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Rural water system functionality and its determinants: a twelve-country study

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This paper presents results from a 12-country study of water systems installed by Living Water International from 2001-2014. Results from a random, representative sample of 3,815 water systems indicate that 77.1% were functional, with an additional 5.8% having limited functionality. These results fall in the upper end of an expected range based on similar studies. Several factors increased the odds of water system functionality, including when water users made financial contributions to the system and whether a community used a management structure. Any type of management increased the odds of functionality, but village water committees had the largest effect. Additionally, Afridev pumps were associated with higher odds of functionality than India Mark II pumps.

Introduction

The purpose of this study is to examine the functionality of rural, communal water systems installed across a wide range of countries by one international NGO using a consistent methodology. In addition to measures of functionality, we also explore associations between functionality and potential contributing factors, such as whether water users made financial contributions and what type of management system, if any, was used. According to Improve International, over 120 independent surveys of water system functionality or sustainability have been carried out over the past several decades. Most of these, however, were limited to one country, or they use methods different enough from one another that the results cannot be meaningfully compared or aggregated (Improve International, 2016).

Over 95% of the systems analysed in this study were drilled water wells (boreholes) equipped with a hand pump or an electric pump. A borehole itself is typically designed to last 25 years or more. Permanent failure of the borehole within that timeframe usually results from poor siting, design, or construction (Carter & Ross, 2016). The hand pump that lifts the water through the borehole typically has a useful life of 6-12 years if well-maintained, after which it must be replaced (Brikke & Bredero, 2003).

The 1980s saw the first significant push toward the sustainability of rural water systems in the form of the Village Level Operation and Maintenance (VLOM) movement. VLOM was based on the notion that communal hand pumps could meet rural water supply needs in most parts of the world if engineers could overcome key design problems. To meet the concept of VLOM, a pump would need to be cost effective, robust, and reliable. A village caretaker with minimal skills and few tools should be able to easily maintain it and purchase replacement parts manufactured in-country (Colin, 1999). Although it technically pre-dated the VLOM approach, the India Mark II pump met many of the VLOM criteria when it came into common use in 1979. The VLOM flagship pump, the Afridev, followed it in 1985.

The VLOM approach achieved *part* of its purpose, in that the widespread adoption of relatively uncomplicated, standardized pumps simplified supply chains and maintenance procedures. The underlying logic, however, that a volunteer caretaker within the community would be able to singlehandedly manage the maintenance of one or more of these pumps proved false, as functionality rates remained lower than desired (Lockwood & Smits, 2011, p.75).

In the late 1980s and early 1990s, it became widely recognized that community members should not be maintaining their own water systems so much as providing leaders to *manage* the maintenance—usually in the form of water committees. These committees generally work with the broader community to set rules for water system use, collect fees or tariffs from community members, and hire external service providers to handle maintenance and repair. Research has shown this approach is more effective than the community trying to handle repairs on their own (Batchelor, Ngatshane, McKemey, & Scott, 2001).

In more recent years, water sector practitioners and researchers have recognized that achieving water system functionality is more complex than it seems (van Soest, Carriger, Casella, & Wells, 2015). One recent study used a systems-thinking approach to highlight the interconnectedness of factors leading to increased functionality. The researchers found that water systems benefiting from high levels of 1) community participation and demand, 2) management capacity to oversee maintenance, and 3) financial cost recovery mechanisms were more likely to achieve long-term water system functionality. When *any one* of these factors erodes, it is likely to cause a cascading decrease in water system functionality over time (Walters & Javernick-Will, 2015).

Living Water International (LWI) installed all of the water systems surveyed in this study. The US-based organization works through affiliated country offices and partner organizations in more than 20 countries to provide WASH solutions. LWI promotes water sustainability in communities through the establishment of community management, technical support, supply chains, and management support. In the effort to achieve *water* sustainability, the intermediate objective has been to achieve *system* sustainability, defined as "empowering communities to keep boreholes and other systems working for their designed life cycles." This definition of system sustainability informed our definition of water system functionality — whether or not the system produced water flow at the time of the survey.

Methodology

This study focused on 3,815 communal water systems installed by LWI in 12 countries from 2001-2014. To determine the population of water systems, we first considered all systems with GPS coordinates stored in LWI's internal database. From there, water systems in countries experiencing violent conflict or health pandemic were removed, as were systems in countries or areas where LWI no longer had operations. When receiving the request to participate in the study, four of the remaining 16 countries did not participate for various reasons, leaving a population of 12 countries. Within these countries, there were 3,815 water systems installed by LWI from 2001-2014 for which we had GPS data.

Sample sizes were calculated to allow for a 10% margin of error and 95% confidence level for each country, yielding a 3% margin of error for the study overall. LWI's central office conducted the random selection process of systems to be surveyed in each country to reduce the risk for non-random selections. Table 1 lists the countries in the study, along with the population of water systems, sample size, and surveys collected.

Table 1. Sample sizes and surveys collected

Country	Population (Water Systems)	Sample size	Surveys collected
El Salvador	475	81	80
Ethiopia	140	58	62
Ghana	54	35	32
Guatemala	290	79	79
Haiti	109	58	53
India	1,332	90	94
Kenya	227	68	84

Mexico	125	57	49
Nicaragua	288	77	70
Rwanda	376	77	84
Uganda	290	73	66
Zambia	109	42	39
Total	**3,815**	**795**	**792**

LWI staff from the participating countries collected data from the selected random sample of water systems by visiting each one in September and October, 2014. They used historical monitoring data, including GPS coordinates, to identify and locate each system. At the site of each system, enumerators recorded technical observations about the status of the water system and asked water users a series questions. They also photographed each system using mobile devices that automatically captured GPS coordinates in the picture's EXIF data. We mapped those coordinates against the historic monitoring data to ensure the correct system was identified. Surveys were conducted for 792 systems, approaching the target of 795.

The enumerators observed the state of water flow from the system. If water was available, the system was considered "functional." They also recorded observable problems, including if the water flow was limited. A local water user was asked if there were any issues, and if either reported limited water flow, the system was considered to have "limited functionality." Systems without available water were considered "non-functional."

Results and discussion

Functionality

Results indicate that 77.1% of the enumerated water systems were functional, with an additional 5.8% having limited functionality. It is difficult to set a benchmark for expected functionality in a set of water systems that spans a 13-year age range and 12 countries. A review of the literature, however, suggests the most common results in single-country studies from these regions range between 60-70% (RWSN, 2009), and a recent paper proposes the rate of functionality in a mixed-age sample cannot be expected to exceed 85% (Carter & Ross, 2016).

Functionality rates varied by region. In sub-Saharan Africa (Ethiopia, Ghana, Kenya, Rwanda, Uganda, Zambia), it was 66.8%. India, the only county from Asia in the study, had a rate of 78.7%. In Latin America and the Caribbean (El Salvador, Guatemala, Haiti, Mexico, Nicaragua), 88.2% of systems functioned. These variances are in line with findings from other studies and datasets—for instance, it mirrors the regional differences found in the Water Point Data Exchange (2016) at the time of the study.

Table 2. Water system functionality by region

Region	N	Functional	Limited Functionality	Non-functional
Sub-Saharan Africa	367	66.8%	8.4%	24.8%
India	94	78.7%	0%	21.3%
Latin America & Caribbean	331	88.2%	4.5%	7.3%
TOTAL	**792**	**77.1%**	**5.8%**	**17.1%**

Contributing factors

To analyse associations between potential contributing factors and functionality rates, we limited the observations in the data set to water systems with one of the four most common types of water pumps: India Mark II, Afridev, U3, or an electric pump. This reduced the number of observations from 792 to 756 (95.5% of the total), but it allowed for more meaningful analysis, especially for how the type of pump technology could be associated with functionality rates.

We used multivariate logistic regression to estimate the association between various factors and water system functionality. This allowed us to control for other factors that can cause variance in functionality, including region and age of the system, and shown in Table 3. The dependent variable is the proportion of functional systems, while the independent variables include the water system's age, region, management type, pump type, and whether there was a financial contribution.

Table 3. Estimated odds ratios (OR) and 95% confidence interval (CI) from a logistic regression of water system functionality

	Log-odds	Odds Ratio (OR)	95% CI for OR
Intercept	-1.21	0.30	0.07-1.15
Region			
India versus Sub-Saharan Africa	1.97***	7.20	3.43-16.34
LAC versus Sub-Saharan Africa	1.97***	7.20	4.28-12.54
Management			
Individual or community members versus none	1.62*	5.04	1.20-21.73
Institution versus none	1.71*	5.56	1.48-21.36
Local government versus none	1.29	3.65	0.73-18.73
Village water committee versus none	2.28***	9.80	2.61-37.84
Age	-0.14**	0.87	0.80-0.95
Pump			
Afridev versus India Mark II	0.62*	1.87	1.12-3.18
U3 versus India Mark II	0.50	1.65	0.60-5.41
Electric versus India Mark II	0.48	1.62	0.88-3.10
Financial Contribution	0.53*	1.70	1.03-2.82

Notes: Null deviance: 769.73 on 755 degrees of freedom; Residual deviance: 659.92 on 744 degrees of freedom
Significance codes: P<0.001 '***'; P<0.01 '**'; P< 0.05 '*'

On average, the odds that a water system functions when water users are making financial contributions to it are 1.7 times higher (p=0.038) than for systems where users make no contribution. This finding is consistent with the literature and supports LWI's approach of encouraging financial contributions from water users.

Holding other variables in the model constant, each type of management system was associated with higher functionality rates. Management by local government, however, was not statistically significant. Village water committees had the largest effect, where the odds of a water system being functional when using this type of management structure are 9.8 times higher (p<0.001) than when no management structure is used. These results suggest the odds of ongoing functionality are improved through having a local management system in place, and that village water committees perform better than other types.

Afridev, U3, and electric pumps appear to increase the odds of functionality when compared to an India Mark II, though Afridev is the only pump with a statistically significant association. Afridev pumps make the odds of functionality 1.87 times higher (p=0.018) than systems with an India Mark II. This is not surprising as Afridev pumps were intended to improve on the India Mark II and designed for simpler preventative maintenance (Wood, 1993).

To further illuminate the effects of these contributing factors, we provide predicted values for proportion of functional water systems in Table 4. While there are not models for every possible scenario, the eight chosen models give comparisons between the variables with statistical significance from the logistic regression. Each model uses the mean age for water systems (4.28 years).

Table 4. Predicted water system functionality based on logistic regression

Model	Region	Financial Contribution	Management Type	India Mark II Pump	Afridev Pump	U3 Pump	Electric Pump
1	Africa	No	None	14.3%	23.8%	21.6%	21.3%
2	Africa	No	Individual or Community Members	45.7%	61.1%	58.2%	57.7%
3	Africa	No	Institution	48.1%	63.4%	60.5%	60.1%
4	Africa	No	Local Government	37.9%	53.2%	50.2%	49.7%
5	Africa	No	Village Water Committee	62.1%	75.4%	73.0%	72.6%
6	Africa	Yes	Village Water Committee	73.6%	83.9%	82.1%	81.9%
7	LAC	No	Village Water Committee	92.2%	95.7%	95.1%	95.0%
8	India	No	Village Water Committee	92.2%	95.7%	95.1%	95.0%

There are several differences in predicted functionality worth noting. Model 5 has a prediction that is 47.7% points higher than model 1 (for an India Mark II pump), showing how substantial the effect is from having a village water committee. When comparing models 5 and 6, the predicted functionality for India Mark II pumps was 11.5% points higher when financial contributions occurred. Finally, in all eight models, the Afridev pump had a higher predicted functionality than the India Mark II — ranging from +3.5% to +15.4% points.

Limitations and future research

This study provides a helpful starting point in our effort to better understand system sustainability, though there were several limitations. First, to perform a larger study across countries, we had to rely on internal staff to collect data. This presents an inherent risk for bias, though we did take steps to reduce this risk, including controlling the random selection process and requiring photos of each system that contained GPS data. We recognize that in some cases enumerators may have had different understandings of how to classify water systems; for instance, it is possible some pumps identified as India Mark II's were in fact equipped with modified downhole hardware (i.e. U3). It is unclear what effect, if any, this would have on the results.

Second, using a binary variable for functionality as an indicator for system sustainability has its weaknesses. This simplified approach allowed us to ensure more consistent results across countries, but it only gives a limited understanding of the status of the system. In future research, we hope to utilize frameworks developed in recent years (e.g. Carter & Ross, 2016) that provide better standards on categories of functionality.

Finally, we hope to go beyond observing the functionality of a water system and conduct research on water service levels. LWI's internal quality standards describe a basic service level with benchmarks for quantity, quality, reliability, and accessibility that can serve as dependent variables in future studies.

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