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Piped water consumption in Ghana: A case study of temporal and spatial patterns of clean water demand relative to alternative water sources in rural small towns

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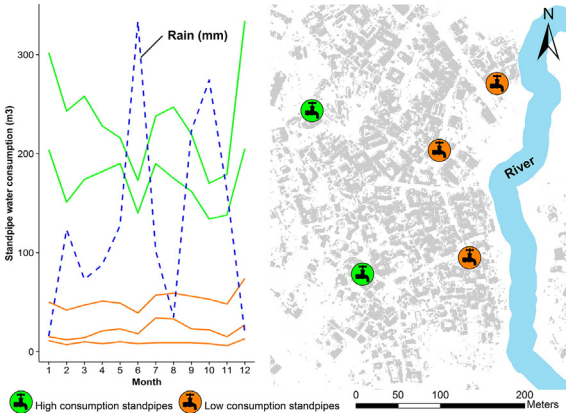
HIGHLIGHTS

- Low water demand from piped water systems results in a low revenue stream.
- Low revenue stream presents a sustainability challenge to rural water systems.
- Water consumption from piped water systems varies temporally and spatially.
- Poor aesthetic water quality as compared to alternative sources reduces piped water use.
- Increasing improved water demand is a health and sustainability priority.

GRAPHICAL ABSTRACT



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ABSTRACT

Continuous access to adequate quantities of safe water is essential for human health and socioeconomic development. Piped water systems (PWSs) are an increasingly common type of water supply in rural African small towns. We assessed temporal and spatial patterns in water consumption from public standpipes of four PWSs in Ghana in order to assess clean water demand relative to other available water sources. Low water consumption was evident in all study towns, which manifested temporally and spatially. Temporal variability in water consumption that is negatively correlated with rainfall is an indicator of rainwater preference when it is available. Furthermore, our findings show that standpipes in close proximity to alternative water sources such as streams and hand-dug wells suffer further reductions in water consumption. Qualitative data suggest that consumer demand in the study towns appears to be driven more by water quantity, accessibility, and perceived aesthetic water quality, as compared to microbiological water quality or price. In settings with chronic under-utilization

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of improved water sources, increasing water demand through household connections, improving water quality with respect to taste and appropriateness for laundry, and educating residents about health benefits of using piped water should be prioritized. Continued consumer demand and sufficient revenue generation are important attributes of a water service that ensure its function over time. Our findings suggest that analyzing water consumption of existing metered PWSs in combination with qualitative approaches may enable more efficient planning of community-based water supplies and support sustainable development.

1. Introduction

Continuous access to adequate quantities of safe water is essential for human health and socioeconomic development. Since the 1980s, African governments have been implementing piped water systems (PWSs) in order to increase water availability in rural small towns (WSP, 2010). In Ghana specifically, PWSs began to be introduced to the rural areas in the 1990s as part of the National Community Water and Sanitation Programme, with 198 new small town PWSs constructed between 1994 and 2003 (Fuest, 2005). Today, approximately 16.6% of rural Ghanaian households rely on pipe-borne water as their main water supply, with 11% obtaining water from public standpipes (SPs) and the remaining 5.6% from private or shared household connections (GSS, 2014). Despite providing the highest and most flexible level of service with better microbiological water quality as compared to other water sources used in resource poor settings (Shields et al., 2015), PWSs are still vulnerable to rural water sustainability challenges.

Functional sustainability of a rural water service, or its ability to provide the same quantity and quality of water over time (Abrams et al., 2001; Carter and Rwamwanja, 2006), among other factors, depends on a sustainable financing mechanism (Harvey and Reed, 2006; Harvey, 2007; Montgomery et al., 2009; Nyarko et al., 2007; Rogers et al., 2002). Research has shown that the vast majority of cost recovery mechanisms in low-income settings do not collect sufficient funds for operation and maintenance (O&M) of water systems, much less retain reserve funds to cover the costs of extending water services as communities grow (Harvey and Reed, 2006; Marks et al., 2014; Nyarko et al., 2007; Singh et al., 1993; Whittington et al., 2009). Low revenue streams are common due to a combination of low water tariffs and willingness to pay, low water consumption (Brikke and Rojas, 2001), and a lack of reliable accounting and auditing processes (Fuest, 2005).

In Ghana, water tariffs that generate sufficient funds for O&M and system expansion and rehabilitation (CWSA, 2014), while not exceeding 1 USD/m^3 (Nyarko et al., 2007), are desired. Ideally, tariffs should not be so high that they reduce water consumption (Hopkins et al., 2004), should reflect supply characteristics such as frequency of supply and water quality, and must be perceived as fair by the end users (Rogers et al., 2002). Apart from an appropriate water tariff, cost recovery of community-managed PWSs is affected by the local administrators' management practices (Brikke and Rojas, 2001). Water committees and town leaders are often tempted to appropriate funds generated from water sales to competing priorities such as the construction of schools, markets and sanitation facilities (Fuest, 2005; Montgomery et al., 2009).

Even in instances when appropriate water tariffs are implemented, low water consumption alone can undermine cost recovery. Variable daily water consumption rates from PWSs have been documented, ranging between 5 and 35 L per person (WSP, 2002), as compared to the 20 L per capita per day minimum recommended by the Joint Monitoring Programme (JMP) and the Ghanaian Community Water and Sanitation Agency (CWSA) to constitute "basic access" (CWSA, 2014; World Health Organization, 2015). Low water consumption from improved water sources is often attributed to a combination of seasonal and spatial patterns in water demand due to the availability of alternative traditional water sources that are free or sold at lower prices than piped water (Brikke and Rojas, 2001; Nyarko et al., 2007; WSP, 2002). A study in Rwanda found that 41% of households used rainwater as their primary water source in the rainy season as compared to 27% using improved wells (Hopkins et al., 2004), implying major temporal shifts in water consumption. Alternative water sources that are often of poorer microbiological quality are chosen for a variety of reasons, including but not limited to cost, convenience, tradition, and preference or suitability for domestic uses (Kosinski et al., 2016; Narayan-Parker, 1988; Nyong and Kanaroglou, 2001). For example, salty taste or tastelessness have been reported in the literature as disincentives for using improved groundwater sources for drinking and water hardness for laundry (DeGabriele, 2002; Fuest, 2005; Nyarko et al., 2007).

Chronically low water consumption with an accompanying low revenue stream can lead to the deterioration of water systems, causing communities to move down on the 'water ladder' (World Health Organization, 2015) and perpetuating the concept of water development in sub-Saharan Africa as a bi-directional process (Eguavoen, 2013). Conversely, high water consumption from PWSs is indicative of continued consumer demand while maximizing revenue, which in turn ensures that the service continues to function over time. In light of PWSs becoming an increasingly common type of rural water supply in sub-Saharan Africa, we studied water consumption patterns in four community-managed PWSs in the Eastern Region of Ghana through the use of water meter records. To our knowledge, no previous studies have provided similar empirical evidence of water demand in low resource settings.

The study had two primary objectives. The first objective was to assess temporal and spatial patterns in water consumption from public SPs. We hypothesized that these patterns are influenced temporally by the rainfall pattern and spatially by the distribution of the SPs and alternative water sources, normalized by the population density. The second objective was to examine how additional PWS attributes, such as perceived appropriateness of PWS water for domestic uses, relative cost, and convenience, may influence water consumption and in turn functional sustainability of the systems. The study objectives were achieved through a mixed-methods community-based approach, which included quantitative and qualitative data.

2. Methods

2.1. Study area and study design

The study was conducted in the Eastern Region of Ghana, which lies in the deciduous forest agro-ecological zone, characterized by a major and minor peak rainfall periods in June and October, respectively (Frenken, 2005). The Harmattan, a persistent prevailing wind from the Sahara region, brings dry season from November to February. In advance of the present study, our study team conducted a comprehensive survey of public water sources in 74 rural towns in the Eastern Region in 2013–2014. All towns relied on a combination of deep groundwater (boreholes or PWSs), shallow groundwater (hand-dug wells), surface water, and privately collected rainwater when available.

Of the 74 towns, seven relied on PWSs as their primary water supply. A PWS typically consists of one or more mechanized source boreholes, from which water is pumped to an overhead storage tank and distributed throughout the community through a gravity-fed network of public SPs and private household connections. At the conception of the study, all 7 PWS towns were considered for inclusion; however, preference was given to larger towns of 4000+ residents with at least 10 SPs