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Identifying opportunities to improve piped water continuity and water system monitoring in Honduras, Nicaragua, and Panama: Evidence from Bayesian networks and regression analysis

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ABSTRACT

Many piped water systems in rural areas of Latin America and the Caribbean provide discontinuous service. In response to service delivery challenges, governments developed the Rural Water and Sanitation Information System to monitor water service levels, infrastructure conditions, water committees, and technical assistance providers. Collected data are combined into metrics to represent water service sustainability. There is little analysis of these data to identify service delivery and system improvement opportunities and the sustainability metrics are unvalidated. Multivariable regression and Bayesian networks were used to analyze variables associated with the availability of 24-h water services using data from 5560 community-based piped water systems in Honduras, Nicaragua, and Panama. The regression models were compared to the sustainability metric. In Honduras and Nicaragua, the proportion of systems providing 24-h service spanned 71 percentage points between sub-national regions. Good condition infrastructure and year-round water source availability were associated with the availability of 24-h service. The availability of support for system rehabilitation in Honduras and for preventative maintenance in Nicaragua were associated with the availability of 24-h services. The Bayesian networks predicted that good condition infrastructure and year-round water source availability were more influential on the availability of 24-h service than management variables such as the availability of external technical support and funds to rehabilitate the system. In each country, insufficient household water tariffs were collected for 90% or more of systems to cover infrastructure, operations, and maintenance costs. The r-squared values for the regression models ranged from 0.22 (Nicaragua) to 0.49 (Honduras) as compared to 0.05 (Nicaragua) to 0.03 (Honduras) for the sustainability metric – suggesting that regression models are better at predicting higher service levels. Rural water service operators, technical assistance providers, local and national governments, and external support agencies could make better use of monitoring data by using interdisciplinary systems approaches to identify improvement opportunities to allocate technical and financial resources to systems with low service levels.

1. Introduction

Continuous, sufficient, safe drinking water services are important for human health, human rights, well-being, and sustainable development (Bartram and Cairncross, 2010). They are urgently needed in rural areas of low- and middle-income countries (LMICs) of Latin American and the Caribbean (LAC) where water service levels are low (Bain et al., 2014a; b). More than 20 million people in rural areas of LAC (16% of the rural population) do not use an improved drinking water source and nearly 40.5 million people in rural areas of LAC (32% of the rural population of LAC) do not use piped drinking water at home (WHO/UNICEF, 2015).

Many piped water systems in LMICs are discontinuous, providing less than 24-h of service per day (Kumpel and Nelson, 2016). Systems providing less than 24-h of service per day are more likely to contain fecal indicator bacteria (Kumpel and Nelson, 2013). An estimated 19% of water sources in LAC contain fecal contamination (Bain et al., 2014a,b). People with discontinuous

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services are more likely to store water at home (Galaitsi et al., 2016) which is more contaminated than source water (Shields et al., 2015). Inadequate drinking water services are a substantial contributor to global burden of disease (Pruss-Ustun et al., 2014). Piped water discontinuity is associated with disease outbreak, including cholera (Jeandron et al., 2015); and piped water system upgrades to continuous service contributed to a reduction in typhoid (Ercumen et al., 2015). People with discontinuous water services may consume water from unsafe, unimproved sources such as surface water. One modeling study suggested that when people consume water from an unimproved source for a few days per month, health gains from a continuous improved source (such as a piped water supply) are negated (Hunter et al., 2009). Another modeling study estimated that intermittent water supply might be responsible for 109,000 diarrheal disability adjusted life years (DALYs) and more than 1500 deaths worldwide every year (Bivins et al., 2017).

In response, local and national government and external support actors supporting rural water services in LAC collaboratively developed the Sistema de Información de Agua y Saneamiento Rural (SIASAR) – the Rural Water and Sanitation Information System – to monitor rural drinking water services. SIASAR was developed to provide reliable and comprehensive water service data for "better and more efficient priority setting, policy creation, project planning, and budget allocation" (Rodríguez and Weiss, 2016).

The objectives of SIASAR are to collect and consolidate data on communities, water systems, water committees, and technical assistance providers (Rodríguez and Weiss, 2016). These four domains were selected because, in LAC, most systems in rural areas are managed by community water committees and committees conduct management (tariff collection, financial accounting) and operations (day-to-day operations, maintenance). Many committees are volunteer-based and receive post-construction support (PCS) services from technical assistance providers (Rodríguez and Weiss, 2016).

Information on water services collected through SIASAR include continuity (number of hours of service per day) and water quality (fecal indicator bacteria, chemical contamination, and chlorine residual). More information is available at the SIASAR website (SIASAR, 2016b). This information is useful for decision-makers and is important to document progress of LAC countries toward policy goals and targets such as the Sustainable Development Goals (SDGs). Target 1 of SDG 6 calls for "universal and equitable access to safe and affordable drinking water for all" (United Nations General Assembly, 2015). Indicator 1 of target 6.1 is the "proportion of [the] population using safely managed drinking water services" (United Nations General Assembly, 2015). Safely managed drinking water services are defined by the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) as services that are available at all times (i.e. 24 h per day), on household premises, and free of fecal and priority chemical contamination (WHO/UNICEF, 2017).

SIASAR data are combined into metrics for communities, water systems, water committees, and technical assistance providers which are intended to represent water service sustainability. Water systems are scored as 'A' ("optimal" service level) through 'D' ("lowest" service level). The sustainability metrics comprise 33 community indicators, 37 system-level indicators, 39 water committee indicators, and 44 technical assistance indicators, respectively (Rodríguez and Weiss, 2016).

The SIASAR sustainability metric is one of more than 200 related metrics and tools developed to date (Boulenouar et al., 2013). A potential problem with many of these metrics and tools is that, in many cases, each included variable is weighted equally, suggesting that all variables contribute equally to water service sustainability. However, rural water service sustainability is a complex systems problem. It is multifactorial, often context dependent, requires consideration of multidisciplinary human- and socio-technical systems, and variables contribute differently to water service sustainability (Amjad et al., 2015). For example, studies from sub-Saharan Africa suggest that system age (Fisher et al., 2015), system type (Cronk and Bartram, 2017), and tariff collection (Foster, 2013), have greater influence on water system sustainability than others such as the availability of alternative water systems and distance to urban centers (Foster, 2013).

No large studies from rural areas of LAC examine variables associated with 24-h water service availability or related service parameters. Available studies are small and there are no multivariable analyses, meaning they could not report the relative influence of different variables on water service levels. For example, a study of 60 water systems in El Salvador examined the influence of circuit rider post-construction support (CRPCS, a model for technical assistance to community water system operators) on piped water system quality and sustainability, and found that communities with CRPCS had safer water, higher tariff payment rates, and higher spending for system repairs (Kayser et al., 2014). A study from the Dominican Republic found high levels of maintenance activities and the availability of savings to be associated with higher water system continuity; however, this study only examined 61 communities and effect sizes could not be reported (Schweitzer and Mihelcic, 2012).

There is an opportunity to gain further insight from SIASAR by using monitoring data and interdisciplinary systems analysis approaches to identify service improvement opportunities. There are also opportunities to optimize SIASAR monitoring without adding cost or time burden. Bayesian Networks (BNs), which are graphical, probabilistic models that represent and quantify complex relationships, may reveal opportunities to improve services (Cain, 2001). These are useful for examining associations in complex environmental systems, modeling decision-making scenarios, and for use in evidence-based decision-making (Carriger et al., 2016). However, there is little application of BNs to water systems and services, especially in LMICs (Phan et al., 2016).

In the largest study of rural water systems conducted to-date in LAC, SIASAR data from Honduras, Nicaragua, and Panama were analyzed using logistic and linear regression and BN models to explore variables that influence water service continuity. The regression models were compared to the SIASAR sustainability metric to examine goodness-of-fit.

2. Methods

2.1. Data sources

Data were obtained from the publicly available, online SIASAR database in November 2016 (SIASAR, 2016a). These cross-sectional data had been collected by the government agency responsible for rural water service provision in each country (i.e. the data collection actors) since 2011. The data collection actors intended data collection to be a census of all rural piped water systems in these countries. SIASAR differs from traditional water point surveys (such as those conducted in countries of sub-Saharan Africa) where a similar monitoring method and survey was used in multiple countries and data are intended to be collected over time.

Data quality assurance and quality control (QA/QC) measures varied by country. For example, systems and communities in Honduras were revisited several times to verify data, whereas few data checks were conducted in Nicaragua and Panama (Borja-Vega et al., 2017). Full details of SIASAR data collection methods are