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2017

watermission
TANZANIA

Study of Solar-powered Prepaid Water Systems in Tanzania

FINAL REPORT

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Contents

Executive Summary 2

Project Overview and Objectives 3

- Overview 3
- Objectives 3

Site Information and Research Methodology 4

- Site Information 4
  - Chanhumba 4
  - Gidewari 4
  - Lulembela 4
  - Burudani Water Kiosk 5
- Research Methodology 5
- Data Collection Instrument Design 5
- Data Analysis 6

Technical Specifications for Project Sites 6

- Chanhumba, Chamwino, Dodoma 6
- Gidewari, Babati, Manyara 6
- Lulembela, Mbogwe, Geita 7
- Burudani Water Kiosk, Dar Es Salaam 7

Results 7

- Project Metrics 7
- Water Consumption Analysis 8
  - Chanhumba 8
  - Burudani 9
  - Other Findings 9
- Perceptions of Stakeholders: Results from Focus Groups, Key Informant Interviews, and Mobile Phone Surveys 10
  - Water Use and Consumption Patterns 10

Water Insecurity Early Warning System Proof of Concept 14

- Questions and Findings 14
  - User Groups 14
  - Weather Data 15
  - Predictive Modeling 15
- Conclusions and Next Steps for EWS Proof of Concept 15

Conclusions & Recommendations 16

- Conclusions 16
- Recommendations 16
- Limitations 17

References 17

Executive Summary

Between May 2016-October 2017 Water Mission-Tanzania (WM-T), in partnership with World Bank, implemented experimental field trials in Tanzania in order to determine the viability and sustainability of solar-powered piped water supply systems and smart water metering technology as a mechanism to improve financial accountability for rural and urban water schemes; and to provide evidence of the potential of smart water dispensers (SWDs) and solar pumping in both rural and urban water sectors to promote sustainable and affordable water service delivery in Tanzania. To achieve this, four project sites were selected and research was carried out to understand the motivations and concerns of key stakeholders, perceptions of community members, and feasibility of scaling this innovative solution across the country. Overall, the study found an overwhelmingly positive response and acceptance of solar-powered water systems and smart water dispensers with mobile prepayment services:

- All projects consistently met water quality targets and experienced less than one day of service outage on average.
- Water sales at all projects have consistently generated average monthly revenue exceeding operational expenses.
- Data provided by Grundfos AQtap smart water dispenser units via the cloud-based Grundfos Water Management System (WMS) showed important but somewhat disparate trends between rural and urban use cases:
    - Chanhumba community experienced an upward trend in both daily water consumption (slope: +89.33) and daily water consumption per unique card (slope: +0.06). This indicates that those who use the water continuously increase their consumption over time.
    - Burudani urban water kiosk in Dar Es Salaam, on the other hand, experienced a downward trend in both overall daily water consumption (slope: -28.58) and daily water consumption per unique card (slope: -3.64).
- Across all sites, respondents reported spending less money on water (avg. 36% less) at the end of the field trials.
- Water users are evenly distributed amongst wealth quintiles, indicating both the poorest and wealthiest find the water accessible and affordable.
- Respondents reporting using the Water Mission system as their primary drinking water source rose by 38%.
- Perceptions of the ability of solar to effectively power the water system rose 16%.
- “Availability” of the water source, which includes perceived access to adequate quantity, queueing time, and functionality of the water point, remained a primary determinant for primary drinking water source selection throughout the field trials. The reported importance of “Cost” quadrupled from baseline to endline (22-83%), while importance of “Quality” tripled (31-92%). This could be an indication that as people experienced a high service level, their demand for more services grew.
- 97% of respondents in Chanhumba and Gidewari reported that paying for water services via prepaid water card was preferred to cash payments.
- Satisfaction with the management of the project by the COWSO (Community-Owned Water Supply Organization) improved by 30% from midline to baseline.

These field trials have found that solar-powered water supply systems equipped with prepaid water meters appear to be a viable solution to systemic water service issue in Tanzania. In order for this solution to be scalable, however, implementers should consider the importance of several factors including: training and long-term support for community-led management; buy-in from, and integration of, the cloud based water management system into the larger water sector management infrastructure; consistent availability of water services for consumers; and affordability of the chosen prepaid water meter technology.

Project Overview and Objectives

Overview

Water Mission - Tanzania (WM-T), in partnership with World Bank, was contracted to implement safe water systems and related training and programming in selected rural communities and urban settings in Tanzania according to the scope described in the Terms of Reference in signed contract no. 7176865 between the World Bank and WM-T.

The scope of the project included rehabilitation of rural and urban water systems. In the rural areas, each project selected was facing common challenges of unrepaired leaks and damages, high operational costs from diesel-powered generators, and community mismanagement of water system funds. Urban kiosk sites in Dar Es Salaam were facing similar infrastructural and financial challenges. Sites included in the final project scope were: Chanhumba, Chamwino, Dodoma; Gidewari, Babati, Manyara; Lulembela, Mbogwe, Geita; and Burudani Water Kiosk in Dar Es Salaam.

Figure 1. Map of Tanzania by Region

The purpose of these field trials was to determine the viability and sustainability of solar-powered water systems and the use of smart water dispensers (SWDs) as a mechanism to improve financial accountability for water schemes in Tanzania; and to deepen the operational knowledge on the latest prepaid meter technology by providing evidence of the potential of smart water dispensers and solar pumping in both rural and urban water sectors to promote sustainable water service delivery in Tanzania.

Figure 2. Rendering of multi-grid smart water dispenser kiosks connected to water supply

Objectives

- Identify initial motivations, concerns, and ongoing perceptions of government personnel, district officials, and community leaders in participating in the trials;
- Gather information on customer satisfaction regarding ease of payment, perceptions of management strategy, and utility of the information and communications technology (ICT) solution in addressing water service issues in Tanzania;
- Gather information on financial, institutional, technical, and social sustainability of water supply systems;
- Understand willingness of Community-Owned Water Supply Organizations (COWSOs) in rural communities to support the capital expenses (CapEx) and technical aspects of the solar installation;
- Determine feasibility of bringing projects to scale.

It is estimated more than 5.3 million people in rural Tanzania are without access to an improved water source (Heymans, 2014). Innovative models of community-based water management which incorporate digital water sales, mobile prepayment, and solar pumping may allow water service providers to reach communities which were previously unreachable, while strengthening the sustainability of water services. Current prepaid water meter technology has the capability to address the milieu of issues plaguing the water sector in Tanzania and could lead to greater sustainability of water services, transparency of management, and ease of maintenance of community water points.

This report provides information on technical the specifications and project performance indicators for each site listed above from May 2016 – October 2017. It also presents results from qualitative and quantitative research designed to address the above-listed objectives, drawing key conclusions and offering recommendations for future consideration.

Site Information and Research Methodology

Site Information

Sites were selected in consultation with the World Bank, Tanzania Ministry of Water, and regional/district/local governments as well as the municipal water authority (DAWASCO) in Dar Es Salaam. Key consideration was given to sites which were experiencing systemic water service challenges and would benefit from solar-powered safe water services. Each site received a customized solution. For this reason, site-specific details are described in detail below.

Site Name	District/Region	Distance to nearest city (km)	Est. Population	Est. No. Households	Est. No. livestock
Chanhumba	Chamwino, Dodoma	70, Dodoma	2,824	500	5,000
Gidewari	Babati, Manyara	40, Babati	3,400	572	8,900
Lulembela	Mbogwe, Geita	30, Ushirombo	13,850	2,000	1,087
Burudani Water Kiosk	Dar Es Salaam	n/a	100 customers/day	n/a	n/a

Table 1. Basic Site Information

Chanhumba

The water system in Chanhumba was commissioned July 28, 2016 and monthly follow-up visits from WM-T are currently ongoing. Chanhumba received 13 Grundfos AQtap smart water dispenser units to retrofit existing taps. These units were operational June 25, 2017. Throughout the field trials, seven (7) of these units were transmitting data to the Grundfos cloud-based Water Management System (WMS) and were available for analysis. This data includes water consumption, credit transactions, technical performance, and service needs. In order to prepay for water using their unique watercard, users first visit a mobile vendor in the community, paying cash to the vendor who then credits their watercard. To replace this interim prepayment system, Vodacom M-Pesa, a mobile phone-based money transfer, financing and microfinancing service, became functional in Chanhumba in November 2017. Because data collection for the field trials ended in October 2017, this feature was not evaluated in this study. Chanhumba is also the only rural site in these field trials responsible for managing a solar pumping and smart water dispenser water supply system at the community-level, through the authority of the COWSO with support from the office of the District Water Engineer (DWE).

Gidewari

The water system in Gidewari was commissioned November 1, 2016. Monthly follow-up visits from WM-T concluded November 2017. In June 2017, Gidewari entered into an agreement with eWATER to receive eWaterPay pre-payment smart taps. These taps were retrofitted to the water system installed by Water Mission. WM-T was not involved in this partnership and has not been able to access disaggregated remote monitoring data from eWATER despite multiple attempts to do so. Therefore, information on the water system in Gidewari presented in this report is taken from WM-T water meters and monthly reports from the COWSO. Mobile prepayment in Gidewari functions through three water vendors who are employed by eWATER. These vendors have smartphones equipped with the eWATER app which enables them to accept cash from users and in turn credit user accounts directly. Each user has a unique eWatercredit tag from which to access the smart taps. Under this management model, the COWSO does not have access to financial information, the ability to access revenue for system repairs, and ultimately does not have the ability to manage water system operations within the community. These restrictions have likely influenced the perceptions of project management under the COWSO in Gidewari.

Lulembela

The water system in Lulembela was commissioned November 15, 2016. Monthly follow-up visits from WM-T concluded September 15, 2017. Lulembela did not receive smart water dispensers. Due to high demand for services beyond the scope of the planned water project, the COWSO approved an extension of the system to include 18 private household connections and an extension to a nearby sub-village. In order to support this extension, the solar pump installed by WM-T

was replaced with a larger diesel-powered pump. These modifications to the water system were conducted independently of WM-T. The modifications have reportedly contributed to issues with water availability across the community, and have likely impacted perceptions of the effectiveness of project management under the COWSO in the community.

Burudani Water Kiosk

Burudani Water Kiosk was commissioned August 12, 2017. Follow-up visits are scheduled until July 2018. Burudani received two (2) Grundfos AQtap smart water dispenser units in July 2017. The smart water dispenser and prepayment system in Burudani is identical to that in Chanhumba. Due to the inability to reach an agreement with DAWASCO (Dar es Salaam Water and Sewerage Corporation), implementation in Burudani was delayed and thus research at this site did not proceed after baseline data collection in June 2016. Therefore, data presented in this report is taken from the Grundfos WMS dashboard and reports collected by WM-T from the COWSO. Two other urban kiosk sites were originally selected for implementation but did not proceed.

Research Methodology

Data collection occurred between May 2016 – October 2017. Research activities consisted of baseline focus group discussions and three phases (baseline, midline, endline) of both key informant interviews and direct-call phone surveys. Baseline focus group discussions and key informant interviews[1] at all four sites took place between May - June 2016, prior to project implementation. Six focus groups were held (one group per project site) at baseline. Participants were residents of the project communities, both males and females, and ranged in age from 23 – 69 years. Midline key informant interviews took place in Chanhumba in August 2016, and in Gidewari and Lulembela in February 2017. These interviews occurred shortly after the projects were commissioned and were under the management of the COWSO with oversight from WM-T. Endline interviews were conducted in October 2017, after monthly follow-up visits had been completed and the projects were independently managed by the COWSOs. A total of 26 key informant interviews were conducted across all project sites over the three data collection phases. Participants held a variety of positions including Water Technician, District Water Engineer, Village Chairman, and System Operator.

All households in the service area were enrolled in SMS (Short Message Service) mobile phone surveys at baseline, with an original sampling frame of 1,304 households. Due to low response rates, the SMS method was exchanged for direct-call phone surveys midway through baseline data collection. Baseline surveys were conducted between August – September 2016, midline surveys between February – March 2017, and endline surveys September – October 2017. At baseline the sample was reduced to 606 households, at midline the sample was 530, and by endline the final sample was 453 households across three communities (Chanhumba, Lulembela, and Gidewari) – an attrition of 25%. Overall, 1,589 surveys were completed across all three data collection phases. Respondent distribution was 77% male, 23% female with an age range of 17-78 years and a mean age of 34 years.

Data Collection Instrument Design

Focus group discussion topic guides were generated to build a body of knowledge around the core issues of water service delivery at project sites, and to understand participants' perceptions at the beginning of the field trials to understand how these changed over time.

Key informant interview guides were tailored to understanding the perceptions of water service providers and other individuals holding key positions relevant to the project. Information collected included perceptions on the solar aspect of the field trials, mobile prepayment, project sustainability, and ease of management or scalability.

The phone survey was designed and managed in KoboToolbox and collected via webform. Surveys contained approximately 32 questions regarding information on primary drinking water source, access to drinking water, perceptions of cost and price fairness, perceptions of the prepayment system and solar-powered water solution, and perceptions of the effectiveness of management.

This study received IRB approval from the Office of Research Compliance at Virginia Tech (IRB 16-273).

[1] Purposive sampling was used to recruit focus group discussion and key informant interview participants (Berg, 2007).

Data Analysis

Survey and smart water dispenser data from Grundfos AQtap units were analyzed using Python Notebooks running on IBM Bluemix Apache Spark in IBM Data Science Experience cloud server. Focus group discussions and key informant interviews were analyzed using Dedoose qualitative analysis software.

Technical Specifications for Project Sites

Detailed information on the specifications of the water systems implemented at each project site are included below.

Chanhumba, Chamwino, Dodoma

- Design service population: 2,500
- Design demand:
    - Liters per day: 22,640
    - Liters per person per day: 10.00
- Pump: Three (3) Grundfos 11 SQF-2 pumps installed in 6" borehole casing
- Power: 6x 250 W array for each 11 SQF-2 pump (18 total solar panels)
- Water Treatment: 2x WM-T erosion Chlorinators
- Replaced pipes and tap stands excluding cattle trough
- Replace HDPE in stream beds with GS pipe, buried in river bed
- Repaired leaks and failed joints with HDPE PN16 compression fittings
- Improvements to water storage tank
- 13 taps were installed with new water meters and Grundfos AQTap smart water dispensers mounted on steel frames
- Watercards issued to community to pre-pay for water services. Customer's cards are currently credited via vendors within the community.

Gidewari, Babati, Manyara

- Design service population: 2,860
- Design demand:
    - Liters per day: 20,440
    - Liters per person per day: 8.00
- Pump: Lorentz PS4000 C-SJ3-32 pump installed in existing 80 m^3 sump
    - PS Communicator for pump control, including remote monitoring and shut-off capability
    - Additional LORENTZ accessories: Stilling tube, SunSwitch, PV Disconnect
- Power: 6 kW Solar Array: Solar World 250-Watt Panels arranged 8x3 array (24 Panels)
- Water Treatment: WM-T erosion Chlorinator
- Three (3) manually operated ball-valves to act as air release valves at local high points in pipelines to prevent lack of flow in due to air-lock; three (3) washout boxes at local low points in pipelines for periodically washing out sediment; three (3) break-pressure tanks to resolve high pressure in lines and at tap stands
- Replaced nine (9) control valves
- Secondary pumping system to pump water to Gidewari tap stand
    - Pump: Grundfos 11 SQF-2 pump in masonry sump
    - Power: 750 W Solar Array composed of 3x SW 250-Watt solar panels
    - 5,000 L PE storage tank located at Gidewari tap stand on 2 m tank pad with float valve
- Replace and bury exposed and damaged sections of HDPE and GS pipes
- Rehabilitated nine (9) taps: repair of the floor at the tap stand, repaired leak in chamber, paint chamber, install water meter
- New float valve and cattle trough

Lulembela, Mbogwe, Geita

- Design service population: 12,000
- Design demand:
    - Liters per day: 19,040
    - Liters per person per day: 20.00
- Pump: LORENTZ PS4000 C-SJ8-15 pump installed in system borehole
    - PS Communicator for pump control, including remote monitoring and shut-off capability
    - Well probe in sump to prevent dry pumping
- Power: 6 kW Solar Array: Solar World 250-Watt Panels arranged 8x3 array (24 Panels)
- Water Treatment: Three (3) WM-T erosion Chlorinators for disinfection and residual
- Rehabilitated 11 public taps: Replaced broken water meters and leaking valves, replaced concrete valve box covers with lockable steel cover, repaired damaged masonry and valve boxes and tap stands, painted water storage tank
- An additional nine (9) private connections were constructed, repaired cattle trough and soak pits at tap stands

Burudani Water Kiosk, Dar Es Salaam

- Design service population: 5,340
- Power: Two (2) 85W solar panels, 1 at each AQtap.
- Water Treatment: WM-T erosion Chlorinator
- Two (2) Grundfos AQtap units enclosed in locking steel enclosure
- Removed kiosk tap stand and re-route all kiosk plumbing
- Trained current kiosk operator on WASH, chlorinator operation, and Grundfos AQtap operation

Results

Project Metrics

Routine and remote monitoring data was collected in order to report on a variety of key project metrics relating to the financial, institutional, technical, and social sustainability of the water supply systems in each community. This information is presented for each project site in Table 2 below. All data presented in this section (except for water quality) for Chanhumba and Burudani is taken from Grundfos AQtap units, while data for Gidewari and Lulembela is taken from Water Mission routine monitoring reports.

All projects consistently met water quality targets and experienced very few global service outages (Table 2). Additionally, the majority of the service area in rural sites is estimated to be using the water as their primary drinking water source. Overall consumption is highest in Lulembela (75,897 liters/day), while the least consumption per person per day is seen in Burudani (3 est. liters/person/day).

	Water Quality[2]	**Avg. Daily Production**	**Avg. No. Users / % of service population served**	**Avg. No. unscheduled system service outages in any 30-day period**
Chanhumba	100% of targets met	24,274 liters/day 61 liters/watercard/day OR 9 est. liters/person/day[3]	396/day[4] 99% of the community is estimated to be accessing the water regularly	0 days

[2] Water quality targets for all Water Mission safe water projects include: Free chlorine residual ≥0.2 and ≤0.5 mg/L, ≤5 NTU turbidity, <1 CFU/100mL total coliforms. The achievement of these targets is reported across implementation and follow-up phases for each site.

[3] The number presented here is a projected estimate based upon data received from the seven (7) AQtap kiosks transmitting data during the field trials.

[4] The number presented here is a projected estimate of total consumers based upon data received from the seven (7) AQtap kiosks transmitting data during the field trials. This number is likely higher as not all users have a watercard, but rather pay in cash.

Gidewari	90% free chlorine residual compliance Turbidity and microbiological water quality targets met	22,595 liters/day 6 est. liters/person/day	94% of the community is estimated to be accessing the water regularly	3 days
Lulembela	100% of targets met	75,897 liters/day 9 est. liters/person/day	90% of the community is estimated to be accessing the water regularly	0 days
Burudani Water Kiosk	50% free chlorine residual compliance Turbidity and microbiological water quality targets met	9,013 liters/day 111 liters/watercard/day 3 est. liters/person/day	81/day 5% of the service area is estimated to be accessing the water regularly	1 day

All projects have consistently deposited money in the bank each month, with average monthly revenue exceeding expenses. Operational cost recovery (OpEx) recorded during the field trials ranges from 315% (Chanhumba) to 146% (Burudani).

Table 2. Key Project Metrics

	Average Monthly Revenue (USD)	Average Monthly Expenses (USD)	Average Net Income(USD)	Savings over study period (USD)	OpEx (%)[5]
Chanhumba	$573	$182	$392	$3,517	315%
Gidewari	$371	$187	$184	$689[6]	198%
Lulembela	$1,132	$533	$598	$2,318	212%
Burudani Water Kiosk	$657	$449	$209	$1,154	146%

Table 3. Financial Performance

Water Consumption Analysis

Data available from Grundfos WMS for AQtap smart water dispenser units in Chanhumba (7 units) and Burudani Water Kiosk (2 units) offered useful findings on water consumption and use patterns within each service area. Each water project began with a special promotional period wherein users could receive a watercard to access the smart water dispenser at a reduced cost of 3500 shillings ($1.57USD), which included 3500 shillings of water credit pre-loaded onto the card. After this promotional period, the cost of a card was 7500 shillings ($3.38USD) and did not include water credit.

Throughout the field trials, Chanhumba saw a consistent upward trend in daily water consumption and number of liters consumed per unique card, while Burudani saw a slight downward trend. The differences in performance of these water supply systems is likely due to a confluence of variables, including increasing private household connections in urban Dar Es Salaam.

Chanhumba

Seven (7) of the 13 dispensers in Chanhumba transmitted data to the WMS during project monitoring and were available for analysis. Chanhumba continued to experience an upward trend in both daily water consumption (Figure 3) (slope: +89.33) and daily water consumption per unique card (Figure 4) (slope: +0.06) throughout the field trials. This indicates that those

[5] Operational cost recovery = % coverage of operational expenses from revenue.

[6] Accurate to April 2017.

who use the water continuously increase their consumption over time. This trend is encouraging for financial sustainability and for the high retention of customers over time.

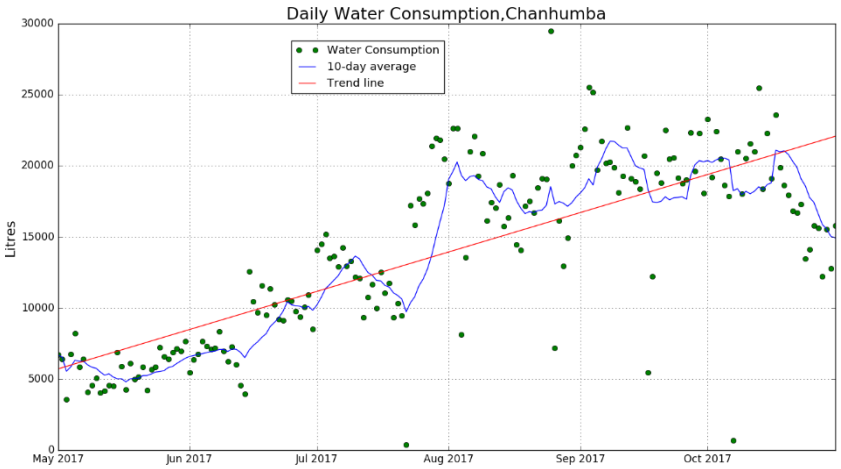

Figure 3. Daily Water Consumption in liters, Chanhumba

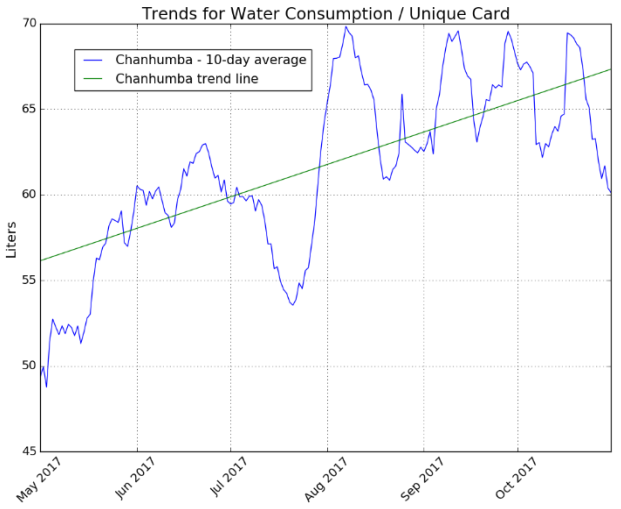

Figure 4. Water Consumption per Unique Card, Chanhumba

Burudani

Burudani, on the other hand, experienced a slight downward trend in both overall daily water consumption (Figure 5) (slope: -28.58) and daily water consumption per unique card (Figure 6) (slope: -3.64). Because research did not proceed in Burudani after baseline, it is difficult to ascertain what the key contributing factors to this downward trend might be. Based on known challenges at Burudani prior to the field trials (such water loss and theft and the increase of private household connections) it is possible these same challenges are still relevant. When comparing this data with weather data, rainfall was found to be negatively associated with water consumption.[7] The downward 10-day average observed in both Chanhumba and Burudani during the latter months of the year may be explained by seasonality, where users tend to collect less water from the taps when rainwater is available. Though multiple years of data would be needed to truly identify a trend in this regard.

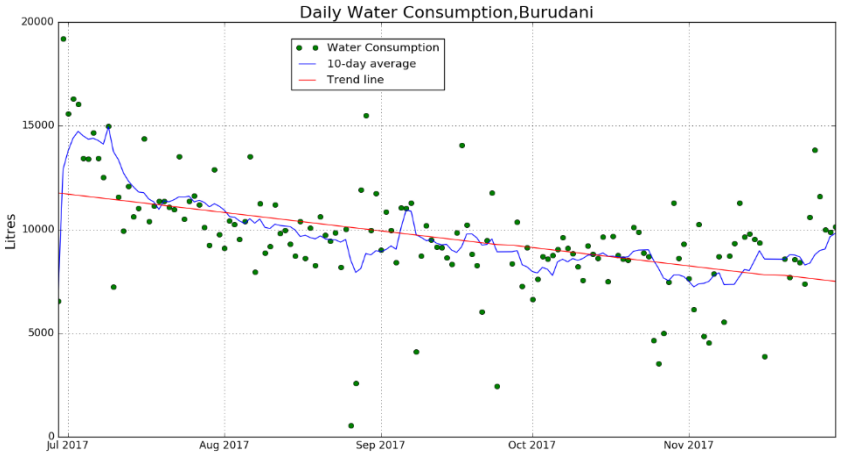

Figure 5. Daily Water Consumption in liters, over time, Burudani

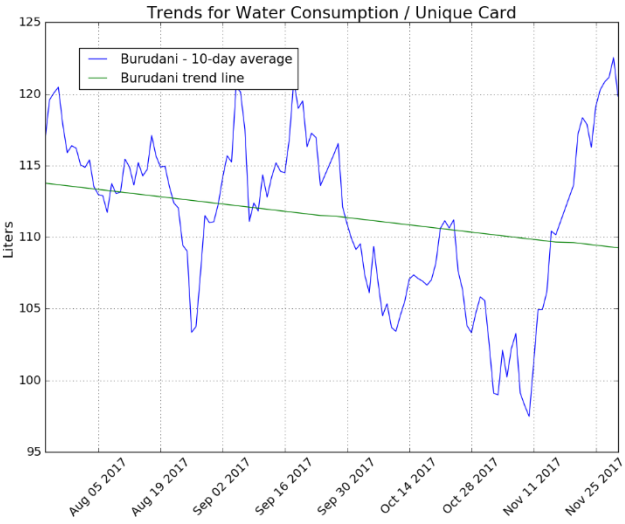

Figure 6. Water Consumption per Unique Card, Burudani

Other Findings

Other patterns identified from the Grundfos WMS show that the majority of users in Burudani spend more than 300 shillings per day, with an average of 3.9 transactions per day per user. In Chanhumba,

[7] Correlation coefficient for water consumption compared to rainfall by day by Weather.com (CSV): -0.226590684931

users spend approximately 50-125 shillings per day, averaging 3.5 transactions per user per day. In Burudani users top up their cards with 100-600 shillings of credit at a time; whereas users in Chanhumba top up 400-600 shillings.

At each site, a number of cards which were issued were eventually tagged as "inactive"- having been used once but then had gone unused for a period of one month or more. In Burudani 48% of water cards issued were inactive by the end of the field trials, with 52% of those having a remaining balance of 15 shillings or more. The average balance on inactive cards in Burudani was 1557 shillings ($0.70USD), enough credit for 31 - 20 liter containers of water. In Chanhumba, 24% of cards issued were inactive by the end of the field trials, and 72% of those cards had credit remaining. This could indicate a high number of lost cards, users who did not choose to continue to use the water system after the promotional period ended, or cards which were stopped due to a reported loss and then re-issued.

Perceptions of Stakeholders: Results from Focus Groups, Key Informant Interviews, and Mobile Phone Surveys

One of the goals of this study was to identify the initial motivations, concerns, and ongoing perceptions of government personnel, district officials, and community leaders in participating in the trials. Interviews and focus group discussions conducted before project implementation highlighted issues around water access and availability and the high cost of both water and diesel fuel for generators, and the inconvenience and uncertainty of accessing diesel fuel. These preliminary interviews also revealed excitement around the promises of solar-powered water services, better access to safe water, and utilizing mobile money systems to pay for water. Other areas of promise included better water infrastructure, and better quality water for a reduced price. These interviews also revealed what communities saw as possible project benefits and challenges. Each of these themes were then followed through the midline and endline interviews.

Another key objective of the field trials was to gather information on user satisfaction and perceptions of a variety of key features of the field trials. This was primarily done through direct-call mobile phone surveys at three phases (baseline, midline, endline) throughout the field trials.

Key findings from both datasets mentioned above are presented here for Lulembela, Chanhumba, and Gidewari below.

Water Use and Consumption Patterns

Expenditure and Consumption

Across all sites, respondents reported spending less money on water (avg. 36% less) at the end of the field trials (endline) as they did prior to the project (baseline) (Figure 7). However, this reduction was primarily seen in Chanhumba and Lulembela, as respondents in Gidewari reported an 80% increase in water expenditure over the course of the field trials. This is likely due to both the rehabilitation of the water system and smart water dispenser solution there, rendering the water more widely available.

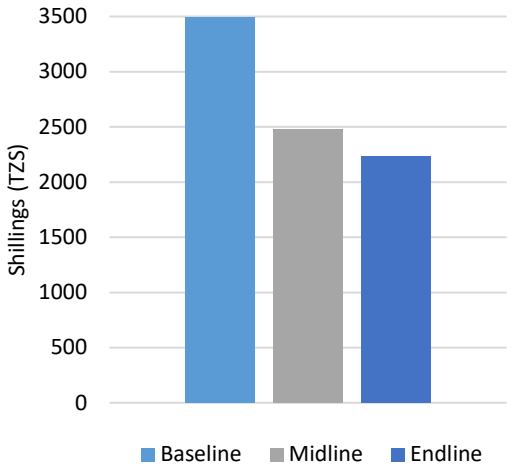

Figure 7: Average reported water expenditure over a 7-day period

It is important to note this overall reduction in expenditure also coincided with a reduction in the volume of drinking water collected by each household. Respondents in Lulembela reported an average 34% reduction in drinking water collected, while Chanhumba reported a 4% reduction. Gidewari, on the other hand, experienced a 31% increase (Figure 8).

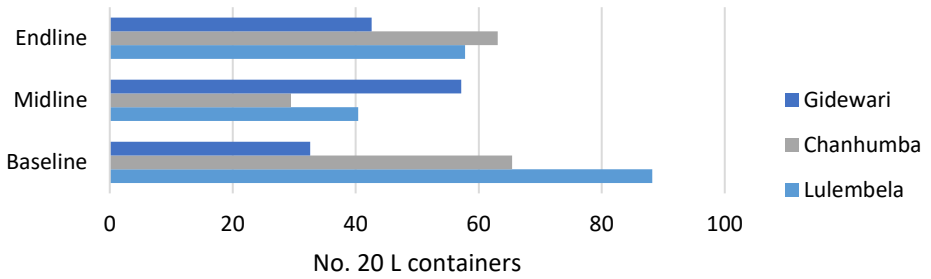

Figure 8: Average reported No. of 20 L containers collected from primary drinking water source in the past 7 days

Primary Drinking Water Source

At baseline, distribution of reported primary drinking water sources across all sites were somewhat evenly disbursed amongst available sources. However, by the end of the field trials, 98% of those surveyed reported using the Water Mission project source as their primary source of drinking water, while the remaining 2% were distributed between hand-dug wells, personal boreholes, and other community sources respectively (Figure 9). Gidewari saw the biggest shift in primary drinking water source use where 89% of respondents reported using a hand-dug well or community borehole at baseline, and 95% reported using the Water Mission project source at endline.

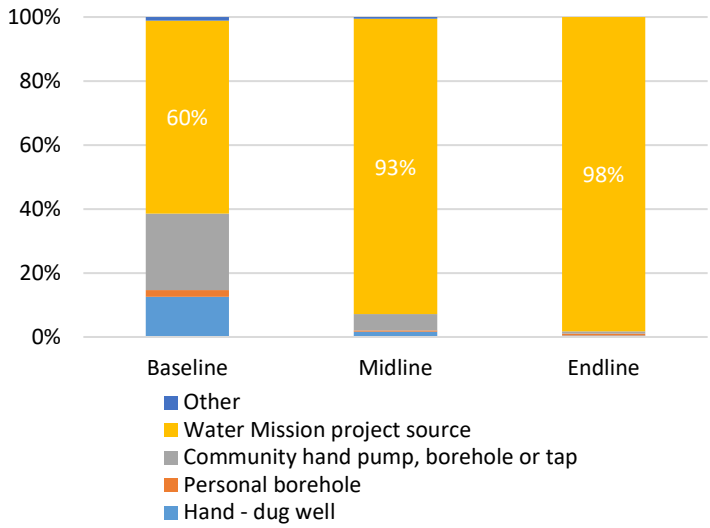

Figure 9: Primary drinking water source distributional differences from baseline to endline

At endline, information was collected on each household in order to assess relative household wealth. This was provided in a composite index score using five wealth quintiles (1=poorest, 5=wealthiest) and comparative national data.[8] This information was then used to understand how household wealth might impact primary water source choices or other relevant variables.

Among the study communities, community source (public borehole, hand pump, or tap) users were exclusively those from Wealth Quintile 2 (Figure 10). This means that poorer people still tended to rely on community-wide sources even after the Water Mission system was installed. However, this population was ~3% of the entire study sample. Those in Wealth Quintile 5 (i.e. the wealthiest) also still tended to rely on personal boreholes and hand-dug wells for their primary drinking water sources. The most important finding to note is that users of the Water Mission system (Water Mission DP) were fairly evenly distributed amongst all wealth quintiles. This indicates that both the poor and wealthy in these communities find the water accessible and affordable.

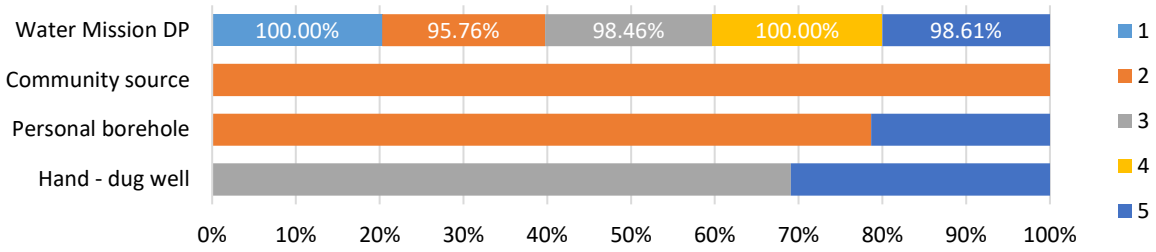

Figure 10: Percent value contributions of wealth quintile score (1 – 5) to primary drinking water source choices

Key Determinants in Primary Drinking Water Source Selection

Phone survey participants were asked to state the reasons they collected from their reported primary drinking water source. "Availability" of the water source, which includes perceived access to adequate quantity, queueing time, and functionality of the water point, remained a primary determinant throughout the field trials. In interviews, improved accessibility of water in Chanhumba was attributed to the rise in more permanent construction and other development within the community. Survey respondents who reported selecting their primary drinking water source based on "Cost" quadrupled from baseline to endline (highlighted below in Figure 11), while the importance of "Quality" tripled. This could be an indication that as people experience a high level of service, their demand for that service increases, as does their willingness to pay.

[8] For more information, see EquityTool http://www.equitytool.org/

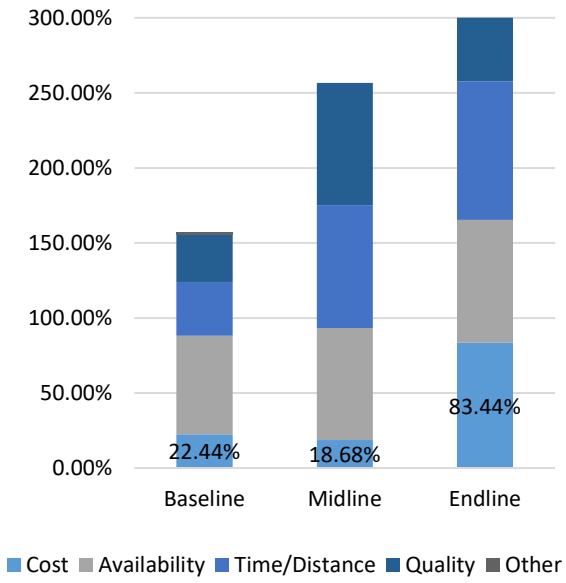

Figure 11: Distributional differences for key determinants in drinking water source selection

Perceptions of Solar Power

At baseline 80% of respondents in Lulembela and 74% of respondents in Chanhumba stated solar would be preferable to diesel for powering the water system. Residents of Gidewari, who already predominantly used solar for lighting in their homes, were overwhelmingly supportive of a solar-powered water system, with 99% stating solar was preferred over diesel. Those who had initially expressed that they believed solar was less reliable than diesel at midline (n=5) indicated this was because it would not be able to function during the rainy season. After a rainy season had passed, one respondent noted: "formally we were worried about the solar system, but we came to [understand] that that was not going to be the problem at all as we are getting water even in the rainy season"

At endline, 100% of respondents indicated solar was either "as good as" or "better than" diesel for powering the water system. Several respondents commented that "solar has reduced the running costs of the project" and that "solar is the best way for us".

Perceptions of Price Fairness

Overall perceptions of the fairness of the price per 20 L container for treated water from the Water Mission system improved from midline (86% indicated the price was fair) to endline (96% indicated the price was fair). However, the average alternate price requested by respondents who stated the price was not fair fell from midline [31 shillings per 20 L container (n=70, 14% of sample)] to endline [16 shillings per 20 L container (n=18, 4% of sample)].[9] As some people became more accepting of the price over the study period, the people who did not agree with the price at endline were those who originally preferred a lower price at baseline.

Mobile Prepayment

Interviewees reported that mobile money in both Chanhumba and Gidewari has allowed for better and more transparent revenue collection, and appears to have reduced tensions between tap operators and customers. At endline, survey respondents in Chanhumba and Gidewari (n=224) were asked a number of questions pertaining to the mobile prepayment and automated water dispenser aspects of the water supply systems in their communities. Recall from above that Chanhumba received Grundfos AQtap smart water dispensers installed and supported by Water Mission, while Gidewari received eWaterpay taps from eWATER, supported directly by eWATER with no oversight from Water Mission.

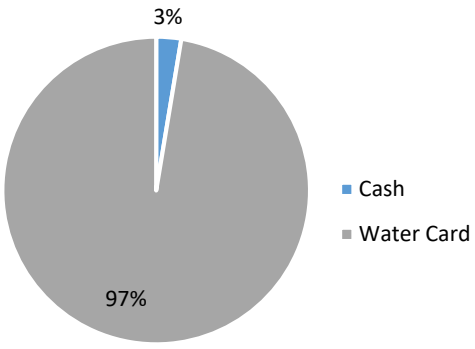

Figure 11: Preferred payment method for water services, Chanhumba & Gidewari combined

When asked which method of payment they preferred for water services, survey respondents overwhelmingly indicated that prepaying via card or tag was their preferred method of choice (Figure 11). When comparing the Grundfos AQtap solution with the eWATER solution, 94% of respondents in Gidewari (n=90) indicated prepaying via watercard was their preferred payment method, while 100% in Chanhumba (n=133) said the same (combined 97% of respondents reportedly favored card/tag) (Figure 11, right).

At endline, 96% of respondents in Chanhumba and 90% of respondents in Gidewari respectively indicated they had water cards for the

[9] Current price of water at all sites is 50 shillings per 20 L container.

automated dispenser system. When asked if they shared these card with other households, 5% of respondents in Chanhumba and 19% of respondents in Gidewari indicated that they did (86% reported sharing the card with just one other household).

For those who reported not having a watercard (7%, n=16), 100% of respondents in Chanhumba attributed this to losing their card, while 80% and 20% of respondents in Gidewari indicated they never received a card or lost their card respectively. Those who reported losing their cards were subsequently asked why they had not replaced them. Responses were equally distributed between "I don't know how to replace the card" and that obtaining a replacement was "too expensive". Of the respondents who reported not having a water card, 78% reported paying the kiosk operator with cash, while the remainder reported sharing a card with another household.

When asked if there had been a time in the past month that the dispenser or prepayment system had prevented them from collecting water, 1% (n=1) of respondents in Chanhumba and 15% (n=14) of respondents in Gidewari indicated that it had. The one (1) respondent in Chanhumba reported that on at least one occasion in the past month the tap was broken; while in Gidewari respondents reported the unavailability of the kiosk agent (50%) and malfunctioning of the tap (29%) were the primary challenges they encountered in using the safe water system (Figure 12).

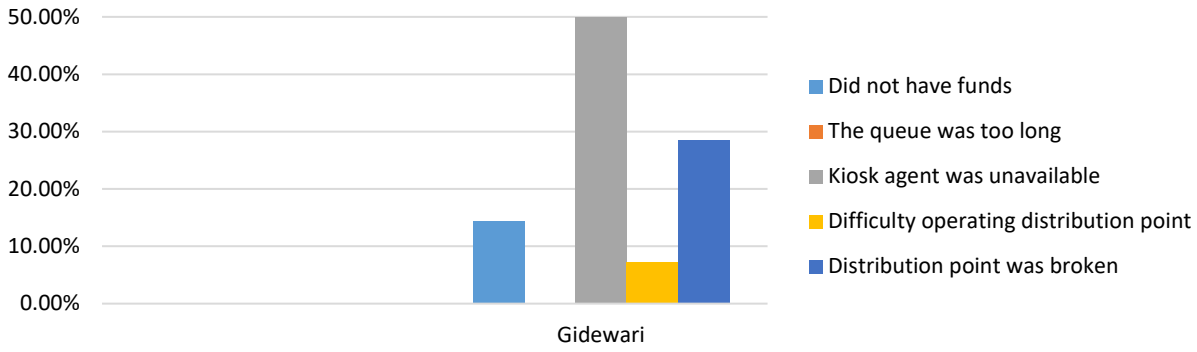

Figure 12: Reported reasons for inability to access water system in the past month

At the end of the survey, respondents were given an opportunity to provide additional comments about the project. Respondents in Chanhumba overwhelmingly commented on the benefits of the mobile money system, stating cash management issues that plagued the water project in the past were now resolved, and previous accessibility issues were resolved as the kiosk was available to consumers without a tap operator needing to be present. One respondent commented: "mobile money is easy to use and it helps us even if you don't have cash … if you have your card credited then it is easy to get water". Respondents in Gidewari made similar reports to the benefit of the prepaid water system, though some reported that the prepayment system was unfair because the tap often malfunctioned, leading water containers to overflow and accounts to be debited more than what the user requested. Others mentioned that if there is no water in the pipes, cards will be debited while only air is dispensed. Despite these challenges, one respondent in Gidewari stated: "the idea of using a prepaid system is the best one, the only problem here is that the card system is not well organised and the water charges are not clear".

Management

Rural water systems are managed by COWSOs (Community Owned Water Supply Organizations) which are responsible for the finances and maintenance of their water supply system with the direct support of the District Water Engineer (DWE) and Ministry of Water (MoW). Baseline focus group discussions and key informant interviews highlighted initial concerns within the community around what was perceived as a lack of training available for the COWSO on the unique water treatment and prepayment technology, and ability of the COWSO to manage such a system long-term. Once the water system was implemented, these technological concerns shifted to infrastructural concerns about the stability of pipes and storage tanks. At endline, reported issues of pipes bursting was a common theme across all sites.

Despite these challenges, perceptions of the effectiveness of the management of the water system by the COWSO improved among survey respondents. Respondents who reported being either "Very happy" or "Happy" with the management of the project and transparency and accountability of the COWSO grew by 30% from midline to endline (highlighted in Figure 13

below). In Chanhumba, respondents commented that there was "good organisation of the project by COWSO" and "good communication with the people".

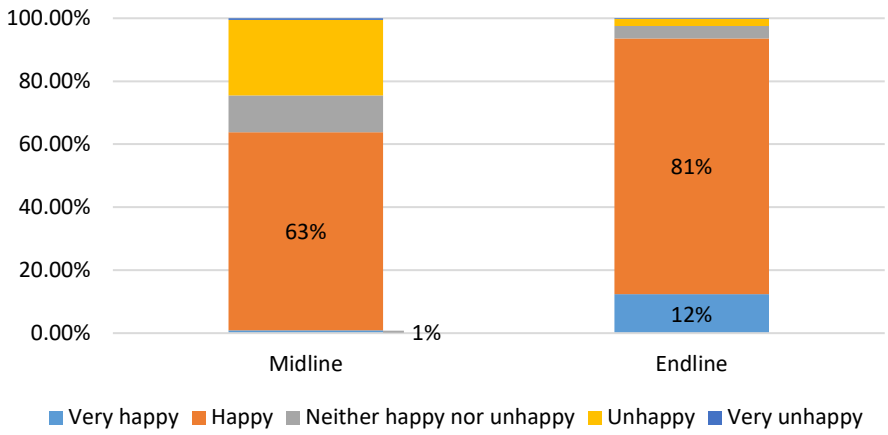

Figure 13: Changes in perceptions of COWSO management

Despite challenges with the prepayment system and reported malfunctioning of smart taps, Gidewari exhibited the largest improvement in perceptions of management from midline to endline, with a 69% increase in those reporting being either "Very happy" or "Happy". In Lulembela, the most requested area of improvement for the management of the water system was for the system to be extended to cover the entire community and reach other neighboring villages.

Water Insecurity Early Warning System Proof of Concept

Since May 2016, Water Mission has been working closely with a team from IBM jSTART in support of a proof of concept of an innovative model for an early warning system (EWS) for water insecurity[10] in rural Tanzania. While extant hydrometerological early warning systems typically utilize climate-related data sources including rainfall, soil moisture, and temperature, this initiative is unique in that it triangulates climate hazard data from virtual weather stations with water consumption data from Grundfos AQTap units and behavioral data from mobile phone surveys. Ultimately, the goal is to better assess water usage behaviors and trends of users in order to increase the understanding of water insecurity in rural, sub-Saharan Africa through predictive modeling.

Questions and Findings

To support a proof of concept for this model, the following questions were asked:

1. What user categories can be generated from water consumption data?
2. Are there associations between water consumption and weather data (min/max temp., evapotranspiration, etc.)?
3. Can we predict behavior of users (individuals or groups?)

These questions are answered in turn below.

User Groups

According to a 2006 World Bank report, "about half of Tanzania's GDP comes from agricultural production (including livestock), the majority of which is rain-fed and highly vulnerable to droughts and floods" (World Bank, 2006), and over 80% of the population in Tanzania derives "their livelihood, income, and employment from the land" (The World Bank Group, 2017). In order to identify potential vulnerable groups in this regard, survey data were subject to rigorous analysis and a user category based on water expenditure was identified. Clusters ranged from A-E, with Cluster A reporting spending the least money on water, and Cluster E reporting spending the most. [11] At endline, those who reported spending the most money on

[10] Water security is defined by the UN as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (United Nations, 2013).

[11] This was in response to the survey question "How many shillings TOTAL did you spend on water, including or animals, in the last 7 days?"

water reported that "cost" was a prohibitive factor in accessing their preferred drinking water source (Figure 14). This cluster also reported the highest number of households who farmed and earned an income from livestock (Figure 15). These findings indicate that those who own livestock spend the most money on water, and can therefore be considered highly vulnerable to water insecurity.

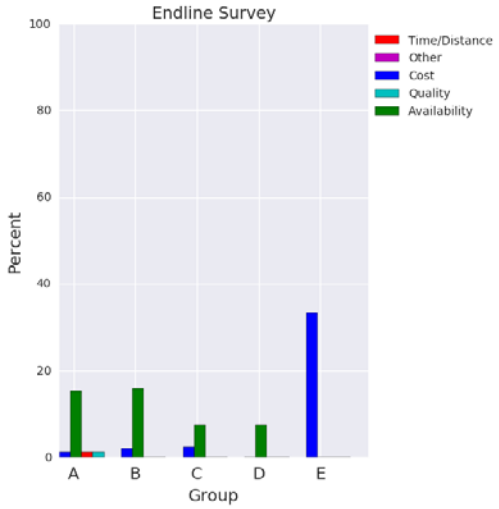

Figure 14: Cluster distribution of key determinants in drinking water source selection

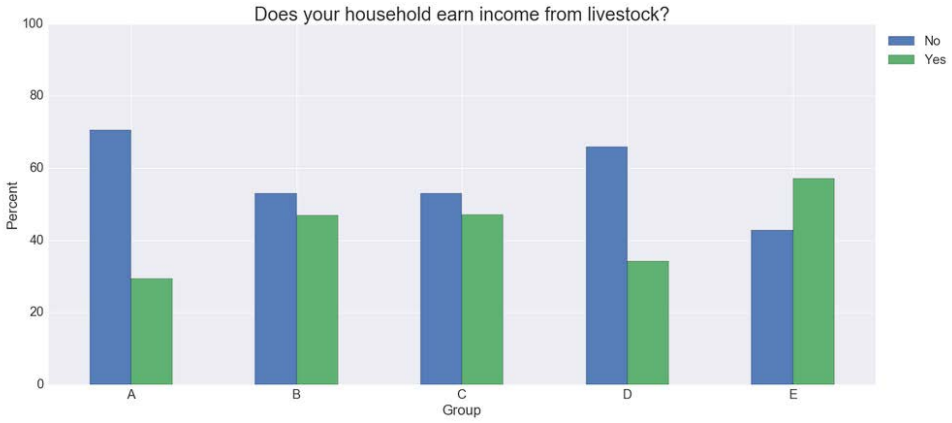

Figure 15: Cluster distribution of households which earn an income from livestock

Weather Data

Using historical weather data and data from Grundfos AQtap units in Uganda (where more longitudinal data was available) rainfall was found to be strongly negatively correlated with water consumption (Correlation coefficient: -0.226590684931), indicating people prefer to use rainwater when it is available as opposed to paying for drinking water.

Predictive Modeling

Again, using data from Grundfos AQtap units in Uganda, IBM jSTART generated a predictive model for weekly expected water consumption. Each weekly set of the input includes ISO week number in year (1-53), maximal and average temperature recorded during the week, rainfall amount for the current week and previous month, water consumption for previous two weeks, number of unique watercards and transactions. The model generated an average error +/- 2104 liters for the last 12 weeks. Figure 16 (left) shows actual data as red dots, predicted water consumption as the blue line, and the light blue area covers predicted value +/- error range. This model proves that water consumption can be predicted using weather data.

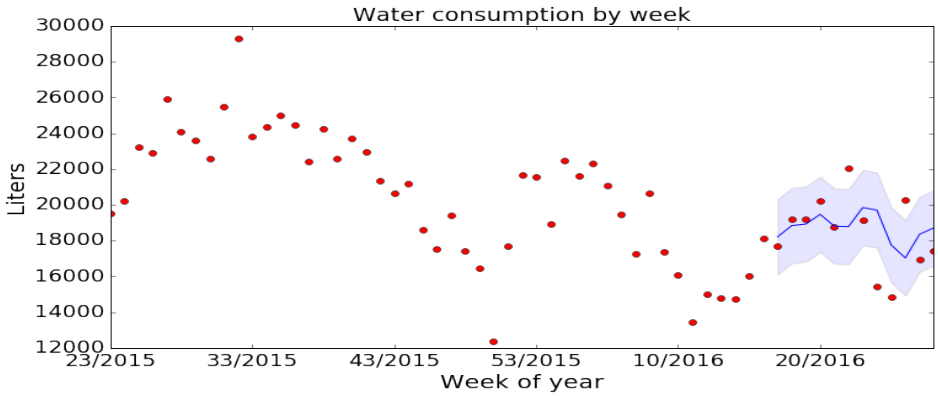

Figure 16: Predicted water consumption by week with error range

Conclusions and Next Steps for EWS Proof of Concept

This proof of concept shows that a predictive model for rural water insecurity can be generated using data from virtual weather stations, water consumption data from smart water dispensers, and mobile phone survey data. Integration of a hydrometeorological early warning system in Tanzania will involve the coordination of a diverse network of stakeholders across multiple sectors, including understanding the capacity of COWSOs and district offices to support such a system. The world-wide Famine Early Warning System Network (FEWS-NET), for example, involves coordination between USAID, USGS, FAO, US

DOA, NASA, and NOAA, and illustrates the need for support from a diverse network of organizations. Due to particular challenges with current data sources, integration of an EWS in Tanzania necessitates investment in real-time climate and hydrology monitoring, institutional data communication processes, and national disaster risk management and response capacity.

A successful early warning system in Tanzania will additionally require significant investment in processes for timely communication of alerts and warnings to relevant stakeholders, including international organizations, national and local governments, and individuals such as farmers and pastoralists. Development of an EWS in Tanzania should support and extend upon current efforts related to a climate-related EWS in Tanzania, including the United Nations Development Programme Climate Information and Early Warning systems project in Tanzania (CI/EWS) (UNDP, 2013), and the Mobile Weather Alert Project (Mobile Weather Alerts for farmers in the Lake Victoria region, 2014).

Conclusions & Recommendations

Conclusions

The field trials of smart water dispensers and prepaid water meters conducted by Water Mission-Tanzania have generated the following conclusions:

- Rural Tanzanians are willing to pay for both a high level of service and water quality.
- Both the poorest and the wealthiest residents of rural communities are able to afford water from the solar-powered water supply system.
- All solar pumping water treatment systems were able to continuously cover ongoing operational costs.
- Initial concerns about the acceptance of solar-powered water supply systems by rural communities proved to be unfounded, and solar power appears to be a viable alternative to diesel.
- Water supply systems which address "availability" of the water service (which includes perceived access to adequate quantity, queueing time, and functionality of the water point) are likely to be more successful, as this is a primary determinant in drinking water source choices for rural households.
- When given the option, consumers overwhelmingly prefer prepaying for water services via watercard to cash payments.
- The cost to both the service provider and users for the physical cards required to prepay for water from smart water dispensers is a point in need of further consideration[12].

Recommendations

These field trials have found that solar-powered water systems equipped with prepaid water meters appear to be a viable solution to systemic water service issues in rural Tanzania. In order for this solution to be scalable, several important programmatic factors must be considered:

- Training and long-term support for treatment system and tap operators, as well as COWSO leadership, will be critical to ensure long-term sustainability.
- Service providers must promote an enabling environment for the COWSO to manage all aspects of the water supply system.
- As seen in Lulembela and Gidewari, communities will likely continuously seek to modify and improve the existing water system in order to meet their changing needs. These modifications should be undertaken with full support of the District Water Engineer's office to ensure a continued high level of water service for all.
- Water supply systems must be integrated into the current water management infrastructure and supported by local, regional, and district-level leadership. This is especially critical for systems utilizing prepaid water meters and their respective cloud-based water management systems.

[12] During the field trials Water Mission-Tanzania incurred a $3.68USD loss for each card issued during the promotional period, and a $0.30USD loss for each card issued thereafter. Attrition of users over the field trials was 32% in Chanhumba and Burudani combined. Both cost, and retention of users, are aspects of water systems including smart water metering technology that will need to be seriously considered before scaling this technology across the rural water sector in Tanzania.

- Availability of materials such as spare parts and chlorine should be considered before implementation.
- Affordability of the prepaid water meter services will be a key determinant in long-term customer retention and project sustainability. Because of this, the following factors should therefore be considered:
    - Durability and affordability of watercards for both customers and the service provider
    - Retention of customers after the promotional period

Limitations

This study was not able to determine several important factors which should be considered when determining the feasibility of scalability of the water supply service model utilized in these field trials. This study only considered the effectiveness of solar-pumping and prepaid water meter systems at the community-level, and did not evaluate the large-scale institutional capacity to finance and carry-out long-term support of the technology. Because Burudani Water Kiosk shared a municipal water meter with three other kiosks, it was not possible to determine the effectiveness of the AQtap smart water dispenser in mitigating water loss in urban Dar Es Salaam. Therefore, it is not possible to comment on the ability of prepaid smart water dispensers to address systemic water service issues in urban contexts in Tanzania. Due to research not continuing in Burudani after baseline, it is also not possible to determine the cause for the downward trend observed in water consumption there. And finally, because the capital expenses of the water supply schemes for these field trials was provided through a grant, it was also not possible to determine the willingness of COWSOs in rural communities to support capital expenses of the project. However, upward trends of increased consumption and use in Chanhumba, along with general positive perceptions of affordability are encouraging evidence to support this.

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