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Evaluating the Level of the Household Water Service Provided by a Private Water Enterprise in Ghana

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Abstract: Innovative service delivery models are attempting to more consistently provide clean water to communities in developing countries. It is imperative that these approaches be evaluated for their performance in these contexts while understating potential consequences. A private service delivery model in Ghana utilizing solar-powered water treatment, circuit rider principles, pre-paid metering, and a district-wide approach was assessed for three years. A quasi-experimental design used key informant surveys, household surveys, and water quality testing to investigate the service received by households under various management schemes. Service indicators were compared using logistic regression analysis. Private customers were shown to have significantly improved quality, annual reliability, and satisfaction ratings ($p < 0.05$) compared with control households, while maintaining the quantity of water collected. However, private customers were more reliant upon multiple water sources to meet domestic needs and suffered from lower affordability scores. About 38% of households used private water services, with no significant relationship with socioeconomic class. It is important for policy-makers and implementers to understand that some people will be unwilling or unable to take advantage of this model, and a transition from free improved sources to paid piped schemes will likely require a period of supporting both systems in order to reach everyone.

Keywords: rural water supply; service delivery models; Sub-Saharan Africa; equity; financial sustainability

1. Introduction

1.1. Background

After decades of fighting for access to improved water sources, the Sustainable Development Goals are now aiming for universal and equitable coverage of safely managed drinking water services by 2030 [1]. These goals strive for a continuous service, safe water quality, and sustainable management at an affordable rate. However, recent estimates suggest that 26% of handpumps in Africa are broken at any given time, with non-functionality rates of over 50% in some regions [2]. Even when improved sources are available, microbiological contamination and an intermittent service can limit the benefits of both handpumps and piped systems [3,4]. This is exacerbated in rural areas, where 80% of people lack access to basic water services [5]. An inadequate institutional capacity, poor financial and asset management, insufficient monitoring and maintenance, and the unsustainable use of water resources have all been cited as causes for the enduring nature of these issues [6–10].

In response to these challenges, new service delivery models are taking shape in order to more effectively and consistently provide clean water to communities in developing countries [11]. Management models of varying complexity can be structured as community-based management, local government management, public water utilities, private companies, or assorted combinations of these options [10,12–15]. Service providers can assume different levels of responsibility, such as only responding to emergency breakdowns, providing regular maintenance, or guaranteeing a regular service [16]. Different financing mechanisms aim to cover various degrees of life-cycle costs in order to incentivize reliable water service provision and sustainability [13,15,17]. Recent studies have found evidence for greatly increased reliability and functionality rates, faster breakdown response times, and increased revenue for water systems managed by these novel service providers [8,17–19].

It is imperative that innovative service delivery models be evaluated for their viability and performance in developing contexts, and their ability to guard against potentially harmful consequences. Community-based management and private utilities have had similar hopes for an improved performance in the past. For instance, the limited ability of community-based management to achieve technical and financial targets has been highlighted in recent years, despite its prevalence in international policy [20–22]. Chowns [23] found that maintenance was rarely done, repairs were delayed or sub-standard, and user committees could not save or collect sufficient funds in community-based systems. From a different perspective, informal water vendors may increase water prices based on demand or provide an unsafe water quality with no regulatory oversight [24]. Large private initiatives have also failed to provide improved water services compared to public utilities [25–28]. Prepaid meters used by private companies have been known to cause diminished hygiene behavior or decreased water usage, and harsh cutoffs or increased incidences of disease at their worst [25,29]. These examples highlight the need to better understand new models with regards to the level of service they provide, as emphasized by the World Bank in their recent summary report [10].

In this mixed-methods study, a quasi-experimental research design was used to assess the impact of a private service delivery model (PSM) on water service provision in Ghana. The study area will first be defined with regards to its geographical and institutional setting. Then, the research design and service level indicators used for evaluation (including the water quality, quantity, accessibility, reliability, affordability, and acceptability) will be described. Next, the results of this multi-year study will show the positive and negative effects of this management style. Finally, the implications of the PSM will be discussed with regards to policy, sustainability, and social justice.

1.2. Site Setting

Nationally, Ghanaian service providers are regulated by the Ministry of Water Resources Works and Housing, with rural communities and small towns (typically with a population of less than 5000) falling under the jurisdiction of the Community Water and Sanitation Agency (CWSA) [27]. The national government established this arrangement in the late 1990's, when it underwent institutional reform. The most common service provider in Ghana, particularly for rural populations, is community-based management, with different tiers of external support, delegation, and ownership. Communities often own a communal source while having a committee that oversees maintenance and tariff collection. Public utilities (Ghana Water Company Ltd.) are more likely to serve large towns, such as a district capital. Religious institutions, mining companies, and self-supply are all present in varying degrees. Informal private entrepreneurs also play a role, especially those that sell sachet water [10,15,27]. Professional PSMs, though historically active in Ghana's urban centers, have only recently made efforts to expand into rural districts [28].

This study occurred in the Wassa East District in the Western Region of Ghana. In 2016, the Wassa East District had approximately 137 communities and a population of about 90,000 people [30]. The district is considered rural, with high rates of agricultural employment, lower incomes, and over 82% of communities having a population of less than 1000 people. There are three larger urban areas where significant trade occurs. Groundwater in the area is generally found to be of a good chemical quality, with the exception of aesthetic issues, such as an acidic pH and high iron, manganese, and aluminum concentrations [31,32]. Surface water, however, can often be polluted by local mining activities in the area.

A number of stakeholders have interest in the provision of water services in Wassa East: the relatively new PSM, the local government, the water management committees, the communities, and an investing NGO. The organizational structure and stakeholder exchanges can be seen in Figure 1. At the service authority level, the local government is responsible for planning, regulating, and maintaining water sources within their district jurisdiction [27,33]. The local government delegated this responsibility to a PSM, establishing a contract to provide water for each interested community at an agreed price point per liter. The local government has acted as a regulatory body to ensure that all obligations are met. Water management committees in each community have also assumed a regulatory role, in addition to managing existing communal water sources. Lastly, an external NGO provided the initial infrastructure capital for the intervention, and continues to provide institutional support to the PSM.

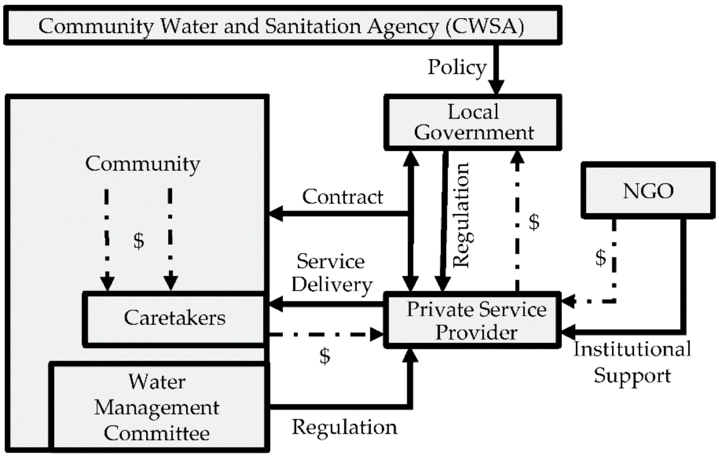

Figure 1. Service provider institutional framework.

The PSM under evaluation in this district is called Access Development. In 2016, the company arranged a formal agreement with the local government to build, own, and operate solar-powered piped systems and boreholes in the area. They have plans to ultimately provide 90% of the district population with access to safe and reliable water; a proportion meant to benefit from economies of scale. The focus of the business is selling water at kiosks, where it is treated by microfiltration, UV disinfection, and chlorination (see supplementary material). However, borehole service contracts are also established in the smallest communities. The company maintains their systems using circuit rider methods of operation [8,34]. The innovation of the PSM lies in their modular technology, which allows a gradual expansion to decentralized sales points, institutions, and household connections. Customers 'pay-to-fetch' from vendors for their water with cash (0.20 GHS per 18 L)—an established practice in the district. The contracted vendors submit requests to the PSM for periodic tank fill-ups using mobile money accounts and pre-paid metering. Revenue is then managed by Access Development in order to maintain their assets through life-cycle planning. Similar models, each with unique approaches and payment structures, are found in Uganda (Whave and Lifeline), Kenya (Fundifix), Burkina Faso (Uduma), and Ghana (Safe Water Network) [15].

Overall, this study aims to understand whether a private service delivery model, such as Access Development, can provide equivalent or improved levels of water service when compared to more traditional management systems in a rural, developing country context. Within this comparison, what risks or consequences are present within the model? When considering historical failures of private providers [25,29], it is important to investigate potential disparity in access based on relative wealth. Given the institutional framework and pre-payment required, it can be hypothesized that overall, the district will benefit from an improved service, but the quantity of water collected and the penetration rates will be lower for those in poor socioeconomic classes.

2. Materials and Methods

A quasi-experimental design was used to evaluate the water service provision of the PSM and compare it with existing management systems in the district. A baseline-endline assessment of an intervention group and a non-equivalent control group allowed comparisons of the overall service across time to be conducted [35]. The baseline surveys were conducted in 2016, prior to the PSM beginning service provision in Wassa East. The endline surveys were completed in 2019, after intervention communities had been under contract with the PSM for six months to two years. Individual cross-sectional assessments could also be completed for each temporal period [36]. Much of the initial analysis will use the 2019 endline data to compare groups, after which the baseline will be used to identify maturity and growth over time. A combination of key informant surveys, water quality testing, and household surveys was used to collect the required data for assessment, which all occurred within a six-week period [37,38].

The key informant survey and water quality testing used one-stage cluster sampling, in which each community was considered a cluster. Thirty intervention and thirty control communities were selected for testing. Communities selected for intervention were decided by the PSM, initiating the quasi-experimental design. The PSM prioritized communities with a poor service, little external support, and favorable political environments. As the decision-making process evolved over time, competition and the population size also factored in to which communities received the service. Statistical comparisons were made between group environments from the baseline to understand potential biases at the onset of the study.

Local enumerators assessed every water point within the sixty selected communities using a key informant survey. Key informants were often representatives of previously established water management committees, but also included chiefs and other local leaders. Recorded water sources included boreholes, protected and unprotected hand-dug wells, kiosks, piped systems, springs, and surface water (such as streams or swamps), in reference to JMP classifications [39]. In total, 318 community water sources were identified. Privately managed water points included kiosks and boreholes. GPS coordinates, photos, and local descriptions were recorded for each water point in order for households to identify their primary source in the household survey. The ability to purchase sachet and bottled water within a community was also noted. Surveys were conducted as semi-structured interviews.

Water quality testing was primarily completed for improved water sources, with a few exceptions. Improved sources were considered to be piped systems, kiosks, boreholes, and protected hand-dug wells. Unprotected hand-dug wells and surface water were only tested periodically. They were assumed to be inferior to improved sources, susceptible to contamination by fecal coliforms, and generally unsafe for consumption [3,39]. Individual household sachet water samples were also not tested. Though not always the case, sachet water was assumed to be free from fecal coliforms, in reference to its positive performance in other studies [40,41].

The household survey utilized a two-stage cluster sampling methodology. After the first community stage, systematic random sampling was conducted to select households in the second stage [42]. Control and intervention households were distinguished by whether their community was serviced by the PSM. Intervention households were further broken down into Users and Non-Users, with a User defined as a household which uses PSM water at least weekly. Further details about the sampling process and ethical considerations can be found in Appendix A.

Households were evaluated for the level of water service that they received based on the human right to water criteria [43–45]. Indicators for the level of water service are summarized in Table 1, with procedural details described in Appendix B. They were assessed based on household responses and the traits of selected water sources [39,46–48]. Statistical comparisons of the intervention and control groups, Users and Non-Users, wealth quintiles, management styles, and technology, were considered. Scoring thresholds can be found in Table S1.

In addition to the service level indicators outlined in Table 1, the JMP service levels were used to assess the overall performance within each group of communities over time. According to this universal standard, households can receive safely managed, basic, limited, unimproved, or no service [5]. A safely managed service is the highest level, requiring water to be on premises, available when needed, and free from fecal contamination. Basic and limited services require access to an improved source, but differ, depending on whether it can be collected within thirty minutes. An unimproved service refers to unprotected wells or springs, while surface water is designated as no service. These service levels allow for more uniform comparisons across studies and time.

Table 1. Water service level indicators [1].

Service	Indicator	Type of Variable	Scoring Limits	
			Low	High
Quality	Fecal coliforms Geogenic contaminants Free Chlorine	Ordinal (4) Binary Binary	>10 MPN/100 mL Below conc. limits Other	0 MPN/100 mL Above conc. limits 0.2–2 mg/L
Quantity	Quantity (L/person/day) Sufficient quantity (perception)	Ordinal (5) Binary	<5 lpd No	>100 lpd Yes
Accessibility	Time spent per trip (min) Distance (m) Congestion (number of users)	Ordinal (5) Ordinal (5) Ordinal (5)	In home <10 m Private	>60 min >1 km Community
Reliability	Annual Reliability (days per year) Daily Availability (hours per day) Functionality	Ordinal (5) Ordinal (5) Binary	<182 days <4 h Non-Functional	>345 days 24 h Functional
Affordability	Affordability (perception)	Ordinal (5)	Never afford	Afford domestic and agricultural needs
Acceptability	Organoleptic properties (perception)	Ordinal (5)	Poor	Excellent

[1] Adapted from Baquero et al. [44].

Relative wealth is the final proxy measure, separate from the service level indicators. The 2014 Ghana Wealth Index was used to compare the socioeconomic status of different households and communities [49]. The national demographic survey can be used to identify households in five ordinal quintiles, separating those responses from a relatively poor household (1) and a relatively rich household (5). In this way, a statistical comparison of socioeconomic classes can be conducted.

The mWater platform was used to aggregate water inventory data with household data. Unique mWater ID's were used to match household responses to their primary drinking water sources. If a household's primary drinking source was not functional when testing occurred, their secondary source established their service level grades. Figure 2 shows the data aggregation process.

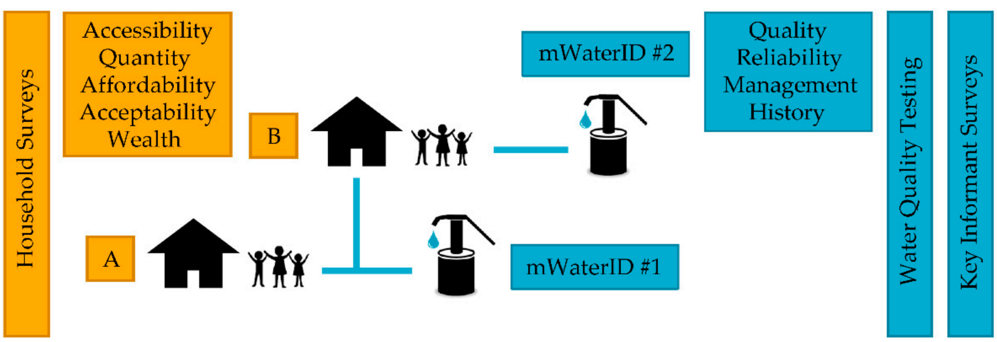

Figure 2. Data aggregation diagram.

Finally, multinomial logistic (binary-dependent variable) or ordinal (ordinal/non-normal-dependent variable) regression was used to determine which factors had a significant effect on service level indicators. The authors conducted a statistical analysis using the software program SPSS and a cluster sampling methodology. If User scores were significantly different to both the Non-User and Control groups, there was strong evidence to support that conclusion. Predictor variables could be controlled by considering all other independent variables as covariates. Adjusted odds ratios rarely produced results that conflicted with the unadjusted values, so only the unadjusted values are reported in this paper.

3. Results

3.1. Descriptive Analysis

The results of the endline descriptive analysis for group demographics are summarized in Table 2. Comparisons of the control and intervention groups of communities were conducted. Since the start of 2016, 15 additional water sources in 11 control communities and 68 (52 by the PSM) in 30 intervention communities had been constructed. Despite this increased access over time, 98% of communities had access to improved water sources in 2016 (Table 2d), with statistically similar functionality rates. The proportions of surface, groundwater, and piped sources were quite similar in 2019, with the vast majority being communal in nature (Table 2c). Piped connections on plots or within the household were rare in the district, with only one control community having a distribution system providing water to each dwelling. Public piped systems had only been built in six larger communities at the baseline, mainly within the control group. The mean population was somewhat higher in the intervention group (Table 2b). This is due to the increased number of mid-sized communities (300–1000 people) within the intervention group, as compared to the control group and district as a whole. The results should be interpreted with this selection bias in mind.

Table 2. Temporal demographics of control and intervention groups.

	Variable	Control *		Intervention *		Total *	
		2016	2019	2016	2019	2016	2019
a	Number of Communities	30		30		60	
b	Mean Population of Communities	**784**		**1017**		901	
	Range	60–3874		198–6252		60–6252	
c	Number of Water Sources	**130**	**145**	**105**	**173**	**233**	**318**
	% Surface Sources	13%	12%	16%	10%	14%	11%
	% Groundwater Sources	**56%**	57%	**82%**	61%	68%	59%
	% Piped Sources	**31%**	31%	**1.9%**	30%	18%	30%
d	Improved Source Available	97%	97%	100%	100%	98%	98%
e	Sampled Households	560	555	549	597	1108	1152
	Removed	19	11	9	13	28	24
f	Rural Quintile (Mean)	3.6	3.4	3.7	3.4	3.7	3.4
	Poorest (0%–20%)	0.5%	1.2%	0.5%	0.1%	0.5%	0.7%
	Poor (20%–40%)	8.6%	15%	11%	14%	9.7%	14%
	Average (40%–60%)	37%	43%	31%	40%	34%	42%
	Rich (60%–80%)	34%	24%	38%	36%	36%	29%
	Richest (80%–100%)	20%	17%	21%	10%	20%	14%

* Bold text denotes $p < 0.05$.

Within household samples, statistically similar proportions ($p > 0.05$) of gender, household size, age range, and education were recorded. Generally, about 80% of respondents had a junior high school education or below, and about 69% of respondents that worked specified subsistence or commercial farming as their primary employment (Table S2). For the national rural wealth index, both the mean score and quintile distributions were statistically similar within a given year (Table 2f). When using national composite scores, which also include people from urban environments, about 78% of households were considered to be among the poorest 40% in Ghana.

3.2. Logistic Regression Analysis

Table 3 presents the multinomial logistic regression for communal water sources within the district in 2019. The binomial descriptive statistics for functionality, annual reliability, and water free from fecal coliforms are shown in conjunction with the odds of a positive performance, as compared to other categorical predictor variables. An odds ratio (OR) compares the odds that an outcome will occur with and without exposure to a given variable [50]. An odds ratio greater than one suggests that a predictor variable produces a riskier outcome, while a value less than one deems the predictor to be more protective than the standard [36]. Each category (management and payment method) uses a standard variable of comparison, which is assigned a null odds ratio (OR = 1). Community-based management and no tariff payment were used as the standards for their respective categories, as they were the most common historical methods of water provision and service within the district. This analysis excludes unimproved surface sources that are clearly inferior.

Table 3. Multinomial logistic regression of water source performance.

Explanatory Variables		n	Functionality *		Annual Reliability > 95% *		Free from Fecal Coliforms *	
			%	OR (95% CI)	%	OR (95% CI)	%	OR (95% CI)
Management Scheme		252						
a	Community	141	62%	1	37%	1	35%	1
b	Private (PSM)	52	**92%**	**0.14 (0.07–0.27)**	**87%**	**0.09 (0.05–0.16)**	**90%**	**0.06 (0.03–0.13)**
c	Religious Institution	8	62%	1.0 (0.20–5.2)	51%	0.56 (0.13–2.5)	13%	3.7 (0.58–23)
d	Local Government	10	50%	1.6 (0.70–3.8)	39%	0.93 (0.40–2.1)	50%	0.54 (0.26–1.1)
e	Individual	24	**88%**	**0.22 (0.09–0.51)**	49%	0.62 (0.27–1.4)	33%	1.1 (0.55–2.2)
f	No Manager	7	52%	1.5 (0.29–7.5)	12%	4.4 (0.93–21)	20%	2.1 (0.33–13)
g	Public Utility	10	60%	1.1 (0.37–3.2)	60%	0.40 (0.13–1.2)	50%	0.54 (0.20–1.4)
Payment Method		266						
h	Nothing	88	51%	1	31%	1	10.1%	1
i	Emergency Funds	15	54%	0.86 (0.42–1.8)	38%	0.72 (0.26–2.0)	12.7%	0.77 (0.29–2.1)
j	Monthly Tariff	17	**95%**	**0.06 (0.01–0.24)**	55%	0.36 (0.11–1.2)	**58.5%**	**0.08 (0.04–0.15)**
k	Pay-to-fetch	146	**79%**	**0.28 (0.15–0.53)**	**59%**	**0.31 (0.16–0.59)**	**68.0%**	**0.05 (0.03–0.10)**

* Bold text denotes $p < 0.05$; surface sources excluded from analysis.

Generally, most variables associated with the PSM showed protective odds ratios (OR < 1) with statistical significance. Improved functionality, reliability, and quality were all observed for privately-managed water points (Table 3b). In addition, individually-managed water sources (Table 3e) showed an improved functionality, which were predominantly self-supplied unprotected wells or standpipes from a community piped system. Community-based management was common within the district (Table 3a), which was primarily conducted through water management committees. Elected members managed over 50% of community water sources, with less than 30% collecting regular payments. Nearly 70% had a member with a senior high school education or better, and almost 90% had a female representative. Privately-managed water sources showed an improved performance compared with community-managed sources, while other management models had a statistically similar quality and reliability (Table 3c–g).

Regular tariff payments, either monthly (Table 3j) or pay-to-fetch (Table 3k), also showed improved odds of a good performance in all categories. When controlling for private water sources, other pay-to-fetch sources still showed improved functionality [OR = 0.37 (0.19–0.70)], reliability [OR = 0.47 (0.24–0.89)], and biological quality [OR = 0.11 (0.06–0.21)]. For more regression analysis involving the age and type of water sources, see Table S3.

Ordinal service level scores from 2019 are presented in Figure 3, which provides a quick summary of the logistic regression analysis of household service level indicators shown in Table 4. Households within the intervention communities were assigned to either the User or Non-User groups based on reported behaviors, practices, and usage rates of competing water sources within a given community. Households were also assigned to a management system based on their primary drinking source. Users (Figure 3a) and households managed by the PSM (Figure 3b) were highly correlated. These groups generally provide a better biological quality and annual reliability; equivalent quantity, collection time, and mean acceptability; and worse affordability, compared to sources managed by the community and the Control group. Non-User and Control groups were also observed to be nearly identical (Figure 3), implying a null effect on Non-Users in intervention communities.

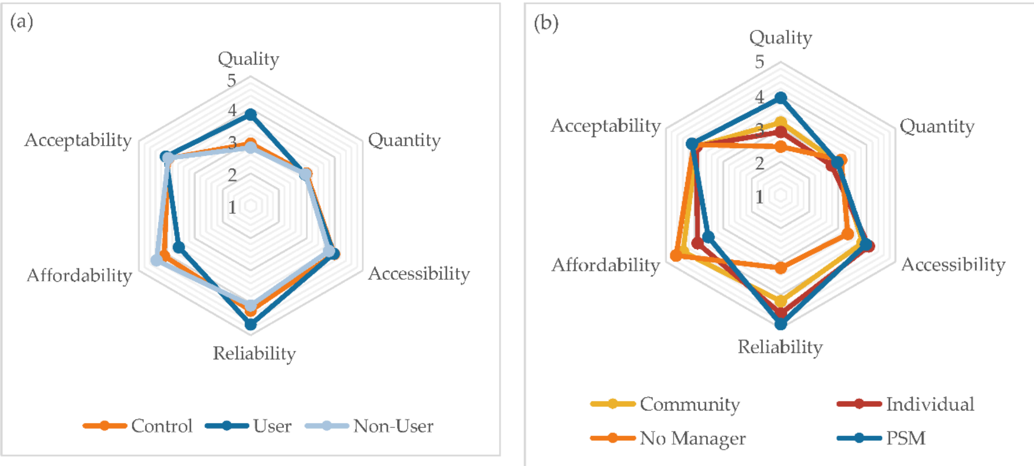

Figure 3. Household service level scores by (**a**) Control and intervention (User vs. Non-User) groups and (**b**) primary source management groups.

Table 4. Multinomial logistic regression for service level indicators by household group.

	Parameter	n	Control	Control vs. User *	Non-User	Non-User vs. User *	User
			%	OR (95% CI)	%	OR (95% CI)	%
	Quality						
a	Use Improved Primary Source	1128	**71%**	**3.8 (1.6–9.3)**	**71%**	**3.8 (2.0–7.2)**	90%
b	Free from fecal contamination (Prim.)	1079	**62%**	**5.7 (2.6–12)**	**54%**	**8.0 (3.7–17)**	90%
c	Free from geogenic contamination	1079	100%	1.0 (1.0–1.0)	100%	1.0 (1.0–1.0)	0.0%
d	Residual chlorine present	1076	**1.5%**	**110 (26–460)**	**2.4%**	**68 (13–370)**	63%
e	Residual chlorine above 0.2 ppm	1076	**0.4%**	**17 (1.5–190)**	0.0%	-	5.7%
	Quantity						
f	Quantity collected above 20 L/p/d	1096	80%	0.86 (0.49–1.5)	76%	1.1 (0.63–1.8)	77%
g	Use of multiple water sources	1128	**41%**	**0.27 (0.14–0.50)**	34%	**0.20 (0.12–0.33)**	72%
h	Sufficient quantity (perception)	1128	**97%**	**0.26 (0.08–0.87)**	93%	0.66 (0.26–1.6)	89%
	Accessibility						
i	Time per trip < 30 min	1114	95%	0.84 (0.35–2.0)	93%	1.1 (0.43–2.7)	94%
j	Distance to water source < 100 m	992	34%	1.9 (0.99–3.5)	**28%**	**2.5 (1.4–4.3)**	49%
k	Congestion > 20 households	1039	94%	1.7 (0.69–4.3)	98%	0.65 (0.19–2.2)	96%
	Reliability						
l	Annual reliability > 345 days	963	64%	2.2 (0.93–5.2)	**48%**	**4.1 (1.9–9.0)**	79%
m	Daily availability > 12 h	1122	**84%**	**0.29 (0.15–0.58)**	**86%**	**0.26 (0.13–0.51)**	60%
	Affordability						
n	Can afford to pay for domestic needs	1128	**78%**	**0.45 (0.23–0.91)**	**87%**	**0.24 (0.12–0.47)**	61%
o	Rural Quintile is above 'Average'	1128	41%	1.5 (0.73–2.9)	43%	1.3 (0.83–2.1)	50%
	Acceptability						
p	'Excellent' taste ratings	1111	23%	1.5 (0.87–2.4)	22%	1.6 (0.95–2.6)	30%
q	'Excellent' odor ratings	1110	**16%**	**2.5 (1.4–4.5)**	**14%**	**2.9 (1.7–4.8)**	32%
r	'Excellent' appearance ratings	1106	**22%**	**2.5 (1.5–4.4)**	33%	1.5 (0.92–2.3)	42%
s	'Excellent' lather ratings	1097	19%	1.5 (0.81–2.7)	17%	1.7 (1.0–2.8)	25%

* Bold text denotes $p < 0.05$.

The results in Table 4 emphasize the generally protective or neutral effect of the intervention effort. Water quality indicators were significantly worse for Control and Non-User households in every parameter except geogenic contamination, which was not an issue in the district as a whole (Table 4a–e). Annual reliability indicators increased for Users (Table 4l) in conjunction with the increased continuity of the PSM water sources in Table 3. Accessibility indicators showed little change for Users with regards to the time spent fetching and household congestion (Table 4i–k). Although a higher proportion of Users were closer to their primary source ($p < 0.01$), this may be more indicative of customer motivations than the company's influence. Acceptability indicators showed slightly increased scores for Users (Table 4p–s), with a significant improvement for odor and appearance ($p < 0.05$). For all groups, ratings tended to fall in the "Good" (4) range, with each household using water sources they preferred. Individual sources tended to have defined traits, such as a poor taste or improved later, which created a clustering effect at the community level.

However, some trends associated with risk were also observed. Despite significantly higher evidence of residual chlorine in User sources (63%), only 5.7% had concentrations higher than 0.2 ppm (Table 4d–e). Household water treatment was uncommon for all households (10%), and Users stored water for two to three days, on average. Considering the risk of microbial deterioration during transport to the dwelling, the low chlorine concentration was likely insufficient to maintain stored water quality under these conditions [3,51–53]. Additionally, daily availability scores were significantly lower for Users (Table 4m; $p < 0.01$). This indicator assessed the number of hours per day that water could be collected from a given source. About a third of Users claimed they could only access water between 8 and 12 h per day. While many free sources were available at any time, the PSM sources required a vendor to be present for tariff collection. This created specific opening hours for collection each day. Therefore, private water systems were more likely to be available throughout the year, but had daily restrictions on time.

Users (37 L/p/d) collected statistically similar quantities of water as Non-User (38 L/p/d) and Control (39 L/p/d) households (Table 4f). This amounts to about 1360 L per household per week in the dry season, on average. However, 72% of Users utilized multiple water sources to supplement 47% of their domestic needs (by volume), on average (Table 4g; $p < 0.01$). Households within the richest quintiles would use sachet water for drinking and PSM water for cooking and hygiene (cleaning, bathing, and laundry) needs (61% of total volume). Households within the other quintiles tended to supplement their hygiene needs with free alternatives, while using PSM water for drinking and cooking (41%–49% by volume). Further information on collection purposes and seasonal trends can be seen in Figures S1 and S2.

With regards to affordability, 61% of Users, 87% of Non-Users, and 78% of Control households felt they could afford to pay for their domestic needs (Table 4n). When refined by a household's primary water source, 57% of kiosk, 88% of borehole, 93% of protected well, and 7.3% of sachet users were able to afford their domestic needs. For context, common pay-to-fetch prices for handpumps are half the kiosk price (0.10 vs. 0.20 GHS per 18 L), and sachet water costs 36 times the price per liter (0.20 GHS per 500 mL).

Service level indicators varied more widely between wealth quintiles in the Control group (Figure 4a) than for Users (Figure 4b). The biological quality, collection time, annual reliability, and affordability all differed significantly between Control quintiles ($p < 0.01$). Within User households, only affordability varied significantly between quintiles ($p < 0.01$). Interestingly, this was primarily related to an increase in sachet water usage by richer User households, who were shown to have significantly lower scores. Note that only one sample in the "Poorest" rural quintile was observed in the intervention communities (and sixteen samples in the Control), so they reflect a low sample size.

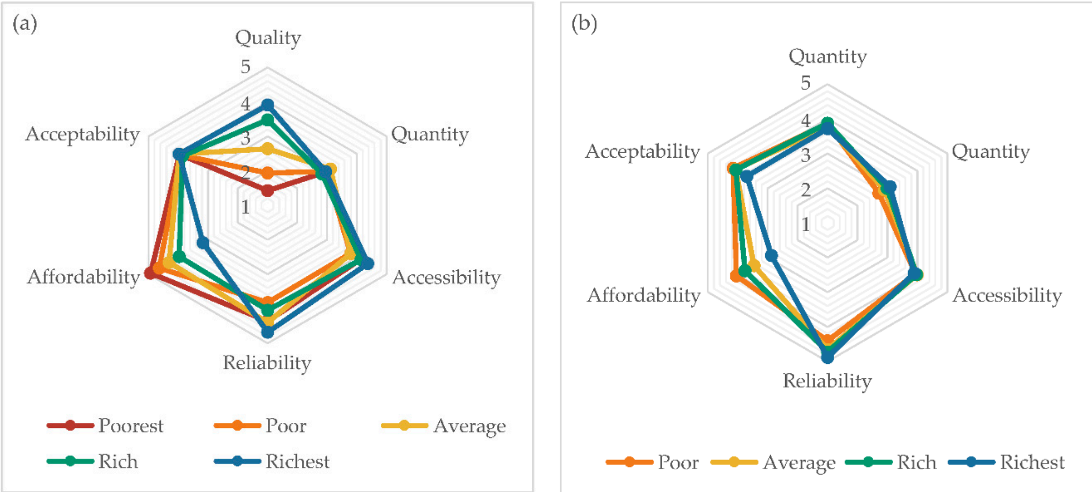

Figure 4. Household service level scores by rural wealth quintile for (**a**) Control and (**b**) Users; note: Both groups have a low sample size for the Poorest quintile—16 Control and one Intervention (excluded).

All of these comparisons with Users reflect the proportion of intervention households that choose to use the PSM water at least weekly (i.e., the penetration rate). While 37% (95% CI [30,44]) of intervention households use PSM kiosks weekly, only 28% (95% CI [22,35]), use them as a primary source and 9.3% (95% CI [6.1,13.8]), exclusively. This is reflected by the same households that use multiple water sources to meet their domestic water needs (Table 4g). Penetration rates for PSM handpumps (56% weekly) tend to be higher than for kiosks, either due to their alternative tariff structure or reduced population. Handpumps are typically constructed in communities with less than 300 people, which is associated with less travel distance and water source options. Moreover, a monthly tariff is charged per household at a rate of 2 GHS per month; estimated to be thirty times less than a kiosk per liter. Interestingly, weekly ($p = 0.43$), primary ($p = 0.24$), and exclusive ($p = 0.50$) penetration rates did not have a significant relationship with socioeconomic status, providing evidence against the study hypothesis.

3.3. Temporal Analysis

Figure 5 presents the overall change in JMP water service provision between 2016 and 2019 when considering a household's primary drinking water source. In control communities, households that received at least a basic water service increased from 53% to 70% [OR = 0.50 (0.31–0.79)]. In intervention communities, households that received at least a basic water service increased from 45% to 78% [OR = 0.24 (0.14–0.42)]. Both groups had a significant decrease of households with a limited service, and the intervention group displayed a drop in households with an unimproved service. A statistically similar group of households with safely managed and no service prevailed over time. Control and intervention households did not exhibit a significant difference in JMP service in any given year. Figure 6 emphasizes these growth patterns, while showing the divergent components of Users and Non-Users. Independently, Non-Users gained an improved service at the same rate as the Control group, while Users gained statistically significant service improvements ($p < 0.05$).

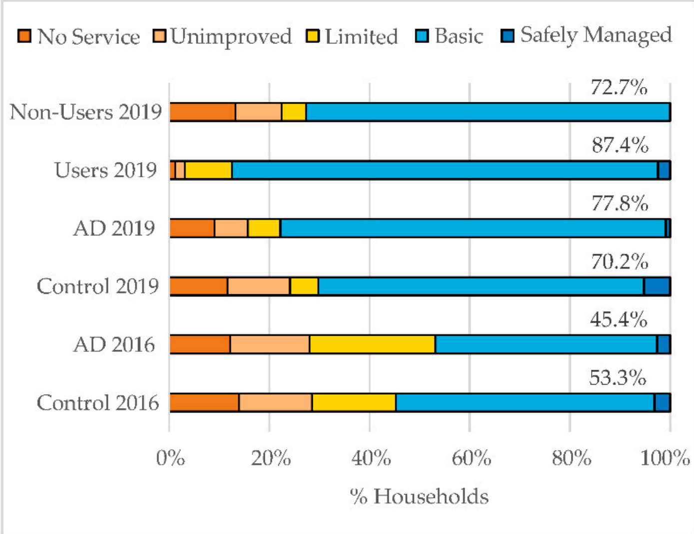

Figure 5. Proportion of households with JMP service levels from 2016 to 2019.

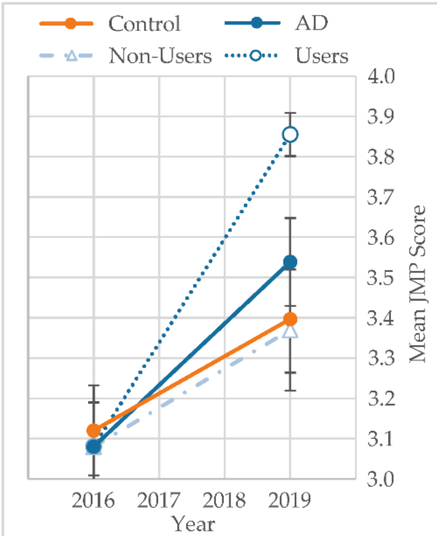

Figure 6. Mean JMP service level scores from 2016 to 2019.

4. Discussion

Customers of the private service delivery model were associated with an improved JMP service compared to customers of historical water service providers within the district (Figure 6). About 90% of PSM water sources were free from fecal contamination and 87% were available more than 345 days per year. This provided User households with an improved water quality and annual reliability compared to Control and Non-User households ($p < 0.01$). Quantity and accessibility (time and congestion) scores were statistically similar between groups. However, achieving a sufficient water quantity required 72% of User households to supplement their PSM water with alternative sources. Such supplements occurred irrespective of household wealth ($p = 0.35$) and suggested a rejection of the study hypothesis. Organoleptic ratings showed higher trends of 'Excellent' scores for Users, although they were not statistically significant without isolating each component (taste, odor, appearance, and lather). PSM Users had significantly worse scores for daily reliability and affordability ($p < 0.01$).

Management traits such as regular maintenance visits and pay-to-fetch practices promoted consistent water system functionality throughout the year. This is apparent in the high reliability of PSM sources, but is emphasized by water sources not affiliated with the PSM continuing this trend (Table 3h–k). This supports previous literature claiming that these practices can produce a more reliable performance [8,17,54,55]. With this in mind, the challenge for the PSM is maintaining vendor availability on a daily basis and avoiding periodic closures. Qualitative observations for vendor absence included daily farming or domestic duties, delays in waiting for a tank to be filled through remote meters, closures due to illness or moving away, and the mismanagement of collected revenue. These examples highlight the importance of human resource management and reducing associated risks for the private operator. Future research should investigate how daily opening hours and short-term closures influence customer usage and spending habits.

Services provided by the PSM were utilized by 38% (95% CI [31,45]) of households within intervention communities (kiosks and boreholes combined). This uptake rate is consistent with the 38% of households identified by Opryszko et al. [40]. For reference, self-reported penetration rates reported by Bhatnagar et al. [13] ranged from 10% to 60%. Although there were slightly increasing trends, uptake ($p = 0.43$), water quantity collected from PSM sources ($p = 0.10$), and the JMP service ($p = 0.17$) from PSM water sources were not significantly affected by relative wealth. This evidence shows that both poor and rich households are being served by private kiosks under the current model. Only the richest quintile shows a difference in usage patterns, but this is more reflective of the disparity of sachet water. For comparison, 78% of the richest and 50% of the poorest households will purchase sachet water at least weekly.

This behavior illustrates how households will strategically use the water resources available to them in order to meet their domestic needs. Only 28% of Users collected kiosk water exclusively, supporting other literature observing the use of multiple water sources [56,57]. Only 57% of kiosk Users claimed that they could afford to pay for all of their domestic needs using PSM water, suggesting that affordability influenced their usage patterns. Given that statistically similar rates of penetration and quantity scores were found between wealth quintiles, other motivations, such as proximity, household size, poor taste, or seasonal alternatives, must have also been impactful [58,59]. Future research on how different motivations impact water source choices in the presence of these pre-payment models could help to determine if higher penetration rates can be attained.

Regardless of why certain households do not choose to use PSM water, the continued dependence on alternative sources poses a challenging governance issue. Whether by inability or choice, not everyone was being served by the PSM. Who, then, is responsible for ensuring continued access to a basic water service for Non-Users? It is possible that the PSM could take on responsibility for maintaining alternative improved sources, but the associated costs could quickly become unsustainable. It is more likely that historical managers, such as the local government or water management committees, will be relied upon to maintain these water sources, by default.

Essentially, multiple stages of infrastructure still need to be maintained by various stakeholders at the same time. Positively, this promotes competition, and can help prevent the PSM from committing extortion. It also highlights the value of a systems approach [60], as both historical and professional providers are promoting access to a community water supply. However, traditional entities are likely to face the same limitations in reliability, quality, and financing as before [23]. If community resources are divided between different providers, it becomes even more difficult to recover life-cycle costs for either system. This challenge emphasizes a tension between equity and sustainability; providing water for all versus full cost recovery [54].

From 2016 to 2019, both control and intervention communities showed significant growth in basic water service provision, according to JMP indicators (Figure 5). For the control group, community-based managers represented the majority of traditional providers (70%) and, subsequently, portray the status quo. Without a dedicated intervention, coverage of the basic service still increased. However, households under this management system received significantly worse reliability and quality scores (Table 3a), often violating all three conditions of a safely managed service. Water services provided by the PSM during this time period were generally free of fecal coliforms and continuously available, but not on premises. When observing that intervention and control households overall did not have a statistically significant difference in access to the basic service or better, this is an important differentiation. However, both approaches have thus far been communal in nature, bringing risks of microbial deterioration during transport (Table 4d,e). It will be interesting to observe whether these trends shift as the PSM focuses on household connections in its next phase of development.

Does this mean that the private service provider had no significant impact? No selection-history events were recorded outside of water source construction for both groups. External contributors influenced both intervention and control communities, including the District Assembly, a local church, NGOs, and a few other isolated groups. Selection-maturation threats might suggest that the different groups simply matured at different rates, creating the illusion of a program effect. However, the cross-over pattern shown in Figure 6, along with the division of intervention households into Users and Non-Users, helps to show that the PSM did have an impact in the intervention group. The maturity rates of Non-Users and Control households are nearly identical, but Users jump up to a higher threshold ($p < 0.05$). This provides evidence that PSM Users initiate the increase of the intervention group scores, but their penetration rate prevents them from being statistically different for the sample population.

A number of limitations to this study should be considered when interpreting the results. First, selection bias could have occurred via the company in community sampling, potentially creating uncontrolled confounders. For instance, in Table 2, communities with a slightly higher population are observed within the intervention group, with less evidence of a piped supply at the baseline. Second, subjective bias could have influenced self-reported data (water sources, quantity, and reliability). Quality control questions were placed within surveys to identify false or incorrect information (e.g., using multiple sources for validation or asking the same question in a different manner). Third, endline cross-sectional comparisons alone cannot demonstrate causal relationships. The initial results sections should be interpreted with the later temporal comparisons in mind. Changes in quantity, accessibility, and reliability indicator scores over time reflected similar conclusions to those of the detailed endline analysis, but quality, affordability, and acceptability used different testing methods in 2016 and could not be equally compared. Households with a safely managed service in 2016 were assumed to have a good quality based on their improved status. Therefore, the safely managed proportions presented at that time are based on the best possible proportion. Likewise, JMP service indicators scores are based on a household's primary water source. When considering all drinking water sources, the results could significantly increase (e.g., all Users have at least a limited service) or decrease (e.g., some sachet water users also drink surface water). An analysis was conducted for each case, but did not influence the conclusions drawn. Finally, the variables included in the regression analysis do not represent an exhaustive list. Factors derived from previous studies provide a more comprehensive list to consider overall [4,6,10,61].

5. Conclusions

Service delivery models across the globe have been developing and evolving with the goal of providing sustained access to safely managed water services. A district evaluation of new and traditional water services has provided a temporal perspective on the outcomes of using a private service delivery model in a rural, sub-Saharan context. The results have provided evidence for an improved household service for PSM Users of all socioeconomic classes ($p = 0.35$) compared to Non-User and Control households. In 2019, over 87% of User households benefited from at least a 'basic' service, compared to 70% of Control households. While this should be expected with a dedicated intervention effort, risks associated with a deteriorating water quality during transport, human resource management, and financial sustainability were still apparent. Furthermore, almost three out of four households still relied on existing alternatives to meet a portion of their weekly water demand.

Ultimately, this research has provided evidence that PSMs can fill an important role of increasing the standard of professional water supply, but they cannot be considered a panacea to rural water provision. Professional workers can produce superior, consistent water, but factors such as competition and affordability will limit the overall uptake. Traditional management schemes will remain relevant as long as there is a demand for both new, mechanized systems and existing improved sources, emphasizing the importance of a systems approach. While multiple providers may promote equity in improved water access, a split market share may prove challenging to financial sustainability. It is important that policy-makers and implementers account for these consequences for similar private service delivery models of the rural water supply.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4441/12/3/693/s1: Table S1. Service level indicator scoring criteria; Table S2. Temporal demographics of control and intervention groups (detailed); Table S3. Multinomial logistic regression of water source performance (detailed); Table S4. Multinomial logistic regression for service level indicators by household group (detailed); Figure S1. Proportion of households using multiple water sources; Figure S2. Quantity of water collected per person per day in the dry and rainy seasons; Figure S3. AD penetration rates by usage frequency vs. (a) water source type or (b) rural wealth quintile; Table S5. Chemical measurement summary of improved water sources; Figure S4. *E. coli* measurements vs. management entity; Figure S5. Mean proportion of total water collected by a household for a given primary source; Figure S6. Proportion of households that use their primary source for each category; Figure S7. Proportion of households that pay for their primary source vs. classification and wealth index; Figure S8. Simple water treatment process flow diagram; Figure S9. Modular technology design of Access Development.

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Conflicts of Interest: The authors declare that funding for research was partially supported by Water4, who initiated the activities of Access Development within Ghana. Furthermore, enumerators were overseen by both Access Development team members and the authors during survey interviews. Guards for quality control were put in place to validate results. The funders and company had no role in the design, analyses, or interpretation of the data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

Satellite images were used to identify and map households within a community. Two random households were chosen for enumerators to begin sampling, after which a set interval was counted before sampling again. The interval and sample size were dependent on the population estimates in census records. Enumerators received a map and GPS coordinates to identify their starting point. If the community was too large, enumeration areas were included as intermediate, randomly selected zones. Household members examined photo records of all community water sources to identify which were regularly used. Unique ID numbers could be referenced back to a database of GPS coordinates, downtime, and water quality testing results.

For the endline, a total of 1152 household samples were taken, with an average of 19.2 samples per community. A total of 24 samples were removed through a number of quality control checks placed within the survey, bringing the total number of samples analyzed to 1128. Consideration for disqualification included duplicates, age (below 18), inconsistencies, improper mental states, or poor accuracy ratings from the enumerators. Household heads, their spouse, or other adults were targeted, in order of priority. GPS tracking allowed for a verification of survey completion and accuracy.

All respondents gave their informed consent for inclusion in this research prior to participating in this study. Identifying information was removed for the protection of the subjects. After reviewing the research protocol, the University of Oklahoma Institutional Review Board deemed that approval was not required. Local enumerators collected survey data and were trained in advance to conduct ethical in-person interviews [42]. Enumerators were multilingual, allowing questions prepared in English to be translated into local dialects (Fante and Ewe) during preliminary testing of the survey instruments.

Appendix B

Water quality was tested for fecal coliforms, pH, conductivity, turbidity, arsenic, fluoride, total chlorine, and free chlorine. Conductivity, pH, temperature, and turbidity were measured using portable, electronic meters. A Quick II Arsenic Test Kit was used to determine the arsenic concentration within 24 h of collection. A fluoride meter, in conjunction with TISAB reagent tablets, was used to test for the fluoride concentration within 24 h of collection. A Hach Chlorine Test Kit, Model CN-70, was used to test for free and total chlorine immediately using DPD and the color disc method (typically in piped systems). Conductivity was adjusted for a standard temperature of 25 °C. Aquagenx© CBT test kits were used to test for the presence of *Escherichia coli (E.coli)*. These kits use a growth substrate and different sized compartments to estimate the most probable number (MPN) per 100 mL sample. The MPN method produces quantitative counts of *E. coli* colonies based on discrete, presence/absence data and statistical analysis. Samples were designated as safe (0 MPN), low risk (1–3 MPN), intermediate risk (3–10 MPN), and unsafe (>10 MPN) based on Aquagenx definitions and WHO standards [49]. Samples were collected during daily field visits to communities and kept within an ice cooler prior to analysis. After the substrate was added and the water was transferred to the compartment bags, the sample was sealed and incubated at 34 °C for 24 h.

Questions within the household survey were used to estimate the quantity of water collected per day based on their household's responses. Volumes were converted to liters using common transport containers and terminology. These usage rates were graded based on the water quantity levels recommended by the World Health Organization [49]. As a secondary proxy, respondents also stated whether the collected quantity was sufficient for their domestic needs. Accessibility was graded based on the time spent collecting water per trip, the distance from the source, and the number of users that collect from that source (congestion). These parameters were determined within the household survey. Distance was estimated using both a perceptive question and the GPS coordinates of the household compared to the coordinates of their primary source. The haversine formula was used to calculate the distance between points, as shown in Equation (A1), where "d" equals distance, "r" equals the radius of the earth, "φ" is the latitude, and "λ" is the longitude [62].

$$d = 2r * \arcsin\left(\sqrt{\sin^2\frac{\varphi_2-\varphi_1}{2} + \cos\varphi_1\cos\varphi_2\sin^2\frac{\lambda_2-\lambda_1}{2}}\right) \quad \text{(A1)}$$

Reliability was graded based on the number of days that a household's primary drinking water source was available throughout the year. Functionality and the hours per day that water was regularly available were also recorded. Water sources were considered functional if they were at least partially working and provided access to water during testing, but they were considered non-functional if they had been closed for more than a week or abandoned. These parameters were requested from multiple sources to guard against recall bias, including key informants, regular users, and households within the community. Affordability was evaluated using a needs-based ordinal scale. Households specified whether they could afford water for domestic and agricultural needs, domestic needs, drinking and cooking, cooking only, or rarely afford the water. For instance, sachet water is frequently only purchased for drinking purposes, which speaks to its perceived affordability. Free sources were automatically given the highest ordinal rating. Acceptability data was collected during the customer satisfaction portion of the household survey. The purpose of this metric was to understand the subjective value people place on each source, in addition to the objective scientific value that was externally assigned. A five-point Likert scale [50] was used to evaluate perceived taste, odor, appearance, and lather.

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