Circuit Rider post-construction support: improvements in domestic water quality and system sustainability in El Salvador

Georgia L. Kayser, William Moomaw, Jose Miguel Orellana Portillo and Jeffrey K. Griffiths

ABSTRACT

Small piped water supply systems are often unable to provide reliable, microbiologically safe, and sustainable service over time, and this has direct impacts on public health. Circuit Rider (CR) post-construction support (PCS) addresses this through the provision of technical, financial, and operational assistance to these systems. CRPCS operates in low and high-income countries; yet, no rigorous studies of CRPCS exist. We measured the impact of CRPCS on 'water quality' and 'sustainability' indicators (technical and administrative capacity, and water supply protection) in El Salvador. In this field-based study, a case-control design was utilized in 60 randomly selected case (28 CR) and comparable control (32 noCR) communities. Microbiological water quality tests and pre-tested structured key-informant interviews were conducted. The operational costs of CRPCS were also assessed. Data were compared using parametric and non-parametric statistical methods. We found communities with CRPCS had significantly lower microbiological water contamination, better disinfection rates, higher water fee payment rates, greater transparency (measured by auditable banking records), greater rates of household metering, and higher spending for repairs and water treatment than comparable control communities. CRPCS is also a low-cost (<$1 per household/year in El Salvador) drinking water intervention.

Key words | Circuit Rider, El Salvador, post-construction support, sustainability, water quality, water supply

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INTRODUCTION

Small community-run drinking water systems (DWSs) frequently cannot provide reliable, microbiologically safe, and sustainable water service over time (Ford 1999; Lee & Schwab 2005; Moe & Rheingans 2006). Aging infrastructure, intermittent service, inadequate water treatment and water quality monitoring, insufficient maintenance, and poor financial management are common (Cotruvo *et al.* 1999; Craun & Calderon 2001; Rizak & Hrudey 2008; Bain *et al.* 2012). This results in the delivery of unsafe drinking water and waterborne disease outbreaks in both rich and poor countries (MacKenzie *et al.* 1994; Semenza *et al.* 1998; Hrudey *et al.* 2003; Blackburn *et al.* 2004; Pattanayak *et al.* 2005; Risebro & Hunter 2007; Risebro *et al.* 2007; Hunter *et al.* 2009; Baldursson & Karanis 2011; Onda *et al.* 2012) and limits the long-term sustainability of the DWSs (Carter *et al.* 1999; Mog 2004; Baumann 2006; Harvey & Reed 2006; McConville & Mihelcic 2007; Schweitzer & Mihelcic 2012). It is estimated that 30–40% of DWSs fail and remain unrepaired because of insufficient operational, technical, and financial capacity, and a lack of post-construction support (PCS) (Mackintosh & Colvin 2003; Hoko & Hertle 2006; Lockwood & Smits 2011). A variety of development actors (non-government organizations and governments) are experimenting with PCS programs to address these

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obstacles. PCS provides technical assistance in operation and maintenance (O&M), and administrative and financial management training to community-run water systems.

A review of the literature reveals that few PCS impact studies exist. A retrospective World Bank study of PCS in Bolivia, Ghana, and Peru, suggests that communities whose system operators attend training workshops, experience better system performance than non-PCS communities (Bakalian & Wakeman 2009; Whittington *et al.* 2009). PCS was associated with improved financial performance and household satisfaction in Peru (Prokopy *et al.* 2008). In Bolivia, however, engineering-oriented PCS had no measurable impact on system function or user satisfaction (Davis *et al.* 2008). The best configuration for PCS is unknown, as are its impacts upon microbiological water quality and its cost.

The Circuit Rider (CR) model of PCS provides ongoing technical assistance to communities and their water system operators to overcome technical, financial, and operational obstacles to successful O&M. This model arose during the 1970s in the United States to help rural communities meet new water treatment standards and water supply needs, and was founded by the National Rural Water Association (Stottlemyer 1999). The name CR describes the circuit of communities that a drinking water technical advisor visits on a monthly basis. Currently, the CR model is operating in Canada, Guatemala, Honduras, El Salvador, and throughout the USA. Communities can receive Circuit Rider post-construction support (CRPCS) by initiating conversations with CR technicians; a government health office can recommend the organization facilitating the PCS to a community; or CR technicians can approach communities. Anecdotal references to its success exist (Trevett & Nuñez 1998; Holden 1999; Stottlemyer 1999); however, no rigorous study of CRPCS has been published.

The International Rural Water Association (IRWA), a non-profit arm of the US National Rural Water Association works with the Asociación Salvadoreña de Sistemas de Agua (ASSA), a Salvadorian NGO, to provide CRPCS in El Salvador. CRPCS was first introduced internationally in 1990 in Honduras, and later in El Salvador in 2001. CRPCS consists of support in four main areas: technical, financial, and administrative management, and water supply protection (see Table 1). CRPCS is provided through trainings, on-call technical support, monthly visits, and capacity building workshops from a government agency or local NGO in El Salvador (Kayser 2008a, 2008b, 2009). Monthly visits allow CRPCS technicians to test for chlorine disinfection and microbiological water quality and address community-specific management needs. Workshops provide training in O&M, water treatment operation, budgeting and accounting, water supply protection, and household metering for operators and Village Water Committee (VWC) members. One CR technician visits the same, approximately, 25 communities every month.

CR technicians first examine the DWS and facilitate a needs assessment. This appraisal includes system conditions (from the source through its treatment and distribution), and VWC activities (Kayser 2008a, 2008b, 2009). These include: the presence of a VWC, VWC responsibilities, operator technical assistance, administration of financial accounting and bookkeeping, household water fees, presence of a VWC bank account for user water fees, presence of water meters, existence of a supply inventory, and plans for maintenance and operation. The technician tests the water for disinfection (residual chlorine) and microbiological quality (*Escherichia coli* and total coliform bacteria). The assessment informs community-specific PCS trainings. CR

Table 1 | CRPCS

	CR technicians provide:
Technical capacity	• Operator trainings and workshops on water system O&M (e.g., chlorine disinfection, pump maintenance) • Monthly testing of village drinking water for microbiological water quality (presence/absence of *E. coli*) and disinfection (residual chlorine) • On-call assistance for technical problems that arise overtime
Financial management	• VWC training in budgeting, accounting, and billing
Administrative management	• VWC training on their responsibilities and information on national water quality regulations
Water supply conservation	• VWC training on the importance of household water meters, protection of the water source with a fence and forest, and watershed protection through reforestation projects

technicians can then provide community-specific PCS, and also relay drinking water standards and inform operators and VWCs about disinfection technologies. Support is provided for chlorine tablet disinfection, rather than manually dosing chlorine in distribution tanks.

In this field-based study, a case-control design was utilized to assess the impact of CRPCS on 'water quality' and 'system sustainability' (defined here with indicators for technical capacity, financial and operational management, and water supply protection) in 60 randomly selected intervention (CR) and control (no CR) communities in rural and peri-urban El Salvador. This study encompassed a population of approximately 87,000 people in 17,400 households in four provinces of the country. Our objective was to measure the actual effectiveness of CRPCS as implemented, rather than potential impact under ideal conditions. We then contrast the impacts of this water supply intervention and its costs.

METHODS

Ethics

Free and informed participant consent was obtained. The Institutional Review Board of the Fletcher School of Tufts University approved this protocol on June 13, 2007.

Research design

We used a case-control design to assess how CRPCS may impact water quality and sustainability metrics in randomly selected intervention (CR) and control (noCR) communities. We randomly selected 60 villages (28 CR and 32 noCR) using primary and secondary data. Primary data included lists of DWSs from regional municipal offices, and a roster of CRPCS communities from ASSA. Secondary data included census information and department maps. Intervention communities were randomly selected from the ASSA roster. Controls were selected in two steps: first, selecting for the presence of a piped DWS from the list compiled from regional municipal offices, and then using geographic data to identify communities similarly located to the randomly chosen intervention communities.

Site description

Sample villages were in the Departments of La Paz, San Vicente, and Usulután. Most villages were located in tropical savannah lowlands, at the bottom of the Rio Lempa watershed, which is the largest in Central America. The Lempa River is contaminated with high levels of fecal coliforms (FUSADES 2008), thus groundwater sources are used by DWSs if possible. The one rainy season is during May–September. All DWSs had a central water tank and a piped distribution system.

Data collection

Field study data collection occurred in February 2009. The operator and the treasurer or president of each VWC was interviewed using previously piloted structured interviews to identify key sustainability metrics. System sustainability metrics were assessed through interview questions in four categories comprising the Sustainability Index: financial, technical, and administrative management, and water supply protection (Table 2). The Sustainability Index was created after an extensive literature review, 39 semi-structured interviews with DWS operators, VWC members, and CR technicians in the United States, Honduras, and El Salvador, and observations of DWSs in the United States, El Salvador, and Honduras to understand factors that contribute to sustainability of DWSs (Cairncross & Feachem 1993; Carter *et al.* 1999; Linares & Rosenweig 1999; Mog 2004; Sohail *et al.* 2005; Baumann 2006; Harvey & Reed 2006; McConville & Mihelcic 2007; Whittington *et al.* 2009).

To assess water quality, standard microbiological (*E. coli* and total coliform) and residual chlorine tests were run on samples obtained from the first and last households on the piped system, which were GPS geocoded. Chlorine residual assays were done on site using HACH DPD free chlorine reagent powder pillows. If communities had more than one DWS, both were tested. Microbiology tests were performed offsite as outlined below.

Sterile Whirl-Pak® bags (Nasco, Modesto, CA) were used to collect 100 mL of water, which was coded and placed on ice. Microbiology tests were performed mid-day for morning samples and evening for early afternoon

Table 2 | Sustainability index

Sustainability variables	
Technical capacity	• Operator has disinfection knowledgeable • Operator has disinfection training • Actual disinfection (chlorine residual) results • Leaky pipes presence • Sufficient spare parts (per operators and VWC)
Financial management	• Monthly user fee presence • Percent of households paying user fee • Late fee for non-payment present • Financial transparency present (monthly user fee place of deposit in bank, VWC members house, or at monthly meeting) • Water system operating costs covered • Cost of water system known
Administrative management	• VWC presence • VWC has women participating • Average monthly operator wage • Average operator work week
Water supply protection	• Fence protects water source • Watershed reforestation • Household meters installed to incentivize water conservation

samples. Samples were plated (3M™ Petrifilm™) and bottled (Colilert®) according to manufacturer instructions and incubated for 24 h at 35 °C in a portable HACH incubation chamber.

Results from the microbiology and residual chlorine measurements enabled a drinking water risk assessment using World Health Organization standards (WHO 2011). 3M™ Petrifilm™ is a simple *E. coli* enumeration method for assessment of high and very high-risk water quality. Colilert® is a presence/absence method that detects *E. coli* contamination at moderate levels. When used together, *E. coli* contamination can be categorized as non-detectable, intermediate, high, or very high risk. This methodology, developed by Dr. Robert Metcalf, has been validated (Chuang *et al.* 2011) and is well suited to sites where laboratory access is limited (Metcalf & Stordal 2010).

Data analysis

We used *t*-tests to assess normally distributed data, Mann–Whitney U non-parametric tests to evaluate non-normal data, Chi-square tests for frequency data, and Fisher exact tests when these frequency data were small (<5) (see Tables 3–7) using IBM® SPSS version 19 software.

The data were also post-hoc re-analyzed without one control community. It had a DWS that was privately run with federal operational funding, unlike all other sampled DWSs that were community run and managed. By chance, this community had been randomly chosen during the selection process. This DWS had the highest number of households served, construction costs, and operating budget. Our results were essentially identical with or without its inclusion. We report the results of analyses with its inclusion.

RESULTS

Comparability of case and control communities

To characterize the comparability of case (CR) and control communities (noCR) and their DWSs, we compared physical factors that could contribute to improved water quality or system sustainability. These factors included: number of households served, DWS age, community managed water system, the presence of private household vs. public taps, water sources, pump use, DWS construction cost, in-kind community contribution and NGO contributions for construction costs, presence of household sanitation facilities, monthly household user fee, average hours of water supply, and distance from nearest paved road (Briscoe *et al.* 1990; Whittington *et al.* 1998; Howard *et al.* 1999; Prokopy 2005; Montgomery *et al.* 2009). No significant differences in the physical factors that might otherwise influence water quality and system sustainability results were detected between CR and noCR communities (Table 3).

Improved water quality and water treatment in CR communities

Twenty percent of noCR water samples assessed with the most sensitive *E. coli* assay were positive versus 3% of CR samples ($p < 0.05$); similarly, 62% of noCR total coliform tests were positive versus 32% of CR communities ($p < 0.001$). CR community operators were significantly more likely to treat their drinking water ($p < 0.001$). In CR

Table 3 | Comparability of control and CR communities

Parameter	Control %	Control N	CR %	CR N	Statistical significance
Average number of households served by water system		362		286	$p = 0.411$[a]
Average age of water system (years)		13		12	$p = 0.970$[a]
Community run water system	97	(31/32)	100	(28/28)	$p = 1.000$[b]
Private household tap	91	(29/32)	89	(25/28)	$p = 1.000$[b]
Public community tap	6	(2/32)	11	(3/28)	$p = 0.657$[b]
Functioning taps	97	(31/32)	100	(28/28)	$p = 1.000$[b]
Source of piped water: ground water	56	(18/32)	57	(16/28)	$p = 0.945$[d]
Source of piped water: surface water	6	(2/32)	11	(3/28)	$p = 0.657$[b]
Source of piped water: spring	38	(12/32)	32	(9/28)	$p = 0.667$[d]
Pump used to access or distribute water	78	(25/32)	82	(23/28)	$p = 0.700$[d]
NGO constructed system	66	(21/32)	75	(21/28)	$p = 0.433$[d]
In-kind contribution to water system construction by villagers	97	(31/32)	93	(26/28)	$p = 0.188$[b]
Households not connected and within the area of the piped system	15		21.5		$p = 1.000$[c]
Access to sanitation (given a % of village)	91		83		$p = 0.765$[a]
Average capital expenditure cost of water system (known in 11/32 control and 17/28 CR communities)		$718,545.45		$602,758.71	$p = 0.495$[a]
Range of households served		22–644, +5,809		31–800	$p = 0.411$[a]
Average monthly household user fee		$3.70		$4.25	$p = 0.441$[c]
Distance from nearest paved road		0.68 km		1 km	$p = 0.765$[a]
24 h of water supplied daily	25	(8/32)	21	(6/28)	$p = 0.746$[d]
Average hours of water supplied daily		9.6 h		8.8 h	$p = 0.070$[c]

[a]Mann–Whitney U test.
[b]Fisher exact test.
[c]Student's *t*-test.
[d]Chi-squared.
*Statistical significance at $p < 0.05$.

communities, 46% tested positive for some residual chlorine compared to 19% of noCR communities ($p < 0.001$) (Table 4).

Enhanced technical capacity in CR communities

CR communities had a significantly higher percentage of operators who reported disinfecting drinking water and disinfection training ($p < 0.001$), significantly less negative community perceptions of chlorine use ($p < 0.05$), and were significantly more likely to use chlorine tablet feeders for disinfection ($p < 0.001$). Twenty-two of 32 control communities had received no PCS. Ten had received a median of 3 days of PCS (noCR) since construction by an NGO or government agency. All CR communities reported CR technician visits within the last three months to conduct chlorine residual testing and/or community chlorination education; 89% reported maintenance assistance or operator training; 61% reported accounting, budgeting, and/or billing training; 40% reported VWC administration training, and 18% reported training in water supply protection.

All DWS operators understood the importance of drinking water disinfection, but in most systems chlorine residuals did not achieve the WHO guideline (0.2 to 2 ppm) or national standard (0.3–1.1 mg/L) (El Salvador Ministry of Social Welfare 2006). Operators ascribed a variety of health benefits for

Table 4 | Water quality

Parameter	Control %	Control N	CR %	CR N	Statistical significance
E. coli presence (Colilert®)	20	(13/66)	3	(2/60)	$p = 0.0051$[a,c]
Total coliform presence (Colilert®)	62	(41/66)	32	(19/60)	$p = 0.0007$[b,c]
Any presence total coliform or *E. coli* (3M™ Petrifilm™)	36	(24/66)	10	(7/60)	$p = 0.0010$[b,c]
Any positive test (Colilert® or 3M Petrifilm™)	59	(78/132)	23	(28/120)	$p = 0.0001$[b,c]
Residual chlorine present	19	(12/64)	46	(26/56)	$p = 0.0010$[b,c]
Residual chlorine sufficient in proximal household (at least 0.2 ppm, WHO guideline	16	(5/32)	32	(9/28)	$p = 0.1340$[a]
Residual chlorine sufficient in proximal and distal households (WHO guideline)	13	(4/32)	18	(5/28)	$p = 0.7210$[a]

[a]Fisher exact test.
[b]Chi-squared.
[c]Statistical significance at $p < 0.05$.

Table 5 | Technical capacity

Parameter	Control %	Control N	CR %	CR N	Statistical significance
Operators report drinking water treatment is important	100	(32/32)	100	(28/28)	$p = 1.0000$[b]
Operators report they treat their communities' drinking water	63	(20/32)	96	(27/28)	$p = 0.0014$[a,c]
Operators received training in drinking water treatment	50	(16/32)	96	(27/28)	$p < 0.0001$[a,c]
Operators report that they have leaky pipes in their systems	31	(10/32)	57	(16/28)	$p = 0.0452$[b,c]
Operators report that they have insufficient funds to purchase parts to make repairs	69	(22/32)	50	(14/28)	$p = 0.1424$[b]
Community members have a negative perception of chlorine	56	(18/32)	25	(7/28)	$p = 0.0151$[b,c]
Use active release chlorine tablet feeders	9	(3/32)	82	(23/28)	$p < 0.0001$[a,c]

[a]Fisher exact test.
[b]Chi-squared.
[c]Statistical significance at $p < 0.05$.

disinfection, but reported that community members believed chlorine made water taste bad, and caused cancer, liver problems, and kidney failure. Community members pressured operators to use less chlorine, or not to chlorinate at all. CR operators, however, were more likely than noCR operators to say that they chlorinated water and to have had detectable residual chlorine in their DWS ($p < 0.005$).

More CR villages reported leaky DWS pipes, perhaps indicating enhanced awareness of system needs, given their significantly higher spending on system repairs than noCR communities ($p < 0.05$) (Table 5).

Improved financial management in CR communities

CR communities had significantly greater water bill payment rates ($p < 0.05$), more spending on DWS treatment and repairs, were more knowledgeable about DWS costs ($p < 0.05$), and were more likely to have water fees deposited

Table 6 | Financial management

Parameter	Control %	Control N	CR %	CR N	Statistical significance
Monthly household water fee charged	97	(31/32)	100	(28/28)	$p = 1.000^{b}$
Households receive water from system and do not pay monthly water fee (reported as a %)	31		17		$p = 0.037^{a,d}$
Operating costs are not covered by household water fees	68	(22/31)	50	(14/28)	$p = 0.142$
Transparency: monthly water fees are deposited in a bank	16	(5/32)	39	(11/28)	$p = 0.048^{b,d}$
Monthly operating cost for water system		$509.27		$1,310.20	$p = 0.007^{a,d}$
Monthly water treatment costs		$17.06		$42.70	$p = 0.003^{a,d}$
Monthly repair costs		$30.00		$398.24	$p = 0.003^{a,d}$
Cost of energy per month		$466.77		$676.62	$p = 0.723^{a,d}$
Average water committee debt		$2,393.00		$2,712.84	$p = 0.011^{a,d}$
VWC charges a fee for late monthly household water fee payment	53	(17/32)	54	(15/28)	$p = 0.973^{c}$
VWC knows the cost of their water system	34	(11/32)	61	(17/28)	$p = 0.043^{c,d}$

[a]Mann–Whitney U test.
[b]Fisher exact test.
[c]Chi-squared.
[d]Statistical significance at $p < 0.05$.

into a bank account than into the hands of a community member ($p < 0.05$). All but one community charged water service fees. Similar amounts were charged by noCR and CR communities for household water service. Monthly operator wages, and energy costs, did not differ between CR and noCR communities. Financial constraints, such as the energy costs for water pumping, were cited as reasons for reducing household water supply.

DWS investments for O&M such as repairs, operator wages, and water treatment were significantly greater in CR communities than in noCR communities ($p < 0.05$). O&M investment was a mean of $509 per month in noCR communities as compared to $1,310 in CR communities. Much of this difference was related to investments for repairs and water treatment. VWC debt was also higher in CR communities as a result of loans for investment in operations (Table 6).

Administrative management did not differ between communities

CR communities were slightly more likely to have a VWC, have women VWC members, and to pay operators a higher wage; but these results were not statistically significant (Table 7).

CR communities were more likely to conserve water supplies

Water meters were more common in CR than noCR communities ($p < 0.05$). Metered communities typically charged a baseline fee for a basic household water allotment, and an additional fee for water consumed above the baseline. Water supply protection via foresting or fencing, however, was similar in both groups. Only one CR community had a watershed reforestation project (Table 7).

Operating costs of CRPCS

The annual operating cost of CRPCS was less than $1 USD per household per year in El Salvador. The ASSA operating cost for the CR program was $50,000 per year, and benefited approximately 51,000 households. This cost includes all CRPCS operating costs, and includes support for fulltime employment for five CR technicians, costs related to monthly community visits, water quality testing, and

Table 7 | Administrative management and water supply conservation

Parameter	Control %	Control N	CR %	CR N	Statistical significance
Administrative management					
VWC present in village	75	(24/32)	89	(25/28)	$p = 0.4913^{a}$
Women participate in the VWC	74	(23/31)	87	(20/23)	$p = 0.3187^{a}$
Monthly wage for operator		$126.20		$149.22	$p = 0.2140^{b}$
Hours operator works per week		48		49	$p = 0.7800^{b}$
Water supply conservation					
Undertake reforestation projects in water supply watershed	0	(0/32)	4	(1/28)	$p = 0.4745^{a}$
Protect water source with forest	28	(9/32)	29	(8/28)	$p = 0.9697^{c}$
Protect water source with fence	69	(22/32)	64	(18/28)	$p = 0.7166^{c}$
Meters installed in households	**9**	**(3/32)**	**32**	**(9/28)**	$\mathbf{p = 0.0498}^{a,d}$

[a]Fisher exact test.
[b]Student's *t*-test.
[c]Chi-squared.
[d]Statistical significance at $p < 0.05$.

biannual workshops initiated for VWCs. Relative to other water-related interventions, this is a very low-cost intervention associated with noteworthy water quality, financial, and technical outcomes. This expense was supported by the International Rural Water Association and from the sale of chlorine tablet feeders and tablets.

DISCUSSION

Communities with CRPCS had significantly safer water with lower microbiological water contamination and higher disinfection rates than control communities. The CR DWS operators displayed better treatment knowledge, and their residents had more positive perceptions about chlorination. CRPCS communities had significantly better financial status, transparency, and greater spending for repairs and water treatment. Household metering, which reduces water waste, was also more common. However, CRPCS was not associated with significantly greater sufficient residual chlorine in the piped network to meet WHO guidelines or national standards or significantly greater source water protection than comparable control communities. Furthermore, CRPCS in El Salvador was supported with outside funding. This suggests that opportunities exist within this framework to improve water quality and sustainability. In sum, CRPCS was associated with significantly better water quality and significantly better financial and operational performance.

This study has several limitations. These data were collected in one region of El Salvador, had a relatively small sample size, and lack prospectively acquired baseline information. Water quality data were collected at one point in time. It could be argued that CR villages were more motivated to support their DWSs than comparable control communities, accounting for both their adoption of CRPCS and better system parameters. (Interviews with Circuit Riders, however, suggest the opposite is true – the worst performing systems VWCs seek out CRPCS.) Our results do not make statements of causality and should be interpreted with caution. Subsequent research might increase the frequency of water quality testing to increase data reliability, interview households within each community to understand community satisfaction with service, and include sanitary inspection to better understand the sources of water contamination. Our results should be confirmed with a prospective study that includes counterfactual communities.

Perhaps increasing confidence in these data, the DWSs were comparable (Table 3), and no evidence of greater community motivation (such as higher DWS operator salaries or greater rates of formally elected VWCs) was present. A strength of this study is that it measured outcomes associated with actual CRPCS implementation. Many public health interventions, when put into practice, do not achieve the benefits seen in efficacy trials where common implementation challenges are minimized. Thus, we believe these data suggest a significant link between CRPCS in practice, and improved water quality and sustainability.

CRPCS is an inexpensive technical assistance model that addresses many of the needs of small DWSs. In El Salvador, CRPCS minimizes the many challenges faced by small DWSs. The CR model is a unique example of PCS as it represents continual, adaptive delivery of PCS over time rather than short-term PCS. Similar to PCS findings in Peru, CRPCS was associated with improved financial performance (Prokopy *et al.* 2008). While this study did not tease out the impact of technical vs. managerial PCS, CRPCS was associated with improved system function in contrast to engineering-oriented PCS in Bolivia (Davis *et al.* 2008). While no prior study examined the impact of PCS on water quality, this study finds promising results for public health. These findings and the low operating cost of CRPCS in El Salvador suggest promising evidence for scale-up of this program in El Salvador and potential for adaption and use of this model in other countries.

CONCLUSION

The CR model of PCS, as implemented in El Salvador, is associated with improved community drinking water quality, improved financial management, better technical capacity, and a higher prevalence of household metering. CR communities had significantly less microbiological water contamination, and invested significantly more on treatment and on repairs than comparable control communities. This suggests better maintenance and operation, and long-term sustainability. These positive outcomes were found by assessing a functioning support program, rather than through a best-scenario efficacy trial, suggesting that these benefits represent what is found during actual implementation. We found CRPCS to lead to significantly less water contamination and better sustainability, at a cost of less than $1 per household per year.

DISCLOSURE

The authors declare no conflict of interest. To assure impartial evaluation, Jose Miguel Orellana Portillo assisted in the design of the CR model in El Salvador, conception of the research idea, and writing about the CR model, but did not contribute to collection and or analysis of these data.

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