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A multi-decadal and social-ecological systems analysis of community waterpoint payment behaviours in rural Kenya

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Abstract

Community-based financing of rural water supply operation and maintenance is a well-established policy principle in sub-Saharan Africa. Yet evidence from over 90,000 waterpoints in five sub-Saharan African countries suggests a majority of communities fail to establish and sustain a revenue collection system. As a result, insufficient finances to repair waterpoints can lead to lengthy downtimes or abandonment, threatening the health and welfare of millions of water users forced to revert to unsafe or distant alternatives. Applying a social-ecological systems framework to community waterpoints in rural Kenya, we empirically assess the prevalence and determinants of financial contributions among water users. The analysis draws on multi-decadal data covering 227 years' worth of water committee financial records consisting of more than 53,000 household payments. Results reveal that non-payment and late payment are prevalent, and payment behaviours are predicted by groundwater quality, waterpoint location, productive water use, and rainfall season. The findings reflect the socio-ecological nature of waterpoint sustainability in rural sub-Saharan Africa and confirm that households are not always willing and able to pay for an improved water supply. This situation is symptomatic of a fundamental operation and maintenance financing challenge that must be addressed if the Sustainable Development Goal of universal access to safe water is to be achieved.

Key words – rural water supply, social-ecological system, collective action, financial sustainability, groundwater, sub-Saharan Africa

1. Introduction

Low levels of water supply sustainability pose a threat to development in rural areas of sub-Saharan Africa. Waterpoints that draw on groundwater – namely wells and boreholes – are the most prevalent and rapidly expanding drinking water supply option across the continent (Banerjee and Morella, 2011), accessed by more than 250 million rural inhabitants. Over the last three decades, community-managed handpumps have been the mainstay techno-institutional approach to rural waterpoint development (Arlosoroff et al., 1987; Harvey and Reed, 2007). Handpumps and community management have long been considered ideal bed-fellows: a low-cost and simple technology for lifting groundwater combined with an institutional model premised on the assumption that local users are willing and able to self-organise. However, with an estimated one in three handpumps non-functional at any one time (RWSN, 2009), flaws in this techno-institutional coupling have become apparent. Communities often struggle to carry out operation and maintenance (O&M) responsibilities, and the resultant service disruptions likely force millions of households to revert to unsafe or far-off water sources at any point in time. In an effort to expand safe water supplies to the 270 million rural Africans who still rely on unimproved sources (WHO/UNICEF, 2015), each year governments and development partners spend hundreds of millions of dollars on an estimated 60,000 waterpoints fitted with handpumps (Sansom and Koestler, 2009). Unfortunately, unless there is an improvement in the way O&M is carried out, historical evidence suggests these investments will fail to generate the desired human development outcomes, and safe water access in rural sub-Saharan Africa will continue to lag behind the rest of the world.

One of the foremost collective action challenges of keeping rural waterpoints functional is the financing of O&M activities. Revenue collection from water users is a well-established cornerstone of community management (Arlosoroff et al*.,* 1987; Briscoe and de Ferranti, 1988), and is widely regarded as critical to sustainability (Carter et al., 1999; Harvey, 2007; Foster, 2013). While full cost recovery – including capital costs – is viewed as unrealistic in rural sub-Saharan Africa (Harvey, 2007), community management proceeds upon the assumption that self-financing of recurrent O&M costs is attainable. Furthermore, it has been argued that neither governments nor donors can be relied upon to finance O&M costs on a long-term basis (Briscoe and de Ferranti, 1988). As a result, community-based financing of O&M is now formalised in rural water policies across the continent (Banerjee and Morella, 2011; African Development Bank, 2010). However, recently assembled waterpoint datasets suggest this expectation is not being met. Pooling data from 92,594 waterpoints fitted with handpumps across five countries reveals 3 in 5 are not accompanied by any form of revenue collection, and only 1 in 5 water user groups chooses to regularly collect and save funds in advance of a breakdown (Table 1).

Table 1. Prevalence of revenue collection for waterpoints fitted with handpumps in five sub-Saharan African countries

Country	Scope	No. handpumps	Handpumps with fee collection (%)	Primary revenue collection approach (%)	
				Upon breakdown	Regularly in advance of breakdown
Kenya	8 counties[a]	2,119	52.2[b]	8.1	44.0
Liberia	National	9,388	46.8[c]	30.2	16.6
Sierra Leone	National	12,003	20.0[d]	15.5	4.5
Tanzania	National	21,884	42.1[e]	13.2	28.9
Uganda	National	47,200	42.8	-	-
Total		**92,594**	**40.4 (37.6[f])**	**17.4[f]**	**20.2[f]**

Authors' analysis based on publicly available waterpoint datasets (Virtual Kenya, 2015; National Water Sanitation and Hygiene Promotion Committee, 2014; Sierra Leone, STATWASH Portal 2014; Government of Tanzania, 2014; Government of Uganda, 2012)

[a] Busia, Embu, Isiolo, Kajiado, Kiambu, Kisumu, Kwale, Turkana. [b] Excludes 229 handpumps with unknown revenue collection regime. [c] Excludes 51 handpumps with unknown revenue collection regime. [d] Excludes 682 handpumps which were under construction, and 12 handpumps with unknown revenue collection regime. [e] Excludes 2,899 handpumps with unknown revenue collection regime. [f] Excludes data from Uganda, which do not distinguish between revenue collection approaches.

Even where arrangements are put in place to regularly collect fees, it has been noted that a sizable proportion of waterpoint users fail to meet their payment obligations (Carter et al., 2010). However, little effort has been made to quantify the extent of this non-payment problem or empirically evaluate the underlying causes. While national water service regulators regularly publish revenue collection metrics for urban piped schemes in sub-Saharan Africa (EWURA, 2013; NWASCO, 2013; WASREB, 2014), the measurement of financial indicators for rural waterpoint systems remains a major knowledge gap. Moreover, though there is an established body of literature examining determinants of willingness to pay for hypothetical water services in rural sub-Saharan Africa (World Bank Water Demand Research Team, 1993; Arouna and Dabbert, 2012; Naiga and Penker, 2014), there have been few attempts to evaluate the conditions affecting actual payment behaviours (Hanatani and Fuse, 2012). This is of critical importance given evidence of a divergence between factors which influence a household's willingness to pay and those which determine their actual behaviours (Griffin, et al., 1995).

2. Conceptual Framework

Insights and analytical approaches from collective action and common-pool resource (CPR) literature have the potential to shed more light on why some communities are able to self-finance waterpoint O&M, while others fail. Scholarly interest in collective action and CPR dilemmas emerged more than four decades ago, when Hardin (1968) theorised that commons used collectively would inevitably result in overexploitation, degradation and collapse of the resource. Olson (1965) also postulated dire consequences for large groups entrusted with solving collection action problems. While these seminal works initiated a wave of theoretical and empirical research, their predictions have turned out to be overly pessimistic. This is not to deny that collective management of CPRs can in some instances lead to overuse and destruction, particularly when users are anonymous, do not communicate, and receive no feedback (Basurto and Ostrom, 2009). However, examples of users successfully collaborating and managing resources in a sustainable fashion have been noted across a range of resource types, including fisheries, forests, grazing pastures and water resources (Basurto and Ostrom, 2009).

More recently, CPR scholars have turned their attention to the conditions under which groups successfully self-organise and sustainably manage resources (Ostrom, 1990; Wade, 1994; Baland and

Platteau, 1996; Agrawal, 2003). Identification of factors which facilitate or hinder CPR management continues to provoke debate, and disagreement as to the size and direction of associations endures (Araral, 2009). Given the complexity of collective action and CPR processes, a single and comprehensive explanatory theory has proved elusive. Analysis and interpretation is often complicated by the feedback relationships that cause variables to affect each other recursively (Meinzen-Dick et al., 2004). Moreover, despite a multitude of studies spanning a range of CPR challenges, two key obstacles have thwarted the accumulation and synthesis of insights. First, CPR management inherently involves interaction between human and environmental systems, thereby bringing together disciplines which traditionally adopt discordant languages and methods. Second, variables measured and assessed are often high in number or inconsistent across studies, thereby complicating efforts to compare findings, conduct meta-analyses and formulate global theories (Agrawal, 2003; Ostrom and Cox, 2010).

In order to counter these challenges, Ostrom (2007; 2009) crafted a multilevel social-ecological system (SES) framework as a common diagnostic tool for analysing factors that influence outcomes for complex environmental and human systems. The SES framework is intended to aid cumulative learning by laying out a classification system and vocabulary that helps organise analysis and communicate findings (Ostrom and Cox, 2010). Shaped by decades of theoretical and empirical work, the framework is premised upon the logic that SES outcomes can be explained by factors contained within four core sub-systems – resource systems, resource units, governance systems, and users – as well as related ecosystems, and broader social-political-economic settings.

To varying degrees, community waterpoints in rural sub-Saharan Africa possess the hallmarks of a CPR – excluding users can be difficult, and use is rivalrous. Community waterpoints also provide fertile ground for applying Ostrom's SES framework. They lie at the interface between social groups and hydrogeological systems, thus a holistic analysis must traverse both social and natural science disciplines. Yet there has been limited empirical analysis linking CPR theory and rural waterpoint sustainability (Hanatani and Fuse, 2012; Naiga and Penker, 2014). Instead, the vast majority of CPR works relating to water management have focussed on irrigation systems which supply water for productive rather than domestic purposes (Araral, 2003; Ostrom, 1992; Meinzen-Dick, 2007).

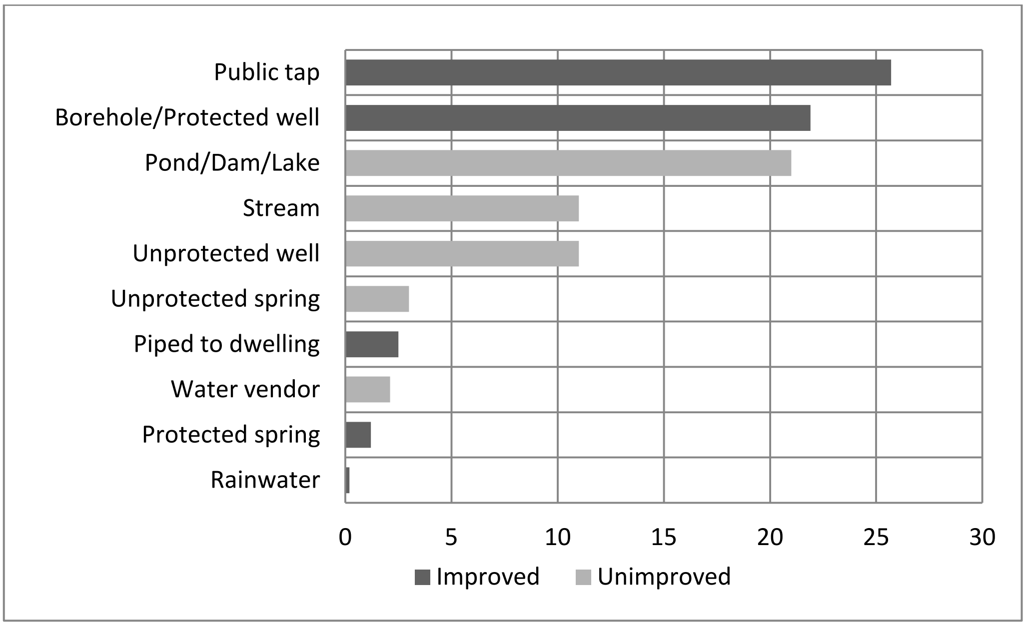
The intent of this paper is to address these lacunae in the literature by empirically assessing the extent and determinants of financial contributions among community waterpoint users on the south coast of Kenya. Drawing on data from a waterpoint census, household survey and water committee financial records, we seek to answer two key questions: (a) what proportion of rural water users contribute finances; and (b) which factors pertaining to the resource system, resource units, governance system, users, and related ecosystem predict collective payment rates.

3. Methods

3.1 Study site

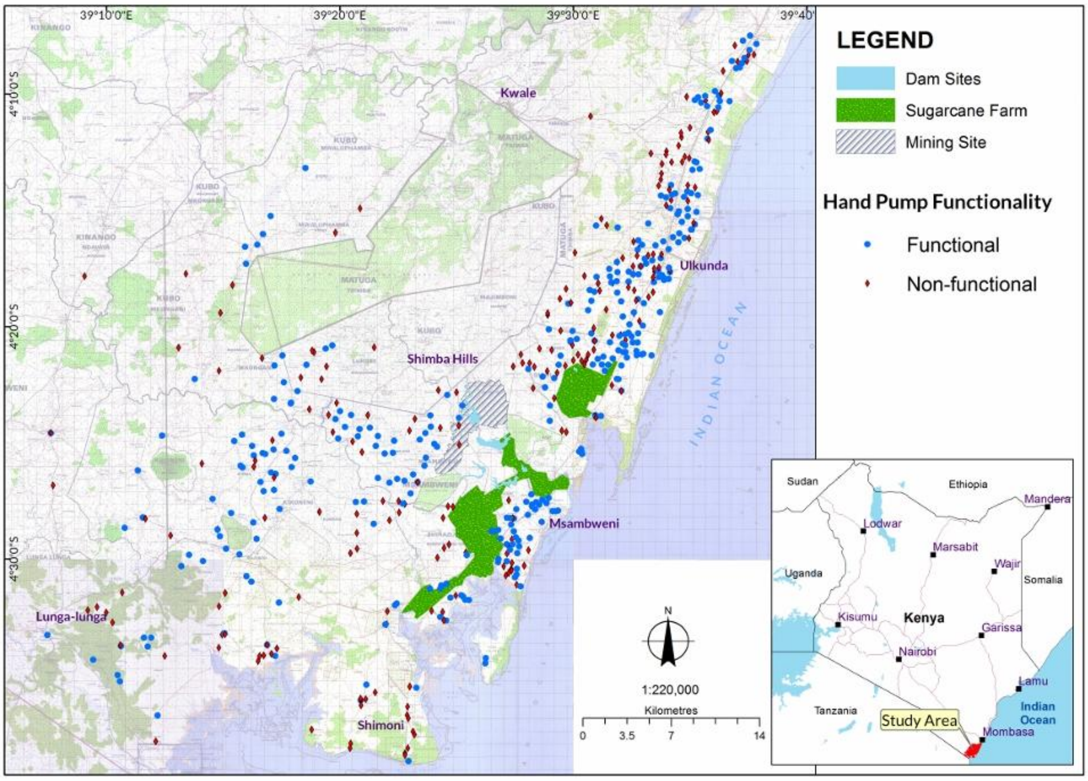
The study site, Kwale County, is situated on the south coast of Kenya, with a population in 2013 of around 730,000 (Commission on Revenue Allocation, 2013). The majority (82%) of Kwale's inhabitants reside in rural areas, and poverty rates are amongst the highest in Kenya (Commission on Revenue Allocation, 2013). Protected wells and boreholes are accessed by more than a fifth of the county's populace, and by 42.5% of households using an improved drinking water source (Figure 1). In particular, boreholes and wells fitted with Afridev handpumps – the focus of this study – are a ubiquitous feature of the rural water supply landscape, owing to successive donor-funded programmes which installed around 580 of these waterpoints between 1983 and 1995 (Figure 2).

Figure 1. Percentage of households in Kwale by main drinking water source (2009)



Data source: KNBS (2012)

Figure 2. Distribution of waterpoints fitted with Afridev handpumps in Kwale, Kenya



The large scale deployment of Afridev handpumps initially grew out of a small field trial, and the early results of the then Kwale Water Supply and Sanitation Project were hailed as a successful example of community-based water supply management (Narayan-Parker, 1988; Rondinelli, 1991; Black, 1998). Ninety percent of the Afridev handpumps currently in place are installed on boreholes, and original drilling records held by the County Government suggest at the time of installation they had a mean resting water level of 17.1m, and mean yield of 2.6 m^3 per hour.

Voluntary community-based committees and revenue collection systems were established alongside the infrastructure investments. A project evaluation report suggests communities were initially urged to establish monthly fees to cover the cost of handpump maintenance (Narayan-Parker 1988). In the beginning, community members were trained to carry out simple repairs, while implementers took responsibility for major repairs and distribution of spare parts (Narayan-Parker 1988). In the ensuing years, private sector retailers took over the supply of spare parts and an assorted division of maintenance responsibilities emerged. By 2013, some communities continued to carry out their own repairs, while others relied upon professional mechanics whose services spanned numerous communities.

3.2 Data collection

A waterpoint census of 571 Afridev handpump locations was carried out across Kwale in August 2013.[1] Key technical, social, institutional, operational, financial and geographical information pertaining to the waterpoint and its management were captured through structured interviews with a community member (a water committee member where possible). Water quality parameters (pH, EC) were also measured where feasible.

[1] This included 19 locations at which Afridev handpumps were originally installed, but had since been replaced by submersible pumps.

Based on a sampling frame informed by the waterpoint census, a survey was then conducted of 3,361 households[2] between October 2013 and January 2014. The survey was administered to a random sample of households within the service area of 531 waterpoints deemed communal in use (mean of 6.3 households per waterpoint, 4.6 residents per household). An in-depth questionnaire captured a range of demographic, socio-economic, water use, water payment and health indicators for each household. In order to randomly select participating households, a sketch map of all dwellings within the estimated waterpoint service area was first drawn by an enumerator in consultation with a local community member. Each household was allocated a number, and the households were then chosen using a random number generator application installed on a tablet device. Women were the respondents for 66.7% of the households surveyed.

Water user payment data were obtained from written financial records kept by water committees. The participating committees were identified throughout the waterpoint census, during which respondents were asked whether documentation was kept of revenue collected and/or expenses incurred. For those communities who stated they kept written records (n=213), a follow-up visit was then undertaken in January 2014.[3] At 100 communities, financial records were located, reviewed and photographed for data entry and analysis.[4] Of these, 65 communities had explicitly documented the payment history of individual households paying on a weekly, monthly, bimonthly or yearly basis. A structured interview with the person presenting the financial records (most commonly a water committee member) was also carried out and additional questions were asked to clarify any uncertainties and ambiguities that were evident in the records.

Prior to all data collection, a research permit was obtained from the Government of Kenya's National Council of Science and Technology, and ethics approval was obtained from the Central University

[2] 12 cases were subsequently excluded from the dataset as the respondent had a poor understanding of the questions and/or there were concerns about the accuracy of the responses.

[3] Due to security concerns, 18 handpumps north of Tiwi which reportedly had financial records could not be visited.

[4] These records covered a range of revenue collection systems, including regular fixed payments (e.g. monthly, weekly, yearly), pay-as-you-fetch arrangements, and reactive 'ad hoc' payments. For a graphical representation of the data collection approach, see Figures S2.1 and 2.2 in the Supplementary Material.

Research Ethics Committee (CUREC) at the University of Oxford. Both the waterpoint census and household surveys were undertaken by trained enumerators and delivered in local languages, predominantly Swahili (53.9% of households) and Digo (42.5% of households).

3.3 Analysis and variables

Data pertaining to the resource system, resource unit, user group and governance system were compiled into a spreadsheet. Waterpoints were only included if they were communally-used Afridev handpumps. Non-functional waterpoints that were communally used prior to breakdown were included, however those that had been upgraded to submersible pumps were not. Household cases were excluded from the dataset where (a) the enumerator recorded concerns over the accuracy of the responses, (b) the enumerator believed the respondent had a poor understanding of the questions asked, or (c) the household did not use the waterpoint to collect water for any purpose. After these exclusion criteria were applied, the dataset included information from a total of 518 community waterpoints and 3,233 households. Table 2 presents the operational and financial status of all waterpoints that met the inclusion criteria.

Table 2 – Operational and financial status of communal waterpoints fitted with Afridev handpumps[a]

	Functional	**Non-functional (< 1 year)**	**Non-functional (> 1 year)**	**Total**[b]
Advanced fees	**161 (53.1%)**	**19 (46.3%)**	**75 (43.1%)**	**255 (49.2%)**
Fixed fees	86 (28.4%)	8 (19.5%)	36 (4.1%)	130 (25.1%)
Annual	*1 (0.3%)*	*0 (0.0%)*	*0 (0.0%)*	*1 (0.2%)*
Quarterly	*1 (0.3%)*	*0 (0.0%)*	*0 (0.0%)*	*1 (0.2%)*
Monthly	*71 (23.4%)*	*4 (9.8%)*	*33 (19.0%)*	*108 (20.8%)*
Weekly	*13 (4.3%)*	*4 (9.8%)*	*2 (1.1%)*	*19 (13.7%)*
Daily	*0 (0.0%)*	*0 (0.0%)*	*1 (0.6%)*	*1 (0.2%)*
PAYF	75 (24.8%)	11 (26.8%)	39 (22.4%)	125 (24.1%)
Reactive fees	**66 (21.8%)**	**7 (17.1%)**	**16 (9.2%)**	**89 (17.2%)**
No revenue collection	**76 (25.1%)**	**15 (36.6%)**	**82 (47.1%)**	**173 (33.4%)**
Total	**303 (100%)**	**41 (100%)**	**174 (100%)**[c]	**518 (100%)**

[a]For a breakdown of surveyed households by operational status and revenue collection category, see Table S3.1 in Supplementary Material. [b]Excludes 19 locations at which communal Afridev handpumps were originally installed, but had since been upgraded to submersible pumps, usually at the expense of an external non-government organisation or local political leader. [c]Includes 1 waterpoint where revenue collection approach could not be determined.

Payment data were collated and inputted into a separate spreadsheet. Variables entered included payment period, date, number of recorded users, number of users contributing payments, tariff amount, and total amount of money collected. All monetary values were converted to Kenyan shillings in 2013 by applying deflator factors obtained from the World Bank Development Indicators database (World Bank, 2014). Payment data not coupled with a date were excluded from analysis. Financial, waterpoint and household data were then linked by way of a unique waterpoint identification code. All subsequent analysis was performed using the statistical software package SPSS (Version 21).

Contribution rates were quantified for different payment frequencies. Measures assessed were (i) collective payment rate (defined as the percentage of recorded users who contributed fees each payment period), and (ii) revenue collection rate (defined as the percentage of revenue collected relative to the theoretical amount that would have been collected had all recorded users paid the full amount[5]). As the financial data were collected in January 2014, community-level indicators were split out by short-term (2013 only) and long-term (pre-2013) rates, to account for the time-dependent nature of arrears.

In order to examine the effect of community and household characteristics on the level of financial contributions by water users, multivariable regression analyses were conducted. Collective payment rate (the outcome variable) was subjected to a generalised estimating equation (GEE) technique. This analytical method accounts for the correlation between recurring monthly observations for a given waterpoint, which would otherwise violate the independence assumption underpinning simple regression. The Corrected quasi-likelihood under independence model criterion (QICC) goodness-of-fit measure was used to identify the best fitting covariance structure. The regression analysis focussed on waterpoints coupled with monthly fee arrangements, as this was the most common revenue collection approach, and was restricted to 2013 financial data, as many of the explanatory variables were dynamic in nature and correspond specifically to that year. As a result of these

[5] In the context of urban water service provision, this measure is commonly termed 'revenue collection efficiency'.

limitations, the data on which the regression analysis was conducted covered a total of 44 waterpoints, 6882 monthly contributions, and 309 surveyed households.

Definitions and mean characteristics of the explanatory variables included in the analyses are presented in Table 3. Ostrom's SES framework guided the selection and classification of variables across core sub-systems (Table S1 in Supplementary Material), in conjunction with theoretical and empirical findings from willingness to pay, rural water supply and broader CPR writings (see Supplementary Material). Month was included as an explanatory variable, given the time-dependent nature of financial arrears. Due to the strong association between electrical conductivity (EC) and taste (Figure S1), separate models were run with each variable included. Household-level variables were averaged across all surveyed households within a community to obtain a community-level measure. The conventional threshold of α=0.05 was applied to identify statistically significant associations.

Table 3. Variable definitions and characteristics for waterpoints, communities and households in Kwale

Explanatory variables	Definition	Mean (SD)				
				WPs with records		
		All WPs[a]	Active WPs[b]	All	Regular payments	2013 monthly payments
Resource system						
Distance (WP-HHs)	Average distance between reference waterpoint and user households (m)	137 (99)	143 (99)	167 (115)	161 (109)	158 (126)
Distance (WP- WP)	Distance between reference waterpoint and nearest active communal Afridev handpump (m)	877 (981)	806 (909)	846 (675)	711 (383)	709 (332)
Distance (WP-SPR)	Distance between reference waterpoint and spare parts retailer (km)	21.9 (15.0)	21.5 (14.7)	25.4 (15.1)	24.0 (14.7)	22.9 (14.9)
Community Mechanic	1 = Handpump mechanic lives in same community as waterpoint	0.48	0.50	0.52	0.48	0.45
Well type	1 = drilled borehole	0.90	0.93	0.99	1.00	1.00
pH[c]	1 = pH of groundwater≥ 6.5	0.70	0.70	0.70	0.72	0.65
RWL[d]	Resting water level prior to handpump installation (m)	15.5 (8.3)	14.7 (7.5)	14.8 (6.5)	14.5 (6.2)	14.0 (5.0)
Resource unit						
Yield[e]	Yield of borehole prior to handpump installation (m^3/hr)	2.6 (1.3)	2.7 (1.3)	2.5 (1.3)	2.3 (1.3)	2.1 (0.9)
EC[c]	Electrical conductivity of water (mS/cm)	1.18 (0.98)	1.17 (0.98)	1.15 (1.00)	1.13 (0.98)	1.11 (0.97)
Taste	Average rating of water taste across wet and dry season (1 = good, 0 = average, -1 = poor)	0.52 (0.53)	0.54 (0.53)	0.61 (0.45)	0.62 (0.46)	0.60 (0.47)
Safe	Percentage of households who believe water is safe to drink all year round	80.9 (25.4)	79.7 (25.9)	86.2 (20.0)	85.8 (21.3)	87.1 (21.8)
Productive use	Percentage of households who use waterpoint for livestock or small-scale irrigation	25.7 (19.8)	26.2 (18.3)	28.0 (18.7)	28.2 (19.0)	26.8 (16.2)
Governance system						
Attendant	1 = waterpoint has an attendant	0.65	0.75	0.64	0.65	0.61
Lock	1 = lock used to prevent unauthorised use of waterpoint	0.52	0.60	0.78	0.74	0.77
Bank	1= funds for O&M stored in a bank account	0.05	0.07	0.14	0.06	0.07
Monthly fee[f]	Fees per month (Kshs)	43.6 (24.7)	47.5 (23.1)	44.9 (24.5)	44.3 (25.8)	42.9 (23.3)
Ramadan	1 = Gregorian calendar months which overlap with Islamic month of Ramadan	-	-	-	-	-
Users						
Group size	Number of recorded water users (households)[g]	38.0 (26.2)	38.0 (26.2)	38.0 (26.2)	38.0 (26.2)	32.6 (20.9)
Welfare index	Average of a multi-dimensional index incorporating household composition, dwelling structure and asset ownership measures (the higher the index, the higher	6.4 (2.7)	6.6 (2.7)	7.0 (2.5)	7.3 (2.4)	7.5 (2.2)

	the welfare level)					
Maize price	Monthly market price of maize (Kshs per kg)	-	-	-	-	-
Night-time lights	Value of night-time lights derived from satellite imagery	5.1 (7.1)	5.4 (7.3)	4.4 (7.9)	4.8 (8.0)	6.0 (9.2)
Participation	Percentage of households who participated in planning and implementation of waterpoint[h]	0.31 (0.24)	0.28 (0.22)	0.32 (0.21)	0.32 (0.20)	0.33 (0.21)
Years	Number of years since handpump installed	21.0 (7.8)	20.9 (8.2)	23.6 (6.3)	25.3 (2.8)	25.3 (2.3)
Alternative	1 = a secondary drinking water source is used concurrently with the waterpoint	0.84	0.81	0.82	0.77	0.77
Related ecosystem						
Rainfall	1 = Period of lowest rainfall (Jan-Mar)	-	-	-	-	-
Number of observations						
Waterpoints		***518***	***344***	***100***	***65***	***44***
Surveyed households		***3,233***	***2,402***	***736***	***477***	***309***

WP= waterpoint, HH = household, SPR = spare parts retailer. [a]Includes all communal Afridev handpumps. [b]Active waterpoints defined as communal Afridev handpumps which were functional or had been functional within the previous 12 months. [c]Water quality characteristics measured for 288 waterpoints (including 281 active waterpoints). EC values were capped at 3999. [d]Data on resting water level available for 214 waterpoints (including 159 active waterpoints). [e]Data on yield available for 201 waterpoints (including 151 active waterpoints). [f]Applies to 95 waterpoints at which a monthly fee arrangement was in place and the fee amount could be recalled by the respondent (including 72 active waterpoints). [g]Group size could only be reliably determined for 49 waterpoints with written financial records that denoted the number of users in 2013 (all of which were active waterpoints), hence parameters do not differ between 'all waterpoints' and 'active waterpoints'. The figures represent an average across all months for which there were financial records denoting user numbers. [h] Forms of participation included contributions (cash, land, food or construction materials) and/or decision making (e.g tariff setting, waterpoint location).

4. Results

Payment data from which a collective payment rate could be computed spanned a 27 year period from 1987 through to 2013, and covered 227 years' of waterpoint operations. When converted to water-person-years (WPYs), a novel metric for sustainability (Koestler et al. 2010), there were approximately 31,350 WPYs worth of payment records. Total payments amounted to US$29,289, with an average of US$129 collected per waterpoint per year, US$5.85 per paying household per year, and US$1.27 per paying person per year.[6]

The revenue collection rate across all financial records obtained was 70.7% (Table 4). For monthly fees, the overall collective payment rate was 71.2%. There was a considerable difference in short- and long-term collective payment and revenue collection rates (Figure 3). For years prior to 2013, 75.4% of households contributed funds each month, falling to 52.8% in 2013. Even within 2013, collective payment rate was highly dependent on the month (Figure 4).

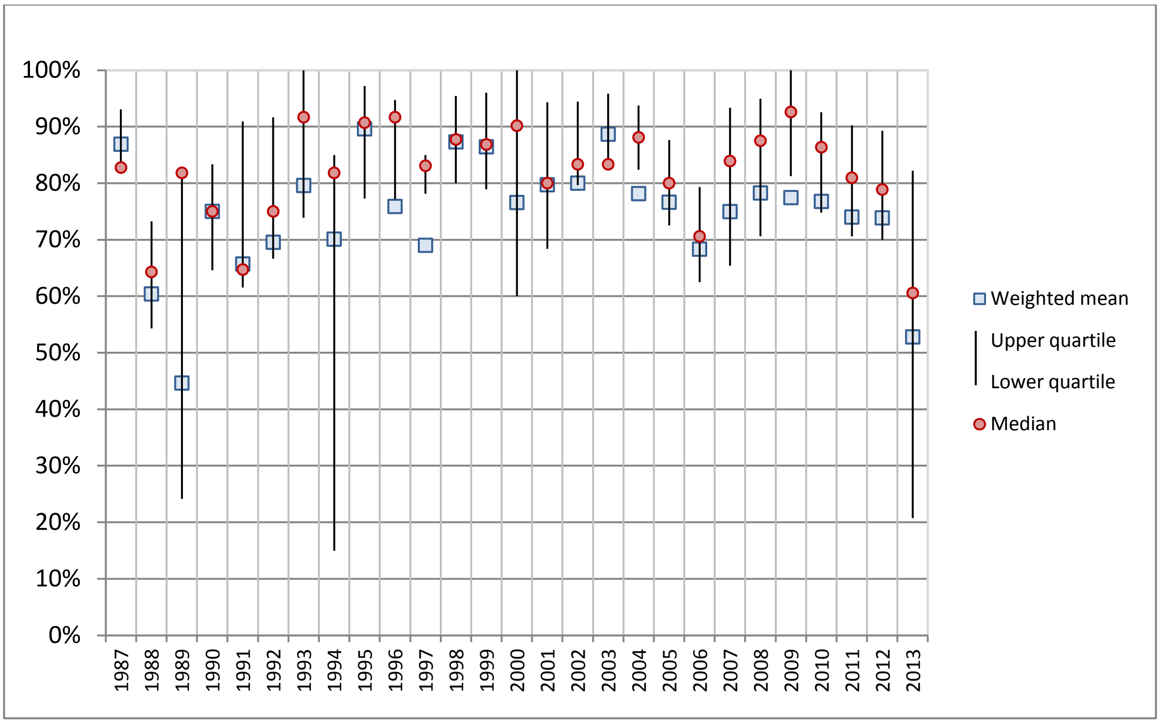
Table 4. Collective payment and revenue collection rates by payment interval

Measures	Payment interval				All
	Weekly	Monthly	Bi-monthly	Annual	
Financial records					
Long term (1987-2012)					
Collective payment rate (%)[a]	64.5	75.4	90.8	86.8	77.3
Revenue collection rate (%)[b]	64.5	71.9	91.2	82.9	74.0
Short term (2013)					
Collective payment rate (%)	77.9	52.8	-	-	53.8
Revenue collection rate (%)	76.3	52.3	-	-	54.1
Total					
Collective payment rate (%)	75.6	71.2	90.8	86.8	73.4
Revenue collection rate (%)	74.1	68.3	91.2	82.9	70.7
Volume of data					
No. of waterpoints	5	57	1	3	65
Operational years	0.7	187.3	5.2	34.0	227.1
No. of household contributions	2,184	49,902	484	722	53,292
Water-person-years (WPYs)	255	26,859	409	3,827	31,350

[6] An exchange rate of US$1 = 86.1 Kshs is used throughout. Per person annual revenue assumes 4.6 people per household (as determined from household survey).

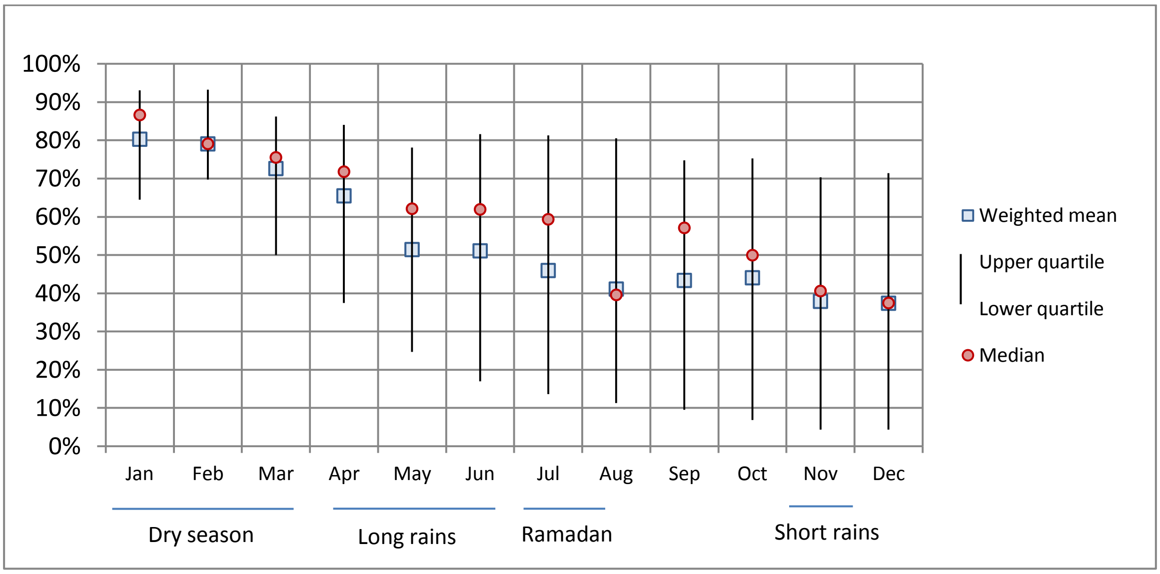
[a]Defined as the number of water users paying divided by the total number of recorded water users. [b]Defined as revenue collected divided by the theoretical amount that would have been collected had all recorded users paid the full amount.

Figure 3. Collective payment rates (monthly fees) 1987-2013[a]



[a]Based on records from 57 waterpoints covering 2,247 months. Number of records obtained for each year can be found in Supplementary Material (Table S2.1). Variation of collective payment rates across communities can be found in Supplementary Material (Figures S3.1 and S3.2).

Figure 4. Collective payment rates (monthly fees) in 2013[a]



[a]Based on records from 44 waterpoints covering 371 months.

Table 5 summarises the results of the collective payment GEE analysis. Based on the QICC measure, a first-order autoregressive structure led to the best fitting model. This covariance structure accords with the expectation in practice that month-to-month contributions are correlated, with correlations strongest in successive months. Collective payment rate exhibited significant positive associations with groundwater pH, productive water uses, taste and dry season, and negative associations with month of the year and mean distance between households and the waterpoint. When considering the explanatory variables' variance and units of measure, effect sizes were notably large for all significant associations except for dry season. Although it did not attain statistical significance, maize price warrants mention as the only other variable to have a p-value less than 0.10 for both models, albeit with relatively modest effect sizes.[7]

Table 5. Results of collective payment rate generalized estimating equation[a,b]

Explanatory variables	**Model 1**			**Model 2**		
	B	**SE**	**p-value**	**B**	**SE**	**p-value**
Resource system						
Distance (WP-HH)	**-0.13**	**0.03**	**<0.001**	**-0.10**	**0.04**	**0.004**
Distance (WP-WP)[c]	27.38	14.42	0.058	20.76	14.65	0.156
Distance (WP-SPR)	0.62	0.84	0.461	0.57	0.45	0.208
Community mechanic	3.30	6.92	0.633	5.94	6.71	0.376
pH	**27.14**	**8.78**	**0.002**	**23.89**	**6.29**	**<0.001**
Resource unit						
EC	-8.82	10.57	0.404			
Taste				**35.66**	**14.24**	**0.012**
Safe	3.10	21.50	0.885	-35.73	25.00	0.153
Productive use	**69.34**	**32.51**	**0.033**	51.54	27.13	0.057
Governance system						
Attendant	2.94	10.48	0.779	11.69	10.30	0.256
Lock	-5.88	11.02	0.594	-8.46	11.57	0.465
Bank	-25.17	15.11	0.096	-14.02	12.32	0.255
Monthly fee	-0.32	0.25	0.202	-0.18	0.19	0.354
Ramadan	-0.05	1.56	0.976	-0.02	1.60	0.992
Users						
Group size	-0.16	0.16	0.305	-0.16	0.15	0.287
Welfare index	-0.83	2.00	0.678	-0.70	1.95	0.722
Maize price	-0.71	0.41	0.083	-0.71	0.41	0.079
Night-time lights	0.82	1.00	0.413	0.25	0.76	0.746
Participation	-40.12	25.46	0.115	-29.54	26.53	0.265
Years	-3.19	1.93	0.097	-2.41	1.64	0.142
Alternative sources	-12.29	11.68	0.293	-16.57	9.30	0.075

[7] When interpreting the effect size it is useful to note that the difference between the annual minimum and maximum maize price per kilogram in 2013 was 11.8 Kshs.

Related ecosystem						
Dry season	**6.40**	**2.90**	**0.027**	**6.35**	**2.95**	**0.031**
Time						
Month	**-3.90**	**0.50**	**<0.001**	**-3.91**	**0.51**	**<0.001**

[a] Bold text indicates statistically significant association ($p < 0.05$). [b]Generalized estimating equation with autoregressive correlation matrix. Regression models based on data covering 44 waterpoints, 371 months and 6,882 household contributions. Community-level data for the following variables were calculated as the average across surveyed households: participation, welfare index, productive use, safe, taste, distance (WP-HH). For the 44 waterpoints included in the model, the survey was administered to 309 household (mean 7.0 per waterpoint). [c] To assist interpretability of results, units have been changed to kilometres

5. Discussion

The results present two major advances in understanding collective action and payment behaviours among rural water users. First, the study provides empirical evidence for what has long been suspected – even where fees are levied, a substantial proportion of rural waterpoint users fail to meet their payment obligations. Second, the results suggest payment behaviours among rural waterpoint users reflect a socio-ecological process influenced by characteristics of water quality, waterpoint location, productive water use, and rainfall patterns.

4.1 Payment prevalence

Despite examining the better managed waterpoints from a highly regarded rural water supply programme, over the long term around one in four households did not pay their fees each month. The decline in payment rate throughout 2013 indicates that among those who do pay fees, between one quarter and one third of the funds are not received in that same calendar year. The total revenue shortfall of 29.4% is in line with the 25-30% gap previously predicted (Carter et al., 2010).

Notably, the payment rate is poorer than the performance of Kenya's rural piped water service providers, which recently reported a revenue collection rate of 91% (WASREB, 2014). This disparity perhaps signals some inherent difficulties of extracting payment from users of community waterpoints as compared to individual piped connections. The social and operational challenge of excluding defaulters, a lower service level depressing user satisfaction, and the voluntary nature of water committee roles are clear disadvantages for community-managed waterpoints relative to professionally-managed piped water services.

4.2 Payment determinants

Payment behaviour determinants emerged across three sub-systems of Ostrom's social-ecological systems framework, illustrating the complex nature of collective action processes. Though this study does not allow for a definitive pinpointing of causal routes, the direction of significant associations can be plausibly explained with reference to users' willingness to pay, motivation levels of committee members and the burden of revenue collection. Tellingly, a number of significant determinants map on to service level attributes that shape the relative value users place on a water supply. Unsatisfactory taste, inconvenient location, lower-cost and closer seasonal alternatives, and frequent breakdown rates linked to low pH are all factors that could undermine both the willingness of users to contribute financially and the motivation of committee members to sustain robust revenue collection systems. Equally, one of the predictors – waterpoint-to-household distance – could conceivably amplify the complexity of collecting payments and enforcing rules, irrespective of users' willingness to pay.

The results highlight the impact groundwater quality can have on users' propensity to pay. The association with pH is consistent with the observation that aggressive groundwater rapidly induces corrosion in handpump components made of mild steel (Langenegger, 1989). Although Afridev handpumps are less vulnerable to aggressive groundwater than other prominent handpump models (Baumann and Furey, 2013), the majority of communities in Kwale prefer to purchase lower cost mild steel pump rods rather than corrosion-resistant stainless steel rods. Generally speaking, corrosion could depress user satisfaction by either increasing the frequency of certain failure modes, or causing an undesirable taste and colour (Langenegger, 1989). Service disruption appears to be a more likely mediator in this context, given that there was no obvious association between taste and pH (p=0.641, Figure S1 in Supplementary Material), and pH remained a significant predictor even when taste was included in model 2.

The link between financial contributions and taste rating agrees with previous findings that user perceptions of water quality and palatability impact willingness to pay and sustainability outcomes (World Bank Water Demand Research Team, 1993; Foster, 2013). The association has important implications for Kwale. Although EC was not a significant predictor, the inverse correlation between taste and salinity level is significant (p<0.001, Figure S1 in Supplementary Material). The EC-taste-payment nexus places a spotlight on the importance of monitoring and protecting groundwater quality, particularly given Kwale's coastal location, history of increasing EC levels (Tole, 1997), and the recent increase in groundwater abstraction associated with commercial agricultural and mining activities in the region.

The association between payment rates and productive use of water (in this case, for livestock and small-scale irrigation) provides tentative support for the 'water pays for water' hypothesis – that is, productive water uses can bolster household incomes and thus enhance the ability of users to pay for their water service (Hall et al., 2015). The financial benefits arising from productive uses of handpump water supplies have been noted previously (Waughray, 1998), however, this to our knowledge, is the first time a relationship between productive uses and revenue collection performance has been empirically demonstrated for any water source type. This is despite the relatively limited potential that handpumps have as a multiple water use technology (van Koppen and Smits, 2010). The underlying mechanisms explaining this link require further investigation. Productive water uses may mean households have greater cash reserves from which to pay fees, or perhaps they possess a greater willingness to contribute because of their economic dependence on the reliable operation of the handpump. Productive users may also have a greater sense of obligation to pay because their water use generates a direct economic benefit.

Distance between a waterpoint and a household is an important service level attribute known to underlie water source preferences, satisfaction levels and willingness to pay (Mu et al., 1990; Masanyiwa et al., 2010; Naiga and Penker, 2014), thus it is logical that waterpoint-to-household proximity translates into healthier contribution rates in Kwale. Additionally, water committees may incur higher transaction costs to collect payments and enforce sanctions in communities with highly dispersed households. Hence the observed relationship may be borne of both the perceived value of a nearby water supply, and the relative difficulty of excluding defaulters.

The finding that rainfall patterns play an important role in shaping households' inclination to pay for an improved water supply is consistent with previous investigations that have identified alternative water sources as a major impediment to willingness to pay and waterpoint sustainability (World Bank Water Demand Research Team, 1993; Whittington et al., 2009; Foster, 2013). We postulate that water users are less likely to contribute during wet periods because the relative value of the waterpoint is diminished, as surface water becomes more abundant and rainwater harvesting becomes possible. Importantly, it was noted in numerous communities that attendants reduced their hours or ceased monitoring waterpoint use during wetter months. This seasonal waning of monitoring activities could either be a contributing driver of the rainfall association or merely a symptom.

4.3Types of non-payers

Further investigation is needed to understand causal mechanisms linking determinants and payment behaviours. It is important to note that non-payment, as measured in this study, is not synonymous with non-cooperation. Discussions with committee members and water users throughout the data collection suggested there were several reasons for non-payment, not all of which contravene locally devised rules (Table 6). It is difficult to estimate the relative size of these non-payment segments, partly because the various categories are reflected in financial records to different degrees, and partly because of the impossibility of retrospectively verifying monthly waterpoint usage for each household and unravelling debt accrual rules. Furthermore, these categories are dynamic and their application to specific households is liable to change as debts are settled or become overdue.

Table 6. Types of non-payers for a given month

Category of non-payer	Waterpoint used?	Payment obligation?	Payment overdue?	Description
1. Free riders[a]	Yes	Yes	Yes	Households that have avoided payment in breach of rules
2. Compliant debtors	Yes	Yes	No	Households from which contributions are not yet required because of formal grace periods
3. Open accessors	Yes	No	No	Households from which contributions have not been sought because revenue collection structures are weak, have collapsed or have been suspended
4. Fee-exempt	Yes	No	No	Vulnerable households who are exempt from paying by way of locally devised rules
5. Source switchers	No	No	No	Households that (temporarily) switch to other water sources and are thus relieved of their obligation to contribute

[a]Over the longer term, some 'free riders' might be better considered 'easy riders' if they do sometimes contribute or they eventually settle their debts. The term 'easy rider' was coined by Cornes and Sandler (1984) in the context of public good provision to describe those who contribute an amount which is less than the 'right' amount, as opposed to true free riders who contribute nothing at all.

Data collected during the household survey suggest seasonal "source switchers" make up a relatively small proportion of non-payers. For the surveyed households located in the communities included in the regression analysis, only 1.3% stop using the waterpoint altogether in the wet season (Table 7). The 6.4 percentage point increase in payment rates associated with dry season therefore outweighs the change in the number of users by a factor of almost 5. Nonetheless, the modest change in the number of users belies what is likely to be a substantial drop in consumption levels during periods of heavy rainfall. For example, although only 4.2% of users stop using the handpump for drinking purposes in the wet season in favour of another source, 19.2% of wet season handpump users begin to augment their drinking supplies with rainwater. Use of surface water as a secondary drinking source also rises by 2.0% during the wet season. The considerable change in productive uses of handpump-supplied water (26.6% to 9.4%) is further evidence of these seasonal consumption patterns.

Table 7. Percentage of households using the waterpoints included in the regression analysis by rainfall season

Water use	Dry Season	Wet Season	Change: Dry to Wet Season
Drinking	97.4%	93.2%	-4.2%
Primary	94.5%	90.6%	-3.9%
Secondary	2.9%	2.6%	-0.3%
Cooking, washing, bathing	99.4%	94.5%	-4.9%
Productive	26.6%	9.4%	-17.2%
Small-scale irrigation	9.7%	1.6%	-8.1%
Livestock	23.1%	8.1%	-15.0%
Any use	**100.0%**	**98.7%**	**-1.3%**

It also appears that "fee-exempt" water users do not significantly contribute to the proportion of non-payers measured in this study. Many communities had in place rules whereby the most vulnerable households were excused from paying fees, essentially being cross-subsidised by other water users. These households usually had little or no income, and generally accounted for between 0-10% of the users at a given waterpoint. However, these non-payers were not formally listed as users in the financial records, and therefore do not impinge upon the payment rate calculations.

The doubling of non-payment levels in 2013 compared with previous years is highly suggestive of widespread late payment practices. Adding weight to this explanation is the monthly trend evident in the regression results: each month in 2013 equates to a reduction in payment rates of 3.9 percentage points. What is less clear is whether these late payers constitute "compliant debtors" or "free riders". Ultimately this hinges on whether or not their late payment is authorized. Either way, by definition late payers will eventually settle their debts, meaning the categorisations for a given month are impermanent.

Responses to other household survey questions shed additional (albeit limited) light on payment behaviours. When households using the waterpoints included in the regression models were asked why they might not always pay their fees, the three most common reasons cited were: (a) insufficient funds (10.4%), (b) because other users avoid paying (7.4%), and (c) a lack of trust that the funds would be used for repairs (1.6%). On average, those attributing non-payment to insufficient funds had lower welfare scores than other households ($p=0.083$). However, such relationships do not divulge to what extent the non-payment is borne of an inability to pay versus an unwillingness to pay. Distinguishing between the two would require a detailed understanding of budgeting priorities and trade-offs at the household level.

4.4 Implications for policy and practice

The notion that waterpoint users are not always willing and able to pay for an improved water supply presents a fundamental challenge for policymakers and practitioners. It is at odds with a key assumption underpinning the policy paradigm that is supposed to chart the pathway toward the Sustainable Development Goal of universal access to safe water in rural sub-Saharan Africa. Adding to the complexity is the multifaceted nature of payment determinants, and the influence of social and environmental heterogeneity.

To better understand the nature and gravity of this policy dilemma, further investigations are needed to illuminate the operational implications of late and non-payment. While there is evidence that revenue collection arrangements are broadly linked with operational sustainability (Foster, 2013), the relationship between household payment behaviours and operational performance requires more nuanced elucidation. There are a variety factors that likely complicate this nexus. For one, the size of the tariff undoubtedly plays a major role in determining whether funds collected are sufficient to ensure the ongoing operation of a waterpoint. Some communities may benefit from large made financial contributions from wealthier households to cover financial shortfalls when repairs are needed. Communities in Kwale also commonly benefit from additional revenue streams, such as volumetric water sales to non-members, one-off registration fees for new members, and fines imposed on households not partaking in certain activities. Finally, a number of the associations (e.g. distance, taste, productive use) may underlie elevated usage levels, which in turn might drive up maintenance costs. An important but unanswered question then is whether better payment rates outweigh any commensurate rise in maintenance expenditure. In other words, collective payment rate is but one of a number of factors that can influence the overall financial performance of a waterpoint.

Although policymakers and planners have limited ability to control environmental and social factors such as groundwater conditions, rainfall patterns and settlement characteristics, results point to a number of measures which could improve the financial prospects of rural waterpoints. First, collective action is likely to be enhanced by situating waterpoints as close as possible to where users reside. Second, recognising and facilitating productive uses of water in system planning, design and management may have the dual outcome of supporting livelihoods and strengthening the water service's financial sustainability. Third, communities using handpumps which are subject to aggressive groundwater should be fully informed about the short- and long-term cost trade-offs of purchasing corrosion-resistant parts. Fourth, prevailing socio-ecological characteristics may provide guidance as to whether community-managed handpumps are the most appropriate water supply option for a particular setting. For example, low-cost protection of family wells – which are unencumbered by the same collective action burdens – may be a more suitable option where seasonal water sources are abundant, populations are dispersed, and groundwater is shallow (see e.g. Sutton, 2011). Fifth, groundwater quality should be closely monitored and protected, especially in a region such as Kwale which is experiencing increased levels of groundwater demand.

Beyond these measures, securing the long-term financial sustainability of rural water supplies will require deeply rooted solutions. If rural communities are to be expected to execute their financial management responsibilities effectively and sustainably across heterogeneous social and environmental settings, they require ongoing external support that includes advice, training, encouragement and monitoring (Harvey, 2007). The long-term nature of this need is clear when one reflects on an early evaluation from the original Kwale Water Supply and Sanitation Project. In 1988, it was reported that all water committees regularly collected cash, and all handpumps were functioning (Narayan-Parker, 1998). In 2013, 42.1% of handpumps were non-functional, and a revenue collection system of any sort was lacking from more than quarter of active communal waterpoints. This is not to deny pockets of excellence identified during the course of field work, including ten communities possessing financial records spanning 10 years or more, and one community which had meticulously recorded each household monthly payment over 23 consecutive years. However, only a minority of communities were able to produce financial records of any sort, indicating substantial room for improving the transparency and accountability of financial management practices.

Clearly financial management is only one piece of the sustainability puzzle. The nature of the predictors identified in this study reinforce the notion that a high quality water service that meets the needs of users is critical to financial sustainability. If rural communities are to escape a low-level equilibrium trap of poor operational and financial performance, strategies to boost revenue collection must be matched with measures that drive a commensurate improvement in waterpoint reliability. Ongoing external support that spans financial, technical and administrative domains is widely advocated as a pathway to attain these objectives (RWSN, 2010; IRC, 2012), and there is emerging evidence of its positive effects (Whittington et al., 2009; Hutchings et al., 2015). Driving a step-change in waterpoint performance might also be achieved by looking beyond the default community management model and experimenting with novel service delivery and financing approaches that involve different scales, actors, and incentive structures (Hope and Rouse, 2013; Koehler et al., 2015; Nagel et al., 2015).

4.5 Limitations

It is important to note that the communities that form the focus of this study are not necessarily representative of rural Kenya or sub-Saharan Africa more broadly. Though surveyed households were randomly selected within waterpoint service areas and share similar traits with households across rural Kenya (Table S3.2 in Supplementary Material), there are some deviations. By virtue of the study's inclusion criteria (the documentation of payments, monthly fee collection), the observations analysed are likely biased towards the better performing water committees and possibly also wealthier households (Table 3 and Table S3.3 in Supplementary Material). Moreover, the results relate to one waterpoint technology type, and most of the systems were installed more than 20 years prior to data collection.

The results and interpretations are subject to a number of other caveats. First, no causal relationships can be conclusively demonstrated between the explanatory and outcome variables. Second, as with any data collection and analysis of this nature, sources of non-sampling error and omitted variable bias cannot be ruled out. Third, the results highlight conditions that undermine and support financial contributions once revenue collection systems are established, but they do not divulge why such arrangements emerge in the first place.

6. Conclusion

This study has empirically demonstrated non-payment and late payment by rural waterpoint users are common, and the propensity of users to pay is affected by factors pertaining to the resource system, resource unit, and climate patterns. The findings reflect the multifaceted nature of waterpoint sustainability in rural sub-Saharan Africa and confirm that households are not always willing and able to pay for an improved water supply. This situation is symptomatic of a fundamental operation and maintenance financing challenge that must be addressed if the Sustainable Development Goal of universal access to safe water is to be achieved. Further investigations are needed to reveal whether the observed associations hold in other social-ecological settings, to understand the causal mechanisms underlying observed relationships, and more fully elucidate the ramifications for sustainable water service delivery.

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Supplementary Material

S1. Independent variable selection

Resource system variables

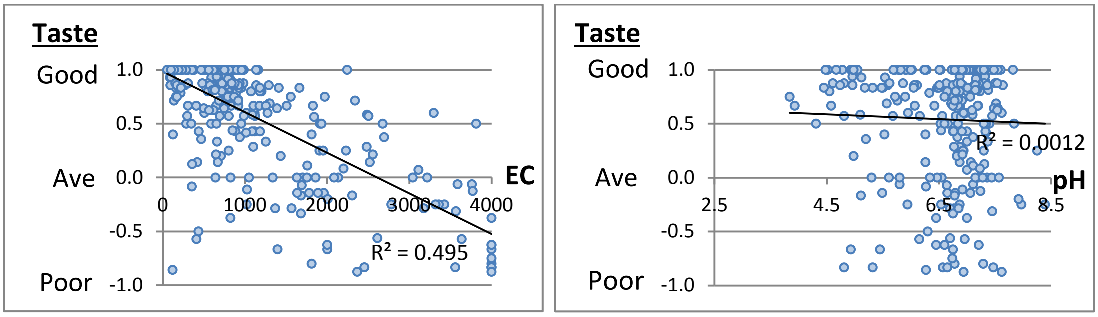
Characteristics of the resource system are those that relate to the aquifer, well and water lifting device. By virtue of the investigation's focus on Afridev handpumps fitted on boreholes, the variable relating to waterpoint technology was held constant. It was hypothesised that waterpoints situated closer to households would facilitate collective action, given the perceived benefit and value associated with a conveniently located water source (Mu et al., 1990; Masanyiwa et al., 2014; Naiga and Penker, 2014; Coster and Otufale, 2014). Conversely, proximate alternative waterpoints might undermine motivation to pay, as the adverse ramifications of failing to act collectively would be reduced. As the waterpoint census captured the GPS coordinates for all Afridev handpumps, the distance between the reference waterpoint and the nearest (active) Afridev handpump was used as a proxy measure. In line with previously observed associations with handpump functionality (Foster, 2013; Whittington *et al.*, 2009), it was hypothesised that greater distances to a mechanic and spare parts retailer would inflate the transaction costs of arranging repairs, consequently lengthening handpump downtime and depressing satisfaction levels. In Kwale, the Afridev has commonly been installed under the assumption it is a village-level operation and maintenance (VLOM) technology, and hence a relevant and feasible measure was whether or not the mechanic lived in the same community as the waterpoint.

Groundwater pH was selected as an exogenous variable likely to impact breakdown frequency, as the rate of corrosion for mild steel handpump components occurs rapidly once groundwater pH drops below 6.5 (Langenegger, 1989). Though Afridev handpumps are better suited to aggressive groundwater than other handpump models, the majority of communities in Kwale opt for mild steel pump rods which are susceptible to corrosion. It was therefore expected that handpumps drawing groundwater with a pH of less than 6.5 would have less predictable benefits and would suffer from poorer collective action outcomes. Resting water levels were also expected to influence breakdown frequencies, however data was not available for a sufficient number of waterpoints.

Resource unit variables

Characteristics of the resource unit are those which correspond to the water supplied. User perception of water quality is a commonly cited driver of demand and handpump functionality (World Bank Water Demand Research Team, 1993; Foster, 2013). Thus user perceptions of taste and safety were expected to influence payment behaviours. Groundwater electrical conductivity (EC) – a measure of salinity – was also chosen as an exogenous variable representing water quality. Salinity is a common water quality complaint among handpump users in sub-Saharan Africa (Langenegger, 1989). Because water becomes less palatable as EC increases ($p<0.001$, Figure S1), a negative association with payment behaviours was expected. While low groundwater pH has also been linked to user dissatisfaction with taste and colour (Langenegger, 1989), the data from Kwale is less supportive of this association ($p=0.641$, Figure S1), and thus pH was considered more relevant to the resource system (and its implications for reliability) than to the palatability of water. Productive use of water (for livestock and/or small-scale irrigation) was also hypothesised to bolster payment behaviours due to the heightened economic value placed on the resource unit. Prior to data collection, seasonality of groundwater availability was also anticipated to be a salient factor, however all waterpoints included in the regression analyses were found to provide a year-round supply. Likewise, data on borehole yields were missing for a substantial number of waterpoints analysed, preventing inclusion of this variable in the regression models.

Figure S1.1. Relationships between water taste and (a) EC, and (b) pH in Kwale.



Governance system variables

Attributes of the governance system pertain to the institutions and rules in place to manage the waterpoint system. Use of a lock to prevent freeriding was representative of an operational rule relating to permitted hours of usage, and hypothesised to boost payment behaviours. It was posited that monthly fee amount would have a negative effect on payment rates, as higher fees would naturally feed into the cost side of a user's decision making calculus. Use of a bank account to store O&M funds was expected to motivate financial contributions by virtue of the heightened security it offers. Presence of a handpump attendant, a role which commonly involves monitoring and sanctioning duties, was postulated to promote collective action. The Islamic month of Ramadan was also expected to influence payment behaviours, as revenue collection arrangements were known to be relaxed during this period.

User variables

User attributes are those characteristics possessed by the group of households that collect water from the waterpoint. Acknowledging the considerable debate among CPR scholars about the influence of group size on collective action outcomes and the relevance of contextual and mediating factors, the number of waterpoint users was expected to exhibit a negative association with collective action success in accordance with major CPR studies (Ostrom, 1990; Wade, 1994; Baland and Platteau, 1996; Araral, 2009).

Socio-economic status was posited to have a positive bearing on payment behaviours. Though there is far from a consensus about the link between CPR management and poverty, a positive relationship was hypothesised here due to the financial nature of the collective action proxy measure, the previously observed association with irrigation fee payment (Araral, 2009), and the parallel findings in willingness to pay studies (World Bank Water Demand Research Team, 1993; Mugabi and Kayaga, 2010; Arouna and Dabbert, 2012; Bogale and Urgessa, 2012). A multi-dimensional household welfare index was constructed by applying principal component analysis to a range of variables relating to dwelling structure (floor, walls, roof), household composition (education, employment, adult-child ratio), asset ownership, sanitation and health. The index was then averaged across households using each waterpoint to obtain a community-level measure. To take into account month-to-month changes in welfare, the market price of maize was selected as proxy indicator for food security as measured by Kenya's National Drought Management Authority (see http://www.ndma.go.ke/).

To distinguish between waterpoints in and around towns and trading centres, and those in more remote villages, location-specific light values extracted from a night-time lights satellite image were used as proxy measures for settlement type. A cloud-free composite image of persistent night-time lighting from 2013 was obtained from the website of the Earth Observation Group, National Centers for Environmental Information (Version 4 DMSP-OLS Nighttime Lights Time Series, image and data processing by NOAA's National Geophysical Data Center).[8] The image was superimposed on waterpoint locations, and light values pertaining to the location of each waterpoint were extracted using GIS software. It was supposed that towns and trading centres might have lower collective payment rates compared with smaller villages, due to the availability of piped and vended water in and around towns and a relative lack of shared norms, values and trust.

Participation in planning and implementation was expected to exhibit a positive relationship with payment behaviours, in accordance with previous studies which found demand-responsive and participatory approaches led to more sustainable water services and improved willingness to pay (Sara and Katz, 1998; Isham et al., 1995; Narayan 1995; Naiga and Penker, 2014). Though, as the

[8] http://ngdc.noaa.gov/eog/dmsp/downloadV4composites.html.

measure in this study captured participation breadth rather than depth, an absence of any positive association would also have been consistent with a recent study from Ghana (Marks, Komives and Davis, 2014). It was also predicted that payment rates would be superior for those communities that had successfully managed the finances of handpump O&M over a longer period of time. A history of joint efforts was expected to enhance confidence and trust among users that if they contribute, so too will others (Fujiie et al., 2005).

A lack of alternative drinking water sources was chosen to represent a community's dependence on the waterpoint. Studies suggest presence of alternative water sources undermine willingness to pay and sustainability (World Bank Water Demand Research Team, 1993; Whittington et al. 2009), hence it was anticipated that a lack of alternative sources would increase users' propensity to pay.

Related ecosystem variables

Rainfall was hypothesised to have a negative impact on payment rates. Dry periods generally offer fewer alternative water sources, leading to an increased reliance on the waterpoint. Given limitations on available precipitation data, a binary rainfall season measure (dry season/wet season) was utilised.

Social, economic and political setting variables

As all waterpoints fell within the same local government jurisdiction and were subject to the same national policy and economic settings, variables within this sub-system were not factored into the analysis.

Time control variable

Given the time-dependent nature of financial arrears, month was included as an explanatory variable.

Table S1.1. Social-ecological systems framework adapted to rural waterpoints in Kwale[a]

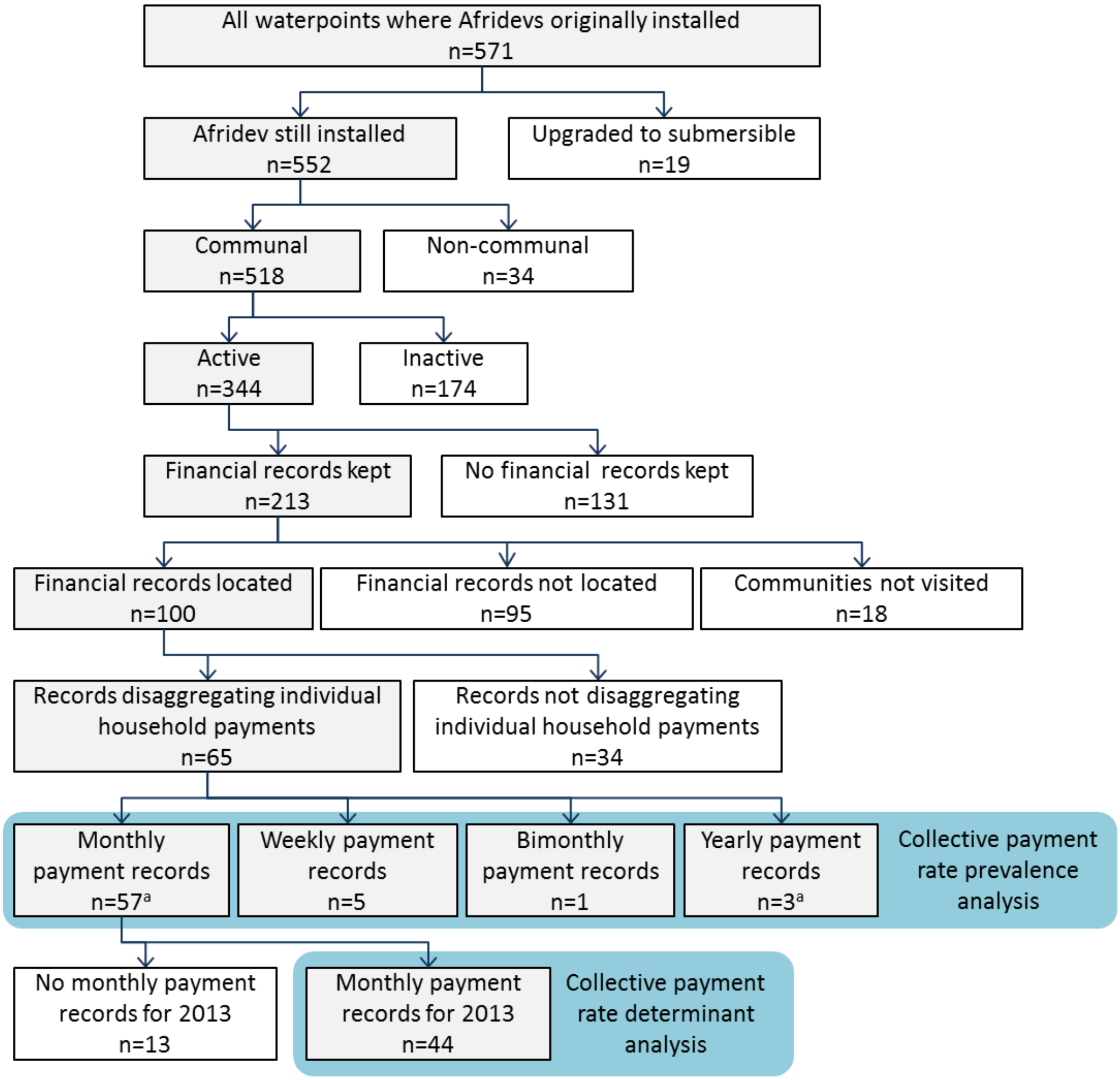
SES Component	Adapted second-tier variables hypothesised to affect waterpoint	Explanatory variables

	management	
Resource system:	RS4: Waterpoint technology	Handpump type (*held constant*) Well type (*held constant*)
	RS7: Predictability of system dynamics	Low pH of water causing corrosion-related failure modes Resting water level driving breakdown frequency (*insufficient data to include in regression models*)
	RS9: Waterpoint location	Location of waterpoint relative to households Location of waterpoint relative to other waterpoints Distance between waterpoint and spare parts retailer Location of waterpoint relative to mechanic
Resource units:	RU2: Groundwater availability	Year-round reliability (*held constant*) Yield (*insufficient data to include in regression models*)
	RU4: Value of water	Electrical conductivity Taste Safe to drink Productive water use (livestock, small-scale irrigation)
Governance systems	GS5: Operational rules	Handpump locked to prevent unauthorised use Funds stored in bank account Monthly fee Payment obligations during months of Ramadan
	GS8: Monitoring and sanctioning processes	Presence of a waterpoint attendant
Users:	U1: Number of users	Number of users
	U2: Socio-economic attributes of users	Welfare index (household composition, assets, dwelling structure) Settlement type (e.g. town, village) measured through satellite detection of night-time lights Food security as measured through market price of maize
	U3: History of collective waterpoint use	Number of years since waterpoint installation Participation during planning and implementation
	U8: Dependence on waterpoint	Alternative drinking water sources used concurrently with waterpoint
Related ecosystems	ECO1: Climate patterns	Rainfall season

[a] Modified from Ostrom (2009)

S2. Approach to data collection and analysis

Figure S2.1. Breakdown of data collection and analysis by number of waterpoints and financial records



[a] Records for both monthly and annual payments were located at one waterpoint

Figure S2.2. Breakdown of data collection and analysis by number of surveyed households

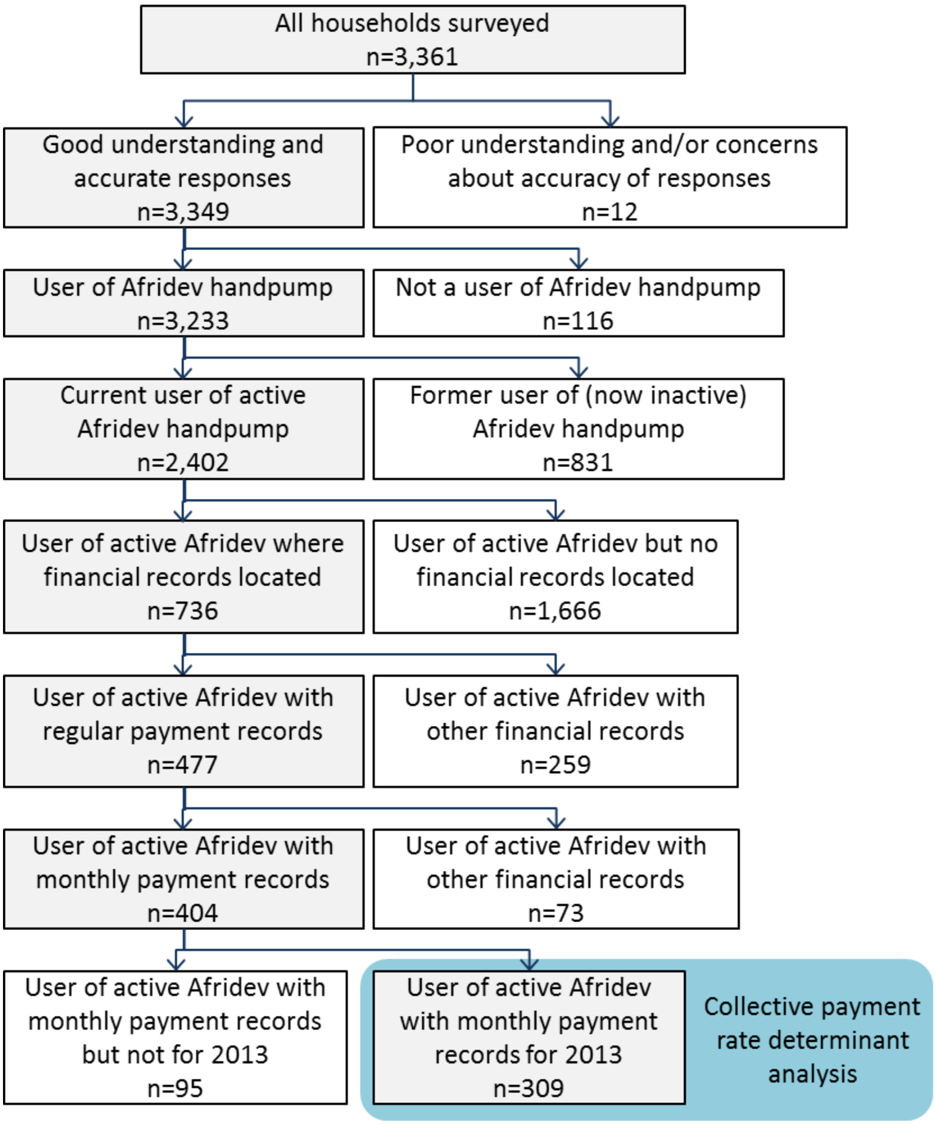
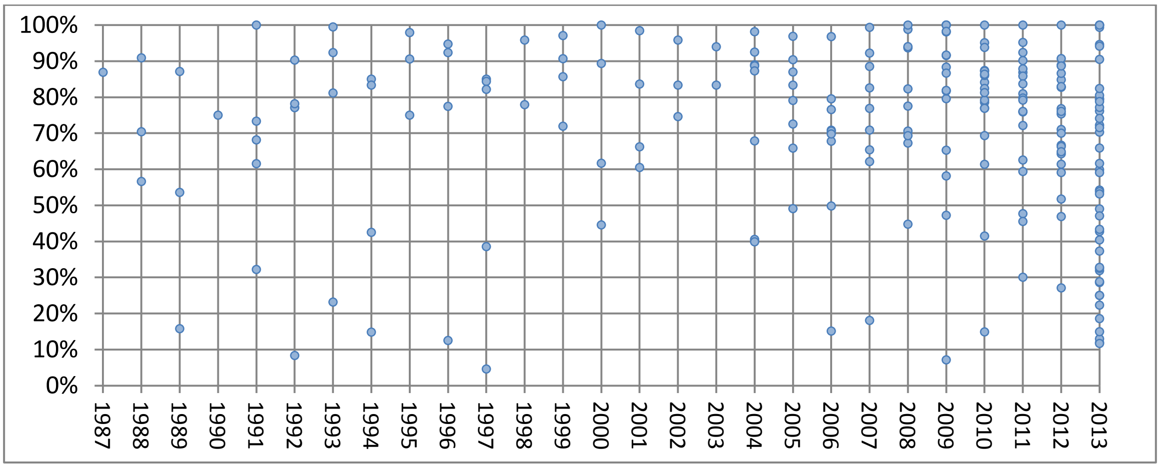


Table S2.1. Number of monthly payment records obtained by year

Year	Months	Waterpoints
1987	5	1
1988	20	3
1989	21	3
1990	12	1
1991	53	5
1992	48	4
1993	48	4
1994	40	4
1995	36	3
1996	40	4
1997	50	5
1998	24	2
1999	48	4
2000	48	4
2001	42	4
2002	36	3
2003	24	2
2004	73	8
2005	88	8
2006	107	9
2007	101	9
2008	120	10
2009	167	16
2010	187	18
2011	208	19
2012	230	23
2013	371	44

S3. Characteristics of waterpoints, households and financial records

Figure S3.1. Mean collective payment rates by year and community (monthly fees) 1987-2013[a]



[a]Each point represents a waterpoint in a given year

Figure S3.2. Collective payment rates by community (monthly fees) 1987-2013[a]

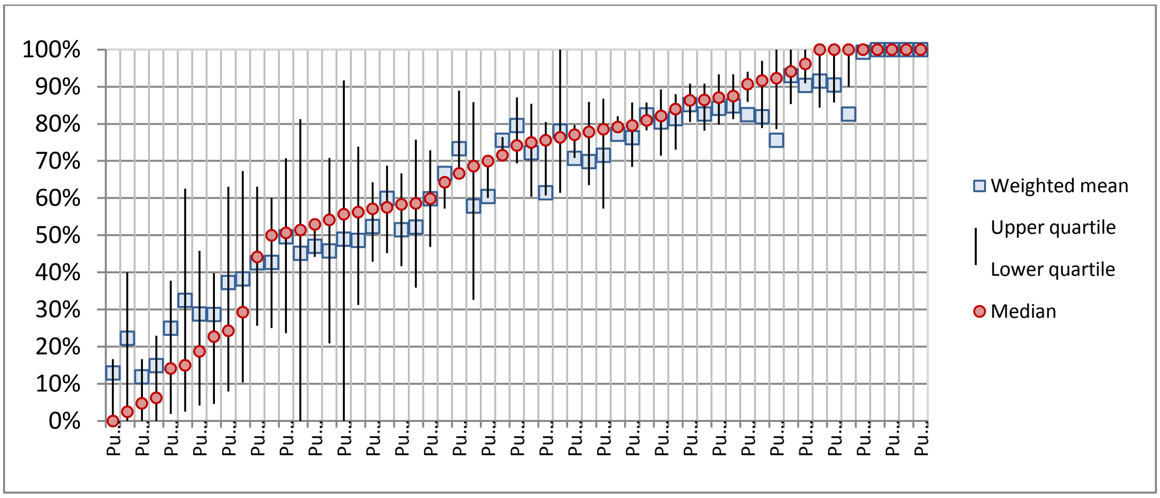


Table S3.1. Surveyed households[a] by revenue collection category and handpump operational status

	Functional	Non-functional (< 1 year)	Non-functional (> 1 year)	Total
Advanced fees	1,245 (57.8%)	179 (63.9%)	394 (49.3%)	**1,818 (56.2%)**
Fixed fees	*671 (31.2%)*	*61 (21.8%)*	*152 (19%)*	***884 (27.3%)***
PAYF	*574 (26.7%)*	*118 (42.1%)*	*242 (30.3%)*	***934 (28.9%)***
Reactive fees	463 (21.5%)	36 (12.9%)	99 (12.4%)	**598 (18.5%)**
No revenue collection	432 (20.1%)	61 (21.8%)	230 (28.8%)	**723 (22.4%)**
Don't know/no response	13 (0.6%)	4 (1.4%)	77 (9.6%)	**94 (2.9%)**
Total	**2,153 (100%)**	**280 (100%)**	**800 (100%)**	**3,233 (100%)**

[a]Includes all households using communal waterpoints fitted with Afridev handpumps

Table S3.2 Comparison of surveyed household characteristics with the most recent census and nationally representative surveys

Household characteristics	Households surveyed using WPs[a]					Rural Kenya			Kwale			Rural Kwale	
	All[b]	Active[c]	Financial records			Census 2009[g]	NHS 2012-13[h]	DHS 2014[i]	Census 2009[g]	NHS 2012-13[h]	DHS 2014[i]	Census 2009[g]	DHS 2014[i]
			All[d]	Regular payments[e]	2013 monthly[f]								
Television	8.9	9.7	7.5	7.8	8.4	-	-	18.9	11.4	-	19.7	-	9.7
Radio	71.5	69.7	72.0	73.8	76.7	-	-	63.1	57.5	-	47.1	-	42.6
Bicycle	45.2	43.3	48.1	52.4	50.2	-	-	24.8	33.4	-	27.6	-	28.2
Mobile phone	84.1	84.6	84.5	85.3	85.4	-	-	80.0	51.5	-	84.1	-	80.3
Motorcycle	10.7	10.4	11.1	10.5	12.0	-	-	8.2	2.1	-	8.1	-	8.4
Natural roof	68.1	66.7	61.1	59.5	56.3	26.3	24.2	17.4	59.9	52.9	43.9	67.1	51.3
Natural floor	71.0	69.8	75.0	71.7	70.9	76.9	66.7	70.0	70.2	62.7	62.9	82.3	77.1
Household size	4.6	4.7	4.5	4.5	4.5	4.9	4.6	4.5	5.3	5.3	4.3	5.7	4.7
Open defecation	45.1	44.2	37.8	35.6	33.3	20.7	-	16.0	51.1	-	43.6	62.4	55.3

WP = Waterpoint. [a]All households using communal waterpoints fitted with Afridev handpumps. [b]n=3,233. [c]n=2,402. [d]n=736 [e]n=477. [f]n=309. [g]Kenyan Population and Housing Census 2009 (KNBS, 2010). [h]Kenya National Housing Survey 2012-13 (MLHUD, 2015). [i]Kenya Demographic and Health Survey 2014 (KNBS and ICF Macro, 2015).

Table S3.3. Mean and median characteristics of waterpoints and communities with and without financial records available[a]

Characteristics	All				Active waterpoints			
	Records available (n=100)	Records unavailable (n=418)	All (n=518)	p-value[b]	Records available (n=100)	Records unavailable (n=244)	All (n=344)	p-value[b]
Functional (% waterpoints)	97.0	49.3	58.5	<0.001	97.0	84.4	88.1	0.001
Resource system								
Distance (WP-HHs) (m)	167 (138)	129 (105)	137 (112)	0.001 (<0.001)	167 (138)	133 (109)	143 (118)	0.004 (<0.001)
Distance (WP-WP) (m)	846 (718)	884 (574)	877 (620)	0.657 (0.031)	846 (718)	790 (534)	806 (580)	0.602 (0.001)
Distance (WP-SPR) (km)	21.0 (17.3)	25.4 (27.0)	21.9 (22.7)	0.009 (0.030)	25.4 (27.0)	19.9 (16.6)	21.5 (22.6)	0.002 (0.006)
Community mechanic (% waterpoints)	52.1	46.5	47.7	0.332	52.1	49.3	50.2	0.651
pH ≥ 6.5 (% waterpoints)[c]	70.3	70.6	70.5	0.968	70.3	70.5	70.5	0.973
Resting water level (m)[d]	14.7 (15.2)	15.8 (16.0)	15.5 (15.8)	0.347 (0.528)	14.7 (15.2)	14.6 (14.8)	14.7 (15.1)	0.911 (0.813)
Well type (% waterpoints)	99.0	87.8	90.0	<0.001	99.0	90.2	92.7	0.004
Resource unit								
Yield (m^3/hr)[e]	2.4 (2.4)	2.6 (2.4)	2.6 (2.4)	0.365 (0.286)	2.4 (2.4)	2.8 (2.9)	2.7 (2.4)	0.147 (0.087)
EC (mS/cm)[c]	1.15 (0.80)	1.20 (0.84)	1.18 (0.82)	0.715 (0.215)	1.15 (0.80)	1.18 (0.82)	1.17 (0.82)	0.799 (0.257)
Taste (rating -1 to 1)	60.9 (80.0)	49.5 (73.6)	51.7 (75.0)	0.031 (0.166)	60.9 (80.0)	50.6 (73.6)	53.6 (75.0)	0.073 (0.380)
Safe to drink (% households)	86.2 (100)	79.7 (100)	80.9 (100)	0.007 (0.074)	86.2 (100)	77.1 (85.7)	79.7 (87.5)	<0.001 (0.008)
Productive use (% households)	28.0 (27.6)	25.2 (25.0)	25.7 (25.0)	0.207 (0.114)	28.0 (27.6)	25.5 (25.0)	26.2 (25.0)	0.256 (0.216)
Governance system								
Attendants (% waterpoints)	63.6	64.9	64.6	0.819	63.6	79.2	74.6	0.003
Locks (% waterpoints)	77.8	45.9	52.2	<0.001	77.8	52.9	60.2	<0.001
Bank account (% waterpoints)	14.0	3.3	5.4	<0.001	14.0	4.1	7.0	0.001
Users								
Welfare index	7.0 (6.8)	6.3 (5.9)	6.4 (6.1)	0.014	7.0 (6.8)	6.5 (6.2)	6.6 (6.3)	0.113
Night-time lights	4.4 (0.0)	5.2 (5.0)	5.1 (0.0)	0.301 (0.014)	4.4 (0.0)	5.8 (6.0)	5.4 (5.0)	0.106 (0.002)
Participation (%)	32.1 (28.6)	30.8 (28.6)	31.1 (28.6)	0.614 (0.449)	32.1 (28.6)	26.7 (25.0)	28.3 (28.6)	0.044 (0.025)
Years since installation	23.6 (25.0)	20.3 (23.0)	21.0 (23.0)	<0.001 (<0.001)	23.6 (25.0)	19.7 (23.0)	20.9 (24.0)	<0.001 (<0.001)
Alternative water source (% waterpoints)	82.0	85.1	84.5	0.441	82.0	80.2	80.7	0.699

[a]Median values reported in parentheses for continuous variables. Household-level variables averaged into single measure for each waterpoint. [b]Chi-square test for categorical variables; Independent samples t-test for continuous variables (with Welch's correction for unequal variances where required); Mann-Whitney U test in parentheses when normality assumption of independent samples t-test violated. [c]Water quality characteristics measured for 288 waterpoints (including 281 active waterpoints). EC values were capped at 3999. [d]Data on resting water level available for 214 waterpoints (including 159 active waterpoints). [e]Data on yield available for 201 waterpoints (including 151 active waterpoints).

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Figure 2
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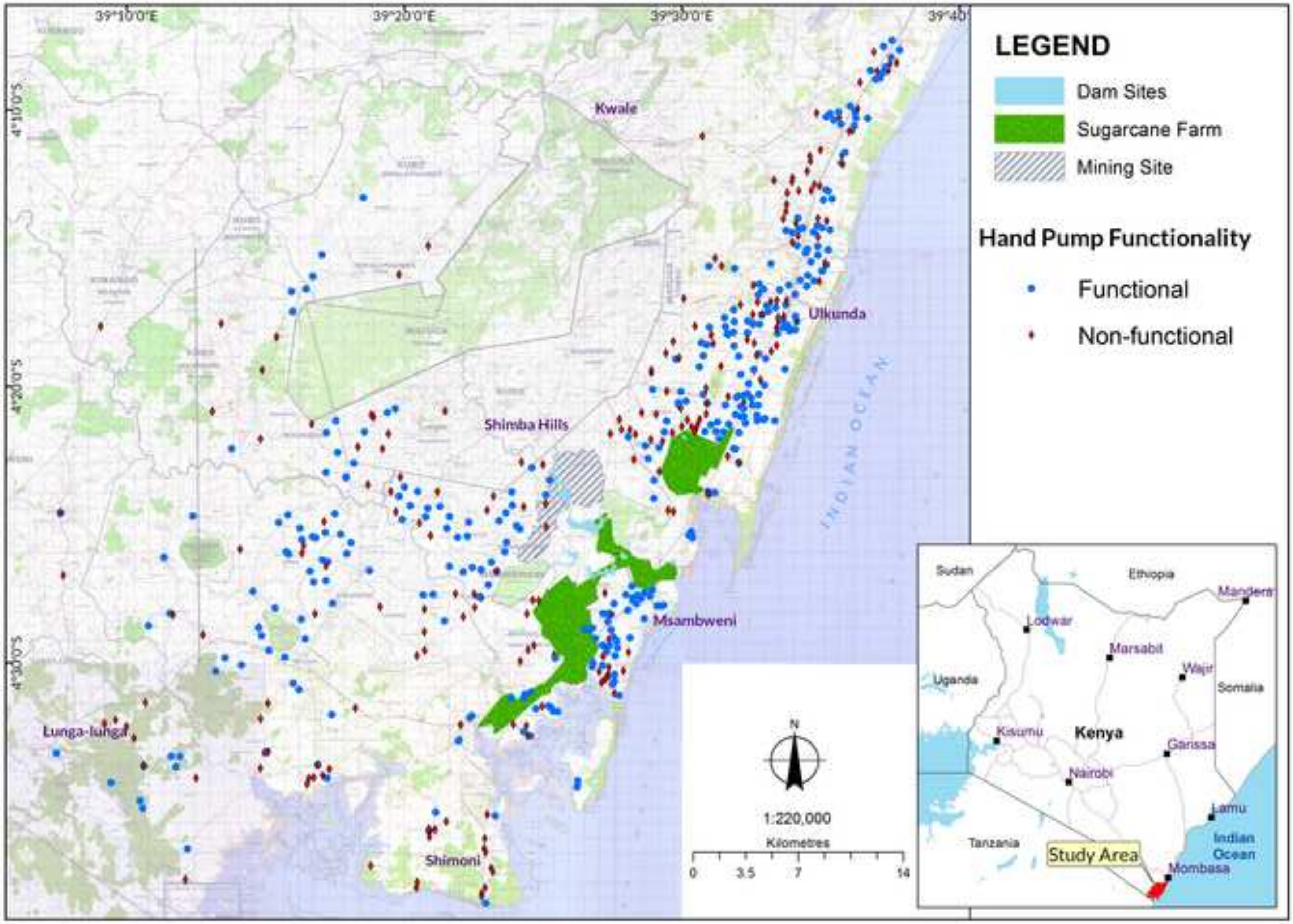

- Study analyses more than 53,000 payments by waterpoint users in rural Kenya
- Results suggest non-payment and late payment are prevalent
- Outcomes predicted by water quality, accessibility, productive uses and rainfall

Graphical Abstract