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Rainfall and groundwater use in rural Kenya

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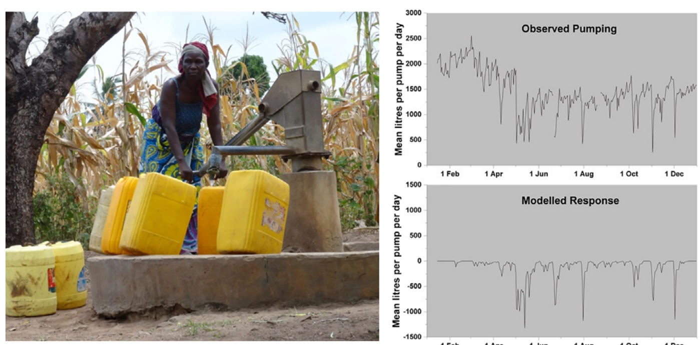
HIGHLIGHTS

- Groundwater use is inversely correlated to rainfall at seasonal and daily time-scales.
- A large short-term reduction in pumping is observed immediately following heavy rain.
- This relationship between rainfall and pumping is modelled and tested.
- The existence of improved water supplies does not guarantee their use.
- The expected health gains of rural WASH systems may not be realised.

GRAPHICAL ABSTRACT



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ABSTRACT

This study examines the relationship between rainfall and groundwater use in rural Kenya, using automatically-transmitted hourly data from handpumps ($n = 266$), daily rainfall records ($n = 19$), and household survey data ($n = 2508$). We demonstrate a 34% reduction in groundwater use during the wet season compared to the dry season, suggesting a large shift from improved to unimproved sources in the wet season. By cross-correlating handpump and rainfall time series, we also reveal substantial short-term changes in groundwater pumping observed immediately following heavy rainfall. Further investigation and modelling of this response reveals a 68% reduction in pump use on the day immediately following heavy rain.

We then investigate reasons for this behavioural response to rainfall, using survey data to examine the characteristics, concerns and behaviours of households in the area where the reduction in pump use was most marked. In this area rainwater harvesting was widespread and only 6% of households reported handpumps as their sole source of drinking water in the wet season, compared to 86% in the dry season. These findings shed light on the impact increasing rainfall variability may have on the Sustainable Development Goal of "universal and equitable access to safe and affordable drinking water for all". Specifically, we suggest a flaw in the water policy assumption that the provision of improved sources of drinking water—in this case community handpumps—translates to consistent use and the associated health benefits. We note that failure to understand and account for actual water use behaviour may results in adverse public health outcomes and maladapted WASH policy and interventions.

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1. Introduction

Rural Africans remain one of the most marginalised populations in terms of water supply, being almost four times more likely to be still reliant on unimproved sources than urban residents, and with rural on-premises supply only creeping forward from 6% in 2000 to 10% in 2015 (WHO & UNICEF, 2015). While small-piped schemes and submersible pumps are available in some places, handpumps which lift groundwater of generally reasonable quality and availability (MacDonald and Calow, 2009) remain a dominant method of supply across rural Africa. Conservative projections from work done by Sansom and Koestler (2009) suggest that there are likely to be more than half a million handpumps in Africa, potentially serving over 100 million people. Despite the SDG goal that everyone has "safely managed" water, in reality a thinly veiled reference to a piped household supply, handpumps will remain an important source of water for many millions of people for decades to come.

A systematic review of faecal contamination of drinking-water in low- and middle-income countries (Bain et al., 2014b) showed that water abstracted from boreholes did not exhibit significantly worse compliance with WHO drinking water standards than piped water, with the studies assessed averaging 35% and 33% sample non-compliance respectively. While certainly an interim or second-best solution to rural water supply, handpumps still warrant attention during the inevitably phased transition to safely managed water. Table 1 shows the WHO/UNICEF Joint Monitoring Programme's definitions for water service levels and the 2015 baseline achievement levels for Sub-Saharan Africa (WHO & UNICEF, 2017b).

Achieving further progress towards universal drinking water security could be complicated by future climate variability. A particular issue is uncertainty in the extent and nature of rainfall extremes and individual rain events, and their impact on water resources and supply systems (Hennessy et al., 1997; Shongwe et al., 2009; Shongwe et al., 2011; Trenberth et al., 2003; Owor et al., 2009; Taylor et al., 2012). Furthermore, we do not fully understand how the biophysical impacts of climate change may affect individual water use behaviour, collective action and the social systems linked to these natural systems (Tversky and Kahneman, 1981; Ostrom, 2010; Guswa et al., 2014; Foster and Hope, 2016). These uncertainties are compounded by scarcity of measured data on rural water use and on the underlying groundwater resources.

In this study we combine novel quantitative data on handpump use with traditional rainfall measurements to examine the empirical relationship between pump use and rainfall. In particular we focus on the effects of extreme rainfall events, and test the hypothesis that handpump users respond to heavy rainfall by reducing the volume of water they pump. Investigating the reasons why this may be may in turn shed light on the impact that increasing rainfall variability, likely to be experienced under climate change, could have on the recently agreed Sustainable Development Goal for "universal and equitable access to safe and affordable drinking water for all" (United Nations, 2015).

2. Study context

The study site is in Kwale County on Kenya's southern coast, around 50 km south of Mombasa. The study site covers an area of approximately 1500 km^2, with a majority rural population. It receives around 1400 mm of rainfall per year with over half the annual rainfall occurring during April, May and June. Geology in the area is variable, with karstic coral formations at the coast, transitioning into sands as elevation increases to the northwest. Population density is high along the coastal strip near the main Kenya-Tanzania highway, becoming lower inland. The urban areas by the coast are served by piped water systems, while the rural population is heavily reliant on around 600 Afridev handpumps installed between the mid-1980s and mid-1990s (Foster and Hope, 2016). This study focuses on these pumps. That Kwale is not geographically, hydrogeologically or socially homogeneous makes it a good research area and the handpump users in different parts of the county experience many of the same geographical and social problems associated with poor service provision that are observed across rural Africa.

A waterpoint mapping exercise in August 2013 recorded 571 Afridev handpumps in the study area, and collected corresponding technical, operational and social information about each pump and its users. Of these 571 pumps, 337 were identified as functional and in use, with 300 selected for the study and fitted with an experimental Waterpoint Data Transmitter (WDT). Developed at Oxford University, the WDT uses a low-cost solid-state accelerometer to sense changes in the movement of the pump handle in order to measure pump use and estimate volumetric abstraction (Thomson et al., 2012). It can be fitted to the handle of any handpump; in this case it was installed in the Afridev handle. In order to test the hypothesis that improved information can lead to faster handpump repairs the data from these transmitters were used to trigger a free maintenance service for 213 of these pumps, with 87 pumps being monitored for use and breakdown but not receiving an augmented repair service. The primary purpose of collecting these data was to inform this rapid maintenance service that succeeded in reducing average downtimes by an order of magnitude to less than two days (University of Oxford, 2014; Thomson and Koehler, 2016; Thomson et al., 2015). These transmitters also provided hourly data on water use patterns. Looking at these pump use patterns revealed an apparent relationship with rainfall. By further interrogating these data this study aims to test the hypothesis that rainfall influences handpump use, and to characterise this relationship. We then discuss the reasons for this relationship and its implications.

3. Data and methods

To examine the relationship between rainfall and pump use we used two data sources. The first was the hourly data generated by the WDTs installed in the Afridev handpumps. Of the 300 pumps selected 266 produced useful data. (Messages were lost mainly due to poor network coverage, some through vandalism and damage, and in a few cases

Table 1
UNICEF/WHO Joint Monitoring Programme service levels.

Service level	JMP definition	Sub-Saharan Africa[b]	SSA urban[b]	SSA rural[b]
"Safely managed"	Drinking water from an improved[a] water source that is located on premises, available when needed and free from faecal and priority chemical contamination.	24%	46%	0%
"Basic"	Drinking water from an improved[a] source, provided collection time is not >30 min for a round trip, including queuing.	34%	36%	43%
"Limited"	Drinking water from an improved[a] source for which collection time exceeds 30 min for a round trip, including queuing.	14%	10%	16%
"Unimproved"	Drinking water from an unprotected dug well or unprotected spring.	19%	7%	27%
"Surface water"	Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal.	10%	2%	14%

[a] Improved sources include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water.
[b] Baseline estimates (2015) for population reaching SDG service levels.