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Why do water quality monitoring programs succeed or fail? A qualitative comparative analysis of regulated testing systems in sub-Saharan Africa

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ABSTRACT

Background: Water quality testing is critical for guiding water safety management and ensuring public health. In many settings, however, water suppliers and surveillance agencies do not meet regulatory requirements for testing frequencies. This study examines the conditions that promote successful water quality monitoring in Africa, with the goal of providing evidence for strengthening regulated water quality testing programs.

Methods and findings: We compared monitoring programs among 26 regulated water suppliers and surveillance agencies across six African countries. These institutions submitted monthly water quality testing results over 18 months. We also collected qualitative data on the conditions that influenced testing performance via approximately 821 h of semi-structured interviews and observations. Based on our qualitative data, we developed the Water Capacity Rating Diagnostic (WaterCaRD) to establish a scoring framework for evaluating the effects of the following conditions on testing performance: *accountability*, *staffing*, *program structure*, *finances*, and *equipment & services*. We summarized the qualitative data into case studies for each of the 26 institutions and then used the case studies to score the institutions against the conditions captured in WaterCaRD. Subsequently, we applied fuzzy-set Qualitative Comparative Analysis (fsQCA) to compare these scores against performance outcomes for water quality testing. We defined the performance outcomes as the proportion of testing Targets Achieved (outcome 1) and Testing Consistency (outcome 2) based on the monthly number of microbial water quality tests conducted by each institution. Our analysis identified *motivation & leadership*, *knowledge*, *staff retention*, and *transport* as institutional conditions that were necessary for achieving monitoring targets. In addition, *equipment, procurement, infrastructure,* and *enforcement* contributed to the pathways that resulted in strong monitoring performance.

Conclusions: Our identification of institutional commitment, comprising *motivation & leadership*, *knowledge*, and *staff retention*, as a key driver of monitoring performance was not surprising: in weak regulatory environments, individuals and their motivations take-on greater importance in determining institutional and programmatic outcomes. Nevertheless, efforts to build data collection capacity in low-resource settings largely focus on supply-side interventions: the provision of infrastructure, equipment, and training sessions. Our results indicate that these interventions will continue to have limited long-term impacts and sustainability without complementary strategies for motivating or incentivizing water supply and surveillance agency managers to achieve testing goals. More broadly, our research demonstrates both an experimental approach for diagnosing the systems that underlie service provision and an analytical strategy for identifying appropriate interventions.

1. Introduction

Poor access to safe drinking water is a major cause of disease and death, particularly among young children in low-income countries. Limited supplies of drinking water and high levels of contamination are estimated to cause over 500,000 deaths per year from diarrheal disease alone; additional health concerns associated with unsafe drinking water include viral and parasitic infections, enteric dysfunction, growth

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faltering, and chemical toxicities (WHO, 2014; Prüss-Ustün et al., 2014; Liu et al., 2012).

Consequently, information about drinking water quality is essential for guiding efforts to reduce waterborne illnesses: accurate water quality data identifies high-risk water sources, determines effective water treatment methods, and contributes to the evaluation of water and sanitation improvement programs. This importance of water quality data is reflected in the framework that is proposed by the WHO/UNICEF Joint Monitoring Programme (JMP) to measure progress toward the United Nations' post-2015 Sustainable Development Goals (SDGs) for drinking water, namely SDG target 6.1, which specifies universal and equitable access to safe and affordable drinking water for all by 2030 (WHO/UNICEF, 2017).

In most countries, regulations for managing drinking water safety also specify two complementary water quality testing activities: (1) operational (or process) monitoring by licensed water suppliers; and (2) surveillance (or compliance) monitoring by an independent agency, usually responsible for public health (Rahman et al., 2011; WHO, 2011). Operational monitoring verifies the effectiveness of treatment and distribution processes and guides corrective actions. Surveillance monitoring includes oversight of regulated water supplies and the assessment of informal and community managed water sources (WHO, 2011).

Despite these established responsibilities for monitoring drinking water quality, water suppliers and surveillance agencies often do not meet regulatory requirements for testing frequencies (the number of tests conducted within a defined time period), which we refer to as water quality monitoring performance. In a previous study of 72 regulated water suppliers and surveillance agencies across 10 sub-Saharan African countries, we found that 85% conducted some microbial water quality testing, yet, only 41% achieved the testing frequencies specified by national standards (Peletz et al., 2016). Water suppliers (all of which operated in urban settings) were more likely than surveillance agencies (which were primarily active in rural areas) to comply with testing requirements. Among both suppliers and surveillance agencies, larger operations (as determined by numbers of people served, annual water quality budget, and jurisdictions at national or regional levels) were positively associated with monitoring performance (Peletz et al., 2016). In contrast, the numbers of water quality staff per population served, years in operation, independent regulation, and documented national standards were not significantly associated with performance (Peletz et al., 2016).

Other studies have identified constraints to water quality testing in low-income settings, which include poor regulatory enforcement and insufficient resources for the personnel, equipment and logistical requirements of operating water quality testing programs (Lloyd and Helmer, 1991; Steynberg, 2002; Lloyd et al., 1987). These findings underlie recommendations for strengthening regulatory enforcement and ensuring financial resources (Rahman et al., 2011; Steynberg, 2002). Additional recommendations for strengthening water safety management include increased reliance on audit-based surveillance in urban areas serviced by regulated water suppliers, and the application of Water Safety Plans to mitigate water quality risks (Rahman et al., 2011; Lloyd and Bartram, 1991; WHO, 2011).

Currently, interventions for improving water quality monitoring performance among water suppliers and surveillance agencies tend to emphasize hardware and knowledge inputs, including upgrading laboratories, supplying equipment, introducing mobile phone applications for data management, and training personnel (US EPA, 2017; African Water Association, 2017; American Chemical Society, 2015; Mistry and Lawson, 2017). In addition, multiple efforts have focused on the development of appropriate testing methods for low-resource settings (Stauber et al., 2012; Bain et al., 2012; Rahman et al., 2010).

The effectiveness of these various recommendations and interventions, however, is rarely tested, and there is limited understanding of the institutional characteristics (termed 'conditions' throughout this paper) that influence water quality monitoring performance. We hypothesized that institutional monitoring performance depends on a range of conditions that extend beyond hardware, training, and financial resources. To test our hypothesis, we applied Qualitative Comparative Analysis (QCA) methods to evaluate the relationships between multiple institutional conditions and microbial water quality testing performance among 26 water suppliers and surveillance agencies across six African countries.

QCA compares cases (e.g., institutions), using both qualitative and quantitative methods, to determine which conditions or combinations of conditions explain variations in outcomes of interest (Jordan et al., 2011, 2016; Rihoux and Ragin, 2008; McAdam et al., 2010). QCA, which is appropriate for an intermediate sample size (5–50 cases), falls between in-depth detailed case studies and large quantitative studies designed to build multivariate statistical models of average effects (McAdam et al., 2010; Kunz et al., 2015; Rihoux and Ragin, 2008). QCA is increasingly used in the water and sanitation sector (Kaminsky and Jordan, 2017): for example, to examine the conditions that influence sanitation infrastructure sustainability (Kaminsky and Javernick-will, 2014), water utility recycling (Kunz et al., 2015), school sanitation management (Chatterley et al., 2014, 2013), rural water supply system sustainability (Marks et al., 2018), and water resources management (Huntjens et al., 2011; Srinivasan et al., 2012). To our knowledge, this is the first study to apply QCA to assess the conditions that influence the performance of water quality monitoring programs. Our research objective was to provide evidence that promotes effective strategies for strengthening regulated water quality testing programs.

2. Materials and methods

2.1. Study context: Monitoring for Safe Water (MfSW)

This study was conducted under The Aquaya Institute's (Aquaya's) Monitoring for Safe Water (MfSW) research program, which studies water safety monitoring and management by regulated agencies (Peletz et al., 2016, 2013). It is important to note that the research context of the MfSW program likely influenced some of the institutional conditions and associations being studied; these program effects are specified in the Discussion section. Water suppliers and surveillance agencies that collaborated with this MfSW study established their targets for microbial water quality testing frequencies according to both government standards and local management needs (e.g., Ugandan national standards specify a minimum of one sample per month for piped systems serving < 2500 people). The MfSW program provided the collaborating institutions with the following financial inputs:

1) *Upfront capacity building grants* to fund additional testing equipment, trainings, and other scale-up costs, provided from May–November 2013.
2) *Per-test reward payments* for each microbial test conducted above baseline levels up to the institution's monthly target. These payments ranged from 5 to 30 USD per test, depending on estimated testing costs, and were provided on a monthly basis from July 2013–December 2014 (the start dates for per-test reward payments varied by institution).
3) *Bonus Payments* if MfSW institutions met testing targets from July 2013–December 2014.

We structured these grants and incentives, to lower financial barriers to better monitoring performance, and, thereby, facilitate the identification of non-financial constraints. We also calibrated the financial packages according to each collaborating institution's testing responsibilities: i.e., institutions required to test more water samples were eligible for larger grants and incentive payments. The amounts that institutions were eligible to receive ranged from USD 12,542 to 77,272.