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Limited Access to Safe Drinking Water and Sanitation in Alabama's Black Belt: A Cross-Sectional Case Study

Jessica Cook Wedgworth · Joe Brown

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Abstract Anecdotal evidence from the 17-county Black Belt region of Alabama has suggested that safe-water access may be limited by piped water infrastructure problems and private well contamination, possibly resulting in degradation of water quality and therefore elevated risk of waterborne disease. On-site sanitation access is limited as well since existing approved technology options suitable for the poorly draining soils that predominate in this area are too costly for many households. We conducted a cross-sectional study of 305 households to examine (i) drinking water quality at the household level (private wells and county public supply), (ii) possible associations between water infrastructure characteristics and drinking water quality, (iii) availability of on-site sanitation, and (iv) risk of Highly Credible Gastrointestinal Illness (HCGI). Participating households completed one survey on water use, basic demographics, health, water system performance, and on-site sanitation and submitted one drinking water sample for analysis of fecal coliform (FC), turbidity, pH, and total and free chlorine. Approximately 8 % of public water system samples and 20 % of private well water samples were positive for FC, with 33 % of piped water supply samples lacking detectable free chlorine. We found a significant increase (OR 4.0, 95 % CI 1.3–14) in HCGI risk for individuals whose drinking water sample was positive for FC. Sanitation access was not universal, with 18 % of households lacking any means of on-site wastewater disposal. Results from this study suggest that safe-water access and on-site sanitation options may be limited in this area. Residents may be subject to increased risk of water and sanitation-related illness.

Keywords Drinking water quality · Infrastructure · Environmental health · Environmental justice

Abbreviations

HCGI	Highly Credible Gastrointestinal Illness
FC	Fecal Coliforms

Introduction

Worldwide, over 780 million people use unimproved drinking water sources (WHO/UNICEF 2012), and one study has estimated the number of people who rely on microbiologically or chemically unsafe water to be 1.8 billion, or about 28 % of the global population (Onda et al. 2012). Safe-water access is a universal basic need and has been declared a human right (UN 2002; Meier et al. 2013). Infectious diseases caused by pathogenic bacteria, viruses, and protozoan parasites are the most common and widespread health risks associated with unsafe drinking water. These problems are usually associated with lower income countries, but underserved areas of the United States may also be at risk.

In this paper, we report on a pilot, cross-sectional study of drinking water quality and on-site sanitation access in Alabama's rural Black Belt region, which faces a number of infrastructure and other challenges that may limit the public's

The authors declare that they have no conflict of interest. All studies have been approved by the IRB at the University of Alabama and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments. All persons gave their informed consent prior to their inclusion in the study.

J. Cook Wedgworth (✉) · J. Brown
University of Alabama, Department of Biological Sciences, Box 870344, Tuscaloosa, AL 35487, USA
e-mail: jjcook@crimson.ua.edu

J. Brown
Department of Disease Control, London School of Hygiene & Tropical Medicine, London WC1E 7HT, UK

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access to safe drinking water. This study aimed to examine: (i) drinking water quality at the household level (both private wells and county public supply) across randomly selected households in one rural, Black Belt county; (ii) possible associations between water infrastructure and household-level characteristics and drinking water quality; (iii) availability of on-site sanitation; and (iv) overall risk of Highly Credible Gastrointestinal Illness (HCGI) in the study population. This initial study was intended to provide baseline and hypothesis generating data for a broader assessment of drinking water infrastructure and risk in the region.

Study Setting

The Black Belt is a geographically distinct region that stretches across the Southeastern United States including parts of the Deep South (Washington 1901; Wimberley et al. 1997). Despite being culturally and historically rich and diverse, the Black Belt is also partly characterized by endemic poverty, high rates of unemployment, and lower than average access to infrastructure and health services (Wimberley and Morris 2002). Most Deep South Black Belt residents are African-American. Indicators of poor health and poor access to care such as infant mortality (ARHA and ADPH 2004; Sanspree et al. 2008; Rosenblatt et al. 2001), prevalence of noncommunicable diseases (Howard et al. 2007; Voeks et al. 2008), and prevalence of HIV/AIDS (Lichtenstein 2007) are all elevated in the region and may be locally very high relative to the rest of the United States.

Safe-Water Access

In Alabama's Black Belt, groundwater is the source of most residents' water, either from private wells or as the source for distribution systems. According to the Alabama Department of Public Health (ADPH), microbial contamination of groundwater is widespread, a fact that has been linked with failing septic systems in the area (Liu et al. 2005). A 2003 study found that 46 % of 175 wells tested were positive for fecal indicator microbes. The same study estimated that 40 % of septic systems in Alabama had failed or were in need of repair in 2003, and an estimated 340,000 low-income people in rural Alabama were at elevated risk of waterborne disease due to contamination of groundwater from failing septic systems (ADPH 2009). In 1997, ADPH estimated that 90 % of septic systems in the Black Belt were failing as a result of the local geology (contributing to widespread areas of low soil permeability) and poor maintenance of on-site wastewater systems.

Methods

This study was conducted over a 10 month period from October 2008 and ending July 2009. The study design was cross-sectional and observational with the purpose of collecting data on potential problems reported by residents and identifying potential linkages between water quality, system performance, and health outcomes.

Participating households were selected at random in a geographically defined study area (one county). All households within the county were eligible for inclusion in the study. Residents used either a public, county water supply system (from groundwater) or an on-site well. Nine (approximately 3 %) of the households we initially approached declined to be included in this study. The population averaged 2.76 individuals per household, and the median age of the residents was 40 years (U.S. Census Bureau 2010). Methods for household recruitment and informed consent were reviewed and approved by the Institutional Review Board of the University of Alabama.

We collected water samples from household taps for analysis. Water quality parameters tested were fecal coliforms (FC), pH, free and total chlorine, and turbidity. Testing for FC was completed in the laboratory via membrane filtration followed by incubation at 44.5 °C on membrane lauryl sulfate broth (MLSB) media, in accordance with Method 9222 in *Standard Methods for the Examination of Water and Wastewater* (Clesceri et al. 2012). Fecal coliforms were recognized by their ability to produce a color change from red to yellow and concentrations were reported as colony forming units (CFU) per 100 ml.

pH and free and total chlorine were tested at the point of sampling using a chlorine/pH test kit and diethyl-p-phenylene diamine 1 and 3 (DPD1 and DPD3) tablets (Taylor Technologies, Sparks, MD). All participants received a water quality report for participation in the study.

We collected individual and household-level data via a researcher-administered survey covering household demographics, socio-economic status, drinking water source characteristics and perceptions, use and handling of drinking water, and household sanitation. Individual-level health data were collected for all members of the household using the previously described metric of Highly Credible Gastrointestinal Illness (HCGI) (Payment et al. 1991; Colford et al. 2005) with a recall period of 7 days. For the purpose of this study, an episode of HCGI was defined as: (i) vomiting, (ii) diarrhea, (iii) diarrhea and abdominal cramps, (iv) or nausea and abdominal cramps. Surveys and water quality data were entered regularly into a Microsoft Excel spreadsheet or Microsoft Access database and copied into Stata (version 8.1).

Observational and survey data collection at household visits were transcribed from questionnaires and double-entered into Microsoft Excel, then copied to Stata (version 8.1) for analysis. We calculated descriptive statistics and examined the water quality data for associations with measured variables. We performed logistic regression reporting odds ratios using presence of fecal coliform in the

Table 1 Selected water source characteristics and calculated associations with presence of fecal coliform in household-level drinking water samples

	FC < 1 cfu/100 ml	FC ≥ 1 cfu/100 ml	OR (95 % CI)	*p*-Value
Number of households	263	42	–	–
Connected to system	182	16	0.27 (0.14–0.54)	<0.001
Well users	46	20	4.3 (2.16–8.50)	<0.001
On-site septic tank	172	28	0.51 (0.064–4.1)	0.528
No or unknown sanitation	51	9	2.72 (0.80–9.31)	0.109
Reported "poor or very poor"				
Taste	21	3	0.89 (0.25–3.10	0.851
Odor	20	1	0.30 (0.039–2.3)	0.242
Color	23	3	0.80 (0.23–2.8)	0.730
Clarity	18	1	0.33 (0.043–2.6)	0.290
Perceived safety	12	1	0.51 (0.065–4.03)	0.523
Intermittent service (piped supply only)	23	2	0.52 (0.12–2.3)	0.390
Functional problems, well	6	4	4.5 (1.2–16.7)	0.024
Free chlorine between 0.2 and 2 mg/l	146	7	0.16 (0.069–0.37)	<0.001
Mean free chlorine (mg/l)	0.69	0.16	–	–

household-level water sample as a binary outcome variable, with covariates tested for independent associations with this outcome.

Results

This study included 305 households: 462 individual participants, 56 % female, 80 % African-American. 20 % of all participants reported their combined household income to be less than $20,000.

Of the 305 water samples we collected, 42 (13.8 % of all samples) were found to contain ≥1 cfu/100 ml FC (Table 1). Of the 42 positive samples, 27 were from county supply connections and 23 were from private wells. Twenty percent (23) of all well user water samples were positive for fecal coliforms. Greater than 33 % of samples from the county water supply system did not contain detectable levels of free chlorine (<0.1 mg/l). Also, greater than 50 % of samples from the county system had levels of free chlorine exceeding 0.5 mg/l, a level which may result in strong taste. 21 (18 %) of well samples were found to have a pH under 6.5, although 89 % of all samples were within the normal range of pH in drinking water, 6.5–8.5.

We asked households connected to the water supply system about their perceptions of water system performance and aesthetic concerns. 37 % of county water customers said that they experienced problems with their connection, most commonly intermittent service, with 13.6 % of all county supply participants reported service interruptions as a recurring issue. 18 % of county water users rated the color of their water poor or very poor, and 12 % rated the taste poor or very poor.

Well users were also asked to give details about their well. 62 % (73) of all well users had a deep well with an average user-estimated depth of 250 feet. 68 % of well users said that they did not experience any problems with their well. Of the 32 % that did experience problems, odor was the most common. Less than 1 % of well users ranked the color of their water poor or very poor, and 8.7 % rated the taste of their water poor or very poor.

We asked a subset of participating households about access to sanitation ($n = 264$). Of the county customers ($n = 198$), 139 (70 %) had septic tanks, and 47 (24 %) reported that they did not have a septic tank or that they did not know what kind of sanitation system was in place. Of the well users ($n = 66$), 53 (80 %) reported having septic tanks and 13 (20 %) reported that they did not have a septic tank or they did not know what kind of sanitation system was in place. A minority of households both county customers and well users combined ($n = 13$) (4 %) had access to a municipal piped sewerage system. Households without septic tanks or a connection to piped sewerage (18 %) discharged untreated domestic wastewater to open ditches, pits, or other surfaces.

17 people reported HCGI that could not be explained by any of the pre-existing conditions we asked about. When comparing risk of HCGI among households, we found that those whose drinking water found to contain ≥1 cfu/100 ml of fecal coliform (FC) were more than three times as likely to have also reported HCGI in the previous 7 days as those whose water sample was negative for FC (<1 cfu/100 ml) and that this result was a statistically significant increase at

Table 2 Symptom data by exposure group and logistic regression output

	FC < 1 cfu/100 ml	FC ≥ 1 cfu/100 ml	OR (95 % CI)	*p*-Value
Number of people	450	57	–	–
Mean age	34.7	37.1	–	–
Self-reported symptoms, 7 day recall				
Diarrhea	6	4	5.6 (1.5–20)	0.009
Abdominal cramps	11	2	1.5 (0.31–6.7)	0.634
Nausea	10	3	2.4 (0.65–9.2)	0.185
Vomiting	7	1	1.1 (0.14–9.4)	0.910
Fever	5	4	6.7 (1.8–26)	0.006
HCGI*	8	4	4.0 (1.2–14)	0.027

*Excluding explanatory factors such as pre-existing conditions (Chrohn's Disease, Diverticulitis, Heartburn, Irritable Bowel Syndrome, Milk Intolerance, Stomach Ulcer, Ulcerative Colitis, Migraine)

the $\alpha = 0.05$ level (OR 4.1, 95 % CI 1.3–13.0). No statistically significant differences were identified when comparing HCGI outcomes between those served by the county supply system and private wells, or when stratifying by age, sex, race or other demographic factors. An initial analysis of these data also indicates a possible association between household that reported problems with the water supply system (intermittent service, service outages, muddy water, poor tasting or smelling water) and HCGI (OR 8.0, 95 % CI 1.0–61). Although the limited sample size does not permit a more sophisticated analysis, these data are suggestive of a link between water quality and water system attributes and reported health outcomes.

Discussion

Our pilot data suggest that safe-water access may be limited in our study area: 13.8 % of all drinking water samples were positive for fecal coliform, and one-third of samples from the county supply system did not contain detectable free chlorine at the time of sampling. The applicable standard for drinking water is <1 cfu total coliform in a 100 ml sample (we used the more specific fecal coliform) and 0.3–0.5 mg/l is the EPA-recommended range for free chlorine residual at the household level (USEPA 2002) to protect against recontamination. Although our data on system performance are limited to subjective self-report from participating households, the relatively high prevalence of reported issues such as intermittent service, high turbidity, and aesthetically displeasing water are cause for concern and further investigation. These may be indicative of system infiltration or contamination between water source and point of use.

73 people reported that they had at least one of the following pre-existing conditions: diverticulitis, heartburn, irritable bowel syndrome, milk intolerance, stomach ulcer, colitis, or migraine. HCGI was scored as positive for only the participants whose symptoms had no other known origin. When the risk of HCGI was compared among households we found a statistically significant increase in the likelihood of reporting HCGI if the participant's water sample was FC positive (OR 4.0, 95 % CI 1.2–14, Table 2).

Although small-scale, decentralized, or rural systems may be particularly susceptible to water quality problems (ADPH 2009) and have been linked to a disproportionate number of disease outbreaks (Sobsey 2006) and health-related violations, we cannot and do not causally attribute the household-level water quality data we report to system age, management, operation, or maintenance. We took household-level water quality samples directly from taps without sterilizing them, leaving open the possibility that any source of detected contamination was in the domestic environment, and not from the source or distribution system. This is certainly the case also for households using on-site wells. Our subsequent data in this study area have focused on microbial source tracking to determine possible origins of microbes detected in household-level drinking water samples (data not shown). These data will help identify possible transmission routes of fecal-oral pathogens and refine options for control measures either at household or system levels. Previous studies have identified poorly performing, failing, or lack of on-site wastewater containment as potential sources of contamination for household drinking water, but to our knowledge this has not been demonstrated in a field setting in this area (He et al. 2011; Liu et al. 2005; ADPH 2009). The dearth of on-site wastewater options for this challenging economic and geological context has resulted in a documented high percentage of failing systems (ibid.) and alarming numbers of households with no wastewater handling or containment technology in place at all. Although no other systematic survey has attempted to estimate the number of households lacking wastewater containment in this area, reports in the popular media of enforcement actions leading to the arrest of residents whose wastewater is not contained (US Water News 2002) suggest that this is not an isolated problem. Media reports describing the arrest of indigent people from Alabama's Black Belt for discharging wastewater due to absent or failing septic systems were cited in a recent report (UN 2011) by the United Nations Special Rapporteur on the Human Right to Safe Drinking Water and Sanitation. The same report stated that the "most common on-site wastewater alternative ranges in price from $6,000 to as much as $30,000" in the area. Unfortunately, standard technologies for properly handling on-site sanitation in areas with low infiltration or "perc" rates (Duran 1997) are too expensive to be practical for many living in this region, which is among the poorest in the USA with a high percentage of the population living below the federal poverty line (Wimberley and Morris 2002). Although grants and assistance may be available for some residents, options were not widely known among residents in our survey. The practical alternatives facing local decision makers seem to be to allow wastewater discharges, at risk to public health and safety, or evict people from their homes with nowhere to go. There is a clear need in this context for innovative approaches to low-cost on-site sanitation, policy measures that increase access to available options for households who can least afford them, and sensitivity among regulators and other stakeholders to the real structural and environmental constraints limiting sanitation access.

Wilson et al. (2008) wrote that "small southern towns show common environmental issues that are currently either understudied or completely neglected by researchers." Our decision to study safe drinking water and sanitation in this context was initially driven wholly by community requests due to ongoing and widespread concerns about the access to and safety of water supplies and sanitation. An unpublished 2007–2008 survey of water access in the community by one of our local non-profit partners revealed that 24 % of the total population did not have domestic water service, with unconnected households generally relying on wells not subject to water quality monitoring. At the time of the survey, connection costs for domestic water services were $475 for mobile homes and $425 for site-built homes, an unaffordable fee for many households in the area. The persistent and interconnected problems of access to water remain understudied, and the public health costs to communities could be high.

This study has a number of known limitations. First, we used household-reported system performance data, which are highly subjective and may have been under- or over-reported by residents. We also used self-reported symptom data with a 7-day recall period to estimate the prevalence of HCGI in this cohort. Self-reported health data are subject to recall bias and therefore may be less reliable than clinical or objectively verifiable measures. Second, this study is a cross-sectional study, presenting a limited snapshot of the area of interest. Although the geographical size of the study area was large (one county), we cannot conclude that these results are applicable across the region or even in adjacent areas that may include similar characteristics. As a cross-sectional study, we could not include factors that may be changing over time. Third, as a pilot study with limited seed funding, we were only able to include 305 households, which limited the sophistication of our analysis for exploring associations between the variables of interest. Although we did not identify any confounders among the variables we included in our study by using an *a priori* 10 % change-in-estimate-of-effect criterion in forward addition and backward elimination of covariates to the regression model, the limited sample size precludes a more sophisticated analysis of confounding.

Conclusion

In this pilot study, we provide initial evidence suggestive of inadequate access to safe drinking water and sanitation in one area of Alabama's Black Belt, at one point in time. Although we cannot generalize from these limited results, the characteristics that define this area are shared across the region. Limited access to water and sanitation may not be unique to this study setting. More research is needed to identify the challenges faced by local utilities, characterize any public health implications of inadequate water supply infrastructure and sanitation options, and develop low-cost strategies for risk mitigation, including acceptable low-cost options for decentralized sanitation in areas where soils are unsuitable for traditional systems. Underserved communities may lack the resources to study and develop innovative solutions for these problems without outside assistance.

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