and non-Hilton funded water points in the region, although qualitative comparisons may still be useful.

2.2. Data Collection

A total of 100 trained enumerators visited 1509 water points, 442 water point management teams, and 4674 households in 570 communities in the Greater Afram Plains region of Ghana in 2011. In addition, pumping test were conducted on 50 water points and water quality samples were collected and tested on 46 of these points.

Data were collected using three survey forms: a waterpoint survey, a household questionnaire, and a WATSAN survey. The waterpoint survey was completed once for each waterpoint located in the 570 communities visited. Objective data such as water point functionality and pump type were collected by direct observation. Waterpoint age and original depth were obtained from World Vision's borehole drilling records. Waterpoint data that could not be collected from direct observation or World Vision's records, such as the number of people currently using each water point or the number of times a water point had failed in the past 12 months, were obtained from the water point management team, if available, or a community leader or other community member, if a management team was not present.

A WATSAN survey was also administered to the WaSH Management Team in each of the 570 communities visited, if one was present. In addition, a household survey was administered to each of ten households in each of the 570 communities visited. Household selection was conducted by survey enumerators, who attempted to select a set of households evenly spread over four geographic quadrants in each community. Data collection was carried out using the FLOW V. 1.0 mobile data collection software on Huawei IDEOS mobile phones running the Android operating system (V 2.2).

2.3. Water Quality Data

Water quality samples were collected for 46 of the 50 water points at which pump tests were conducted. These samples were not collected using standard sampling techniques and presterilized sample containers. Rather, Voltic® brand bottled water was purchased and the 1.5 L bottles were emptied at the water point, then refilled with water from the borehole being tested. These samples were then transported to the Environmental Quality Engineering laboratories of the Civil Engineering Department of the Kwame Nkrumah University of Science and Technology (KNUST) for analysis. Standard quality assurance and quality control (QA/QC) procedures for water quality sample collection, including the collection of field blank and duplicate samples, were not conducted, reducing the validity of the results obtained.

Samples were analyzed for 21 physical/chemical parameters and 3 microbiological parameters using standard methods [10]. Briefly, pH and temperature were measured using a portable WTW 340 pH meter. Color was measured using a Lovibond Nesslerizer color comparator. Conductivity and total dissolved solids (TDS) were determined using a MI-MT PSS–00 Eutech Multi-parameter pH meter and further confirmed using a WTW conductivity meter. Alkalinity and total hardness were determined by the titrimetric method and chloride was determined using the Mohr argentometric method.

Sulfate, phosphate, nitrite, and nitrate were determined by colorimetry using HACH DR 3800 and HANNA-HI 83200 spectrophotometers. Fluoride was measured using a WTW F 800 ion selective electrode. Sodium and potassium were determined via flame emission photometry. Manganese, Iron, Magnesium, Calcium and Potassium were determined via flame atomic absorption, using a Perkin Elmer 3110 FAA spectrometer. *E. coli*, total coliforms, and salmonella were determined via membrane filtration using Chromocult® agar.

2.4. Data Inclusion Criteria

Data collected by direct observation, such as water point functionality and handpump type, were deemed to be of adequate quality, and were included in this study. Similarly, data on user numbers and past water point failures, collected by administering surveys to knowledgeable community members such was water point management teams, were also included. Household survey data related to objective and subjective outcomes on which the respondent was likely to be a reliable authority, such as household size and user satisfaction with water access, were also included. However, self-reported data related to outcomes on which the respondent was unlikely to be a reliable authority, such as household survey data on the perceived causes of water point failure, were discarded. Furthermore, where functional WaSH committees were not present, and other community members provided self-reported data on the number of individuals using a water point and the number of system failures in the past 12 months, these data were regarded with greater skepticism than objective observations and expert self-reports.

2.5. Data Analysis

Data were downloaded from the FLOW tool's Google app engine cloud platform and imported into SPSS for preliminary analysis by WSA and its consultants. Additional data analysis was performed by The Water Institute after importing these data into Stata SC (Statacorp, College Station, TX). Summary statistics were tabulated for key variables in all surveys. In addition, standard univariate and multivariate statistical tests, including t tests, one-way ANOVA, and logistic regressions, were used to characterize the relationships between key variables.

3. Results

3.1. Descriptive Statistics

3.1.1. Improved Water Points

A total of 1509 water points funded by the Hilton Foundation as well as other funders were enumerated. Of these, 1393 (92.3%) were classified as improved, while the remaining 116 (7.6%) were classified as unimproved (Table 1).

Table 1. Proportion of water points classified as improved

Is the water point improved?	Freq.	Percent
No	116	7.69
Yes	1,393	92.31
Total	1,509	100

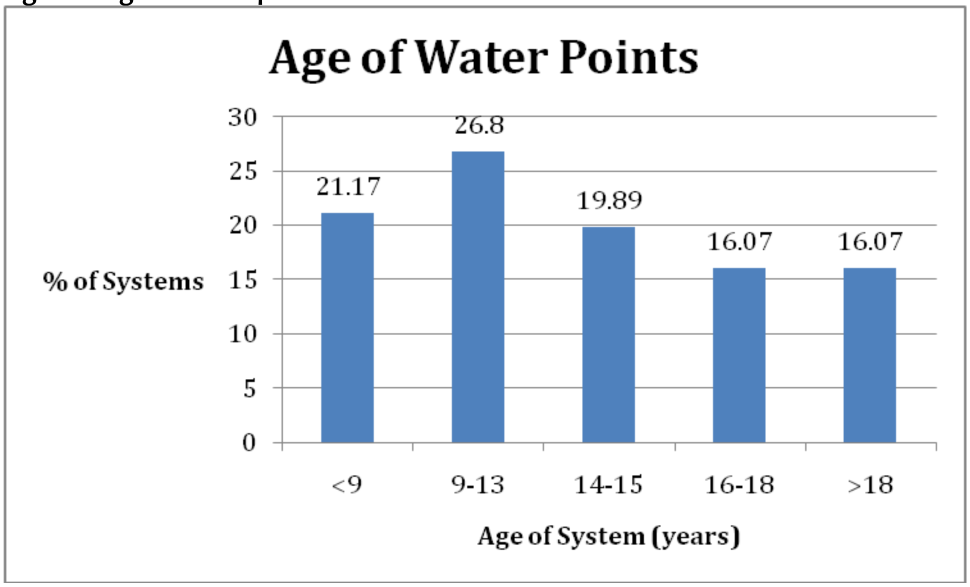
3.1.2. Age of Water Points

The median age of the water points enumerated was 14 years, with a minimum age of less than one year and a maximum age of 60 years. The distribution of water point ages shows that 60% of water points were between 9 and 18 years old (Table 2, Figure 1).

Table 2. Age of water points

Age of water point group	Freq.	Percent
<9	282	21.17
9-13	357	26.80
14-15	265	19.89
16-18	214	16.07
>18	214	16.07
Total	1,509	100

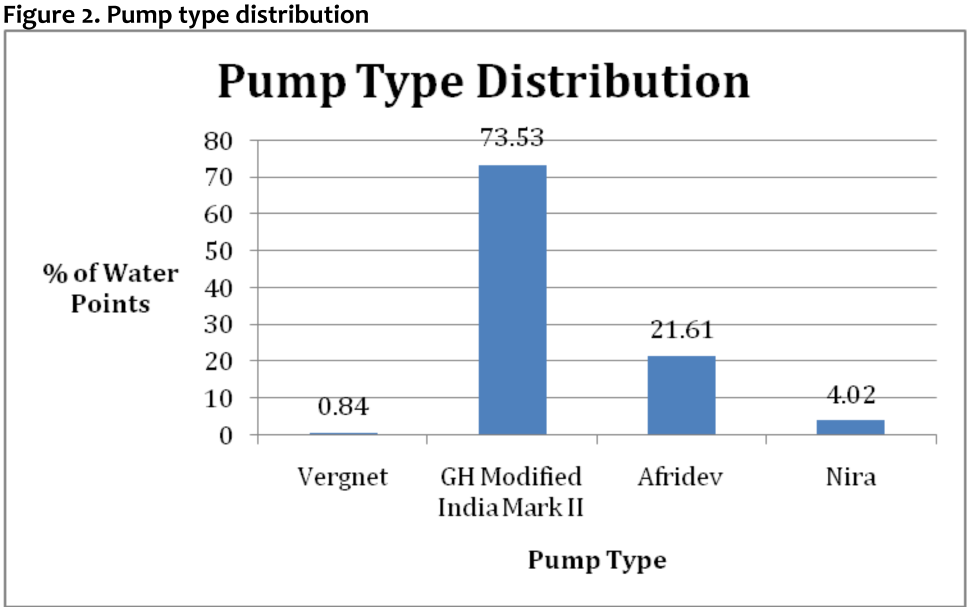
Figure 1. Age of water points



3.1.3. Pump Type

The waterpoint survey results show that the majority (73.5%) of the water points enumerated were Modified India Mark II pumps, with the remainder comprised primarily of Afridev pumps (21.6%), as well as a few Nira (4%) and Vergnet (0.8%) pumps. These results are consistent with the observation that the majority of the water points were installed by World Vision, which primarily uses India Mk II pumps, with a sizable minority installed by UNICEF, which largely employs Afridev pumps (Figure 2).

Figure 2. Pump type distribution



3.1.4. Rehabilitation

A significant fraction of water points in the study area (30%) had been rehabilitated at some point in the past, while the majority (62%) had not (Table 3). For approximately 8% of systems, it was not known whether the water point had been rehabilitated.

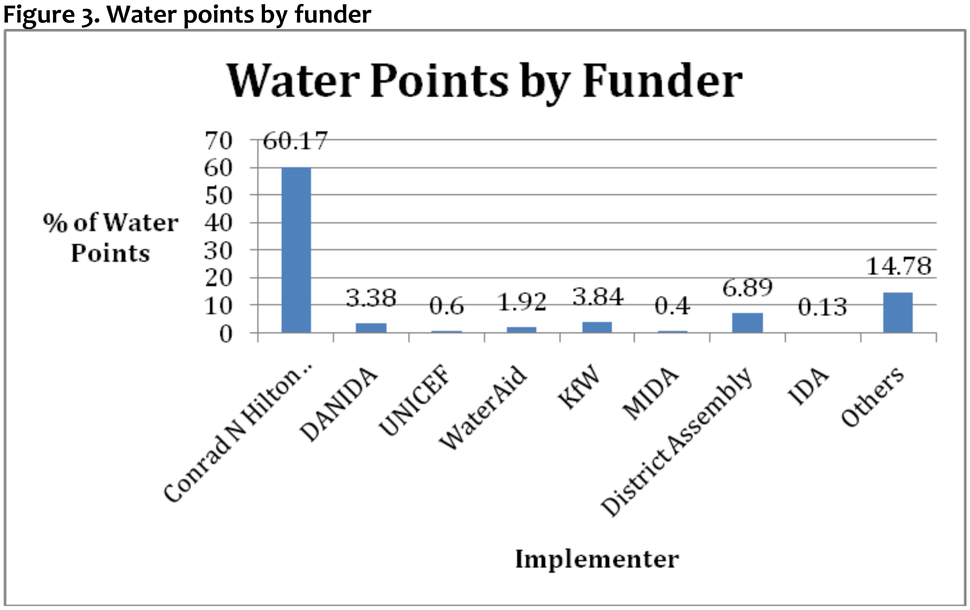
Table 3. Water point rehabilitation

Has the water point been rehabilitated?	Freq.	Percent
No	942	62.43
Yes	451	29.89
No Response	116	7.69
Total	1,509	100

3.1.5. Funder

The majority of the enumerated water points (60%) were funded by the Conrad N. Hilton Foundation, with the remainder funded by local District Assemblies (District offices of Ghana's Community Water and Sanitation Agency) and other NGOs (Figure 3).

Figure 3. Water points by funder



3.1.6. Number of users.

Of the 1509 water points enumerated, the number of users was reported for only 520 systems. For these 520 water points, the median number of users was 50, while the average number of users was 115. Only 7% of these water points had 300 users or more (Figure 4). This finding is particularly significant because many implementers estimate the number of beneficiaries reached by multiplying the number of installed water points by 300, the maximum number of users who may share a borehole, according to Ghana's national standards. However, in the case of the 520 communities in the GAP for which user numbers were available, such a calculation leads to a dramatic overestimation of the actual number of users. The total number of users for all 520 systems was 59,627, whereas multiplying 520 systems by 300 users per system leads to an estimate of 156,000, nearly three times the figure obtained through estimation using survey data (Table 4).

Figure 4. Users per water point

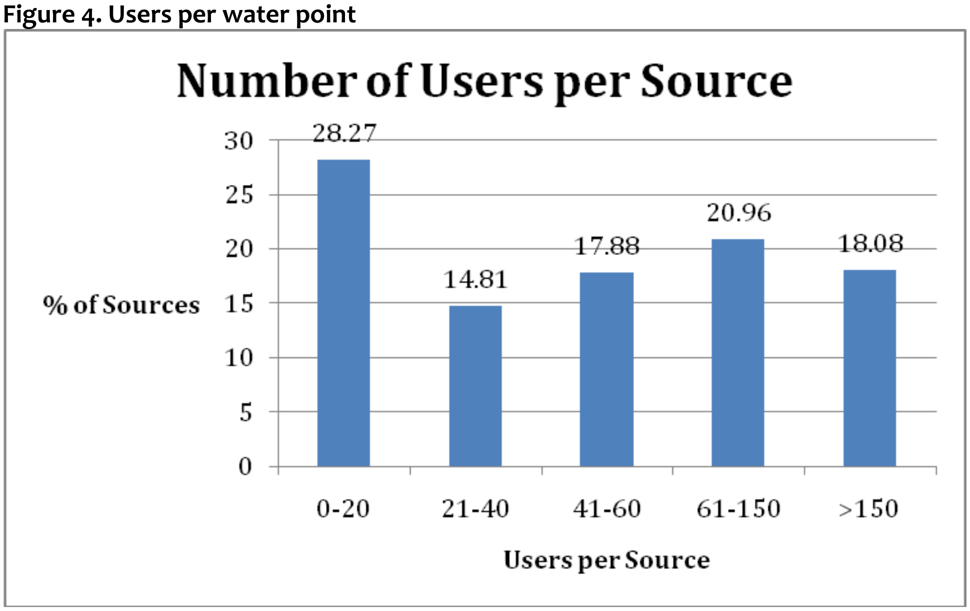


Table 4. Users per water point

Number of Water Points for which user numbers are available	**520**
Estimated total beneficiaries (assuming 300 users * 520 systems)	156,000
Calculated number of users based on survey results	59,627
Percent of systems meeting national standards (<300 users/source)	93%

3.1.7. Monitoring and evaluation.

Of the 440 systems for which responses were reported, 54% reported that some monitoring and evaluation system was in place for their water point, while the remaining 46% reported that no such system was in place (Table 5). However, these self-reported figures were not independently verified, and it is unclear whether a meaningful common definition of "monitoring and evaluation" system was shared by all respondents.

Table 5. Monitoring and Evaluation

Is there any Monitoring and Evaluation system in place?	Freq.	Percent
No	205	46.49
Yes	236	53.51
Total	441	100

3.2. Water Safety

3.2.1. Water Quality Testing

For 24% of the water points studied, survey respondents reported that water quality testing was conducted, while for 52% of systems, it was reported that no water quality testing occurred. In the case of the remaining systems, respondents did not know whether testing was conducted, or no response was recorded (Table 6).

Table 6. Water quality testing

Is there any regular water quality testing?	Freq.	Percent
No	780	51.69
Don't Know	254	16.83
Yes	359	23.79
No Response	116	7.69
Total	1,509	100

3.2.2. Household Water Storage

Households reported storing water in a variety of containers. The majority (80%) reported storing water in large open-mouthed containers such as basins, buckets, and large tanks, which do not meet the standard definition for safe water storage [11], since a hand can easily be inserted into the container (Table 7). Furthermore, 29% of households reported leaving water containers uncovered, while another 14% reported that they did not know whether their water storage container was covered (Table 8). These self-reported figures may well include significant response biases.

Table 7. Water storage container

In what type of container do you store water?	Freq.	Percent
Safe storage		
Bottles	37	1.0
Unsafe storage		
Basin	1,199	31.2
Bucket	163	4.2
Storage Tank	1,725	44.9
Other		
Other	714	18.6
Total	4,670	100

Table 8. Presence of a cover on water storage containers

Do the storage containers have covers? (self-report)	Freq.	Percent
No	1,115	29.05
Don't Know	534	13.91
Yes	2,189	57.03
Total	3,838	100

3.2.3. Household Water Treatment

The majority of households (94%) reported consuming their drinking water without any prior treatment, while 6% reported treating their water before drinking (Table 9).

Table 9. Household water treatment

Does your household treat water at the household level?	Freq.	Percent
No	4,407	94.37
Yes	263	5.63
Total	4,670	100

3.2.4. Source Water Quality

Water quality data were collected from 46 of the 1509 boreholes in the study area. The majority of these sources (82%) did not contain detectible *E. coli*, while 13% contained *E. coli* at concentrations between 1 and 10 colony-forming units (CFU) per 100 mL, constituting low health risk, and 5% contained 11-100 CFU/100 mL, constituting moderate health risk [1]. While *E. coli* itself is rarely pathogenic, it is used by the World Health Organization (WHO) as a relatively reliable indicator of human fecal contamination in drinking water (ibid). In addition, 89% of samples contained detectable total coliforms, while 66% contained detectable *Salmonella* sp. (Table 10, Figure 5).

Water points were also evaluated for several chemical parameters, and the results are reported in Table 11. Out of the 46 water points sampled, 9% exceeded the WHO guidance values for nitrate, while 7% exceeded the WHO values for nitrite. A significant minority of systems also exceed WHO guidelines for pH, conductivity, turbidity, and color, although these deviations do not represent major health risks. It should be noted that due to the limitations in sample size and collection procedures, generalizable conclusions about water quality from water points in the GAP cannot be drawn from the physical/chemical and microbiological data below.

Table 10. Bacteria concentration in source water

Concentration	Total Coliform	*E. coli*	Salmonella
0	10.9%	81.6%	34.2%
1-10	4.3%	13.2%	28.9%
11-100	47.8%	5.3%	34.2%
100-1000	37.0%	0.0%	2.6%
>1000	0.0%	0.0%	0.0%

Figure 5. Bacteria concentrations in source water

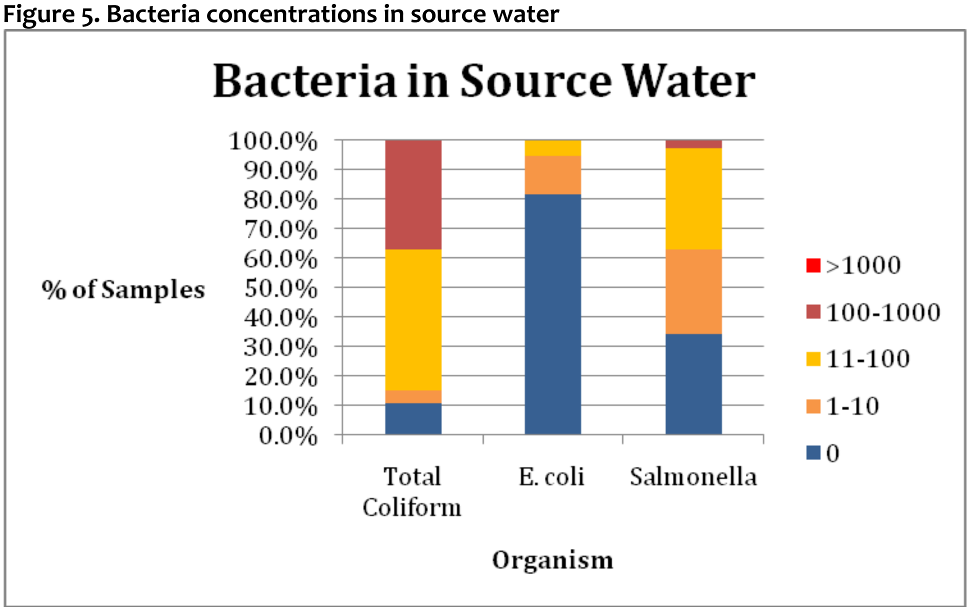


Table 11. Chemical water quality data for source water

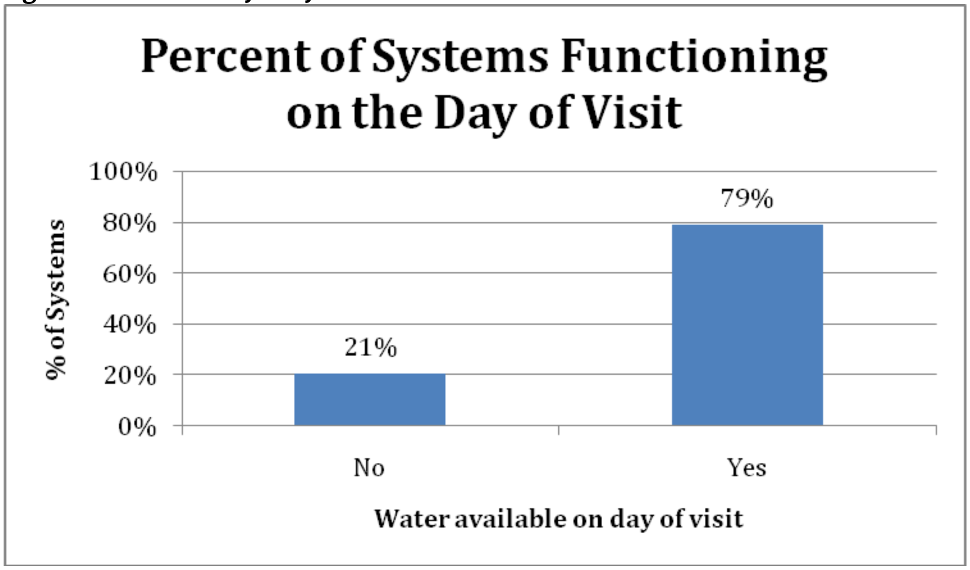
	pH	Turbidity	Conductivity	T.D.S.	Color
	-	NTU	mS/cm	mg/L	TCU
WHO Standard	6.5-8.5	5	-	1000	15
Mean	6.67	2.89	558.15	288.24	924.80
Median	6.7	0.33	451	225	5
% Compliant	68.9	88.9	91.1	97.8	90.0
% Noncompliant	**28.9**	**11.1**	**8.9**	**2.2**	**10.0**
	Total Hardness	Ca Hardness	Calcium	Magnesium	Alkalinity (HCO3)
	mg/L	mg/L	mg/L	mg/L	mg/L
WHO Standard	500		100	150	500
Mean	145.96	80.02	31.43	20.25	158.03
Median	154	64.05	25.65	18.07	131.76
% Compliant	100.0	N/A	97.8	N/A	100.0
% Noncompliant	**0.0**	**N/A**	**2.2**	**N/A**	**0.0**
	No3-N	No2-N	Manganese	Iron	Fluoride
	mg/L	mg/L	mg/L	mg/L	mg/L
WHO Standard	10	0.1		0.3	1.5
Mean	3.63	0.02	0.02	0.07	0.57
Median	2.2	0.01	0.009	0.05	0.559
% Compliant	91.1	93.3	N/A	100.0	97.8
% Noncompliant	**8.9**	**6.7**	**N/A**	**0.0**	**2.2**
	Chloride	Sulfate	Potassium	Sodium	
	mg/L	mg/L	mg/L	mg/L	
WHO Standard	250	250	30	200	
Mean	43.77	3.64	1.64	14.36	
Median	26	1.8	1.1	11	
% Compliant	97.8	100.0	100.0	100.0	
% Noncompliant	**2.2**	**0.0**	**0.0**	**0.0**	

3.3. Functionality

3.3.1. Overall system functionality

At the time of data collection, water was available from 79% of the water points visited (Figure 6).

Figure 6. Functionality of systems



3.3.2. Functionality VS system age.

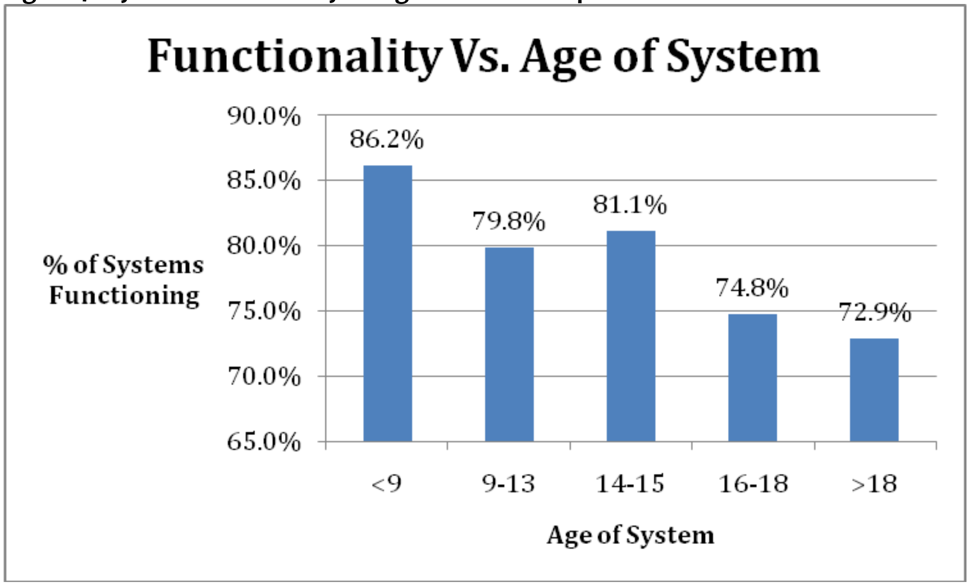
System functionality decreased with increasing age. A pairwise comparison using Tukey's post test showed that the oldest 40% of systems had significantly lower functionality than the newest 20% of systems (Table 12, Figure 7). Water was available from 86% of the newest 20% of systems on the day of the visit, while only 73% of the oldest 20% of systems were functioning. A logistic regression model showed that system functionality decreased by approximately 2% for each additional year of system age, after correcting for other factors (see model below).

Table 12. System functionality VS age of the water point

Age of water point group	% Functionality	Group
<9	86.2	B
9-13	79.8	AB
14-15	81.1	AB
16-18	74.8	A
>18	72.9	A

Groups with no letters in common are significantly different at the 95% Confidence level.

Figure 7. System functionality VS age of the water point



3.3.3. Functionality VS funder

In the univariate analysis, functionality varied with the organization funding the water point construction (Table 13), but these differences were not statistically significant. Of 908 water points funded by the Hilton Foundation, 80% were functional and provided water on the day of the site visit. Water points funded by DANIDA, UNICEF, KfW, District Assemblies, and other organizations had levels of functionality ranging from 77% to 93%, although none of these levels of functionality were significantly different from each other or from the Hilton water points at the 95% confidence interval. Furthermore, the study design does not allow meaningful quantitative comparisons to be made between the representative sample of Hilton-funded water points and the convenience sample of water points constructed by other funders.

However, interesting qualitative comparisons can be made. When system functionality was examined by age and funder, it was found that Hilton-funded systems that were more than 15 years old tended to have higher levels of functionality than systems of comparable ages constructed by local district assemblies, although most of these differences were not statistically significant at the 95% confidence interval (Table 14, Figure8). Some of the observed differences in functionality may be related to differences in management structure, tariff collection, and pump type, among other factors. This conclusion seems to be supported by the regression model described below, as the funder did not significantly affect functionality after controlling for these other factors.

Table 13. System functionality by funder

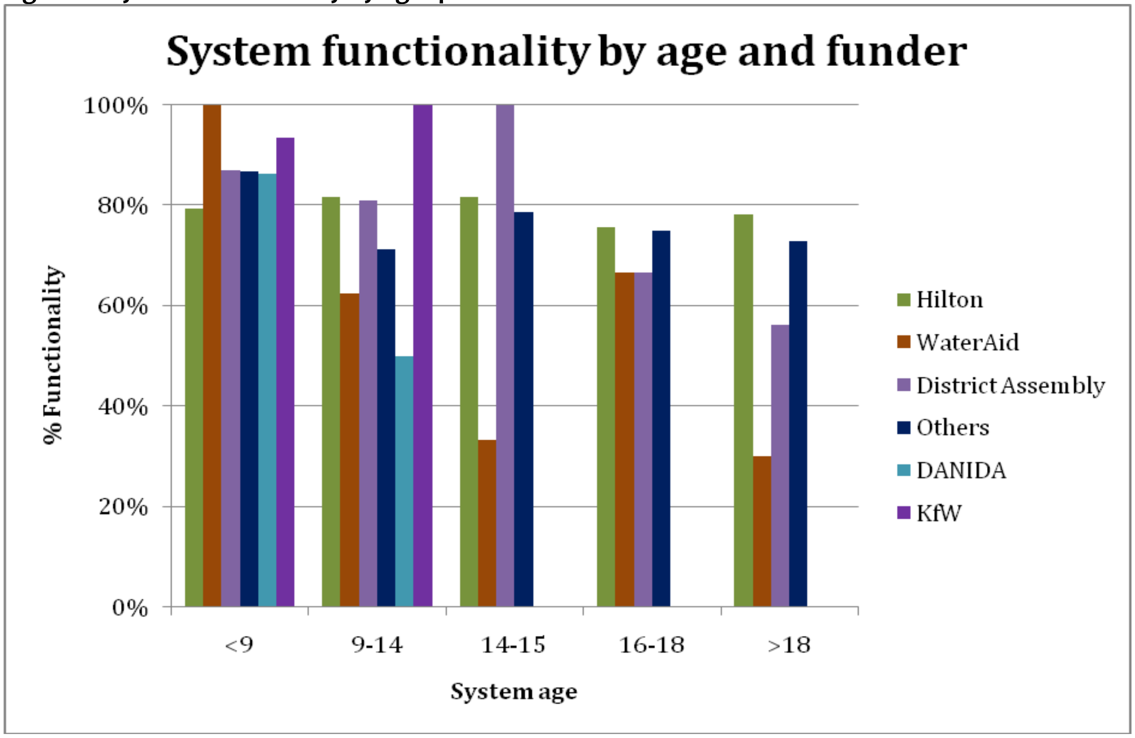
Waterpoint Funder	% Functionality	N	Average Age (y)
Hilton Foundation	79.8	908	14.53
DANIDA	82.4	51	5.37
UNICEF	88.9	9	11.63
WaterAid	48.3	29	16.43
KfW	93.1	58	6.82
District	78.8	104	10.55
Others	76.7	223	14.75

Table 14. System functionality by age quintile and implementer

Age group	Conrad N. Hilton Foundation	DANIDA	WaterAid	KfW	District Assembly	Others
<9	79.41 (68)	86.36 (44)	100 (1)	93.48 (46)	87.04 (54)	86.76 (68)
9-14	81.62 (272)	50 (4)	62.5 (8)	100 (7)	80.95 (21)	71.11 (45)
14-15	81.66 (229)	-	33.33 (3)	-	100 (4)	78.57 (28)
16-18	75.68 (185)	-	66.67 (6)	-	66.67 (6)	75 (16)
>18	78.13 (128)	100 (1)	30 (10)	75 (4)	56.25 (16)	72.73 (55)

Where fewer than 5 water points constructed by a particular funder exist within a particular age range, functionality values are shown in grey, to signify the large uncertainty of these values.

Figure 8. System functionality by age quintile and funder



3.3.4. Functionality VS pump type.

Functionality was found to vary by pump type, with Afridev pumps showing higher levels of functionality than Vergnet pumps in the univariate (uncorrected) analysis. However, these effects were not found to be significant at the 95% confidence interval when corrected for system age, region, management structure, and other factors. Similarly, there was no significant difference in the percent of systems that had reportedly broken down in the past year as a function of pump type. While the differences between the two most common pump types, India Mk II and Afridev, were quite small, there was a slight trend towards higher functionality and less frequent breakdown of Afridev pumps, even after controlling for other factors.

Table 15. System functionality by pump type (Univariate Analysis)

Pump Type	% Functionality	n	Functionality Group	% Breakdown in last year	Breakdown Group
Vergnet	60.0	10	A	50.0	A
GH Modified India	77.9	878	AB	48.6	A
Afridev	85.7	258	B	43.8	A
Nira	79.2	48	AB	50.0	A

Groups with no letters in common are significantly different at the 95% confidence level.

3.3.5. Functionality VS management structure.

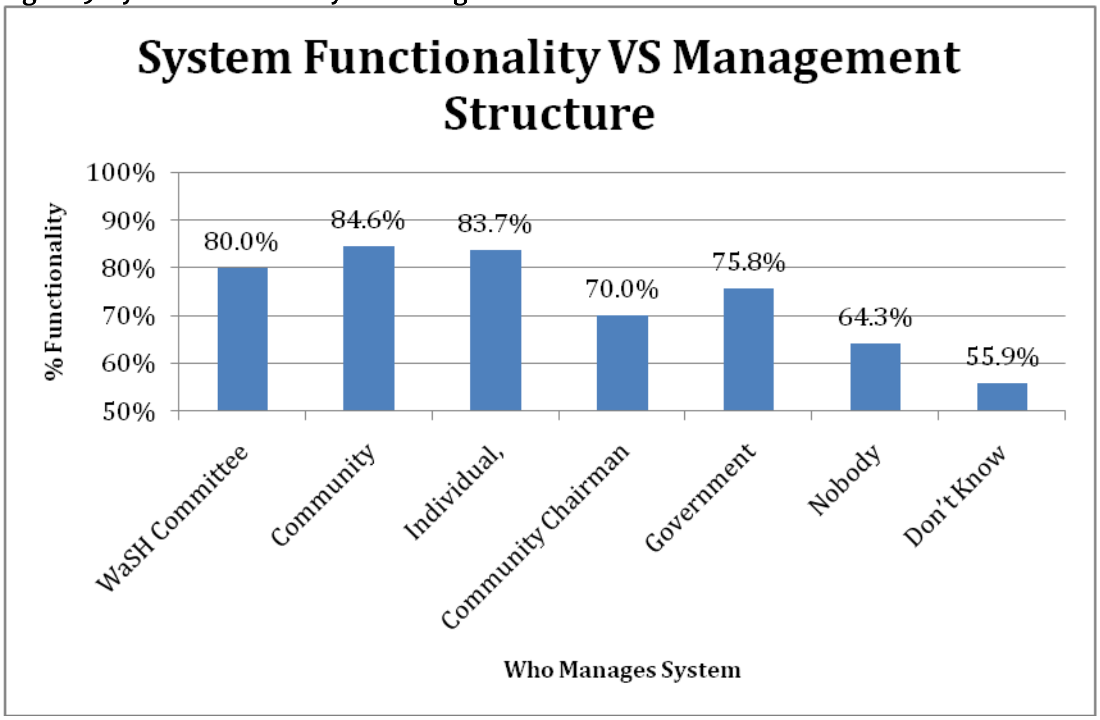
Water point functionality was found to be strongly correlated with the presence of a clear management structure for the system (Table 16, Figure 9). Specifically, in the univariate analysis, water points managed by a WaSH committee or caretaker had significantly higher rates of functionality (80% and 84%, respectively) than systems for which the management structure was not known to respondents (56%). Systems for which the users reported that no management structure existed also had low rates of functionality (64%), although these were not significantly different from other management structures, possibly due to the small number of such systems (n=14). After controlling for other factors, these effects were found to be even more significant: specifically, water points with no identifiable management structure (users responded either "don't know" or "nobody" when asked who manages the water point) were only 37% as likely to be functional as systems with an identifiable water point management structure (any other response). By contrast, the percentage of systems which had reportedly failed within the last 12 months was not significantly correlated with the management structure.

Table 16. System management and functionality

Who Manages	% Functional	n	Functionality Group	% failure in last year	Failure Group
WaSH Committee, WATSAN, Committee Members	80.0	957	A	49.4	A
Community	84.6	13	AB	53.8	A
Caretaker, Individual,	83.7	209	A	44.0	A
Assembly Man, Community Chairman	70.0	10	AB	40.0	A
Government	75.8	33	AB	42.4	A
Nobody	64.3	14	AB	48.5	A
Don't Know	**55.9**	**68**	**B**	42.9	A

Groups with no letters in common are significantly different at the 95% confidence level.

Figure 9. System functionality VS. management structure



3.3.6. Functionality VS tariff collection

Waterpoint functionality was also found to be correlated with the collection of a user tariff. 83% of systems with a tariff were functional on the day of the visit, while only 76% of systems with no tariff were working (Table 17, Figure 10). Surprisingly, the collection of a tariff was also correlated with significantly higher rates of system failure within the previous 12 months (Table 17). This difference was found to be significant at the 95% confidence level. Interestingly, it made no difference whether the tariff was collected on a monthly basis or a per-trip basis (Table 18).

The presence of an identifiable management structure in combination with the collection of a tariff was associated with high levels of functionality (83%), while the absence of both a tariff and an identifiable management structure was associated with low levels of functionality (55%). These differences were statistically significant at the 95% confidence interval in the univariate analysis (Table 19). After controlling for other factors, systems with both a tariff and an identifiable management structure were found to be 3.8 times more likely to be functional than systems with neither, and this result was found to be significant at the 95% confidence interval. Furthermore, it was found that nonfunctional systems with no tariff collection scheme and no identifiable management structure had significantly longer service interruptions than systems with either a tariff, an identifiable management structure, or both (Table 20).

Table 17. Functionality VS tariff collection

Tariff	% Functionality	% Failure in last year
Yes	83.2*	54.1*
No	75.8*	41.3*
Management		
Yes	80.5*	48.3
No	57.3*	47.6

*Results significantly different at the 95% confidence interval.

Figure 10. System functionality VS. tariff collection

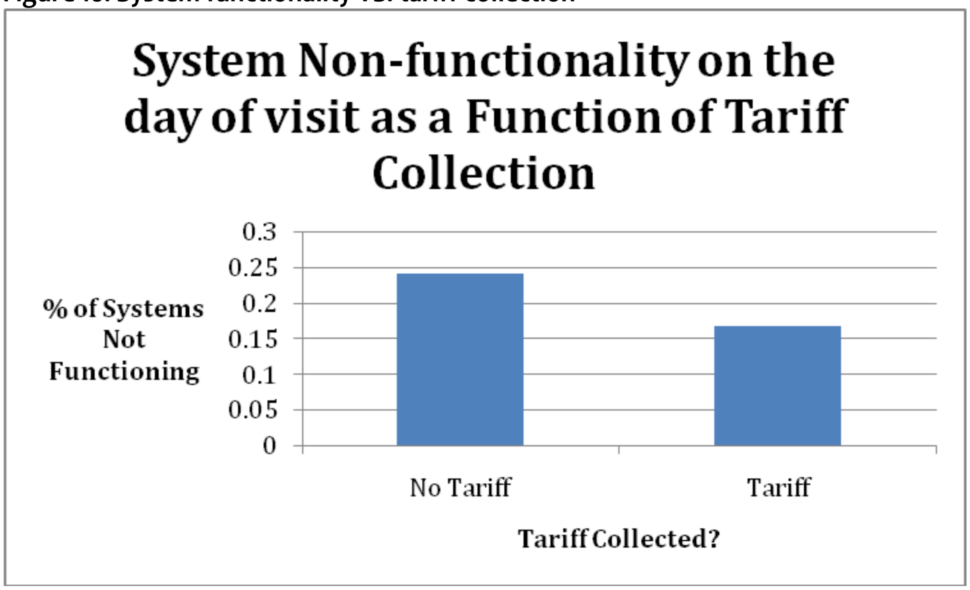


Table 18. Functionality VS Tariff Collection Method

Tariff Collection	% Functioning	N	% Failure in last year
Per Trip	83.6	377	52.0
Per Month	83.5	200	58.5

(Differences were not significant at the 95% confidence interval)

Table 19. Functionality VS tariff collection and presence of an identifiable management structure

	Management structure	
Tariff	Yes	No
Yes	**83.6% (A)**	61.9% (AB)
No	**77.4% (A)**	**55.7% (B)**

Groups with no letters in common are significantly different at the 95% confidence level.

Table 20. Mean number of days out of service for broken water points VS tariff collection and presence of an identifiable management structure

	Management structure	
Tariff	Yes	No
Yes	697 (A)	278 (A)
No	1006 (A)	**2483 (B)**

Groups with no letters in common are significantly different at the 95% confidence level.

3.3.7. Functionality VS pumping difficulty

System functionality was found to be significantly lower, and reported failures within the past 12 months were significantly higher for systems whose users reported that it was sometimes so difficult to pump water that the well was not used (Table 21). While this is perhaps an intuitive finding, the results are nonetheless noteworthy. It should be observed that the question is a rather ambiguous one; users may have responded "yes" to indicate that the pump is often difficult to operate under normal conditions due to mechanical problems or poor borehole yields; alternatively, they may have answered "yes" to indicate that on the frequent occasions when the water point is broken, they find it difficult to pump water. Clearly the former interpretation would be more meaningful than the latter, and a revised survey design could eliminate such ambiguities in future studies.

Table 21. Functionality VS reported difficulty pumping

Difficulty pumping	**% Functionality**	**% Failure in last year**
Yes	78.06*	59.96*
No	86.83*	37.29*

*Values in the same column significantly different from each other at the 95% confidence interval.

3.3.8. Functionality VS number of users

System functionality was found to vary significantly as a function of the number of users reported to be collecting water from each system (Table 22). Specifically, systems with 21-60 users were found to have significantly higher levels of functionality than those with either more than 60 or fewer than 21 users. It should be noted that data on the number of users per system was only available for 520 out of 1509 systems, and these systems were significantly different from the overall sample in terms of functionality, management structure, and other variables. Thus, while these results may be indicative of trends among all systems, they are not necessarily generalizable to the full sample, or to all water points in the GAP.

Table 22. Functionality VS Number of users (n = 520)

User group	% Functionality	n	Functionality Group
0-20	82.3	147	A
21-40	94.8	77	B
41-60	92.5	93	B
61-150	84.4	109	A
>150	79.8	94	A

Groups with no letters in common are significantly different at the 95% Confidence level.

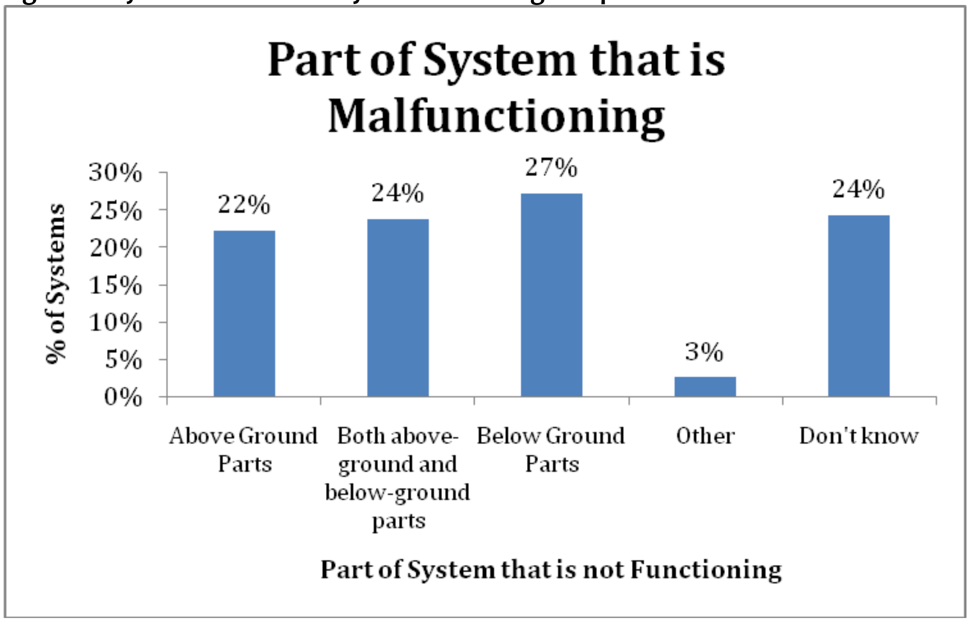
3.3.9. Tariff collection by funder

Systems funded by The Conrad N. Hilton Foundation, Wateraid, and the District Assembly had the lowest rates of tariff collection, while those collected by KfW, Danida, and others had significantly higher rates of tariff collection (Table S2). Many of these differences remained significant even after controlling for the greater age of systems built by the funders in the first group.

3.3.10. Source of system malfunction

The part of the system that was responsible for waterpoint failure varied between systems, but failures of below-ground parts were slightly more common (27%) than failures of above-ground parts (22%), while simultaneous failures of above and belowground parts were also common (24%). Many users also did not know which parts were responsible for the failure (Figure 11).

Figure 11. System breakdown by malfunctioning component



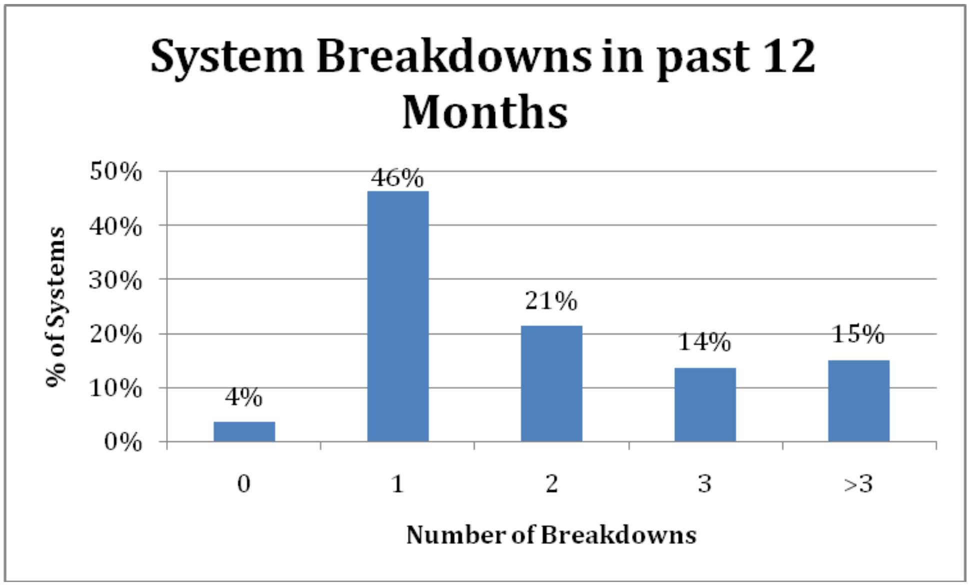
3.3.11. System failure in previous 12 months

While only 20% of systems did not provide water on the day of the visit, nearly half (47.5%) of all systems had reportedly experienced one or more breakdowns in the past 12 months (Table 23). Of systems with one or more failures in the past 12 months, 50% had experienced two or more failures, while 15% had broken down more than three times (Figure 12).

Table 23. System failure in previous 12 months

Has the system broken down in the last 12 months?	Freq.	Percent
No	732	52.5
Yes	661	47.5
Total	1,393	100

Figure 12. System breakdowns in past 12 months



3.3.12. Modeling system functionality

Multivariable logistic regression was used to model the percentage of water points functional on the day of the site visit as a function of key sustainability factors. Several were found to significantly affect waterpoint functionality (p<0.20) in univariate analyses. These were:

1. Presence of an identifiable management structure
2. System age
3. Tariff collection
4. Region
5. Pump type
6. Rehabilitation
7. Difficulty pumping
8. Number of users

However, while data was available for most systems on the first 7 factors, data on the number of users per water point was only available for 34% of systems. As a result, this factor was excluded from the main model.

Based on the model, the fraction of systems functioning on the day of the visit was given by:

Equation 1. Estimated fraction of water points functioning VS age, tariff, management, region, pump type, rehabilitation, and difficulty pumping.

$$\text{logOdds (functionality)} = 0.212 + 0.984 * M - 0.0212 * A + 0.353 * T + 0.156 * H - 0.627 * D - 0.321 * R_2 - 0.255 R_3 + 0.523 * P_2 + 0.906 * P_3 + 0.532 * P_4$$

The above model produced the following Odds Ratios:

Table 24. Odds ratios for water point functionality for all systems (n=1090)

	Variable	Odds Ratio	[95% Conf. Interval]
A	System Age (years)	0.979‡	(0.956-1.003)
T	Tariff collection (1 = yes; 0 = no)	1.423*	(1.020-1.986)
M	Identifiable management structure	2.675*	(1.510-4.737)
H	Water point Rehabilitation	1.169	(0.816-1.674)
D	Pumping difficult	0.534*	(0.381-750)
R1	Ashanti Region	1 (reference)	N/A
R2	Brong Ahafo Region	0.726	(0.489-1.076)
R3	Eastern Region	0.775	(0.523-1.147)
P1	Vergnet Pump	1 (reference)	N/A
P2	India Mk II Pump	1.687	(0.398-7.155)
P3	Afridev Pump	2.474	(0.562-10.900)
P4	Nira Pump	1.701	(0.333-8.684)

*Odds ratios significantly different from 1 at the 95% confidence interval
‡Odds ratios significantly different from 1 at the 90% confidence interval
Odds ratios >1 mean increased functionality, OR < 1 means decreased functionality

These odds ratios indicate that the probability of a system functioning decreases by approximately 2% for each additional year of age, increases by 40% when a tariff is collected, and increases by 168% when an identifiable management structure is present (Table 24). Tariff and management structure are significant at the 95% confidence interval, while age is significant at the 90% CI. In addition, systems that were sometimes so difficult to pump that they were not used were, unsurprisingly, significantly (47%) less likely to be functional on the day of the site visit. Furthermore, water points located in the Brong Ahafo and Eastern Regions had slightly lower levels of functionality than systems in the Ashanti region, although these differences were not significant at the 95% CI. Finally, systems using India Mk II, Afridev, and Nira pumps were more likely to be functional than systems using Vergnet pumps, although these results were not statistically significant at the 95% CI. Additional factors such as the system's funder were not found to significantly affect waterpoint functionality estimates after controlling for the factors above.

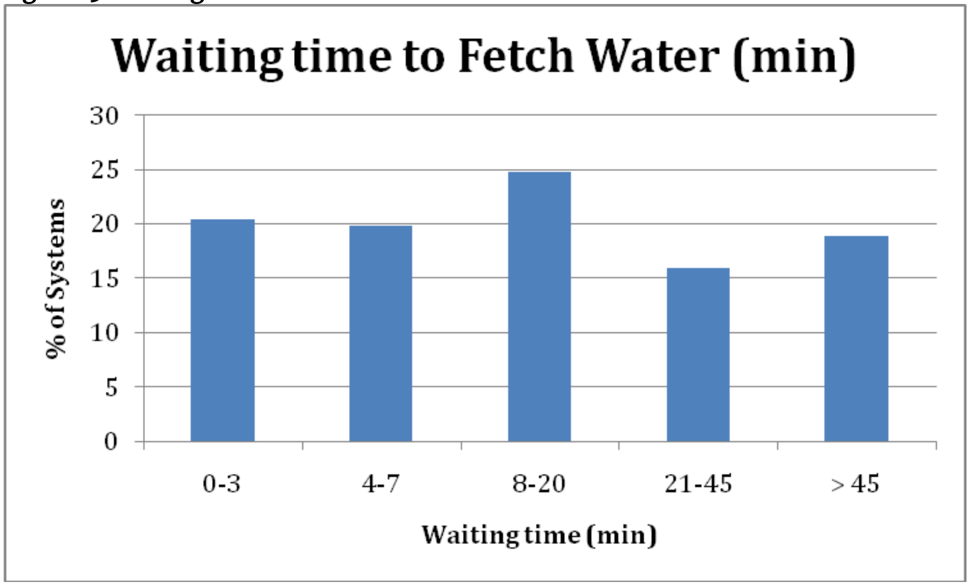
When the same regression was repeated for Hilton-funded systems only (n=718), none of the above factors were found to be statistically significant at the 95% confidence level, and only the presence of an identifiable management structure was significant at the 90% confidence level (Table S4). The decreased significance for variables in this subset of water points may be due in part to the smaller sample size (718 vs 1090 water points). However, it also appears that the effects of system age, pump type, tariff collection, and region are less pronounced for Hilton-funded systems than for water points constructed by other funders.

A similar regression model using data from all implementers found that the likelihood that a system had failed in the past 12 months depended on waterpoint age, region, system rehabilitation, and the collection of a tariff, but not on management structure or pump type (Table S5). The finding that tariff collection and rehabilitation were correlated with increased rates of failure in the past 12 months was the opposite of what would typically be expected, a result that is addressed further in the Discussion section.

3.3.13. Waiting time to fetch water

Users reported significant wait times at the water point (Figure 13). While the shortest 20% of wait times were three minutes or less, 19% of users reported wait times of more than 45 minutes per trip.

Figure 13. Waiting time to fetch water in minutes



3.4. Hydrogeological Data

Hydrogeological data were collected for 50 of the 1509 water points surveyed. These water points had a median depth of 34 m and a median flow rate of 54 L/min (Table S3).

3.5. User Satisfaction

79% of users report that they are currently able to collect enough water to meet their needs, while 20% report that they are unable to collect enough water (Table 25). By contrast, 69.5% of users report that their water supply is adequate year-round, while 30.5% report that it is not (Table 26).

Table 25. User assessment of water supply adequacy

Does the water source provide enough drinking water for the household?	Freq.	Percent
No	902	20.49
Don't Know	39	0.89
Yes	3,462	78.63
Total	4,403	100

Table 26. User assessment of year-round water supply adequacy

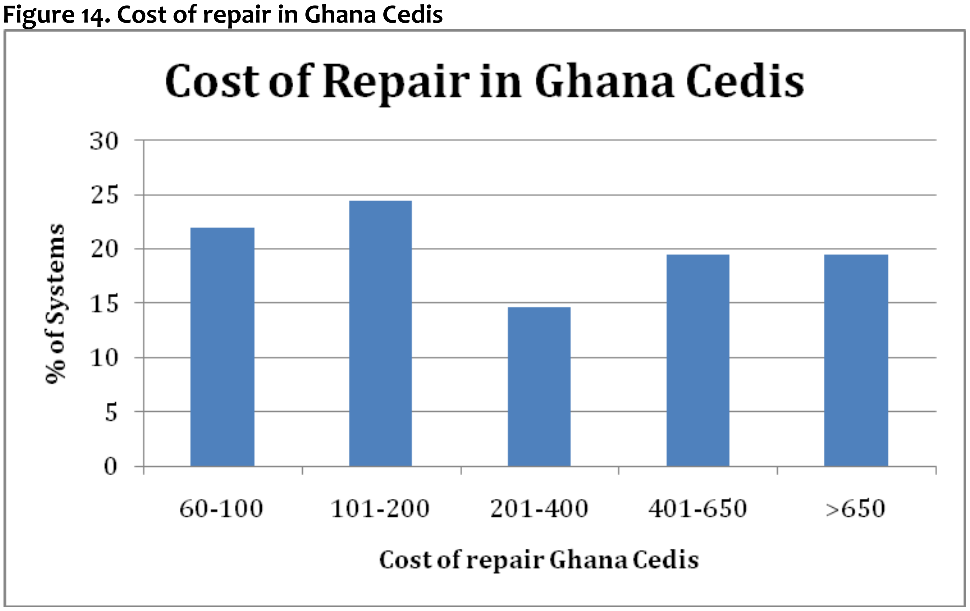
Is the improved water system able to meet your water needs year round?	Freq.	Percent
No	425	30.5
Yes	968	69.5
Total	1,393	100

3.6. Barriers to Sustainability

3.6.1. Cost of Repairs

The cost of repairing water points varied substantially among systems in the study area. The least expensive 20% of repairs had costs between 60 and 100 Ghana Cedis (19-47 USD at current exchange rates), while the costliest 20% of repairs cost more than 650 Ghana Cedis (>305 USD at current rates, Figure 14).

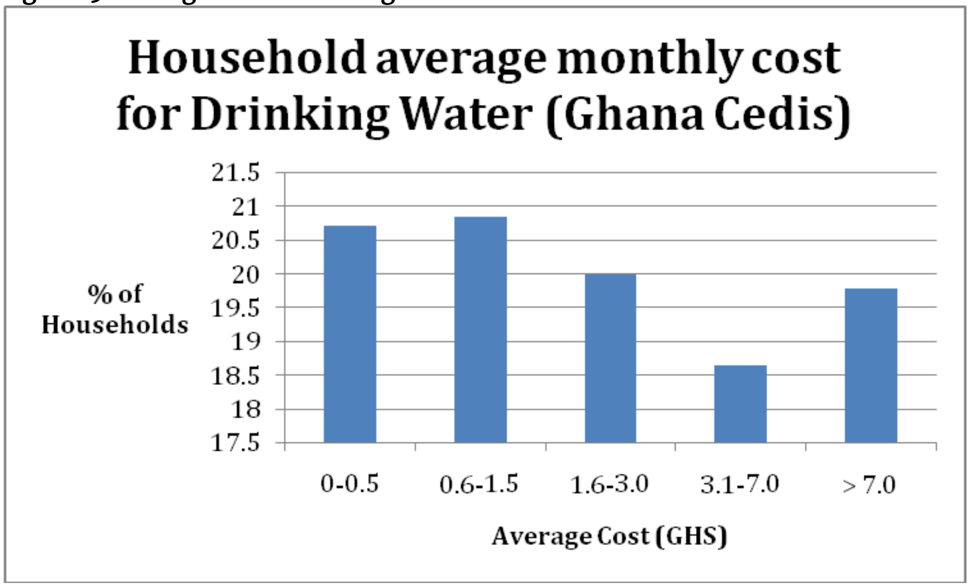
Figure 14. Cost of repair in Ghana Cedis



3.6.2. Cost of water use

The amount that users paid for water also varied significantly. The 20% of users who paid the least for water had estimated total payments of 0-0.50 Ghana Cedis (0-0.24 USD) per month, while the 20% of users who paid the most for water paid > 7.0 Ghana Cedis (> 3.3 USD) per month (Figure 15).

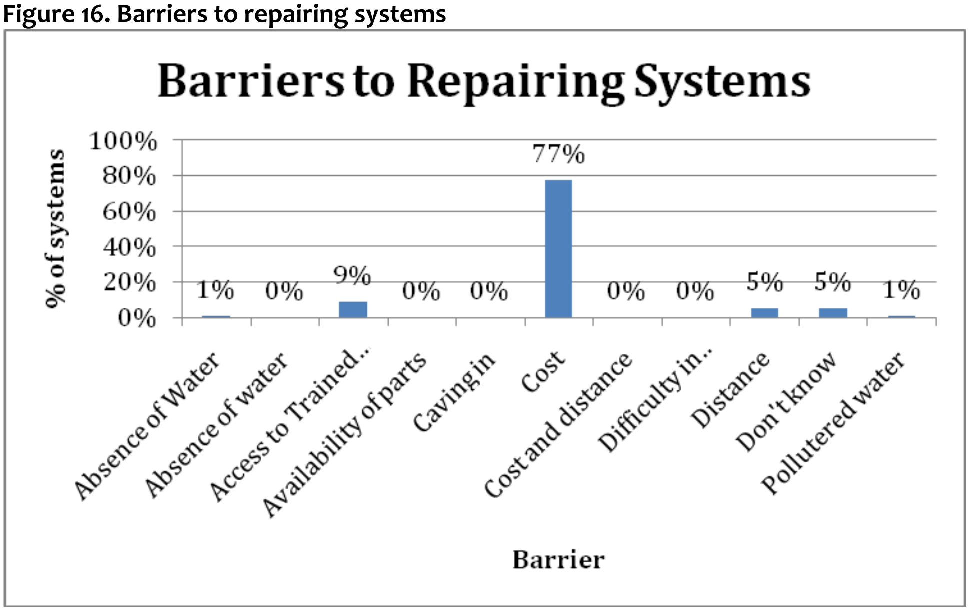
Figure 15. Average cost of drinking water in Ghana Cedis



3.6.3. Barriers to repairing systems

Users reported that cost was the single greatest barrier to repairing damaged water points (Figure 16). Specifically, 77% of users reported that cost was the greatest barrier to water point repair, with access to a trained mechanic being the second most common response (9%).

Figure 16. Barriers to repairing systems



4. Discussion

Based on the above results, a number of factors were found to affect the sustainability of water points. Age was a significant factor for water points in the GAP, but one that is largely beyond the control of drinking water and sanitation implementers. Furthermore, the effect of water point age on system functionality was surprisingly small relative to other factors: only -2%/year for all water points (compounded annually, so that a 30-year old system would be 0.979^30 = 53% as likely to be functional as a new system). Furthermore, the effect of age on water point functionality was even smaller for Hilton-funded systems, and was not statistically significant, suggesting that Hilton-funded systems retained higher levels of functionality over time, after controlling for other variables. By contrast, the paramount importance of an identifiable waterpoint management structure was clearly highlighted by the project results. For both Hilton-funded systems and systems built by all funders, the presence of an identifiable management structure was correlated with functionality levels that were two or more times higher than those of systems without identifiable management.

The collection of a user tariff was also associated with significantly (42%) higher levels of functionality. Furthermore, tariff collection was strongly correlated with the presence of an active management structure (Table S6). This correlation is a relatively intuitive one, since an effective management structure is likely to be a prerequisite for regular tariff collection.

The significant correlation of pumping difficulty with lower levels of functionality was also an intuitive finding, and was robust for all systems in the GAP, as well as for the subset of Hilton-funded systems. Overall, systems for which pumping was so difficult that they were sometimes not used were found to be nearly 50% less likely to be functional, while Hilton-funded systems with pumping difficulty were approximately 40% less likely to be functional. This may be because pumping difficulty is associated with mechanical handpump failure, poor borehole recharge rates, or other hydrogeological and/or mechanical problems. Difficulty pumping was also associated with a statistically significant (100%) increase in reported trailing twelve-month (TTM) failure rates.

By contrast, the finding that tariff collection was associated with higher rates of water point failure during the past 12 months (Table S5) was a counter-intuitive one, and these results cannot be fully explained based on the data collected in the present study. However, the interpretation that tariff collection causes boreholes to fail seems clearly implausible. Rather, it is possible that systems with recent failures are more likely to actively collect user tariffs in order to finance additional future repairs. Alternatively, some unidentified confounding variable may be at play. For example, it may be the case that better-managed systems are both more likely to collect tariffs and more likely to have WaSH committee members who can accurately recall water point failures that occurred within the past 12 months.

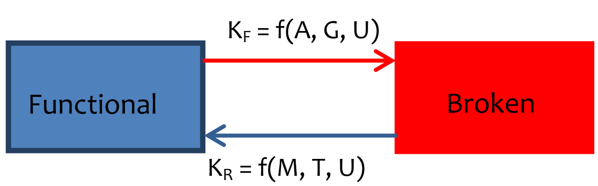
The finding that higher TTM failure rates were correlated with water point rehabilitation is also difficult to explain. One possibility is that boreholes that fail frequently are more likely to be targeted for rehabilitation. In addition, a higher percentage of surveyed systems in the Brong Ahafo and Eastern regions had been rehabilitated, relative to the Ashanti region, and water point failure rates in the former two regions were found to be higher than in the latter. Thus, boreholes requiring rehabilitation in these first two regions may be particularly likely to be adversely affected by underlying hydrogeological conditions, making them more susceptible to failure. In any case, the relationship between tariff collection, borehole rehabilitation, and TTM failure rates requires further study using more rigorous longitudinal methods, since self-reports are known to become unreliable with longer recall periods, and 12 months is almost certainly too long a recall period for accurate self-reported water point failure results.

Waterpoint functionality was not significantly correlated with handpump type, although the data suggested that India Mk II, Afridev, and Nira handpumps tended to be associated with higher levels of functionality than Vergnet pumps. It is possible that these pump types are easier to repair, either due to the availability of parts, the ease of maintenance, or the prevalence of mechanics trained in repairing these pump types. The finding that the reported time required to obtain spare parts was correlated with TTM failure rate, but not functionality on the day of the visit, is an interesting finding, and cannot be easily explained. It is possible that this variable is subject to recall bias, with systems that have experienced recent failures reporting longer times to obtain parts.

One potentially telling outcome of this work is the finding that availability of water on the day of the visit depended strongly on management structure and tariff collection, while the reported occurrence of a failure within the past 12 months did not depend on management at all, and appeared to be higher when tariffs were collected. This finding, if accurate, suggests that the main benefit of an active management team able to collect tariffs is the ability of this team to repair broken water points, rather than to prevent water point failures from occurring in the first place. In other words, the data suggest that all water points may periodically fail, but well-managed water points are repaired more quickly, leading to greater levels of functionality for these systems at any given time. This hypothesis is also consistent with the finding that cost was overwhelmingly the most commonly cited barrier to repairing broken water points, and the finding that the reported time required to obtain spare parts did not significantly affect water point functionality.

Based on overall functionality and TTM failure rate findings, we hypothesize that water points fail at some rate that is correlated with age, hydrogeology, and user numbers, and are repaired at some rate that is correlated with the presence of a functioning management structure, regular tariff collection, and user numbers.

Figure 17. Diagram of waterpoint functionality equilibrium



While we would expect the number of users to increase the rate of waterpoint failure, the results suggested that higher levels of waterpoint functionality were associated with intermediate numbers of users (20-60) in the current study, and that while higher numbers of users led to reduced functionality, very low user numbers also decreased the likelihood of a water point being functional. This could be because large numbers of users place great mechanical strain on a water point, while very small numbers of users create financial strain because their tariff contributions may be inadequate to finance system repairs. However, the small amount of data available on user numbers makes it difficult to determine whether these results are meaningful and representative of all water points in the GAP, or are an artifact of the particular types of water points for which data on the number of users were available (typically better-managed water points with active committees that could provide such information). In addition, confounding by some unknown third factor that is collinear with user number might also contribute to the apparent effect of user numbers. More work will be required to determine which of these possibilities, if any, is valid.

The overall findings of this work are largely intuitive: older systems fail somewhat more frequently than newer systems, as do systems where users have difficulty pumping water, while good management and effective tariff collection result in systems being repaired more quickly when they break down. However, the relative effect sizes of the different sustainability factors have important implications for the management of rural community water points. To maximize the sustainability of safe water systems, implementing organizations must prioritize the establishment of durable WaSH committees with the ability to collect adequate user tariffs, as these related factors were found to be the most important determinants of water point functionality. In addition, regular monitoring may be essential to ensure that WaSH committees remain functional and continue to collect tariffs. This monitoring may be particularly critical for systems where users have reported difficulty pumping enough water to fill their containers.

While eventual rehabilitation or replacement of aging systems will remain a necessity, the results of this study suggest that a 2 year-old system without a functioning management structure is less likely to provide water at any given time than a 20-year old system with an active WaSH committee that is regularly collecting tariffs. Since rehabilitating WaSH committees and other "software" may be far less costly than rehabilitating boreholes and associated "hardware," WaSH implementers may be able to increase the sustainability of water points at relatively low cost by expanding their use of reliable, low-cost methods for regularly monitoring borehole management and tariff collection, and rehabilitating or reconstituting WaSH committees as necessary. Furthermore, since systems for which pumping is reportedly difficult are far less likely to be functional than systems without such problems, pumping difficulty at the time of water point installation or subsequently should be seen as a significant warning sign that the source may be at elevated risk of failure, and may require rehabilitation or replacement in the future. Finally, particularly low or high numbers of users per water point may also be a risk factor for system failure, although more work is needed to confirm that this relationship is a meaningful one.

Needless to say, no water point lasts forever, and systems may eventually fail due to factors such as mechanical breakdown, siltation, changing groundwater levels, and other causes. Nevertheless, such failures should be infrequent, and it may be possible to predict these failures with increasing accuracy through regular and systematic monitoring. Future monitoring and evaluation efforts may seek to monitor basic water point functionality (including pumping difficulty) and user numbers, management team presence and activity, and tariff collection, as well as microbiological water quality with relatively high frequency (e.g. one to two times per year) and high spatial resolution (i.e. at every water point in a region), while hydrogeological factors and chemical water quality may be monitored with relatively lower frequency and reduced spatial resolution (e.g. every n^{th} water point in a region, and every 1-5 years, depending on the parameter). Donors and nonprofits may seek to invest in independent capacities to conduct such monitoring, but may achieve greater sustainability and added value by coordinating their efforts with national monitoring schemes, particularly if high-quality data can be shared between national governments and NGOs.

Finally, the user data from this study suggest that current beneficiary accounting practices, which are commonly used across NGOs in the drinking water and sanitation field, may not be sufficiently accurate. If regular monitoring efforts can include the collection of accurate data on the number of individuals using each water point, as well as on the functionality of that water point and the safety of the water produced, more accurate estimates of the numbers of beneficiaries being reached, as well as the levels of service they are receiving, may be obtained. Accurate and timely estimates are critical, as they can shift service delivery towards providing higher levels of service with higher functionality rates to the greatest possible number of unserved and underserved individuals.

5. Conclusion

The results of the Sustainable Water Services Delivery project suggest that the majority of water points installed in the Greater Afram Plains region by the Conrad N. Hilton Foundation appear to be providing safe drinking water to many tens of thousands of individuals at any time. However, at any given time a significant minority of these water points are not functioning, while an unknown fraction of functional systems may produce water of questionable microbiological quality. Moreover, the number of individuals benefitting from these systems may be less than half of what would be estimated using traditional beneficiary calculation methods common in the WaSH sector in West Africa.

The results of this work suggest that regular monitoring and evaluation of WaSH committee functionality and tariff collection, as well as of water point functionality and water quality, can support pro-active rehabilitation of critical software and hardware, greatly improving the functionality and sustainability of water points in the region, as well as the safety of the water these systems are providing. Moreover, beneficiary calculation methods based on monitoring data, rather than on national standards for users per system, may help provide a more realistic picture of the number of individuals benefitting from safe water interventions.

Rather than becoming discouraged by the fraction of water points that experience periodic failure, sector participants should view this study as highlighting the resilience of current hardware and software implementation methods, while also emphasizing important opportunities to further improve these methods in the future.

6. References

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7. Supporting Information

Figure S1. System functionality by pump type and age

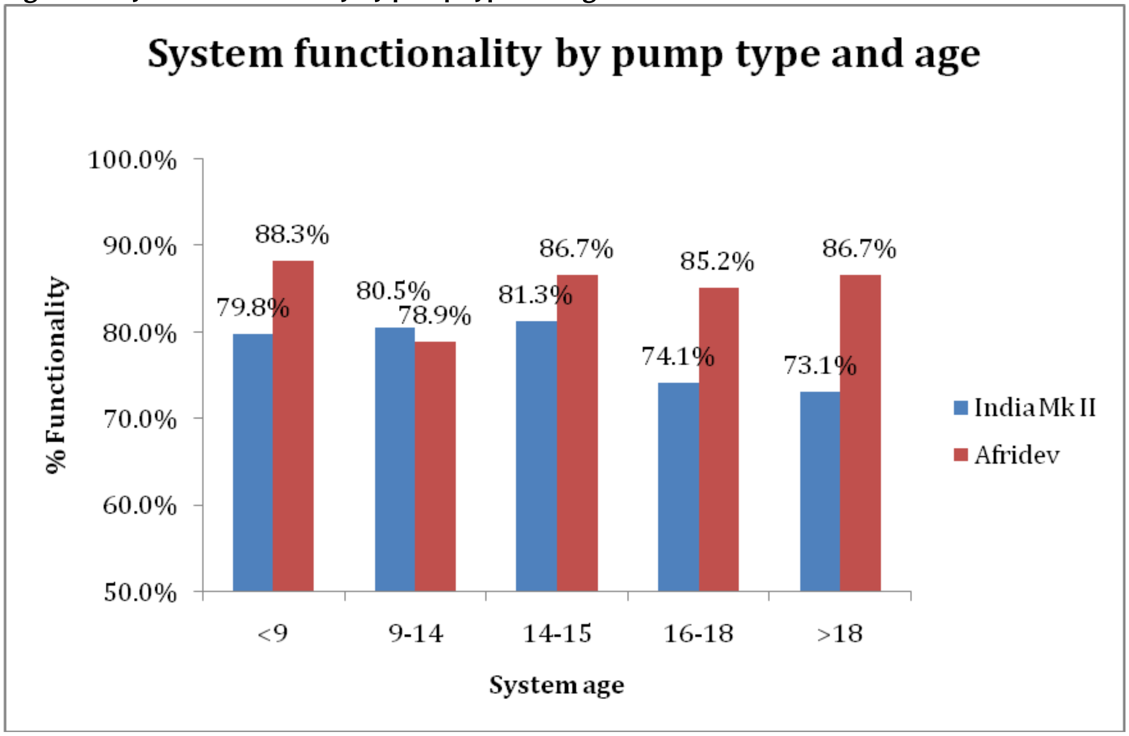

Table S1. System functionality by management system and tariff collection

	No known management		known management	
Age group	No tariff	Tariff	No tariff	Tariff
<9	60.0%	33.3%	85.9%	89.8%
9-14	57.1%	55.6%	76.4%	87.7%
14-15	100.0%	83.3%	79.1%	82.4%
16-18	40.0%	0.0%	77.0%	71.0%
>18	25.0%	100.0%	65.7%	78.5%

Table S2. Tariff collection by funder

Waterpoint Implementer	% Tariff Collection	Tariff Group
World Vision	42.5	A
DANIDA	84.3	C
UNICEF	66.7	ABC
WaterAid	31.0	A
KfW	81.0	C
District Assembly	48.1	A
Others	56.5	B

Groups with no letters in common are significantly different at the 95% Confidence level.

Table S3. Borehole depth and flow rate

	Depth (m)	Flow (L/m)
Mean	35.1	135.7
Median	33.8	54
Min	27.6	10
Max	52.1	1400

Table S4. Odds ratios for water point functionality for Hilton-funded systems (n=681)

	Variable	Odds Ratio	[95% Conf. Interval]
A	System Age (years)	0.994	(0.954-1.034)
T	Tariff collection (1 = yes; 0 = no)	1.132	(0.765-1.675)
M	Identifiable management structure	2.222*	(1.075-4.597)
H	Water point rehabilitation	1.323	(0.861-2.032)
D	Difficult to pump	0.601*	(0.403-0.897)
R1	Ashanti Region	1 (reference)	N/A
R2	Brong Ahafo Region	0.819	(0.521-1.289)
R3	Eastern Region	0.982	(0.608-1.586)
P1	Vergnet Pump	N/A	N/A
P2	India Mk II Pump	1 (reference)	N/A
P3	Afridev Pump	0.929	(0.513-1.682)
P4	Nira Pump	N/A	N/A

*Odds ratios significantly different from 1 at the 95% confidence interval

ǂ Odds ratios significantly different from 1 at the 90% confidence interval

Odds ratios >1 mean increased functionality, OR < 1 means decreased functionality

Table S5. Odds ratios for water point failure within the past year for all systems (n=830)

	Variable	Odds Ratio	[95% Conf. Interval]
A	System Age (years)	1.002	(0.980-1.025)
T	Tariff collection (1 = yes; 0 = no)	1.414*	(1.044-1.915)
M	Identifiable management structure	0.929	(0.450-1.920)
H	Water point rehabilitation	1.819*	(1.321-2.506)
D	Difficult to pump	2.069*	(1.532-2.794)
R1	Ashanti Region	1 (reference)	N/A
R2	Brong Ahafo Region	1.319	(0.901-1.931)
R3	Eastern Region	0.821	(0.566-1.190)
P1	Vergnet Pump	1 (reference)	N/A
P2	India Mk II Pump	0.289	(0.028-2.937)
P3	Afridev Pump	0.217	(0.021-2.236)
P4	Nira Pump	0.329	(0.030-3.650)
PQ1	Parts quintile 1	1 (reference)	N/A
PQ2	Parts quintile 2	1.511‡	(0.981-2.328)
PQ3	Parts quintile 3	2.323*	(1.383-3.904)
PQ4	Parts quintile 4	1.688*	(1.111-2.567)
PQ5	Parts quintile 5	1.845*	(1.204-2.827)

*Odds ratios significantly different from 1 at the 95% confidence interval

‡ Odds ratios significantly different from 1 at the 90% confidence interval

Odds ratios >1 mean increased failure rate, OR < 1 means decreased failure rate

Table S6. Correlation matrix for key variables in this study

	Age	Tariff	Management	Pump Type	Region	Rehabilitation	Funder	User #
Age	1							
Tariff	-0.0353	1						
Management	0.0163	0.1208*	1					
Pump Type	-0.2755*	0.1109*	0.047	1				
Region	0.2353*	0.0162	-0.0292	-0.1263*	1			
Rehabilitation	0.1522*	0.1324*	0.082	0.0026	0.1634*	1		
Funder	-0.0554	0.1043*	-0.0689	0.3361*	-0.0947*	-0.0274	1	
User #	-0.0106	0.0182	0.0595	-0.0141	0.1096	0.0692	-0.0448	1
Difficult to Pump	-0.0099	0.1266*	-0.0023	0.0258	-0.057	0.1190*	0.0976*	0.02

*Odds ratios significantly different from 1 at the 95% confidence interval