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Why prepaid technologies are not a panacea for inclusive and sustainable rural water services in Tanzania?

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Abstract

Poor sustainability of rural water schemes is a major problem in service delivery in sub-Saharan Africa. About half of the schemes fail one year after commissioning, mostly due to poor operation and maintenance. Many communities fail to collect and manage water revenue. Prepaid technologies are argued to remedy the poor water revenue management. However, it is not clear to what extent prepaid systems can contribute to the sustainability of rural water schemes. This paper assessed the performance of three different cases where prepaid technologies were used in Tanzania. Although the technologies used can simplify water revenue collection, they are not a panacea to deliver sustainable and equitable water services. The capital cost of the prepaid system is often paid for by donors, which is not being recovered, hence the notion of cost recovery is biased here. Also, a strong institutional capacity and knowledge is required alongside the technology. Therefore, the technology which is being promoted as better for improving cost recovery is, instead, causing a burden on water users.

Keywords: Inclusion; Prepaid system; Sustainability; Tanzania; Water innovation

Highlights

- Prepaid system is a techno-deterministic innovation that attempts to construct a new reality for rural water service provision.
- Nevertheless, it is not a panacea, as it cannot solve all the problems of rural water supply.
- The capacity to make effective use of the online data is an important element of the prepaid system.
- Transparency of the business model is a key determinant of the success of technological innovations in rural water service provision.

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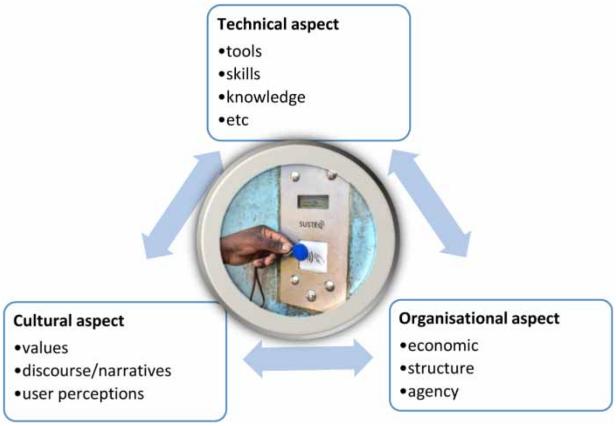
- Prepaid technology is an attempt to mimic a conventional urban utility model, but very few African urban water utilities are performing well.

Graphical Abstract



Introduction

The challenges of sustaining rural water schemes in many sub-Saharan African countries are unique and complex. In Tanzania, after decades of government and donor investments, nearly 50% of the rural population still lack access to improved drinking water (Joseph *et al.*, 2018). The stagnating coverage is partly because 20% of new rural water points fail within one year of commissioning (Joseph *et al.*, 2018). Since the 1980s, the global consensus was that the poor functionality of rural water schemes in many parts of the world can be addressed through community-based management (Kamruzzaman *et al.*, 2013). Tanzania like many other sub-Saharan African countries embraced this concept, and for nearly three decades it has been implementing decentralized rural water management. For instance, the Tanzania National Water Policy of 2002 clearly states that it is the responsibility of communities to operate, maintain and sustain their water supply infrastructure. Tanzania has established over 3,000 Community Owned Water Supply Organizations (COWSOs) to manage newly developed rural water schemes. The national policy also mandates district water engineers (lately called district managers) to support COWSOs with registration, as well as provide them with guidelines on operation and maintenance, monitor and report their progress (Lemmens *et al.*, 2017). More recently, the Water and Sanitation Act of 2019 changed the name of Community Owned Water Supply Organizations to Community Based Water Supply Organizations (CBWSOs). The Act also transformed the responsibilities for rural water and sanitation service delivery with the establishment of the Rural Water and Sanitation Agency (RUWASA) that will be mandated to sustainably plan, design, construct and manage water supply and sanitation services in the rural parts of Tanzania mainland. RUWASA is also responsible for ensuring that CBWSOs are established and have the capacity to manage water and sanitation services in rural areas. RUWASA operate through regional and district managers who are tasked with overseeing the operation of CBWSOs.

However, communities still face challenges and are not able to sustainably manage their water schemes (Hutchings *et al.*, 2017; Whaley & Cleaver, 2017). There is emerging consensus that the high failure of rural water schemes is the outcome of poor local financial and cost recovery management by community organizations (Haysom, 2006; Lockwood & Smits, 2011), lack of spare parts and limited technical capacity to repair broken schemes (Hope, 2015; Klug *et al.*, 2018), as well as weak institutional support mechanism. A study of 19 sub-Saharan African countries found that only 30% of rural households pay for their water (Foster & Hope, 2017). Another large-scale study of rural water points in Kenya found that schemes where users pay as they collect water were more likely to generate significant revenue than those using monthly billing systems (Foster & Hope, 2017). The study also found that water points without clear billing strategy tend to have longer downtimes (average 34.7 days) than pay as you collect schemes (average 12.9 days). Functionality is also reported to vary by type of technologies used (Cronk & Bartram, 2017). For instance, Nira borehole handpumps were found more functional than Afridev and India Mark II handpumps in Tanzania (Cronk & Bartram, 2017). The availability of support services to enable communities to cope with external shocks and stresses are therefore reported as some of the critical factors to achieve sustainability (see also Hutchings *et al.*, 2017).

It was concluded that community management may only be suitable for simple water technologies such as handpumps, protected springs, but technically complex water schemes require innovative models, e.g., private management or hybrid management (Kamruzzaman *et al.*, 2013). Researchers have argued that for rural water service to be sustainable, it requires professionalization of the rural water service provision (Moriarty *et al.*, 2013). The 2019 Tanzania Water Supply and Sanitation Act seems to promote professionalization of the CBWSO. For example, it recommends that a water technician is in charge, and that an account technician is employed to manage the finances.

Alongside the promotion of the professionalization agenda, there is also a push for innovation in water revenue recovery. Currently, innovation in tariff and billing processes, specifically those using mobile payment systems, is argued to overcome the problem of water fee collection in rural schemes (Hope *et al.*, 2011; Ikeda & Liffiton, 2019).

Use of prepaid technologies are not new in the drinking water sector in sub-Saharan Africa. Early versions were first used in the urban water system in South Africa, Uganda, Kenya and Zambia (Von Schnitzler, 2008; Harvey, 2012; Heymans *et al.*, 2014; Hanjahanja & Omuto, 2018). The technology was originally developed for use in the electricity sector in South Africa (Casarin & Nicollier, 2008; Von Schnitzler, 2008). In Kampala, prepaid technology was implemented by the National Water and Sewerage Authority as a pro-poor water services strategy, which according to the utility, led to efficiency in water use and better cost recovery (Berg & Mugisha, 2010).

However, early experience with prepaid technology in the urban water sector was challenging (Heymans *et al.*, 2014), for instance, it reportedly led to protests in South Africa in Johannesburg and Soweto (Von Schnitzler, 2008; Berg & Mugisha, 2010). Some researchers also argue that the technology is being used by water utilities to differentiate water services across urban space and people, particularly the poor (Boakye-Ansah *et al.*, 2019; Guma, 2019). Nevertheless, the technology is lately being primed as the remedy for the sustainability problem in the rural water supply sector. Several developers and service providers have therefore sought to use the mobile money infrastructure and near field communication (NFC) technology to develop new models of the prepaid technologies (Hope *et al.*, 2011; Guma, 2019; Ingram & Memon, 2019). As argued by Guma (2019), these new forms of prepayment network knit together a diversity of actors, e.g., mobile service providers, bankers, water utilities, households, shopkeepers, etc. Many of these actors are driven by profit motivation than supporting sustainable access to safe water in rural areas.

Although the contribution of prepaid systems in improving performance of water schemes may be promising, there is currently limited information on the extent to which it can contribute to sustainable delivery of inclusive rural water services. This paper examines the dynamics engendered by three pilot prepaid water innovation projects in Tanzania. It analyses how the innovation which aims at improving the functionality of rural water schemes is contributing to sustainability of the rural schemes. In the next section, we present the conceptual framework used to analyse the performance of the prepaid systems. The third section presents the material and methods used, while the results section provides findings from the case studies. In the conclusion section, we draw practical lessons to support effective policy responses to these forms of water innovation.

Concepts and framework for analysis of rural water services innovation

The rural water sector can be understood as a highly institutionalized socio-technical regime (Fuenfschilling & Truffer, 2014). In this socio-technical system, the interplay between low-cost technologies for rural water exploitation, actors (governments, NGOs) and local institutions have evolved over time.

To study the performance of the technologies in this context, we conceptualize the innovation as an integration of three aspects: technical, cultural and organizational (for details see Pacey, 1983). Drawing on Pacey (1983), the technical aspect includes the different knowledge, skills, techniques, tools and machines that have been put together to produce the prepaid water meter. For instance, the knowledge, skills and techniques of how to control water and money flows using electric systems, mobile computing and internets of things that have been applied. Under the cultural aspect, goals and values associated with improved revenue, reliability of services and increased functionality are projected. Also, that creative use of modern approaches is seen as a sign of progress and professionalization in the rural water sector. The organizational aspect projects higher economic return on investment and benefits from real-time monitoring of water schemes. This, it is assumed, will translate into timely repairs since money can easily be allocated to fix non-functioning water points; also, that the transparent tariff will lead to higher user satisfaction and increased willingness to pay.

We use the above aspects to distinguish three elements for structuring our analysis, as follows (Figure 1): (1) technology and material elements (technical aspects); (2) water actors' network and revenue management (organizational aspects); and (3) users' perceptions and access levels (cultural aspects). We first analyse what technical and material elements are brought together under the prepaid system. Then we look at how the new networks and organization contribute to revenue managements. Lastly, we assess the user's perception and satisfaction.

To assess how the promoters of prepaid technologies attempt to reconfigure the institutionalized socio-technical regime, the concept of mimicry is used (Fuenfschilling & Truffer, 2016). Mimicry is a process whereby actors connect novelty with the existing institutions to increase the chance of acceptance and adoption (Fuenfschilling & Truffer, 2016). The promoters project values and benefits of using the digital innovation in solving the problem of sustainability through transparent revenue collection, and timely repairs without necessarily changing the existing institutional structures. It is a techno-deterministic process that attempts to construct a new reality for rural water service provision. To understand the

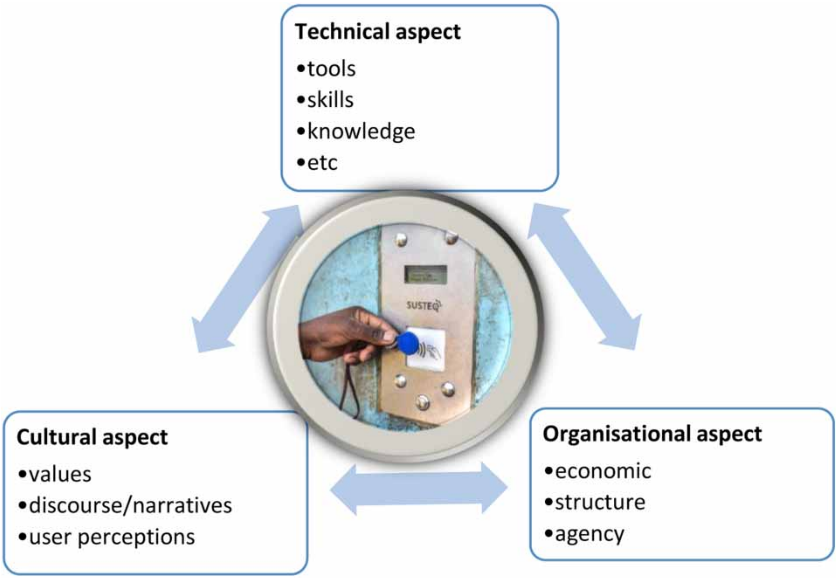


Fig. 1. Prepaid water system as a socio-technical system.

reconfiguration capacity (see Fuenfschilling & Truffer, 2016) of the technology, we study the ownership model and the way it is being promoted and used in the rural water supply setting in Tanzania.

Material and methods

The study was carried out between March and April 2019 in three purposively selected districts of Kishapu (Maganzo ward), Karatu and Babati in Tanzania. These were districts where three different types of prepaid technologies have been in use for over a year (Figure 2). The first two cases, Kishapu and Karatu, are of mixed urban and rural context, while in the third case study, Babait district, the schemes are in two rural villages.

Fig. 2. Photograph of the three prepaid technologies in Kishapu, Babati, Karatu in order from left to right (photographs by Phil Kabuje).

A mix methods approach was used to collect data on the performance of the prepaid water system. Methods used included literature reviews, household questionnaires, semi-structured interviews and field observations (Table 1). Semi-structured interviews and field observation notes were synthesized and included in the narratives of this paper (Table 1).

Table 1. Methods and number of interviews.

Method	Kishapu	Babati	Karatu	Total	Remarks
Questionnaires in Open Data Kit software in android tablets	666	490	629	1,785	Randomly selected households. Structure included demographic information, water use practices, and challenges
Semi-structured interviews (agents, NGOs, users, vendors, local leaders)	39	34	28	101	21 agents, 61 users, 5 NGO staff, 2 local leaders, 6 utility staff, 3 district managers, 3 vendors
Field observations	3	2	1	6	Visiting the water points to observe and informally discuss water collection practices of users

Case study results

In this section, we present findings from the case study districts.

Location 1: Kishapu water supply scheme and prepaid technology

In Kishapu, the water supply scheme was implemented by ICS (International Child Support), a Netherlands-based non-governmental organization, in partnership with the District Council. ICS was responsible for initial operation, while Susteq, a Netherlands-based start-up company supplied and installed the prepaid technology. The project was entirely donor funded and delivered through a newly created water utility, Maganzo Water Supply and Sanitation Authority (MAGAWASA).

Water technology and the material elements. There were no formal drinking water supply schemes in Maganzo town or in the nearby villages before this scheme. The system receives treated water from Lake Victoria supplied by Kahama Shinyanga Water Supply and Sewerage Authority (KASHWASA). The water is stored in two overhead tanks (capacities 135 and 80 m^3) and then distributed by gravity to 25 public kiosks in Maganzo town and Masagala village to about 28,000 people. The water demand is estimated at 120,000 litres per day during rainy seasons and 215,000 litres per day in dry seasons, respectively.

The 25 public kiosks are all fitted with the Susteq prepaid technology. The technology consists of a water dispenser (kiosk), shop-hub, water-tags, mobile money transfer application interface (API) and an online dashboard for system monitoring. The dispensing system has a memory card for data storage, wireless GSM/GPRS network with SIM (subscriber identification module) card, radio frequency identification (RFID) communication system, antenna and a solar panel. Users can collect water by taping their tags on the kiosk. The shop-hub, which is used as water credit sale point, is operated by local shopkeepers (agents or Wakala in Swahili), and it has the same technical specification as the water-hub. The agents were selected by the street chairmen and contracted to sell water credits. The agents transmit collected funds to the water utility. Water credits can also be purchased through mobile-money platform, but this was not yet activated. For the system to work correctly, the water-hub and shop-hub need to have mobile talk time credit for sending and/or receiving critical updates or alert messages to/from either the system administrator or agents.

Water actors' network and revenue management. The water network includes MAGAWASA (water utility), agents, mobile phone operators (Vodacom), water users, water vendors, Susteq, KASHWASA, ICS, the Energy and Water Utilities Regulatory Authority (EWURA), RUWASA district manager and Kishapu district council. KASHWASA is the bulk water supplier of the utility. The water utility uses the prepaid technology to improve its water revenue collection and operation and maintenance. The utility's field technician is responsible for monitoring of the infrastructure and conducting minor repairs. There is also a manager responsible for managing the accounts and sending water credits to the local agents. The utility team were trained by ICS and Susteq on how to manage and fix the prepaid system. At the end of implementation, ICS handed over the water scheme to the Kishapu district council and ceased contact with the utility. However, Susteq still provides system updates, or repairs whenever there is a breakdown (e.g., when the kiosk fails to dispense water).

The process of water and money flow between different actors is as follows. The water tariff was set by EWURA, the agency responsible for setting water tariffs in urban towns. According to EWURA, water tariff of USD0.015 per 20 litres is enough for cost recovery of the project (USD1 dollar is approximately 2,300 Tanzanian shillings (TZS)). However, this price is still high, USD0.75 per cubic metre[1], and water is collected at the distribution point. Also, the process of setting the tariff was a bit of a struggle. Although the households were willing to pay more for a reliable water service, the tariff setting turned political. ICS proposed USD0.022 for 20 litres and used demonstration taps to test households' willingness to pay. According to the ICS field team, the fee could allow for recovery of capital and operational costs. However, local leaders were not happy with the tariff and wanted a much lower price. Such protracted negotiation epitomizes the political nature of the water tariffs; it is not only the problem of revenue collection that is important but also the local socio-political dimension of service provision.

Susteq is responsible for the technology updates and maintenance of the online system, while KASHWASA supplies treated bulk water at USD0.25 per m^3 to the utility. The average bulk water cost is USD1,186 per month (range USD484–1,893 per month). Ten agents located near the kiosks are each allocated water credits worth USD65.2 to sell to users. The agents transfer collected funds using mobile money to the water utility account and receive 5% (USD3.3) commission. Once the transfer is confirmed, a new batch of water credits is transferred to the agents. The utility pays the mobile money service provider (M-Pesa) USD326.1 per month, which is about 28% of bulk water cost. The transactions can be monitored through the online revenue management dashboard. Presently, about 51% of the external costs are for telecom and commissions not bulk water[2] (Table 2).

Users' perceptions and access to water services. The water users are satisfied with the tariff, while shopkeepers also welcomed the additional income to their businesses. About 88% of the 666 households

[1] For comparison, tariff for in-house connection with consumption above 15 m^3 is USD0.77 per m^3 in Arusha city.
[2] Excluding utility operation and maintenance costs.

Table 2. Cost estimates of installing and operating Susteq technology.

Costs centre	Frequency	Costs (USD or %)
CAPEX (Unit cost of hardware and associated accessories-tags/card, battery, solar panel, etc.)	One-off	1,500
Costs of training and installation of one unit of prepaid system	One-off	included in CAPEX
Financial transaction fees (mobile money transactions)	Monthly	USD326.1 per month
Agents fee (commissions)	On sale	5% of water credits sold
Hosting (covers the infrastructure required to host the meter on the platform)	Monthly	None
Software licence, data, and hosting fees	Various model	None

surveyed reported that the kiosks provide sufficient quantity of water and 69% stated that it is available at the kiosk 24 hours a day (Table 3). The distance to collect water also reduced from over 6–8 kilometres to less than 1 kilometre. About 45% (301/666) of the households used to fetch water from sources located more than 1 kilometre from their dwellings, while 42% (282/666) used to spend more than 1 hour to make the round trip. A significant number, about 36% (236/666), used to buy from vendors. Water access has improved after the project; 30% (203/666) are within 50–200 m of a kiosk and only 11% (70/666) still go more than 1 kilometre to fetch water. Round trip time reduced to less than 15 minutes for about 54% (423/666) of the households surveyed. However, most households, 70% (464/663), reported frequent queuing at the kiosks. Only 1% (5/439) of the households have not yet queued, while some 67% (296/439) queued some days of the week. The prepaid system has not eliminated the problem of queues, but water is available for about 24 hours per day.

Before the project, households would buy water at USD0.22–0.44 per 20 litres from vendors. Vendors are now only serving households and offices willing to pay someone else to collect their water.

Table 3. Households' access to water and satisfaction.

Distance to main water source	($n = 666$)	Per cent
Within 50 m	172	26
Between 50 and 200 m	203	30
More than 200 m but within 500 m	145	22
More than 500 m but within 1 km	72	11
More than 1 km	70	11
Household water access		
Using prepaid	621	93
Buy from vendors	8	1
Other water	37	6
Household satisfaction with prepaid system		
Very dissatisfied	15	2
Not satisfied	22	3
Neutral	45	7
Satisfied	317	48
Very satisfied	267	40

The project has not only reduced by half the price of water sold by vendors, it is also very convenient for the vendors, as stated by one vendor stated in Maganzo town:

> '*I am selling 20 litres at 200 Tanzanian Shillings but if someone gives me his/her card I charge 100 Tanzanian Shillings. There are guest houses, hotels and busy people who require someone to collect their water. Every day I take 125 buckets (250 litres) to 5 households and fill the water tank of a bank nearby at 10,000 Tanzanian Shillings. Before the project, I was collecting water at Mwadui some 3 km from town for free and selling it at 400 Tanzanian Shillings. Although I now get less profit because most households have cards and can collect water from nearby kiosks, the new system also reduced my distance to the water source.*'

There is no lifeline provided for the poorest households to access water from the prepaid kiosk; 79% (525/666) of the households stated that everyone pays with the card. As a result, about 33% (121/367) of the households use alternative sources, e.g., (un-)protected dug well. Some claim that alternative water sources are mostly used for washing clothes while water from the kiosk is used for cooking and drinking. The current mode of exclusion arises from the cost of buying the water tags, which were initially given for free but are now being sold at about USD3.9. The high price could mean that those not able to pay will resort to using other water sources, including buying from vendors.

Since there were no water schemes in the area, the high level of users' satisfaction is not directly linked to the prepaid technology. The tariff is transparent, and the collected money is being deposited in the utility bank account. However, the usage of revenue is difficult to verify outside paying for bulk water, hosting and telecom fees, agents' commissions, minor repairs and staff salaries. Concerning the utility breaking even, the entire financial records were not available for our analysis. We obtained the financial summary for the year 2018 and noticed that there is a mismatch between the utility's record and the online database. The online database indicates that the revenue for 2018 was about 96 million TZS (about USD42,000) but it is only about 56 million TZS (about USD24,000) in the utility record. We compared money transferred by the local agents in the month of October 2018 with the online records and noticed that the former was greater by about 1.3 million TZS (about USD565). The difference between the agents and system generated figures may be attributed to the fact that not all credits were used to collect water by the end of October and there may also be some carryovers from the past months. A careful analysis of the data generated (i.e., water usage, mobile money transaction, and virtual water credits created and sold) is therefore required. However, the utility currently does not have the competencies needed to complete such critical analysis of the generated data. The manager states that for them to effectively operate the prepaid system and make better use of the data, proper training and continuous support is required. In her statement: '*We have ten kiosks but currently only seven are working, the main problem is how to fix them, it needs more expertise*'.

The frequency of the prepaid technology breakdown has also increased. In February 2019, two kiosks were closed, and the technician stated that the kiosks were dispensing 40 litres instead of 20 litres due to control valve failure. Also, that sometimes the usage data are lost from the memory cards or the mobile internet data vanish hindering data transmission to the online database. In addition, the long spare parts supply chain (e.g., flow meter and control valves are currently sourced from the Netherlands) is still a problem. In April 2019, a local company, Merry Water Limited, agreed to start stocking spares for the technology in Tanzania.

Although MAGAWASSA has full access to the online dashboard, all data are stored in the server of Susteq in the Netherlands, which raises another question of ownership of water data: is it the technology developer or the utility? Susteq indicated that it is working towards establishing a local data centre in the country. So far, MAGAWASSA has shifted its attention towards increasing the share of in-house water connections which is more attractive financially. In February 2019, there were already 122 house connections and in August 2019 this had increased to about 300 connections. More so, this is being driven by the fact that Maganzo is quickly transforming from a rural settlement to a small town. The increased attention on households' connections could mean that the utility will soon limit their efforts in maintaining the prepaid kiosks or even abandon them altogether.

Location 2: Karatu water supply scheme and prepaid technology

Karatu water project was implemented by Catholic Relief Services a non-government organization in partnership with Diocese of Mbulu Development Department, Grundfos, and two CBWSOs: Karatu Village Water Supply (KAVIWASU) and Endamarariek – Endabash Water Supply (ENDAWASU). Two water schemes were constructed, one in Karatu town (operated by KAVIWASU) and the other in Qaru village (operated by ENDAWASU).

Water technology and the material elements. Karatu water scheme comprises two deep boreholes fitted with solar pumping systems, elevated storage tanks, transmission and distribution networks, and water kiosks (water ATMs). There are also some household connections in the urban areas. In both the urban and rural water schemes, groundwater is pumped to elevated storage reservoirs and then supplied to users through 20 distribution points. A small storage tank is provided as backup supply at all distribution points. The borehole in ENDAWASU scheme supplies water to ten distribution points, while there are ten kiosks in Karatu town. Five kiosks in town are connected to the groundwater source while the remaining five are connected to KAVIWASU's old water scheme drawing water from a nearby river.

The prepaid system consists of Grundfos AQTap water dispensing unit, smartcards for storing water credit, online water management system (WMS) and solar powered water kiosk. The AQTap accepts smart cards that are either pre-loaded with water credits to dispense water to consumers. It is also used by the administrator to login to the machine to carry out repair works. It is also used for water credit management, e.g., moving credits from one card to another or checking the balance. Water credits can also be purchased using mobile money transfer and then activated at the AQtap or transferred directly to users by the vendors at the kiosks. Vendors (appointed local agents) have cards that can be preloaded with water credits by the system administrator or transferred onsite at the kiosk. The operation is structured in a way that the administrators can send water credits to vendors who, in turn, sell it to users at the kiosks. Vendors receive cash from the user and then transmit it to the administrator to be deposited in the CBWSO bank account. The fact that it is possible to transfer water credit from one user's card to another or from a vendor's card to a user or system administrator to a vendor's card simplifies water sales and revenue collection.

At every kiosk there are vendors selling and activating users' water cards, and operating the kiosks, e.g., opening for water users. Opening hours are dependent on a vendor's availability at the kiosk, so water may not be available 24 hours per day, which is a disadvantage of the setup. In some cases, households informally agree with the vendors on the opening hours. In Karatu town, most vendors open their kiosks from 06:00 am to 09:00 pm. However, during rainy seasons, some kiosks remain closed for most parts of the day. In the village areas, kiosks are also closed most of the time because of the low number of users compared to the urban areas.

Water actors' network and revenue management. The Karatu system functions through a network comprising the system administrator (utility or CBWSO), vendors (water ATM caretakers), users, CRS and service technicians. Although Grundfos supplied the technology it is not directly involved. Ril Solution Limited, a local company, was contracted to deal with the system technical repair. The CBWSOs are responsible for creating water credits and initialization of the water, while vendors are responsible for selling credits to users.

The Karatu project was implemented in an existing CBWSO, and during implementation, CRS worked with the utility and the district authority. Karatu District Manager is responsible for supervision of the operation of the CBWSOs.

Regarding revenue, both KAVIWASU and ENDAWASU receive 70% of the water revenue and pay the staff responsible for system administrator. The vendors receive 30% of water revenue from their kiosks (Table 4). The water vendors seem to benefit more from this arrangement. According to CRS, when the mobile money becomes operational, the transaction costs will be reduced to about 3.5% of the revenue generated from the kiosks.

Users' perceptions and access to water services. We interviewed 629 households in Karatu; 37% were collecting water from the prepaid kiosks (Table 5), 20% buy from vendors and 27% had in-house or yard tap connections. In addition, about 16% are using other water sources (rivers, dug wells, etc.). Households using prepaid kiosks are satisfied with the technology, and only 4.7% of the 231 households were not satisfied. In addition, 90% of the households (208/231) believe that the money collected will be used to pay for maintenance of the water systems.

Households still queue at the prepaid water kiosk; 44% stated that they often queue while about 30% queue daily and 49% queue some days of the week. On average, it takes 35 minutes to make a round trip to collect water. There is also no lifeline water provided; it is assumed that vulnerable households can access service from vendors. The vendors are allocated 60 litres per month for cleaning the kiosk, and it is this water that is believed can be given to vulnerable groups. Most households, 71% (326/457), stated that everyone can afford the price of water at the prepaid system. However, 18% (131/457) stated that the poorest household may not afford it.

Table 4. Cost estimates of installing and operating Karatu Grundfos technology.

Costs centre	Pay frequency	Costs (USD or %)
CAPEX (unit cost of hardware and associated accessories-tags/card, battery, solar panel, etc.)	One-off	3,000
Costs of training and installation of one unit of prepaid system	One-off	Included in CAPEX
Agents fees (commissions)	On sale	30% of water credits sold
Financial transaction fees (mobile money transactions)	Monthly	Not in use
Hosting (covers the infrastructure required to host the meter on the platform)	Monthly	None
Software licence, data, and hosting fees	Various model	None

Table 5. Households' access to water and satisfaction.

Distance to household's main source[a]	**($n = 388$)**	%
Within 50 m	94	24
Between 50 and 200 m	87	22
More than 200 m but within 500 m	105	27
More than 500 m but within 1 km	63	16
More than 1 km	39	10
Household water access	**($n = 629$)**	%
In-house connection	172	27
Using prepaid	231	37
Buy from vendors	125	20
Other water	101	16
Household satisfaction with prepaid system	**($n = 231$)**	%
Very dissatisfied	1	0.4
Not satisfied	10	4.3
Neutral	12	5.2
Satisfied	128	55.4%
Very satisfied	80	34.6

[a]Only households not having house connection or buying from vendors.

About 26% (60/230) use the prepaid system because they perceived the water to be of good quality, while 20% (46/230) reported that availability is their most important criterion for selecting the water their household uses for drinking and cooking. Before the project, vendors had developed lucrative businesses of selling water to households. The following statement from one of the vendors at the water kiosk highlights the positive changes:

> '*Two years ago, I was buying 20 litres of water at USD0.022 and selling it at USD0.11–0.13 but after the installation of these technology and improvement in water supply my profit has decreased. There was only one water point in the community, I could sell about 150 buckets per day, making up to USD13.0 per day. Nowadays I only supply households who are reluctant to come to fetch water at the kiosk, and I charge them USD0.087 for 20 litres. I use my card to fetch water with my card from the kiosk at USD0.011 per 20 litres, making a difference of USD0.076. These households, especially the working class, were used to buying water at USD0.13, so my new price is considered cheaper now. There are also who households sends me to fetch water using their smartcards, depending on the distance from the kiosk to the household, I charge them USD0.043–0.065 for 20 litres.*'

However, not all vendors are happy with the commission from sales of water credit, with some claiming that they are made to wake up early every day to open the kiosks for the households to fetch water. One vendor said: '*I cannot even participate in any of my other activities*.' Another vendor decided to increase the price of water credit to get more money, but CRS was able to control price tampering. Although the use of mobile money can prevent malpractices, it is impossible to eliminate completely such practices, especially in remote areas without a mobile money service.

Location 3: prepaid system and water schemes in Babati district

The third type of prepaid technology, namely, eWaterpay, was installed in two existing water schemes in Endanachan and Gidewari villages in Babati district. The water supply scheme in Endanachan village was constructed by WaterAid in 2016. The system comprises a 78 m deep borehole installed with a solar pumping unit, a water storage tank (50 m^3), a 8.3 km distribution network and 13 water distribution points. The investment cost for the project is estimated at about 290 million TZS (USD126,000).

Gidewari village water scheme was constructed around 2014–2015 and funded by Water Mission and WaterAid. Water is pumped from a spring at a rate of 6.5 m^3 per hour and transmitted to two 45 m^3 storage tanks. The water pump can either be powered by a standby generator or a solar power system. Water from the tanks flows by gravity to ten distribution points located on a 14 km long distribution network. The schemes are managed by CBWSOs who are supported by RUWASA's District Manager.

Water technology and the material elements. In 2017, eWater, a UK-based company, entered into agreement with the two CBWSOs and Babati district council to install its prepaid technology in all the 23 water distribution points of Endanachan and Gidewari. The technology uses the same principles as the ones implemented in Maganzo ward and Karatu district. It also combines mobile money, NFC contactless pay system, and the internet of things. The system comprises NFC-enabled magnetic tag (water card), tap dispenser powered by solar, online database and eWatercare platform. The water cards were initially given for free but at the time of the study new users were buying them at USD0.22. Water credits can be purchased through mobile money or direct transfer by registered water seller (wakalas) using smartphone app and NFC transfer mechanism. To fetch water, users place their card on the dispenser, remove it when the container is full, and their card is charged for the number of litres dispensed. The eWater taps are not installed inside a kiosk making it accessible throughout the day. eWatercare which is an online asset management system is used for live monitoring of all the water taps. Using eWatercare, the operator can detect a fault in the system and make repair plans.

At the time of the study, 12 out of the 23 eWater taps were not functional. The eWater manager stated that the system was being affected by the poor design of the water infrastructure. He stated that in Gidewari, the scheme requires frequent pumping because of low pressure in some parts of the scheme's network. He also stated that the solar battery installed by eWater appeared to fail just six months from the date of manufacturing. Due to the frequent battery failure, water availability at the taps is about 18 hours per day.

Water actors' network and revenue management. eWater offers two type of business model for its prepaid technology: (1) the private operator model and (2) the essential model. The private operator model is where the company installs its taps, operates and maintains the water supply scheme as an independent private operator as per agreement with the client (CBWSO or a utility). Only the essential model was implemented in Tanzania. Under the essential package, the company sells its prepaid taps, software and trains the utilities how to use it. The cost for the taps can either be paid upfront or through a loan repayment (Table 6). Also, under the essential model, the company charge about 8% of the water sales for data hosting and mobile money fees.

Table 6. Cost estimates of installing and operating eWater technology.

Costs centre	Frequency	Costs (USD or %)
CAPEX (Unit cost of hardware and associated accessories-tags/card, battery, solar panel, installation, training, etc.)	One-off	3,200
Costs of training and installation of one unit of prepaid system	One-off	Included in CAPEX
Agent's commission fees	On credit sale	5% of water credits sold
Financial transaction fees (mobile money transactions)	Monthly	3% total revenue collection
Hosting (covers the infrastructure required to host the meter on the platform)	Monthly	5% of the total revenue collection
Software licence, data, and hosting fees (starting two years after the project ends)	Monthly	USD13 per tap

Basically, every month, eWater takes 5% for the infrastructure required to host the meter on its platform and 3% for financial transaction cost, respectively. At the time of research, eWater was not yet charging data and hosting fee because the project was donor funded. However, after two years, the company is expecting to start charging 10 GBP (about USD13.0) per tap per month for data and licensing fee.

In the eWater system, water revenue is first deposited into the company account and only transferred to the utility after eWater has taken its share. This setting of revenue flow was initially contested by the CBWSOs.

The eWater business model transfers the responsibility of revenue management from the CBWSOs to the private company. However, the financial risk remains with the CBWSOs; eWater does not take responsibility for low sales of water. The model also does not strengthen the capacity of CBWSOs to directly collect and manage their own water revenue. The only change is the way revenue is collected from users and an additional surcharge on the water utility.

Users' perceptions and access to water services. The eWater case also has no provision for lifeline water. The agents are allocated water credit of USD0.22 per month for cleaning the distribution points, which is assumed can be accessed by vulnerable members of the community.

In Endanachan village, two elderly persons are being allocated water credit of USD0.22 per person per month. However, eWater says it is the responsibility of CBWSOs to determine the number and names of vulnerable households. Not everyone is collecting water from the prepaid taps, some of the households have resorted to using shallow wells, hand pumps and river water. Some public schools and hospitals are relying on nearby agents to get water through informal loan arrangement. One agent stated, '*I often use my card to provide water to a nearby secondary school and collect a check at the end of the month*.' About 64% of the 490 households surveyed fetch water from the scheme, while 36% rely on other water sources. The reason for not using prepaid water varies, but only 7% stated the water is expensive. The 77% either have dug wells or there are no nearby prepaid taps.

Before the water scheme, 29% of the households spent more than 1 hour collecting water and after the project, 55% spent less than 15 minutes at the water tap. Collection time therefore decreased after the water project. However, less than 50% of households are satisfied with the prepaid system. The low level of satisfaction could be attributed to the fact that over 91% (446/490) of the households used to get their water for free, and only 7% (36/490) paid cash per collection. Finally, the agents are not happy with the 5% commission they are receiving, and agents have complained about lending their tags to households without money. One agent stated: '*the 5% is nothing since we use nearly the same amount of money to buy voucher for internet connection*.'

Discussion

Although the prepaid technologies are now presented as a radical shift in rural water sector revenue management, this type of innovation still comprises old models of service delivery. It can therefore be classified as an incremental technological and organizational change (see Wehn & Montalvo, 2018). All the projects presented coupled conventional technical aspects of water supply engineering knowledge and tools (e.g., deep groundwater, pumps, storage, gravity transmission, distribution points) with new elements (e.g., automated water dispensers, solar energy for water pumping, NFC tags, mobile phones and online management system). Karatu water project combined old and new water schemes, and the Babati and Maganzo schemes are new water infrastructures. The schemes have improved access to water in previously underserved rural areas. In all the cases, the cultural elements have, to some extent, been demonstrated. Users have expressed high levels of satisfaction with their schemes. The prepaid technology allows a transparent revenue collection process, but from an organizational aspect it is an expensive investment. The non-water costs (kiosks, telecom, commission costs hardware, e-valves, etc.) are quite high and yet with a shorter lifespan compared to water infrastructure.

The technologies cost about 7–9% of the project capital investment costs. There are also other hidden costs (e.g., hardware and software upgrade, maintenance, transaction, installation, training, etc.) making it expensive for large-scale rural deployment. A typical Tanzania rural village has on average ten water points, and assuming an average unit cost of a prepaid meter is USD2,000, it will cost up to USD20,000 to install ten meters in a single village. Currently, most CBWSOs struggle to raise revenue through user charges, so only a handful may be able to afford these costs. The technologies can hardly be scaled up by communities themselves unless there is donor funding or an alternative innovative financing model is put in place. This poses a serious challenge of replacement once the hardware needs to be changed.

The prepaid technology attempts to mimic the conventional urban utility model (see also Hutchings *et al*., 2017). Through adoption of innovative water billing, bookkeeping and data management, the technology also enabled professionalization of the community management. Financial transaction is now mediated by a mobile money platform, and the community organization can call upon the support of the developers in the case of breakdown. Its potential in facilitating reliable financial and information flow is primed as one of the benefits of prepaid technologies (Koehler *et al*., 2015). However, all our cases are not acting as a reliable, transparent and secure conduit for information and financial flow; it is still difficult to track funds flow and use.

Nevertheless, the technology creates new material, social and technological relations in the rural water sector (Schmidt, 2020). As conceptualized by Schmidt (2020), the cases depict an arena whereby telephone providers, vendors, community organizations and prepaid technology developers form a relational network that transmits water and money using non-water infrastructures (cloud computing, internet of things, etc.). The network even though primed as efficient by the promoters, introduces new costs and overheads in the forms of licensing, data hosting and service fees to the poor rural households.

The technology is, therefore, not a panacea, as there are still sustainability challenges that the prepaid technologies are not able to adequately solve. First, there is high frequency of breakdowns of the prepaid technologies and water schemes. All the study cases reported frequent filter clogging, control valve failure, kiosk dispensing more water, etc. which increases the burden on users. A Karatu town user stated: '*when there is no water at the kiosk, we are forced to buy expensive water from vendors who are selling at USD0.087–0.11*.' Although most of these breakdowns can be resolved locally, major breakdowns of the prepaid components still involve long supply chains, and they require the technology developer's intervention. For instance, when the control valves in Maganzo scheme are broken, Susteq from the Netherlands must be involved in fixing them.

Second, the organizational model of the prepaid technology is also not entirely transparent and in the interest of the water utilities. At times, the distinction between the developer and the private operator get blurred on all aspects of the prepaid systems (e.g., data ownership, technical support, supplier, customers, consumers, etc.). For instance, eWater is taking the role of the technology developer, the supplier and/or the private operator. The ambiguity in the business model whereby the technology developer also becomes the operator may not only be a source of mistrust among the parties but also increases the costs of service delivery. Transparency is thus a key determinant of the success of technological innovations in rural water service provision. A study of perceptions of users towards water prepayment in Tanzania concluded it leads to disenfranchisement of vulnerable populations, and also presents technical difficulties to some users (Sherry *et al*., 2017).

Third, prepaid technology does not mean the socio-political struggles over water service provision are eliminated altogether. In the words of one of the project engineers:

> '*at the beginning, I focused on design of the water supply infrastructure, contracting and supervision of the civil works. I didn't think much about the social aspect of the project. I only realised that it is equally important when local leaders started complaining. Some leaders wanted to be the ones to launch the project, while others wanted to lower the water tariff*.'

Finally, although the goal of the prepaid technology is to reduce non-revenue water and improve on the management of the collected money, fund management remains a challenge. It is not clear how the collected money is being used beyond paying for operation and maintenance. There is no proper financial reconciliation being done. The utilities also lack the capacity to make effective use of the online database, e.g., to critically evaluate the performance of different kiosks. As a result, improved revenue collection is not being translated into better planning for the scheme operation.

Conclusions

This paper analysed the performance of the prepaid technologies installed in Tanzania, studied their business models, costs and the way they are being promoted and used in the rural setting of Tanzania. The cases discussed provided evidence that prepaid systems alone cannot sustain rural water supply schemes. The prepaid technologies are being promoted as transparent and simple means for water revenue management. The central argument is that any user with a card can collect water with minimum guidance and support. Also, that it connects existing institutions with new digital technologies, thereby projecting an innovative way of solving the sustainability problems of rural water service delivery. As the paper has analysed, prepaid system is a techno-deterministic innovation that attempts to construct a new reality for rural water service provision. The promoters of the technology project a view of radical innovation through mimicry of conventional urban utility mode of billing, bookkeeping and data analytics. The promoters also attempt to connect digital novelty with the existing water institutions as a way to increase its chance of acceptance and adoption in the rural water sector.

Nevertheless, it is not a panacea, and cannot solve all the problems of rural water supply. In spite of many earlier findings, it could be that some people have the illusion that a technical artefact such as prepaid technologies could solve the operational and sustainability problem of rural water supplies. Our study clearly shows that this is not the case, although prepaid devices seem to have several advantages. Its contribution to the overall performance of the three cases is difficult to disaggregate as all the schemes were newly constructed. Also, the current focus on the technical aspect of the prepaid kiosk, tags, pipes, etc., means that insufficient innovation is being made on the management model and user data ownership. Long-term sustainability of a rural water scheme will strongly depend on the business model adopted and the capacity of the utility to make sense of the data being generated and plan for future service extension. Presently, none of the utilities or CBWSOs can make such long-term plans. There is also still the age-old challenge of long and complicated supply chain of spare parts. Finally, the prepaid technology is just one aspect of the rural water service provision, and the communities will still need to be externally supported to sustainably manage their schemes.

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Data availability statement

All relevant data are included in the paper or its Supplementary Information.

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