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Key Points:

- Waterpoint financial peaks and troughs mirror seasonal rainfall patterns in rural Kenya
- Pay-as-you-fetch waterpoints generate more revenue and are repaired faster than those charging flat fees
- Households are more likely to use an unimproved drinking water source when a waterpoint has a pay-as-you-fetch system

Supporting Information:

- Supporting Information S1
- Data Set S1
- Data Set S2
- Data Set S3
- Data Set S4

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Evaluating waterpoint sustainability and access implications of revenue collection approaches in rural Kenya

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Abstract Water policies in many sub-Saharan African countries stipulate that rural communities are responsible for self-financing their waterpoint's operation and maintenance. In the absence of policy consensus or evidence on optimal payment models, rural communities adopt a diversity of approaches to revenue collection. This study empirically assesses waterpoint sustainability and access outcomes associated with different revenue collection approaches on the south coast of Kenya. The analysis draws on a unique data set comprising financial records spanning 27 years and 100 communities, operational performance indicators for 200 waterpoints, and water source choices for more than 2000 households. Results suggest communities collecting pay-as-you-fetch fees on a volumetric basis generate higher levels of revenue and experience improved operational performance compared with communities charging flat fees. In both cases, financial flows mirror seasonal rainfall peaks and troughs. These outcomes are tempered by evidence that households are more likely to opt for an unimproved drinking water source when a pay-as-you-fetch system is in place. The findings illuminate a possible tension between financial sustainability and universal access. If the Sustainable Development Goal of "safe water for all" is to become a reality, policymakers and practitioners will need to address this issue and ensure rural water services are both sustainable and inclusive.

1. Introduction

Community-based financing is widely regarded as a precondition for waterpoint sustainability in rural sub-Saharan Africa [*Churchill et al.*, 1987; *Briscoe and de Ferranti*, 1988; *Carter et al.*, 1996, 1999; *Harvey*, 2007]. Community management has been the dominant rural water supply paradigm embraced by governments, donors, and nongovernment organizations (NGOs) for over three decades, and is premised upon the expectation that local water users are willing and able to self-organize and cover the cost of operation and maintenance (O&M) activities [*Arlosoroff et al.*, 1987; *Harvey and Reed*, 2007]. Although taxes and transfers play a role in subsidizing major repairs [see, e.g., Ministry of Water and Environment (MWE), 2011; *Ministry of Local Government and Housing* (*MLGH*), 2007; *Jones*, 2013], technician salaries and equipment [see, e.g., *Hystra*, 2011], and spare part supply chains [*Harvey*, 2007], the bulk of funding to pay for O&M costs is expected to derive from tariffs paid by waterpoint users. Indeed, the principle of self-financing O&M is now formalized in policies and assumed in many financing plans across the continent [*African Development Bank*, 2010; *Banerjee and Morella*, 2011; *GLAAS*, 2014]. However, there is an absence of empirical evidence or policy consensus on the optimal revenue collection approach from financial, operational and safe drinking water access perspectives, and communities independently adopt a diverse range of strategies.

The arguments in support of community-based financing of rural water O&M are multifold, and sit within a broader debate about user financing of basic social services [*Reddy and Vandemoortele*, 1996]. Governments and donors have long been considered ill-equipped to reliably finance recurrent water service costs [*Briscoe and de Ferranti*, 1988; *Churchill et al.*, 1987]. Additionally, the expectation of self-financing fits with the tendency of donors and NGOs to approach water supply interventions as one-off projects, the importance placed on local ownership of water supply systems, and a cultural idealization that rural communities will harmoniously cooperate and act collectively [*Franceys et al.*, 2016; *Harvey and Reed*, 2007]. *Briscoe and de Ferranti* [1988] also advance justifications based on principles of equity and efficiency, as user contributions raise money in a nondistortionary way, minimize waste, and liberate donor and government funds to

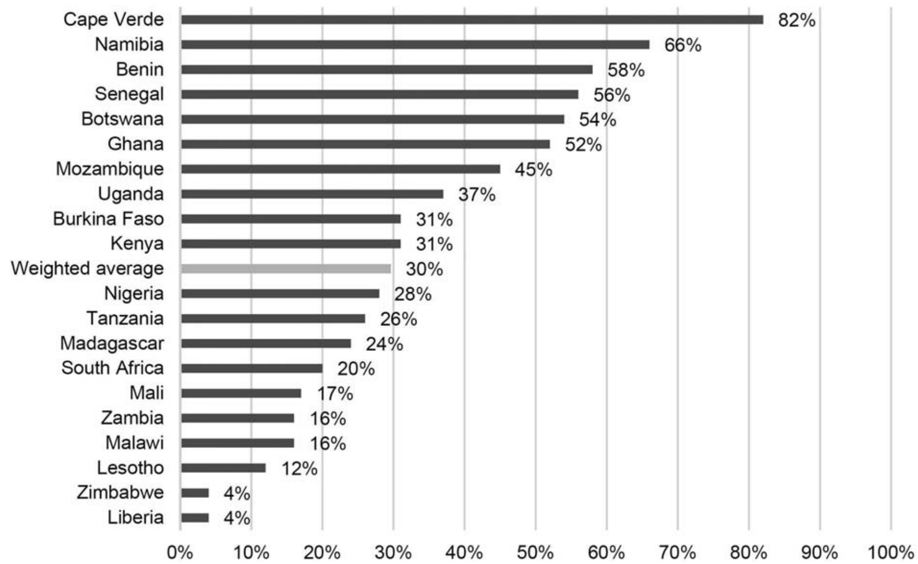

Figure 1. Proportion of households that pay for water in rural sub-Saharan Africa in 2008/2009 ($\boldsymbol{n} = 17{,}156$). Authors' analysis of data from Afrobarometer household surveys [*Afrobarometer*, 2015].

expand improved water supply access to the poorest and hardest to reach. Notwithstanding these rationales, the principle of financing direct O&M costs through user tariffs has not gone uncontested. *Ahuja et al*. [2010], for example, suggest subsidies may be justified by evidence that rural households often undervalue safe drinking water and that behavioral biases prevent welfare-maximizing choices. Equally, it has been noted that other sectors, such as education and health, have been more open to the option of subsidizing services, thereby enabling the reduction or abolition of user fees [*Ahuja et al*., 2010; *Franceys et al*., 2016].

Nonetheless, there appears to be a mismatch between policy and reality in the rural water sector, with evidence suggesting that user contributions are the exception rather than the norm in rural areas. Nationally representative surveys across 19 sub-Saharan African countries in 2008–2009 found only 30% of rural households pay for water (Figure 1), at a time when improved water coverage in rural areas those countries collectively stood at 54% [*UNICEF/WHO*, 2016]. In contrast, the same surveys found three in four households paid for water in urban settings [*Afrobarometer*, 2015]. The problem is acute for community waterpoints fitted with handpumps; in some countries around three in five lack any form of revenue collection, and non-payment and late payment practices are prevalent [*Foster and Hope*, 2016]. The implications of this situation are substantial. The inability of communities to raise sufficient funds to pay for repairs is a major reason why the operational performance of handpumps is often poor [*Carter et al*., 1999; *Harvey*, 2007], and by extension, why an estimated one in three are nonfunctional at any point in time [*Rural Water Supply Network*, 2009].

Although handpumps are considered a low-cost technology, the amount of money required to ensure their ongoing operation in aggregate terms is substantial. *MacArthur* [2015] approximates that 823,000 waterpoints are fitted with handpumps across the continent, serving up to 184 million people. Combining these coverage estimates with handpump O&M unit costs formulated by *WASHCost* [2012], the recurrent handpump expenditure requirements across sub-Saharan Africa may lie between $368 million and $552 million (PPP, 2011) a year. Furthermore, an estimated 60,000 waterpoints are fitted with handpumps every year [*Sansom and Koestler*, 2009], thus recurrent expenditure needs could be rising by $26 million to $41 million (PPP, 2011) annually.

1.1. Rural Waterpoint Revenue Collection Approaches in Policy and Practice

While government involvement in water tariff regulation is widely accepted and practiced in urban settings [*Banerjee and Morella*, 2011], engagement in rural waterpoint tariff formulation is less pronounced. In contrast to utility-provided piped water services, the distinction between users and water service providers for community-managed rural waterpoints is ambiguous. Concerns about monopolistic profit-making and

Table 1. Prevalence of Revenue Collection Approaches for Waterpoint Fitted With Handpumps in Selected Sub-Saharan African Countries[a]

			Revenue Collection Approach (%)			
Country	Scope	No. Handpumps	Payment Upon Breakdown	Flat Fee (per Week/Month/Year)	Pay-as-you-fetch (per Bucket/Jerrican)	No Revenue Collection
Kenya[b]	Eight counties[c]	2119	8.1	22.2	21.8	47.8
Liberia[d]	National	9388	30.2	16.6		53.2
Sierra Leone[e]	National	12,003	15.5	2.1	2.3	80.0
Tanzania[f]	National	21,884	13.2	22.0	6.8	57.9
Uganda	National	47,200				57.2
Total		92,594	17.4[g]	15.5[g]	4.7[g]	59.6 (62.4[g])

[a]Modified from *Foster and Hope* [2016]. Authors' analysis based on publicly available waterpoint data sets [*Virtual Kenya*, 2015; *NWSHPC*, 2014; *Sierra Leone STATWASH Portal*, 2014; *Government of Tanzania*, 2014; *Government of Uganda*, 2012]. Data for Liberia, Sierra Leone, and Uganda also available at https://www.waterpointdata.org/.

[b]Revenue collection prevalence rates exclude 229 handpumps with unknown revenue collection status.

[c]Counties include Busia, Embu, Isiolo, Kajiado, Kiambu, Kisumu, Kwale, Turkana.

[d]Revenue collection prevalence rates exclude 51 handpumps with unknown revenue collection status.

[e]Revenue collection prevalence rates exclude 682 handpumps which were still under construction, and 12 handpumps with unknown revenue collection status.

[f]Revenue collection prevalence rates exclude 2899 handpumps with unknown revenue collection status.

[g]Excludes data from Uganda, which do not distinguish between revenue collection approach.

consumer exploitation therefore take a lower priority. Although price setting for rural waterpoint repair services is not always beyond the purview of local governments [see, e.g., *Mommen and Nekesa*, 2010], policies are commonly agnostic about revenue collection approach. This is perhaps unsurprising given community-based decision-making regarding waterpoint tariffs is a central tenet of community management and participatory planning.

Among those policy, strategy, and guideline documents that venture into the realm of rural water tariffs, there is little consensus about preferred payment models and guidance is often non-specific. For example, the rural water supply strategy in Sierra Leone advocates for tariffs in the "form of levies, monthly payments per household or periodic harvests" [*Ministry of Water Resources* (*MWR*), 2013]. Uganda's rural water O&M framework leaves it up to communities to choose any one of nine methods [*MWE*, 2011], and the *African Development Bank* [2010] guidelines present an even greater multiplicity of possibilities relating to how, when and where funds could be collected. Guidance in Malawi and Tanzania simply advises communities to collect "maintenance funds from each user household" and "establish a mechanism to pay the full costs of O&M" respectively [*Ministry of Irrigation and Water Development* (*MIWD*), 2010; *Ministry of Water and Livestock Development* (*MWLD*), 2002]. At the more prescriptive end of the spectrum, Ghana's *Community Water and Sanitation Agency* [2011] stipulates that handpumps should be accompanied by pay-as-you-fetch (PAYF, also known in other contexts as "pay-as-you-go") revenue collection systems, while Zambia's handpump O&M guidelines suggest fixed financial contributions could be made monthly, bi-annually or annually [*MLGH*, 2007].

Data from over 90,000 waterpoints fitted with handpumps in five countries indicate the most common revenue collection strategy is reactive contributions when a handpump breaks down, followed by flat fee payments (weekly, monthly, or annual) and pay-as-you-fetch fees (per jerrican or bucket) (Table 1). Significant variation in preferred strategies is evident across countries and regions. For instance, while PAYF appears to be relatively uncommon in Table 1, between 50% and 90% of communities in certain regions of Ghana have such a system in place [*Komives et al*., 2008; *Adank et al*., 2013]. Diverse approaches have even been noted within individual villages in Mali [*Jones*, 2010]. To add to the complexity, communities sometimes assume hybrid, dynamic or differential tariff permutations based on a host of factors, including membership status, purpose of water use, family size, livestock ownership, religious holidays, and rainfall season.

1.2. Community Waterpoints: Common-Pool Resource or Private Good?

Economists commonly characterize goods and services according to the twofold criteria of subtractability and excludability. Subtractability—also known as rivalry—describes the extent to which one person's consumption reduces the availability of the good or service for others. Excludability refers to the degree to which consumption of a good or service can be denied. *Samuelson* [1954] proposed the concept of subtractability as a way of distinguishing between private and public goods, while the importance of excludability emerged by way of landmark analyses of collective action [*Olson*, 1965], common-pool resources [*Hardin*, 1968], and club goods [*Buchanan*, 1965]. Soon after, *Musgrave and Musgrave* [1973] combined the attributes of excludability and subtractability into a single framework, with *Ostrom and Ostrom* [1977] subsequently populating their two-by-two matrix with four types of goods: (i) private goods, (ii) public goods, (iii) club (toll) goods, and (iv) common-pool resources.

Depending on the context, water can assume features of any of the four types of goods [*Haneman*, 2006; *Young and Loomis*, 2014; *Easter and Feder*, 1997]. Community waterpoints equipped with handpumps in rural sub-Saharan Africa have typically been regarded as a common-pool resource [*Naiga and Penker*, 2014; *Foster and Hope*, 2016], on the premise that use is subtractable and excluding noncontributors is difficult. This assumption of low excludability is grounded upon the observation that measures to prevent noncontributors from accessing the handpump are often weak or absent. Subtractability reflects the reality that use of the handpump incurs a marginal cost greater than zero, be that in the form of a unit operation and maintenance cost (i.e., "wear and tear"), a contribution to queues and congestion at the waterpoint, or a reduction in the availability of the groundwater resource. *Hardin* [1965] predicted overuse and degradation would be the inevitable fate of common pool resources, on the assumption that narrow self-interest of users would trump cooperative endeavors to manage the resource collectively. Applying this pessimistic forecast to communal waterpoints fitted with handpumps, one might expect rampant free-riding, resulting in insufficient funds to carry out repair work when the system breaks down. However, as with other resource types [see, e.g., *Wade*, 1987; *Basurto and Ostrom*, 2009], the reality has proved more complex than this simplified prognosis. There are instances of communities successfully managing and financing waterpoint O&M over many years, just as there are cases where communities fail to establish and sustain revenue collection systems, with waterpoints quickly falling into a state of disrepair.

A low level of excludability need not be an inherent property of waterpoints if communities are able to apply institutional and physical measures to restrict access [*Koehler et al*., 2015]. Generally speaking, the characteristic of excludability is both mutable and a question of degree [*Baumol*, 1986]. The approach to revenue collection—in particular, pay-as-fetch (PAYF)—may have an important bearing on a waterpoint's level of excludability. Usage under a PAYF regime is contingent on a concurrent payment to an attendant who is located at the waterpoint during hours of operation to monitor use and regulate access. The attendant sells the water on a volumetric basis, and their remuneration is commonly linked to the overall sales. As excludability is an inherent basis of PAYF arrangements, community waterpoints morph into a private good, theoretically reducing the risk of free-riding and lessening the collective action demands in relation to rule compliance and enforcement. In contrast, when regular flat fees or reactive contributions upon breakdown are levied, a household's water use for the relevant period commonly precedes payment, making cooperation more dependent on mutual trust, shared norms, and the threat of sanctions. While in some situations these arrangements can engender high levels of compliance, evidence of nonpayment practices suggests they are susceptible to free-riding [*Foster and Hope*, 2016]. Over time, the imposition of sanctions may result in de facto excludability measures for past defaulters; however the incentives to continuously monitor and regulate waterpoint usage in order to enforce access rules are likely to be weaker than under a PAYF model, and a second-order free-rider problem may emerge.

A waterpoint's level of excludability also has potential consequences for its accessibility, and therefore raises broader policy issues. The concept of accessibility lies at the heart of global and national policy goals, frameworks, and laws, most notably the Sustainable Development Goal (SDG) for universal access to safe drinking water and the human right to water [*UN Committee on Economic, Social and Cultural Rights*, 2003; *United Nations General Assembly* (*UNGA*), 2010]. A comprehensive evaluation of waterpoint revenue collection approaches must therefore consider both the consequences for the financial and operational performance of the water service, and the drinking water source choices of households. Of particular pertinence is whether operational measures that promote the sustainable delivery of safe water services undermine the inclusiveness of those services. Any potential tension between these goals could have important implications for an SDG and human right that conjoin universal safe water access with notions of affordability, equitability and availability. In this way, a holistic analysis of PAYF arrangements must navigate similar concerns pertaining to the use of prepaid meters in urban areas [*Heymans* et al., 2014; *Wesson*, 2011].

The ramifications of revenue collection approaches extend beyond just a waterpoint's level of excludability, and there are a number of other possible trade-offs. Each strategy has potential advantages and disadvantages relating to the conduciveness to cash flow patterns of users, susceptibility to misappropriation, and availability of cash on hand when breakdowns occur. However, a discussion of pros and cons is necessarily theoretical, as there is a dearth of empirical evidence on the implications of different revenue collection approaches. Some observations are supportive of PAYF systems in terms of revenue generation, though they reveal little about whether greater revenue levels translate into more reliable water services. Based on findings from a major handpump sustainability study, *Harvey* [2007] suggests that PAYF arrangements draw in the most revenue. Private operators of rural waterpoints—though uncommon—also tend to prefer a PAYF revenue model [*Keesiga and Kimera*, 2014; *Haas and Nagarajan*, 2011], suggestive of superior income generation. Even sparser are insights into the access outcomes associated with different approaches. *Churchill et al*. [1987] ventures a rare opinion on the matter, cautioning that tying waterpoint fees to volumetric consumption could discourage water use among low-income households, or cause them to revert to unimproved sources.

1.3. Study Aims

This study seeks to empirically assess whether choice of revenue collection approach—particularly PAYF—influences the financial performance, operational sustainability, and use of community waterpoints in Kwale, Kenya. The investigation sets out to test whether different revenue collection approaches lead to disparities in the amount of income collected (taking into account both revenue and expenditure), operational downtime, and use of unimproved drinking water sources. The analyses utilize a unique data set integrating a waterpoint census, large-scale household survey, and water committee financial records.

2. Methods

2.1. Study Site

Kwale County is located on the south coast of Kenya, between the city of Mombasa to the north, and Tanzania to the south. In 2013, Kwale had a population of approximately 730,000 people, four-fifths of whom lived in rural areas [*Commission on Revenue Allocation*, 2013]. Based on a poverty gap index measure, the region is one of the most impoverished in Kenya, ranked 41st out of 47 counties [*Commission on Revenue Allocation*, 2013]. According to the census in 2009, protected wells and boreholes were the main sources of water for 21.9% of the county's households [*Kenya National Bureau of Statistics*, 2012].

Kwale holds an important place in the history of rural water supply programming in sub-Saharan Africa as it was the location for the first ever large-scale deployment of Afridev handpumps [*Baumann and Furey*, 2013]. County government records suggest 574 waterpoints were equipped with Afridev handpumps between 1983 and 1995, most drawing water from an unconfined aquifer in Pleistocene sands and coral limestones. On average, these waterpoints had a static water level of 17.1 m and a yield of 2.6 m^3 per hour around the time of installation [*Foster and Hope*, 2016]. Community-based waterpoint committees were setup from the outset and tasked with the job of collecting user fees, usually on a monthly basis [*Narayan-Parker*, 1988]. Community members were originally trained to service and repair handpumps in line with a village-level operation and maintenance (VLOM) approach, though in the ensuing years many communities began to make use of the services offered by professional handpump mechanics operating across larger areas. The program was subsequently hailed for its achievements, and was considered an exemplar of community-based water supply management [*McCommon et al*., 1990; *Rondinelli*, 1991; *Black*, 1998]. Figure 2 presents the locations of communal Afridev handpumps in Kwale in 2013, and their characteristics are summarized in Table 2.

2.2. Data Collection

Data underpinning this study were collected in three separate campaigns: (a) a census of 571 waterpoints fitted (or formerly fitted) with Afridev handpumps; (b) a survey of 3361 households near to the sampled waterpoints; and (c) an audit of financial records kept by 100 water committees. Both the waterpoint census and household surveys were undertaken by trained local enumerators and delivered in local languages, predominantly Swahili and Digo. Prior to data collection, research permits and approvals were obtained from

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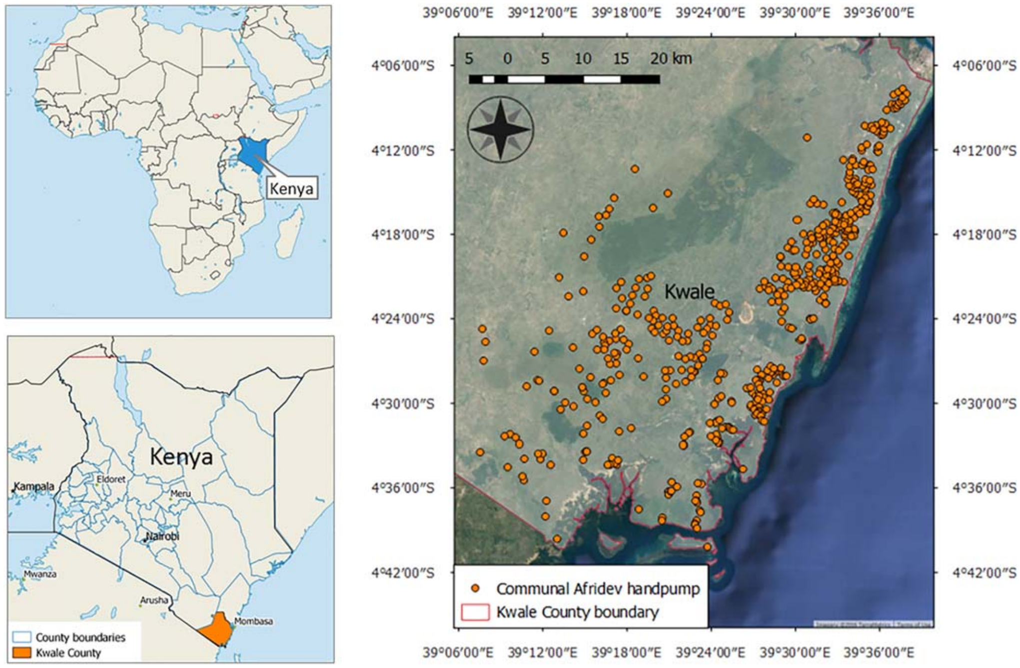

Figure 2. Study site and location of communal waterpoints fitted with Afridev handpumps in Kwale County. Underlying satellite imagery: *Google, Terrametrics* [2016].

the Government of Kenya's National Council of Science and Technology and the Central University Research Ethics Committee at the University of Oxford.

The waterpoint census was conducted in August 2013, and captured technical, institutional, operational, financial, and geographical information through structured interviews. Waterpoints were excluded from analysis in this study if they were not for communal use, or the handpump had been replaced by a submersible pump. Table 3 presents the revenue collection status of all communal waterpoints fitted with an Afridev handpump. As part of the waterpoint census, respondents were also asked whether written financial records were kept. For those communities who answered in the affirmative ($n = 213$), a follow-up visit was undertaken in January 2014, with the exception of 18 handpumps that could not be visited for security reasons. At 100 communities, financial records were located and photographed for later analysis.

Between August 2013 and January 2014, a questionnaire was administered to a random sample of 3361 households within the service area of communal waterpoints (mean of 6.3 households per waterpoint, 4.6 residents per household). The survey captured demographic, socioeconomic, and water use information for each household and its members. A cleaned sample of 3349 households was used for analysis, excluding 12 cases with poor respondent understanding or concerns about the accuracy of responses.

Table 2. Characteristics of Communal Waterpoints Fitted With Afridev Handpumps in Kwale ($n = 518$)

Measure	Mean (SD)
Yield[a] (m^3/h)	2.6 (1.3)
Static water level[b] (m)	15.5 (8.3)
pH[c]	6.60 (0.86)
Electrical conductivity[c,d] (μS/cm)	1182 (984)
Age (years)	21.0 (7.8)
Average distance from households to waterpoint (m)	137 (99)
Distance from waterpoint to spare part retailer (km)	21.9 (15.0)

[a]Government data on yield drawn from borehole drilling records for 201 waterpoints, and pertain to the time of installation.
[b]Data on static water level drawn from borehole drilling records for 214 waterpoints, and pertain to the time of installation.
[c]Water quality characteristics measured for 288 waterpoints.
[d]Individual electrical conductivity values were capped at 3999.

2.3. Analysis

The analysis focused on sustainability and access outcomes associated with three revenue collection approaches: (i) PAYF arrangements, whereby water is paid for by the bucket/jerrican, (ii) flat fee arrangements,

Table 3. Revenue Collection Status of Communal Waterpoints Fitted With Afridev Handpumps ($n = 518$)

Revenue Collection Approach	Frequency
Regular payments in advance of breakdown	255 (49.2%)
Flat fees	130 (25.1%)
Annual	*1 (0.2%)*
Quarterly	*1 (0.2%)*
Monthly	*108 (20.8%)*
Weekly	*19 (13.7%)*
Daily	*1 (0.2%)*
Pay-as-you-fetch (per jerrican/bucket)	125 (24.1%)
Reactive payments upon breakdown	89 (17.2%)
No revenue collection	173 (33.4%)
Total	518 (100%)[a]

[a]Includes one waterpoint where revenue collection approach could not be determined.

whereby a fixed fee is paid on a periodic basis (per week, month, year), and (iii) ad hoc arrangements, whereby fees are not regularly collected in advance of breakdown. Analysis was conducted to quantify waterpoint revenue, expenditure, net income and operational downtime, and determine whether significant differences in these outcome measures could be observed between revenue collection approaches. Access outcomes were evaluated by testing whether any revenue collection approach was significantly associated with choice of unimproved drinking water sources. All analyses were performed using the statistical software package SPSS (Version 21).

2.3.1. Financial Performance

Financial data were collated separately for three types of recorded revenue: PAYF records presented as daily water sales; flat fee records in the form of payments itemized by household (hereafter termed "flat fee payment" records); and flat fee records in the form of general cash flows (hereafter termed "flat fee cash flow" records). Although they covered fewer handpumps than the flat fee payment records, the flat fee cash flow records had the advantage of including expenditure items, and also additional revenue that derived from alternative income sources such as nonmember PAYF fees, membership registration payments, reactive or special contributions, and fines imposed on rule-breakers. As a result, they were arguably a truer reflection of how funds are generated in different ways, and also allowed for the calculation of net income (defined as revenue minus expenditure). High quality records were denoted in two ways. First, "Type 1" high quality records were identified where 12 or more consecutive months were represented. Second, "Type 2" high quality records were defined as those where 12 or more consecutive months of the year were represented and both revenue and expenditure were documented. As the records spanned 1987–2013, all monetary amounts were converted to 2013 values by applying deflator factors obtained from the World Bank Development Indicators database [*World Bank*, 2014]. Figures in 2013 Kenyan shillings were then converted to US dollars using an exchange rate of 1 USD to 86.1 KES. Monetary amounts were also converted to US dollars at purchasing power parity (PPP), with these results presented in the supporting information.

To compare financial performance across different revenue collection approaches, summary statistics for revenue, expenditure and net income were calculated for all records and the two categories of high quality records. To ascertain whether there were significant differences in the monetary amounts raised and expended under different approaches, independent samples t tests were performed. Where homogeneity of variances was violated, the Welch t test was run instead. Due to concerns regarding presence of outliers and nonnormal distribution of residuals, Mann-Whitney U tests were also run to determine if there were differences in the median values. Statistical significance was determined using the standard $\alpha = 0.05$ threshold. Average revenue, expenditure, and net income amounts were then calculated by month to appraise temporal variations, particularly in response to rainfall patterns.

2.3.2. Operational Performance

To determine whether revenue collection approach was associated with waterpoint operational performance, a data set was created which included one outcome variable (downtime), eight control variables, and four dichotomous variables of interest: (i) PAYF versus Flat fee, (ii) PAYF versus Ad Hoc, (iii) PAYF versus Other, and (iv) Flat fee versus Ad Hoc. Downtime was defined as the number of days between the point of initial breakdown and subsequent repair. As highlighted by *Carter and Ross* [2016], the duration of breakdown is an important indicator that provides a more nuanced understanding of waterpoint performance beyond a binary functionality measure. To minimize recall bias, the analysis was limited to those waterpoints that had broken down and been repaired at least once in the previous 12 months. Two hundred waterpoints met this inclusion criterion. The number of breakdown events for each waterpoint was limited to five. On the basis that all included waterpoints had undergone at least one repair in the previous 12 months (which must have been financed from some source), communities reporting that they collected no fees were combined with those that reported they collected funds upon breakdown into a single category labelled "ad hoc." Control variables were chosen based on their plausibility as factors that might influence waterpoint downtime, as drawn from empirical and theoretical rural water literature. They consisted of: (a) average distance between households and the handpump [*Mu et al*., 1990; *Naiga and Penker*, 2014; *Foster and Hope*, 2016; *Arouna and Dabbert*, 2010], (ii) distance to the closest alternative Afridev handpump [*Foster and Hope*, 2016; *Koehler at al*., 2015], (iii) distance to the spare parts retailer [*Foster*, 2013], (iv) proximity of the handpump technician [*Foster*, 2013], (v) user perceptions of water taste [*Langenegger*, 1987*; Foster and Hope*, 2016], (vi) prevalence of productive water use [*Foster and Hope*, 2016], (vii) average household welfare level [*Arouna and Dabbert*, 2012], and (viii) the number of repairs carried out in the previous 12 months.

After summary statistics were calculated, Generalized Estimating Equations (GEE) were run to ascertain whether revenue collection approach exhibited an association with downtime, while controlling for the potential confounders. The GEE was the chosen analytical method as it adjusts for the correlation between breakdown events pertaining to the same waterpoint, which would otherwise violate the independence assumption underpinning traditional regression techniques. To assess the influence of outcome variable outliers, GEEs with a log-transformed outcome variable were run, and results were compared. A series of logistic regression GEEs were then run with outcome variables dichotomized at different downtime thresholds, allowing for a more nuanced understanding of the relationship between revenue collection approach and operational performance. The choice of correlation structure was based upon the lowest quasi-likelihood under independence model criterion (QIC) statistic.

2.3.3. Waterpoint Access

In order to appraise the access implications of each revenue collection approach, first the prevalence of alternative drinking water sources was calculated for all three revenue collection approaches in both wet and dry season. Second, the odds of a household opting for an unimproved drinking water source was determined across revenue collection approaches for both wet and dry season. This regression analysis again employed GEEs to adjust for clustering of households around waterpoints, and controlled for distance between the household and the waterpoint and user perceptions of taste of water in recognition of the high value users place on these service attributes [*Foster and Hope*, 2016; *Mu et al*., 1990]. To limit recall bias, analysis was limited to those households located in the service area of handpumps that were functional, or had been functional at some point in the previous 12 months. The definitions of unimproved sources were based upon the Joint Monitoring Programme classifications [*UNICEF/WHO*, 2015]. The analysis was disaggregated by welfare thirds (tertiles) to assess whether associations were consistent across different socio-economic strata. These welfare tertiles were derived from a multidimensional welfare index constructed by applying principal component analysis to household socio-economic indicators, including dwelling structure, asset ownership, education levels, and infrastructure characteristics, in accordance with the method outlined by *Filmer and Pritchett* [2001] (see supporting information). Dividing households into three welfare categories ensured sample sizes were large enough for the GEEs to converge.

3. Results

3.1. Financial Performance

Table 4 presents waterpoint revenue, expenditure, and net income summary statistics. Compared with flat fees, PAYF regimes generated more revenue, had higher levels of expenditure, and overall returned a greater net income. Depending on the subset of records analyzed, annual PAYF sales per waterpoint were $299–$313 greater than flat fee payment records, and $167–$249 higher than flat fee cash flow records. Although annual costs associated with PAYF systems were $16–$86 greater than flat fee arrangements, in total PAYF maintained net income levels that were $102–$232 higher.

Independent samples *t* tests and Mann-Whitney *U* tests found the difference in revenue between PAYF and flat fee payment records was statistically significant (Table 5), as was the difference between PAYF and flat fee cash flow records (High quality—Type 1). Disparities in expenditure were only significant when running the Mann-Whitney *U* test on all records. The higher level of net income associated with PAYF was significant for both types of high quality records when applying independent samples *t* tests, and the Mann-Whitney *U* test also yielded a significant result for Type 2 high quality records.

The revenue generated by both PAYF and flat fee strategies varied considerably by month, and appeared to rise and fall inversely with rainfall levels (Figure 3). Revenue tended to peak in February–March in the midst

Table 4. Summary Statistics for Revenue, Expenditure, and Net Income by Revenue Collection Approach[a]

Financial Measures (USD per Year)	All Records			High Quality Records—Type 1[b]			High Quality Records—Type 2[c]		
		Flat Fees			Flat Fees			Flat Fees	
	PAYF	Cash Flow	Payments	PAYF	Cash Flow	Payments	PAYF	Cash Flow	Payments
Revenue									
Mean	421.5	254.2	122.5	436.5	191.9	123.9	458.8	209.8	
SD	387.4	291.2	97.2	451.4	143.8	99.1	490.2	121.2	
Median	276.6	148.8	91.5	270.2	158.0	92.1	282.9	176.8	
Years of data	*46.8*	*136.0*	*231.2*	*37.1*	*116.0*	*214.4*	*27.8*	*56.8*	
No. waterpoints	*22*	*42*	*66*	*17*	*26*	*39*	*13*	*18*	
Expenditure									
Mean	247.0	160.7		193.6	135.2		186.3	169.4	
SD	234.1	175.2		119.7	92.9		131.1	120.0	
Median	171.8	111.7		174.4	118.3		177.0	139.0	
Years of data	*35.6*	*107.9*		*31.2*	*84.1*		*27.8*	*56.8*	
No. waterpoints	*19*	*40*		*14*	*22*		*13*	*18*	
Net income									
Mean	229.6	126.9		244.3	41.4		272.5	40.4	
SD	317.1	251.1		361.7	69.1		381.3	73.7	
Median	114.3	55.4		111.7	30.6		111.7	33.3	
Years of data	*41.6*	*83.3*		*35.9*	*59.9*		*27.8*	*56.8*	
No. waterpoints	*20*	*37*		*13*	*18*		*13*	*18*	

[a]Note: Results in International $PPP (2013) can be found in supporting information Table S1.
[b]Defined as 12 months or more of consecutive records.
[c]Defined as 12 months or more of consecutive records, including both revenue and expenditure data

of the dry season, and fell to a minimum in May–June during the period of heaviest rainfall. A similar, but less marked, pattern was also evident for expenditure. The seasonal fluctuations were also less apparent for flat fee payment records. Relative to May–June, revenue levels in February-March were 2.9–3.2 times greater for PAYF, 3.6–4.5 times greater for flat fee cash flow records, and 1.2–1.3 times greater for flat fee payment records. Equivalent expenditure ratios were 1.5–2.1 for PAYF, and 2.1–4.1 for flat fees. Notably, revenue from flat fee cash flow records was on par with flat fee payment records during the rainy period (May–July) but was discernibly higher during the dry period between January and March. On average, waterpoints with flat fees experienced net losses during the wettest period, whereas waterpoints with PAYF generated a profit year-round (Figure 4). In both cases, net income is highest in the dry months of February and March.

Table 5. Differences in Revenue, Expenditure, and Net Income by Revenue Collection Approach[a,c]

Records	Independent Samples *t* Test		Mann-Whitney *U* Test		
	Mean Diff (95% CI)	*P*	U	Mean Rank	*p*
PAYF Versus Flat Fee (Payments)					
Revenue					
All records	**299.0 (125.9–472.1)**[b]	**0.002**	**1288**	**70.0 versus 36.0**	**<0.001**
High quality records—Type 1	**312.6 (78.8–546.3)**[b]	**0.012**	**518**	**39.5 versus 23.7**	**0.001**
PAYF Versus Flat Fee (Cash Flow)					
Revenue					
All records	167.2 (−4.8 to 339.3)	0.056	**664**	**41.7 versus 27.7**	**0.004**
High quality records—Type 1	**244.6 (7.2–482.0)**[b]	**0.044**	**301**	**26.7 versus 18.9**	**0.047**
High quality records—Type 2	249.0 (−51.0 to 549.0)[b]	0.096	155	18.9 versus 13.9	0.135
Expenditure					
All records	86.3 (−22.9 to 195.5)	0.119	**515**	**37.1 versus 26.6**	**0.029**
High quality records—Type 1	58.4 (−13.8 to 130.6)	0.109	200	21.8 versus 16.4	0.141
High quality records—Type 2	16.9 (−78.1 to 111.8)	0.713	129	16.9 versus 15.3	0.650
Net income					
All records	102.5 (−50.8 to 255.6)	0.186	469	33.9 versus 26.3	0.098
High quality records—Type 1	**202.9 (30.7–375.2)**[b]	**0.049**	197	21.1 versus 14.6	0.060
High quality records—Type 2	**232.2 (0.00–464.3)**	**0.050**	**171**	**20.1 versus 13.0**	**0.031**

[a]Note: Bold values indicate statistically significant association ($p < 0.05$).
[b]Welch *t* test performed as homogeneity of variances was violated.
[c]Note: Results in International $PPP (2013) can be found in supporting information Table S2.

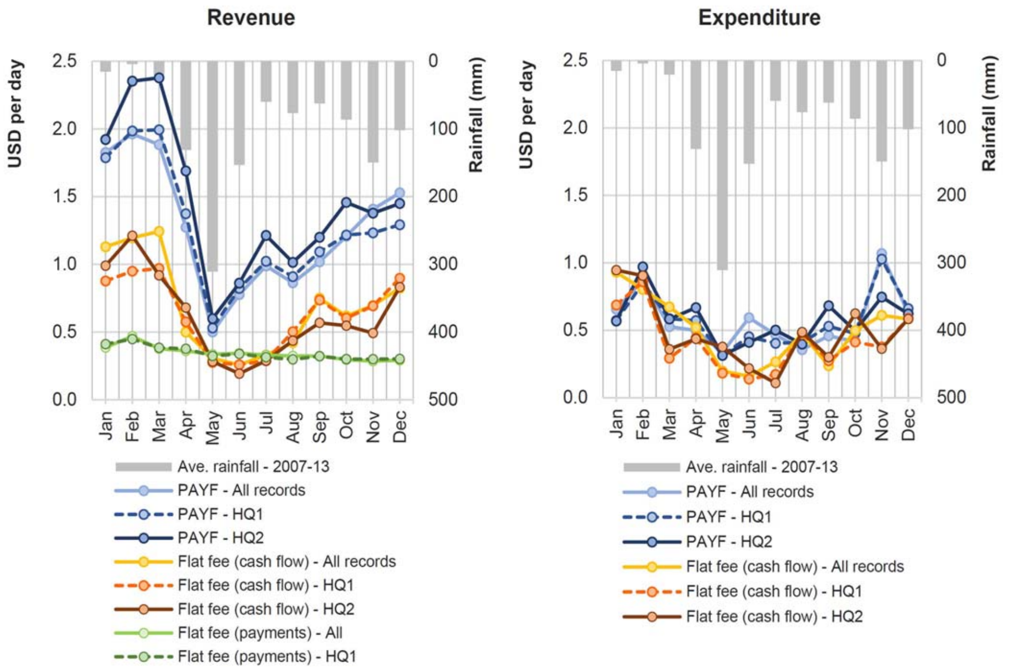

Figure 3. Waterpoint revenue and expenditure by month. Monthly rainfall data extracted from Kwale Drought Monitoring Bulletins prepared by Kenya's National Drought Management Authority (http://www.ndma.go.ke/).

3.2. Operational Performance

Table 6 summarizes the characteristics of waterpoints included in the downtime analysis, and Table 7 presents the results for the GEE assessment of downtime by revenue collection approach. Overall, PAYF waterpoints experienced average downtime that was 21.8 days less than flat fees. When adjusting for covariates, the difference in downtime between PAYF arrangements and both flat fee and ad hoc revenue collection was statistically significant (equivalent to 17.5 days and 12.4 days, respectively). All else held constant, there was no significant difference in downtime between flat fee and ad hoc arrangements. When running the GEEs with the natural log of downtime, PAYF maintained a statistically significant advantage over flat fees, suggesting the relationship was not solely due to influential outliers.

The results of the GEE logistic regression analyses in Table 8 demonstrate that the adjusted odds of a waterpoint being repaired within 21 and 30 days were significantly higher for PAYF systems relative to ad hoc payments. Likewise, the adjusted odds of having repairs carried out within 30 days were significantly higher

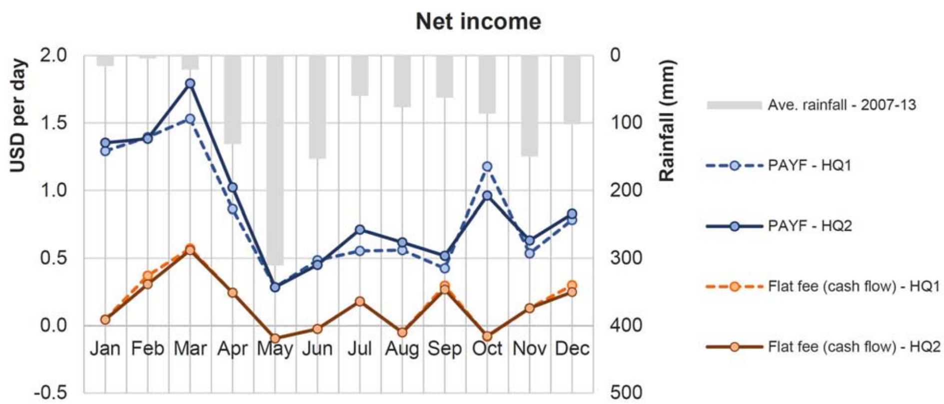

Figure 4. Waterpoint net income by month.

Table 6. Summary Statistics for Variables Included in Downtime GEE Models[a]

Variables	Definition	PAYF (n = 43) Mean	PAYF (n = 43) SD	Flat Fees (n = 62) Mean	Flat Fees (n = 62) SD	Ad hoc (n = 95) Mean	Ad hoc (n = 95) SD
Outcome Variable							
Downtime	No. days a waterpoint is nonfunctional for each breakdown event	12.9	28.7	34.7	72.4	36.0	76.0
Control Variables							
WP-HH Distance	Average distance between reference waterpoint and user households (m)	132.6	82.1	143.5	116.3	131.2	61.2
WP-WP Distance	Distance between reference waterpoint and nearest active communal Afridev handpump (m)	809	579	607	289	828	1269
WP-SPR Distance	Distance between reference waterpoint and spare parts retailer (km)	21.1	16.8	20.7	14.5	22.7	13.1
Community mechanic	1 = Handpump mechanic lives in same community as waterpoint	0.51	0.51	0.55	0.50	0.43	0.50
Taste	Average rating of water taste across wet and dry season (1 = good, 0 = average, −1 = poor)	0.62	0.43	0.65	0.42	0.47	0.56
Productive use	Percentage of households who use waterpoint for livestock or irrigation (%)	23.2	15.3	25.5	15.1	24.3	18.9
Welfare index	Average of a multidimensional index incorporating household composition, dwelling structure, asset ownership, and infrastructure measures (the higher the index, the higher the welfare level)	7.1	2.5	7.3	2.4	6.0	2.9
No. repairs	Number of repairs carried out in last 12 months	2.4	1.3	2.8	1.5	1.9	1.1

[a]WP = waterpoint, HH = households, SPR = spare parts retailer.

for PAYF systems compared with flat fees, and the thresholds of 10 and 14 days attained *p* values of less than 0.1. There were no significant results for any payment comparison between the downtime thresholds of 2, 4, and 7 days. Nor were there significant results for downtime threshold when comparing flat fees and ad hoc payments.

3.3. Waterpoint Access

The proportion of households opting for alternative drinking water sources by revenue collection approach is presented in Figure 5, and adjusted odds ratios for unimproved drinking water source use are summarized in Table 9. Use of alternative water sources was highest among households within the service area of waterpoints with ad hoc payment arrangements (21.8% in dry season; 26.0% in wet season), followed by PAYF (15.8%; 20.2%), and flat fees (12.0%; 13.2%). When adjusting for distance to the waterpoint and perceptions of taste, households surrounding waterpoints with PAYF fees were significantly more likely to opt for unimproved water sources than those in the vicinity of waterpoints with flat fees, a relationship that was evident in both wet and dry seasons. The association was also significant for households in each of the top two welfare tertiles. Relative to ad hoc fees, PAYF arrangements were only associated with greater use of unimproved drinking water sources during the wet season for the middle welfare tertile. Taste and distance to the waterpoint also emerged as significant predictors of unimproved water source use across seasons and welfare strata.

4. Discussion

The analyses offer four major insights into how revenue collection approach can influence waterpoint sustainability and drinking water source choices. First, PAYF revenue collection systems generate significantly more revenue than flat fees. Although this advantage is tempered by a higher cost base, PAYF is

Table 7. Results of GEE Regression Analysis With Downtime as Outcome Variable[a]

Tariff Structure	Event Downtime *B*	Event Downtime (95% CI)	Event Downtime *p*	Log_e (Event Downtime) *B*	Log_e (Event Downtime) (95% CI)	Log_e (Event Downtime) *p*
PAYF versus Flat fee	**17.5**	**(4.9–30.1)**	**0.007**	**0.39**	**(0.02–0.76)**	**0.039**
PAYF versus Ad hoc	**12.4**	**(1.2–23.6)**	**0.029**	0.16	(−0.25 to 0.57)	0.444
PAYF versus Other[b]	**13.2**	**(4.6–21.9)**	**0.003**	0.26	(−0.05 to 0.58)	0.099
Flat fee versus Ad hoc	−7.5	(−23.3 to 8.4)	0.357	−0.24	(−0.69 to 0.20)	0.280

[a]Note: Bold values indicate statistically significant association ($p < 0.05$). WP = waterpoint, HH = household, SPR = spare parts retailer. Results adjust for WP-HH Distance, WP-WP Distance, WP-SPR Distance, community mechanic, taste, productive use, welfare index, and number of breakdowns. Analysis includes 93 waterpoints (181 breakdown events) with PAYF, 62 waterpoints (171 breakdown events) with flat fees, and 43 waterpoints (105 breakdown events) with ad hoc arrangements.
[b]"Other" comprises both flat and ad hoc fees.

Table 8. Results of GEE Regression Analysis With Downtime Threshold as Outcome Variable[a]

Downtime Threshold	PAYF Versus Flat Fee			PAYF Versus Ad Hoc			PAYF Versus Other[b]			Flat Fee Versus Ad Hoc		
	OR	(95% CI)	p	OR	(95% CI)	p	OR	(95% CI)	p	OR	(95% CI)	p
2 days	1.08	(0.45–2.60)	0.862	0.65	(0.29–1.47)	0.305	0.84	(0.41–1.70)	0.625	0.64	(0.30–1.39)	0.260
4 days	1.43	(0.65–3.18)	0.377	0.81	(0.36–1.82)	0.615	1.06	(0.53–2.14)	0.861	0.66	(0.33–1.29)	0.219
7 days	1.38	(0.65–2.92)	0.405	1.08	(0.48–2.45)	0.844	1.24	(0.64–2.39)	0.521	0.67	(0.34–1.31)	0.240
10 days	1.91	(0.93–3.94)	0.080	2.06	(0.90–4.72)	0.087	**1.96**	**(1.01–3.81)**	**0.048**	0.96	(0.47–1.97)	0.917
14 days	2.35	(0.87–6.36)	0.092	2.26	(0.81–6.28)	0.118	2.32	(0.98–5.48)	0.056	1.10	(0.48–2.50)	0.823
21 days	2.24	(0.61–8.19)	0.222	**3.45**	**(1.07–11.14)**	**0.039**	2.53	(0.92–7.01)	0.073	1.22	(0.50–2.97)	0.655
30 days	**7.00**	**(1.85–26.58)**	**0.004**	**7.43**	**(1.40–39.44)**	**0.019**	**1.73**	**(1.25–25.30)**	**0.025**	1.07	(0.39–2.91)	0.896

[a]Note: Bold values indicate statistically significant association ($p < 0.05$). OR = Odds ratio. All results adjust for WP-HH Distance, WP-WP Distance, WP-SPR Distance, community mechanic, taste, productive use, welfare index, and number of breakdowns. Analysis includes 93 waterpoints (181 breakdown events) with PAYF, 62 waterpoints (171 breakdown events) with flat fees, and 43 waterpionts (105 breakdown events) with ad hoc arrangements.

[b]"Other" comprises flat and ad hoc fees.

still associated with higher levels of net income. Second, revenue and expenditure fluctuate according to rainfall levels, with cash inflows and outflows peaking during the dry season. Third, PAYF systems are significantly associated with shorter operational downtime, and a greater likelihood of repairs being carried out within 3–4 weeks. Fourth, relative to flat fees, the adjusted odds of a household using an unimproved drinking water source is significantly higher when they are located in the vicinity of a PAYF waterpoint.

The higher levels of revenue generated by PAYF contributions accord with the hypothesis that a waterpoint managed as an excludable private good can prevent free-riding, and reduce the collective action burdens that might otherwise encumber common-pool resources. However, the disparity in financial and operational outcomes may also in part be linked to the size and frequency of financial contributions involved. The mean PAYF tariff was \$0.026 per 20 L (\$1.3 per cubic meter), compared to the mean annualized flat fee of \$7.18 per household per year. Therefore, on average, a household could only collect 15 L per day (less than one standard-sized jerrican) under a PAYF model if they were to spend the same amount as the flat fee average. Notably, the mean PAYF tariff is around double the average unit price charged by water utilities in African cities for customers with household connections [*Banerjee and Morella*, 2011], and comparable to drinking water charges in some cities in high income countries [*International Water Association*, 2014]. In other words, PAYF arrangements not only preclude nonpayment and enforce cooperation, they also likely translate into a higher price of water per unit of consumption.

Revenue summed from flat fee cash flow records was \$68–\$132 higher than flat fee payments, a disparity that can be attributed to supplementary income sources beyond the standard household fee payments. For the waterpoints that documented the source of additional revenue, 53.3% derived from PAYF sales to nonmembers, 21.6% from membership fees, 18.1% from reactive contributions, 2.8% for ad hoc special collections, 2.4% from sale of goods or spare parts to other communities, and 1.8% from fines related to rule breaking. This signifies that revenue collection strategies are far more complex and dynamic than

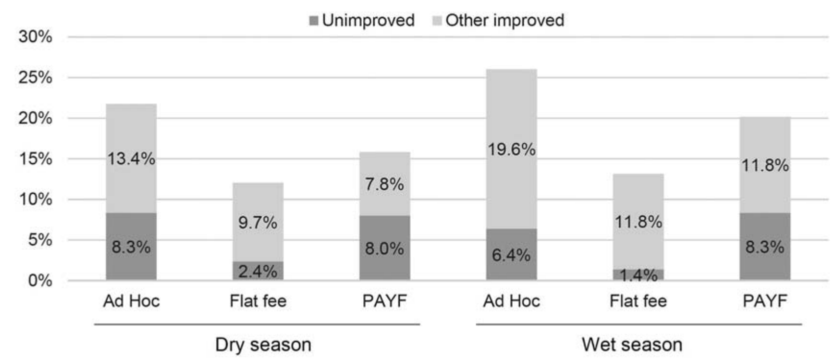

Figure 5. Percentage of households using alternative drinking water sources by revenue collection approach and season (***n*** = 2448).

Table 9. Results of GEE Multivariable Regression Analysis With Unimproved Drinking Water Source as Outcome Variable (n=2,190)[a]

Welfare Index	Variables	Dry Season Odds Ratio (95% CI)	Dry Season p	Wet Season Odds Ratio (95% CI)	Wet Season p
Tertile 1 (Lowest)	*Revenue Collection*				
	PAYF	1		1	
	Flat fee	0.481 (0.131–1.763)	0.270	0.369 (0.108–1.260)	0.112
	Ad Hoc	1.144 (0. 485–2.698)	0.758	0.849 (0.404–1.788)	0.667
	Taste	**0.384 (0.248–0.596)**	**<0.001**	**0.469 (0.310–0.710)**	**<0.001**
	Distance	1.002 (1.000–1.004)	0.109	1.001 (0.999–1.003)	0.341
Tertile 2	Tariff				
	PAYF	1		1	
	Flat fee	**0.158 (0.035–0.718)**	**0.017**	**0.105 (0.025–0.447)**	**0.002**
	Ad Hoc	0.624 (0.286–1.362)	0.237	**0.406 (0.173–0.956)**	**0.039**
	Taste	**0.297 (0.184–0.478)**	**<0.001**	**0.318 (0.194–0.520)**	**<0.001**
	Distance	1.002 (1.000–1.005)	0.074	**1.003 (1.001–1.006)**	**0.004**
Tertile 3 (Highest)	*Revenue Collection*				
	PAYF	1		1	
	Flat fee	**0.066 (0.004–0.995)**	**0.050**	n.a.	
	Ad Hoc	1.351 (0.509–3.586)	0.546	0.997 (0.333–2.986)	0.995
	Taste	**0.271 (0.169–0.436)**	**<0.001**	**0.275 (0.160–0.473)**	**<0.001**
	Distance	**1.004 (1.002–1.006)**	**<0.001**	**1.003 (1.001–1.006)**	**0.018**
All	*Revenue Collection*				
	PAYF	1		1	
	Flat fee	**0.107 (0.027–0.427)**	**0.002**	**0.123 (0.048–0.314)**	**<0.001**
	Ad Hoc	0.768 (0.407–1.451)	0.416	0.769 (0.421–1.404)	0.392
	Taste	**0.402 (0.313–0.517)**	**<0.001**	**0.416 (0.319–0.542)**	**<0.001**
	Distance	**1.002 (1.001–1.004)**	**0.002**	**1.002 (1.001–1.004)**	**0.002**

[a]Note: Bold values indicate statistically significant association ($p < 0.05$).

categorical survey responses suggest. It also indicates that a proportion of the overall revenue for flat fee arrangements comes in the form of reactive payments, presumably to plug a shortfall when repairs are needed. PAYF records lacked a similar diversity of revenue streams, suggesting revenue from PAYF sales is generally sufficient to cover O&M costs when they arise, without the need for additional contributions to make up for any deficit.

Although PAYF systems collect more cash, this is partially offset by a higher cost base in the order of $16–$86 per year. Much of this disparity likely stems from the additional expenses incurred when remunerating the attendants that are central to PAYF systems. For those waterpoints that disaggregated expenditure items, the annual nonmaintenance cost component associated with PAYF was $54 higher than for flat fees ($88 versus $34). Furthermore, on average, attendant wages accounted for 28.5% of expenditure for PAYF waterpoints, compared with 4.5% for flat fee systems. These could well be underestimates, as in some cases the attendant wages may have been deducted from the revenue before it was recorded. Expenditure differences could also be linked to larger group sizes and higher levels of usage, which in turn may increase the frequency of failures and drive up repair costs. The counter argument is that the volumetric nature of PAYF fees might discourage handpump use for needs where water quality is deemed less important, such as bathing and productive uses. This in turn could have perverse health consequences by undermining hygiene behaviors that are contingent on sufficient quantities of water. Financial data is equivocal on the matter: although PAYF waterpoints incur annual maintenance costs $31 higher than flat fee waterpoints ($139 versus $108), the difference may be negligible when weighing up unit maintenance costs per operational day that account for the additional downtime experienced under a flat fee system.

To our knowledge, this is the first time a seasonal trend in revenues and expenditures has been documented for community waterpoints in rural sub-Saharan Africa. This mirrors the observed impact of rainfall on both water consumption and waterpoint maintenance workloads in rural areas of Kenya and Burkina Faso [*Foster*, 2012; *Curtis et al*., 1993; *Oxford/RFL*, 2015]. The inverse relationship between revenue and rainfall is most likely linked to the increase in availability of alternative water sources during wet season brought about by the creation of surface water bodies and opportunities to harvest rainwater. During these wetter periods, users may therefore switch from the waterpoint to a more convenient or lower-cost alternative source for some or all of their water needs. Concurrent with a reduced dependence on the waterpoint, monitoring and enforcement of access rules may also weaken during wetter periods. When factoring in additional revenue sources, flat fee cash flows exhibited far more seasonal variation than flat fee payments. This discrepancy is probably due to the additional PAYF contributions by nonmembers and reactive payments which are included in cash flow calculations, both of which are more likely to fall within drier months. This is corroborated by the fact revenue documented in flat fee cash flow records for the months of February and March was 2.1–3.3 times that of flat fee payments, yet the two data sources yielded similar estimates for the wetter period in May and July.

The significant relationships observed in the operational downtime GEEs provide evidence that PAYF systems lead to improved waterpoint performance, to the magnitude of 10–20 days fewer downtime days per breakdown once adjusted for covariates. Greater reserves of cash on hand and stronger financial incentives to repair waterpoints promptly may both be contributing factors. Surprisingly, there was no evidence that communities paying flat fees experience shorter downtime than those collecting funds on an ad hoc basis, defying the theory that cash on hand would allow for prompter repairs. A possible explanation is that the amount saved in advance under a flat fee arrangement is often insufficient to cover the cost of a repair and reactive payments are still required, thereby amplifying the average downtime per breakdown. This hypothesis is supported by the cash flow data, which shows reactive contributions are still commonly needed where flat fee arrangements are in place. Moreover, high quality flat fee records reveal only a slim margin between average revenue and expenditure, suggesting these arrangements are vulnerable to lumpy and irregular maintenance costs. Adding weight to this argument is the conclusion that the downtime relationship is most pronounced for a threshold of 30 days, perhaps indicative of costly major repairs that exceed cash reserves for flat fee systems but not PAYF. The corollary is that simply collecting revenue to cover "average" handpump O&M costs is insufficient—a financial buffer is needed to cope with above-average repair costs if and when they arise.

The dual associations between PAYF and both operational and financial outcomes concur with commonly articulated foundations of water service sustainability. That is, financial and operational performance is mutually reinforcing [*Rouse*, 2007]. Yet, on its own, revenue collection approach is by no means a panacea for rural water sustainability. While PAYF may reduce the complexity of the collective action challenge, it does not absolve water users from working collaboratively. Communities and water committees that decide to adopt PAYF still need to agree on, and maintain oversight of, roles, responsibilities and rules. Ultimately, their willingness and ability to carry out these tasks effectively are likely influenced by a myriad of social, institutional, and environmental factors [*Whittington et al*., 2009; *Foster*, 2013; *Fisher et al*., 2015]. Although it was associated with the shortest downtime relative to other approaches, repairs for PAYF waterpoints in Kwale still took an average of 12.9 days to effect. By most measures, service disruptions of such length are unsatisfactory [*Hope*, 2015], and adverse health ramifications of switching to unimproved water sources are likely to materialize before this threshold is reached [*Brown and Clasen*, 2012]. Furthermore, 31.2% of waterpoints accompanied by a PAYF arrangement had been in a state of disrepair for more than a year, a nonfunctionality rate consistent with flat fees. This perhaps points to failure modes and other systemic institutional weaknesses that revenue collection arrangements alone cannot address. While bolstering revenue collection is critical if waterpoints are to shift from a low-level equilibrium to a virtuous cycle of strong financial and operational performance, so too are other measures to support waterpoint reliability and reparability. For this reason, external support is advocated across the spectrum of financial, administrative and technical responsibilities that communities currently assume [*Harvey and Reed*, 2007; *Rural Water Supply Network*, 2010; *IRC*, 2012]. Alternative maintenance models that reallocate roles, responsibilities, incentives and risks among communities, government, and private enterprise have also been proposed as a pathway forward [*Harvey and Reed*, 2007; *Hope et al*., 2012].

While the findings suggest PAYF has perverse implications in relation to safe drinking water access, it is unclear to what extent this might be linked to the increased level of excludability or the higher unit cost of water. Notably, the relationship holds for the top two welfare categories, indicating it is not attributable solely to affordability factors. Either way, the result points to a tension between policy prescriptions pertaining to financial sustainability and goals targeting expanded coverage of safe water supplies. On the one hand, the global SDG and the Government of Kenya's Vision2030 promote universal safe water access. So too does the human right to water, as recognized under international law and enshrined in the Kenyan constitution [*UNGA*, 2010; *Government of Kenya*, 2010]. At the same time, it is assumed in Kenya, and in most other countries in sub-Saharan Africa, that responsibility for financing rural water supply O&M rests with communities. Yet in Kwale, the revenue collection strategy that is associated with the best financial and operational outcomes also appears to drive a proportion of households towards unimproved water sources.

This presents a conundrum for practitioners and policy-makers: how to achieve universal access to safe and reliable water services if this is not always matched by a universal willingness and ability to fully cover the costs of operation and maintenance among water users. This challenge is by no means a new one. It is a key reason why a supply driven approach to rural water programming met with disappointing results [*Briscoe and de Ferranti*, 1988]. However, with the escalated ambition to achieve universal access, policymakers, and practitioners will need to devise strategies that concurrently expand coverage to the 270 million people without improved water source access (*UNICEF/WHO*, 2016) and ensure sustainable systems of operation and maintenance, even where some users lack the requisite demand and wherewithal to pay the full costs of those services. It is for this reason alternative financing sources may need to play a greater role in covering recurrent maintenance costs in the coming years [*Franceys et al*., 2016].

4.1. Study Limitations

The analyses and interpretations in this study come with a number of qualifications and limitations. First, the operational outcome indicator utilized in the sustainability analysis was self-reported downtime for the previous 12 months, and therefore susceptible to recall bias. To mitigate this issue, future studies should seek to measure downtime in a more robust fashion, possibly through the use of emerging monitoring technologies [*Thomson et al*., 2012; *Nagel et al*., 2015]. Second, the results may be affected by selection bias, as the inclusion criteria limited the financial analysis to those committees keeping financial records, the operational analysis was focused on those waterpoints which had had at least one breakdown and repair in the previous 12 months, and all analyses were restricted to waterpoints that had been functional at some point within the previous 12 months. As such, those waterpoints analyzed tended to have slightly wealthier users, produce better tasting water, and exhibited other geographical and hydrogeological differences compared with those waterpoints that did not meet the inclusion criteria (see supporting information Tables S3 and S4). Third, no causal relationships can be conclusively demonstrated between explanatory and outcome variables, and the effects of confounding or reverse causation cannot be ruled out. For example, there may be other unobserved factors that explain why users are able to repair the handpump more promptly or opt for unimproved sources that also underlie the community's decision to adopt a particular revenue collection approach. Finally, the accuracy of the revenue and expenditure calculations is dependent on the quality of the original records kept by water committees. Though anomalies and ambiguities evident in the records were discussed and clarified with water committee members, the possibility of undetected errors or omitted information cannot be ruled out.

5. Conclusions

This study has shed light on the relationships between revenue collection approach, the financial and operational performance of waterpoints, and the water source choices of households in rural Kenya. Though it remains an uncommon revenue collection strategy in some parts of rural sub-Saharan Africa, the evidence from Kwale County suggests that pay-as-fetch waterpoints generate more income and experience shorter downtime than waterpoints with flat fee arrangements. The trade-off is that a higher proportion of households opt to use an unimproved drinking water source, either because of the increased excludability, the higher unit cost of water, or a combination of the two. Thus in Kwale, neither pay-as-you-fetch nor flat fee arrangements can be said to achieve the twin goals of sustainable and universally accessed water services. Further investigation is required to understand why some communities independently choose pay-as-you-fetch arrangements, and the extent to which there is a community consensus on the adoption of an exclusionary model that accepts higher costs and unimproved drinking water use in exchange for superior operational outcomes. Regardless, if the SDG of "safe water for all" is to become a reality, policymakers and practitioners cannot tacitly endorse such trade-offs, but instead must ensure rural water services are financially viable, reliable and inclusive. Action research is required to determine the combination of institutional, financial, and operational arrangements needed to make this happen.

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