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Planning rural water services in Nicaragua: A systems-based analysis of impact factors using graphical modeling

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ABSTRACT

The success or failure of rural water services in the developing world is a result of numerous factors that interact in a complex set of connections that are difficult to separate and identify. This research effort presented a novel means to empirically reveal the systemic interactions of factors that influence rural water service sustainability in the municipalities of Darío and Terrabona, Nicaragua. To accomplish this, the study employed graphical modeling to build and analyze factor networks. Influential factors were first identified by qualitatively and quantitatively analyzing transcribed interviews from community water committee members. Factor influences were then inferred by graphical modeling to create factor network diagrams that revealed the direct and indirect interaction of factors. Finally, network analysis measures were used to identify “impact factors” based on their relative influence within each factor network. Findings from this study elucidated the systematic nature of such factor interactions in both Darío and Terrabona, and highlighted key areas for programmatic impact on water service sustainability for both municipalities. Specifically, in Darío, the impact areas related to the current importance of water service management by community water committees, while in Terrabona, the impact areas related to the current importance of finances, viable water sources, and community capacity building by external support. Overall, this study presents a rigorous and useful means to identify impact factors as a way to facilitate the thoughtful planning and evaluation of sustainable rural water services in Nicaragua and beyond.

1. Introduction

The challenges of providing sustainable access to rural water services in developing countries often go far beyond that of the technology itself (Kaminsky and Javernick-Will, 2014). Indeed, many water systems (wells, gravity-fed systems, etc.) tend to fail or operate suboptimally due to a myriad of social, environmental and political factors that confound water service sustainability (RWSN, 2011; Lockwood et al., 2003; WaterAid, 2011; Davis, 2014). In most cases these factors are interconnected and interact as a system, producing outcomes that are often difficult to plan for or adapt to (WaterAid Malawi, 2003; Sara and Katz, 1997; WaterAid, 2011; Ramalingham et al., 2008; Ramalingham, 2014). While water sector literature has identified a number of important factors that affect the sustainability of rural water infrastructure, there is limited research that explicitly addresses the systemic nature of factor interactions. Improving understanding on how factors interact as a system would in turn enable practitioners to plan initiatives that target specific programmatic areas that yield the greatest overall impact on water service sustainability, which this study calls *impact factors*. Thus, the aim of this study was to rigorously investigate how factors that influence rural water service sustainability interact as a system.

The identification of influential factors for water service sustainability in the developing world, and the associated assessment and evaluation methods used to analyze the impact of these factors, has been the focus of many research efforts within the water sector over the past two decades. As a testament to this level of sector attention on sustainability, a recent study of both scholarly and non-scholarly water sector literature by Walters and Javernick-Will (2015) identified 93 articles that focused specifically on factors that influence rural water service sustainability. In their study they identified 157 unique factors mentioned to influence water service sustainability, and aggregated these factors into the 25 sub-factor groups and 8 “sustainability factors” shown in Table 1.

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Table 1
Summary of sustainability factors found in water sector literature (Walters and Javernick-Will, 2015).

Sustainability factor	Sub-factors
Government	Laws & policy Management Governance
Community	Participation Demand Satisfaction
External support	Type of support Cooperation Post const. supp.
Management	Maintenance Skilled operator Women involvement
Financial	Cost recovery Financial management Cost of system or part
Technology construction & materials	Spare part availability Tech. appropriateness Construction quality
Environment & energy	Resource management Source protection Energy availability/ Reliability
Water system functionality	Quality Quantity Reliability Coverage

Many of the factors shown in Table 1 have been used in past studies as metrics and indicators within quantitative evaluation tools to assess the potential for water service sustainability, both for existing and future services. In a study by Lockwood et al. (2003), a typology of these evaluation tools was presented as those which either assess sustainability using "tabular analysis" or "regression-based analysis" (Lockwood et al., 2003). Both types of tools have advantages and limitations in their application and analytical ability.

Tabular analysis tools evaluate survey data by scoring and aggregating factors to derive a composite score commonly presented as frequencies, averages or percentages relative to some level or threshold of service sustainability (e.g., Hodgkins, 1994; WSp, 1996; Bhattarai, 2005; Sugden, 2001; WaterAid Malawi, 2003; Godfrey et al., 2009, 2013; Schweitzer and Mihelcic, 2012; USAID, 2013; Boulenouar et al., 2013). A major benefit of tabular analysis is that the data need not be directly measurable to evaluate sustainability, but instead may be interpreted by the researcher using a pre-defined scoring criterion. A major limitation of the tabular analysis methods is the inherent subjectivity that may influence the results, potentially making the data biased, and as a result, inaccurately representing the realities in the field.

Regression analysis techniques measure the significance of the relationship between one or more independent variables (i.e., factors) on one dependent variable (i.e., sustainability). Statistical techniques used by regression analysis are typically either bivariate or multivariate linear regression (e.g., Narayan, 1995; Sara and Katz, 1997; Mukherjee and Wijk, 2003; Foster, 2013). A major benefit of these techniques is their ability to identify the presence of correlations between factors in a way that limits bias and subjectivity on the part of the researcher. Unlike tabular analysis, however, regression analysis requires that all data be measurable, a point which frequently makes its proper use considerably more difficult and costly to conduct.

While both types of sustainability assessment techniques have unique strengths and weaknesses, one common weakness is the inability to evaluate or correlate the systemic interaction of factors (Sugden, 2001; Jordan et al., 2011). This systemic interaction may be thought of as a web of factor influences that are both *direct* (Factor A influences Factor B), as well as *indirect* (Factor A influences Factor C by first influencing Factor B). Therefore, an improved evaluation of sustainability would be achieved by considering these direct and indirect interactions (Sugden, 2003). Thus, this study aimed to advance understanding and practice on rural water service sustainability in developing countries by investigating a means to assess the factors that impact sustainability using a systems-based analysis.

To accomplish this objective, the technique developed in this study exploits the aforementioned strengths of both tabular and regression analysis by first collecting and analyzing case study data to find and score factors, and then uses these data to probabilistically identify systemic factor interaction and impact through graphical modeling and network analysis. More specifically, this study used qualitative and quantitative data analysis methods that culminated with *graphical modeling* to display the systemic interaction of influential factors in the form of *factor networks* . The techniques presented in this paper are demonstrated using a case study of rural water service functionality in Darío and Terrabona, Nicaragua. In this research, the term sustainability is reframed as the *long-term service functionality* of a particular type of water supply technology, based on water quality and service reliability. The following research questions that guided these research efforts were:

- RQ1: What are the factors that influence long-term functionality of rural water services in communities in Terrabona and Darío Nicaragua?
- RQ2: How do these factors form interconnected networks?
- RQ3: Based on an understanding of factor interaction as a network, what are the most important factors for long-term functionality of rural water services in Darío and Terrabona?
- RQ4: How do factor networks differ between Darío and Terrabona, and what do these differences show?

To answer these questions, data was obtained using semi-structured interviews with community water committee (CWC) members in charge of water system operation and maintenance in Darío and Terrabona Nicaragua. Interviews were first analyzed to identify recurring factors that appeared influential to long-term water service functionality. Graphical models then were used to graphically represent conditionally-dependent connections that existed between these factors as a way to build factor networks. Factor networks were then structurally analyzed using *point* and *graph betweenness centrality* measures to identify impact factors based on their overall connectivity within the network. These impact factors were then used to inform potential program strategies for rural water services in Darío and Terrabona.

2. Research methodology

This research employed a multi-method approach that culminates with graphical modeling to build factor networks, and used network analysis to structurally analyze these networks to find the most impactful factors on long-term water service functionality in Darío and Terrabona, Nicaragua. The requirements for graphical modeling and network analysis guided the selection of the research methods. First, interviews and community water system assessments were conducted with CWCs in Darío and Terrabona, Nicaragua. Second, these data were qualitatively coded to identify pertinent factors (addressing RQ1), which were then quantitatively categorized as binary variables to aid in graphical modeling. Third, these data were entered into a graphical modeling software, which iteratively built dependence graphs to display the interaction of factors within factor networks for both Darío and