Water quality associated public health risk in Bo, Sierra Leone

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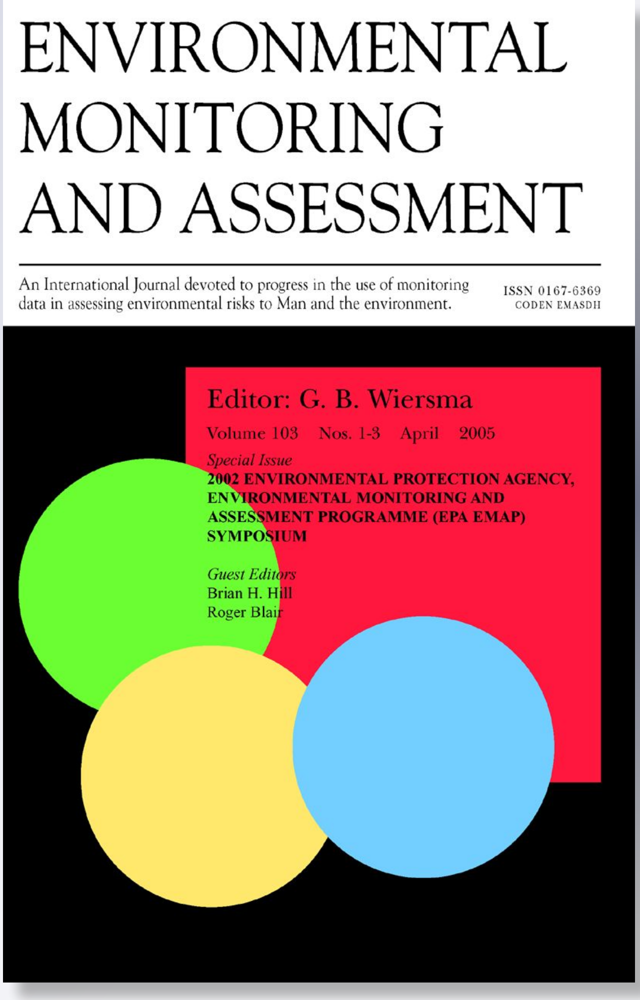

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Abstract Human health depends on reliable access to safe drinking water, but in many developing countries only a limited number of wells and boreholes are available. Many of these water resources are contaminated with biological or chemical pollutants. The goal of this study was to examine water access and quality in urban Bo, Sierra Leone. A health census and community mapping project in one neighborhood in Bo identified the 36 water sources used by the community. A water sample was taken from each water source and tested for a variety of microbiological and physicochemical substances. Only 38.9% of the water sources met World Health Organization (WHO) microbial safety requirements based on fecal coliform levels. Physiochemical analysis indicated that the majority (91.7%) of the water sources met the requirements set by the WHO. In combination, 25% of these water resources met safe drinking water criteria. No variables associated with wells were statistically significant predictors of contamination. This study indicated that fecal contamination is the greatest health risk associated with drinking water. There is a need to raise hygiene awareness and implement inexpensive methods to reduce fecal contamination and improve drinking water safety in Bo, Sierra Leone.

Keywords Groundwater · Water resources · Waterborne diseases · Microbiology · Physicochemistry · Sierra Leone

Introduction

Inadequate access to water and sanitation is one of the leading contributors to mortality worldwide, with

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Abu J. Sundufu and Anthony P. Malanoski contributed equally to this manuscript.

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millions of residents of developing countries dying of diarrhea and other water-related diseases every year (Prüss-Üstün et al. 2008). More than 80% of the residents of low-income countries use groundwater for drinking purposes (Pedley and Howard 1997). Groundwater systems are prone to contamination with biological and chemical substances as a result of poorly protected wellheads, unlined or poor-quality wells, or seepage from latrines or sewers that reach aquifers and the water table (Pedley and Howard 1997; Howard et al. 2003). The main concern of biological contamination is waterborne pathogens, such as bacteria, viruses, protozoa, and helminthic parasites, which pose widespread risks to health when drinking water that is untreated or insufficiently treated (Savichtcheva and Okabe 2006). Tests for the presence of *Escherichia coli* and fecal coliform are used as indicators of bacteriological contamination (Edge and Hill 2007; Cabral 2010; Foppen and Schijven 2005; Howard et al. 2003; Muniesa et al. 2006; Personne et al. 1998; Powell et al. 2003; Schets et al. 2005; van Lieverloo et al. 2007; Kozuskanich et al. 2011; Savichtcheva and Okabe 2006). In addition to microbiological contamination, chemical substances in water, such as fluoride, nitrates, arsenic, and lead and other heavy metals, can also have adverse health effects (Prüss-Üstün et al. 2008; Reimann and Banks 2004; Islam et al. 2000). Tests for the presence or absence of these substances provide information about the chemical quality of water (Mukhtar and Tahir 2007; Reimann and Banks 2004).

In Sierra Leone, a lack of water quality and sanitation are major problems in both rural and urban areas. Significant efforts were made by the national government of Sierra Leone to increase access to safe drinking water and sanitation facilities after independence in 1961 and during the International Drinking Water and Sanitation Decade (1981–1990) (Donkor et al. 2007). During these years the Water Supply Division of the Ministry of Energy and Power was responsible for water supply and sanitation outside Freetown, while the Guma Valley Water Company supplied the city of Freetown and its environs. A civil conflict in Sierra Leone from 1991–2001 forced large numbers of internally displaced persons to seek refuge in the cities and larger towns that were seen as safer than their home communities (Kallon 2008). After the conflict, the Sierra Leone Water Company was established to oversee the water supply and sanitation situation nationwide outside Freetown (Donkor et al. 2007). Despite these efforts, there is still little or no access to pipeborne water and adequate sanitation in many communities. Alternative sources of water, such as rainwater and ground water, have become the primary sources of drinking water for many people living in new, unplanned urban and peri-urban settlements and in rural areas. Pit toilets are the most common sanitation facilities since there is no sewer system in most areas in Sierra Leone.

Internal migration caused by the civil conflict led to the doubling of the population of the city of Bo, which is now the second largest metropolitan area in Sierra Leone, with about 150,000 residents in the city (Koroma et al. 2006). The Kulanda Town community, located on the northern edge of Bo, became one of the major destinations for internally displaced persons, and the population has doubled in the past seven years (Ansumana et al. 2010). Prior to the increase in population, Kulanda Town had little access to protected water sources and latrines. Population growth has further strained the basic services available in this overcrowded settlement. In total, Kulanda Town has a population of about 3,894 persons in 637 households residing in 197 residential structures (Ansumana et al. 2010). Residents mostly rely on groundwater for their domestic water uses. At present, access to safe drinking water is estimated to be limited to 22% of the population in Sierra Leone (25% in Bo district) (Donkor et al. 2007), and there is a high incidence of water borne diseases (WHO 2006; Prüss-Üstün et al. 2008).

The goal of this research project was to assess the health risk associated with drinking water in the Kulanda Town community. In particular, we sought to identify all of the drinking water sources in the community and to assess the quality of the drinking water available from each water source. The samples were collected in September which is the wet season in Sierra Leone. Heavy rainfall can potentially leach mineral and waste materials into shallow wells (WHO 2008), so it was thought that the highest risk of microbial contamination would be during the wet season. The objective is aiming to find out the potential health risks during the worst case scenario.

Materials and methods

Water source identification A participatory geographic information system was developed and used in conjunction with a household census to enumerate the residents of Kulanda Town in Bo, Sierra Leone. The details of the study have been described elsewhere (Ansumana et al.

2010). The door-to-door health census was conducted in April 2010 after approval of the research protocol by Njala University, George Mason University, and the US Naval Research Laboratory. Participants in the household census were asked to identify the household's water resources and sanitation facilities. In total, 33 wells within Kulanda Town and three water wells outside Kulanda Town were identified as water sources. Some of these were protected wells or boreholes connected to taps, but most were unprotected, unlined hand dug wells (Table 1). A Garmin Global Positioning System was used to collect the geographical coordinates of all 36 drinking water sources and the closest toilet to the water source. The distance between two GPS coordinates is reported in meter (Table 1). ArcGIS was used to process and map the locations (Fig. 1) (Ansumana et al. 2010). Subsequent to the original data collection the distance from the GPS coordinates to regions on the maps used for farming were determined using ArcGIS tools.

Water sample collection One sample from each of the 35 water sources was collected in September 2010. One-liter plastic containers sterilized with 10% nitric acid were used in the collection process to prevent reduction or loss of target analytes. For tap water systems connected to boreholes via a reservoir, the faucet of the taps were inspected and all forms of water leaks, aerators, strainers, and debris removed, then water was run for approximately 5 min before sample collection. Water wells with hand pumps were operated to clear standing water in the water column, and the outlet pipes were sterilized with alcohol prior to sample collection. A weight of a suitable size was sterilized and attached to sampling tubes with a piece of sterilized string to collect water from water wells without hand pumps. Samples were preserved immediately upon collection with 10% HNO_3. The preserved samples were kept on ice packs to maintain a temperature of 4°C until analysis, which was completed within 10 days.

Microbiological techniques All 36 samples were tested for *E. coli*, fecal and non-fecal coliform, and turbidity (NTU) using an Oxfam DelAqua water testing kit (Guildford, UK) designed to conform to the parameters specified in *World Health Organization Guidelines for Drinking Water Quality, Volume III* (WHO 2008). Coliform levels in the water samples were determined by using the membrane-filtration technique. Three volumes of water from each sample (10, 20, and 50 ml) were measured and filtered through a membrane filter with pore size 0.45 μm in the pre-sterilized filtration unit assembly to trap any bacteria present. The filters were then placed on top of sterile absorbent pads soaked in membrane-fecal-coliform broth in pre-sterilized petri dishes and incubated for 18 to 24 h at 44°C after a 60-min resuscitation period. The formation of blue colonies on the filters indicated fecal coliforms and pink colonies indicated non-fecal coliforms. These colonies were counted and expressed per 100-ml water sample.

Physical characterization Water conductivity, pH, and total dissolved solids (TDS) were determined using a calibrated HACH portable conductivity meter (Model CO150, HACH Company, Loveland, CO), pH meters (EC10, HACH), and a total dissolved solid meter (CyberScan PC300, Wagtech WTD, Palintest House, Kingsway, Team Valley, Gateshead, Tyne and Wear, UK), respectively. The pH of the water samples were measured immediately after sampling.

Chemical techniques An HACH DR/2010 Spectrophotometer (HACH) was used according to the HACH Water Analysis Handbook (4th edition) to determine the concentration of ferrous iron (Fe^{2+}), fluoride (F^-), manganese (Mn), nitrate-nitrogen (NO_3^--N), and sulphate (SO_4^-). Ferrous iron was measured using the 1,10-phenanthroline method to prevent the oxidation of ferrous iron to ferric iron. The HACH ferrous iron reagent powder pillow was added to a 25-ml water sample in the sample cuvette. After a 3-min reaction time, the concentration of dissolved ion was measured at 255 and 510 nm. For fluoride, the sodium 2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphthalene disulfonate (SPADNS) method (Sen et al. 1998) was used to determine the concentration. A 10-ml water sample was measured into one sample cell and 10-ml deionized water into the second sample cell. About 2 ml of SPADNS solution was measured into each sample cell and a 1-min reaction time allowed. The concentration of F^- was measured at wavelength of 580 nm. For manganese, the periodate oxidation method was used to determine the concentration. A 10-ml water sample was mixed with buffer powder pillow (citrate type, HACH), then with sodium periodate powder pillow. After a 2-min reaction time, the sample was measured at a wavelength of 525 nm. Nitrate-nitrogen levels were determined

Table 1 Distribution in bacterial counts and water collection points, household information

Sample	Well depth (m)	Distance[a] (m)	Distance[b] (m)	Distance[c] (m)	Type of toilet	Use	Occupants	Fecal coliform count[d]	Water sources[e]
1	2.13	50–150	29	24	Pit	D	13	0	Unlined
2	5.79	151–500	20	160	Pit	ND	23	0	Lined
3	11.98	<50	28	135	Pit	D	35	75	Lined
4	3.66	<50	15	58	Pit	ND	59	3	Unlined
5	6.10	<50	19	41	Pit	ND	10	0	Unlined
6	7.50	<50	32	90	Pit	ND	21	0	Lined
7	4.72	50–150	35	56	Pit	ND	43	0	Unlined
8	3.35	50-150	18	151	Pit	ND	21	0	Unlined
9	10.0	151–500	77	33	Pit	D	120	0	Lined
10	3.96	<50	18	24	Pit	D	17	15	Unlined
11	2.13	50–150	07	19	Pit	D	18	35	Unlined
12	33.99	<50	51	151	Flush	D	04	10	Lined
13	7.32	50–150	20	65	Pit	D	23	10	Unlined
14	6.10	<50	30	100	Pit	ND	25	65	Unlined
15	16.98	50–150	21	55	Pit	D		0	Lined
16	6.10	151–500	11	150	Flush/pit	D	24	0	Unlined
17	2.44	<50	18	30	Pit	D	10	25	Unlined
18	1.83	151–500	27	36	Pit	D	16	35	Unlined
19	3.66	50–150	02	38	Pit	ND	11	0	Unlined
20	4.27	<50	30	70	Pit	D	21	0	Unlined
21	7.92	50–150	18	89	Flush	ND	05	35	Unlined
22	3.66	50–150	08	37	Pit	D	25	15	Unlined
23	2.44	>500	30	31	Pit	ND	46	10	Unlined
24	3.05	50–150	24	115	Pit	ND	19	0	Unlined
25	7.32	<50	32	95	Pit	ND	70	65	Unlined
26	4.08	<50	05	43	Pit	D	07	55	Unlined
27	2.59	<50	19	33	Pit	ND	25	15	Unlined
28	3.35	50–150	08	210	Pit	ND	32	0	Unlined
29	21.34	50–150	34	100	Flush/pit	D	67	35	Lined
30	2.01	>500	17	51	Pit	ND	18	55	Unlined
31	2.80	151–500	19	26	Flush	ND	24	15	Unlined
32	4.57	50–150	14	40	Pit	D	30	25	Unlined
33	1.52	<50	10	46	Pit	D	29	35	Unlined
34	5.49	<50	07	105	Pit	D	25	45	Unlined
35	20.0	<50	60	138	Pit	D	–	15	Lined
36	34.0	<50	36	178	Pit	D	45	0	Lined

"–" information is not available, *D* drinking, *ND* non-drinking

[a] House to Water source

[b] Water source to toilet facilities

[c] Water source to field

[d] The number indicated colony counts/100 ml

[e] Lined and unlined

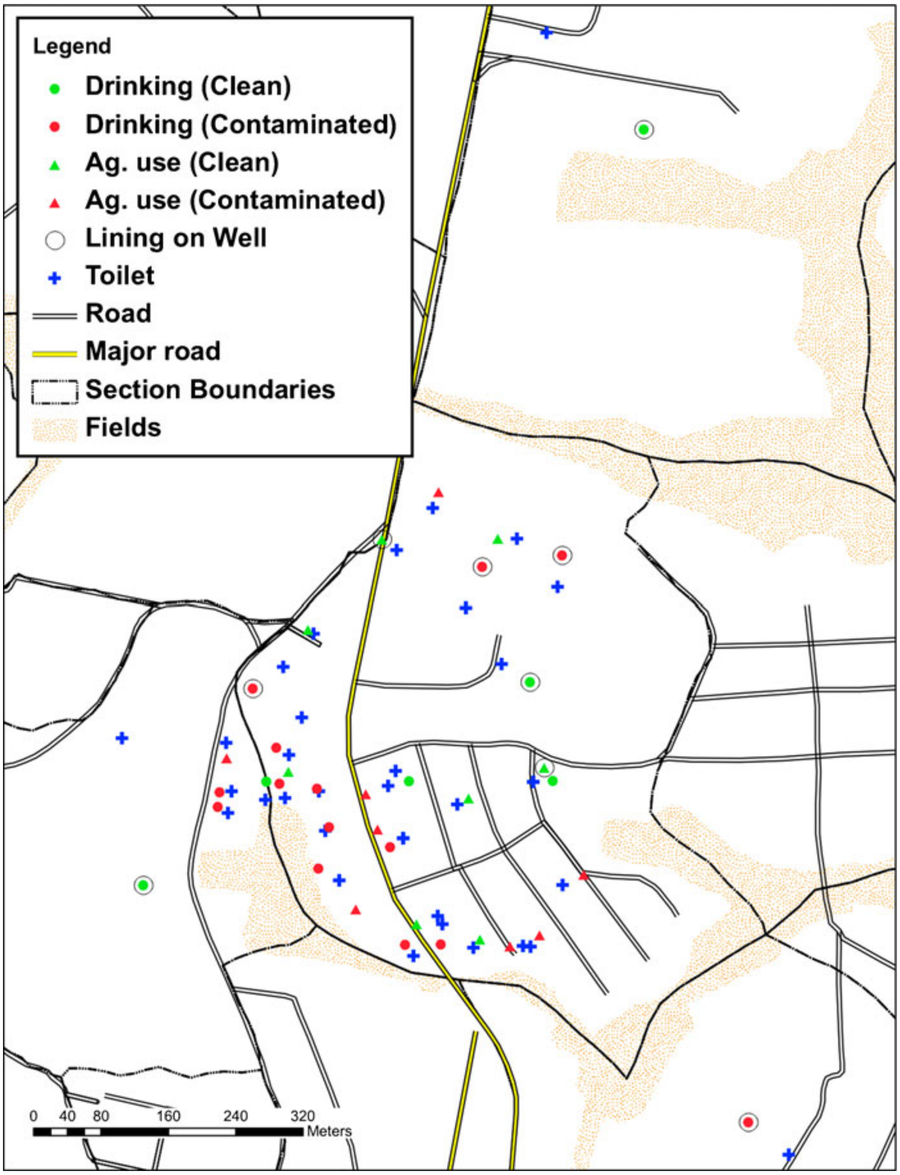

Fig. 1 Locations of all 36 drinking water sources. The *circles* represent wells that are used for drinking, and the *triangles* represent wells that are for agricultural use. The *crosses* indicate the closest toilet to each well. Clean indicates no fecal coliform in the sample. Contaminated means fecal coliform count of greater than 0 counts/100 ml

using the Cadmium Reduction Method at 400 nm (McIlvin and Altabet 2005). A 25-ml sample cell was filled with the water sample and another sample cell served as the sample blank after being filled with deionized water. The contents of one Nitra Ver 5 nitrate reagent powder pillow (HACH) were added to the cells with the water samples. After six minutes of reaction time, the NO_3^--N level was measured. A similar method was used to measure sulfate using the Sulfa Ver 4 Method (HACH) at 450 nm.

Analytical water test tablets prescribed for Palintest® Photometer 5000 (Wagtech, Thatcham, Berkshire, UK) series were used for analyzing the concentration of calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrite (NO_2^-), phosphate (PO_4^{2-}), and sulphite (SO_3^-) based on the procedures outlined in the Palintest Photometer Method.

Statistical analysis The only contaminant that was above World Health Organization (WHO) guidelines in significant numbers, fecal coliform with a count of greater than 0 counts/100 ml, was examined with statistical analysis to determine if the presence of contamination was associated with any of several household characteristics. Each household's primary well was designated with a value of 1 if contaminated and 0 if safe. The characteristics considered were the use of water from the well (drinking vs. agriculture use), the presence of an inner lining for the water well, the well depth, the number of closest household occupants, the distance between the water well and closest household's toilet facility, and the distance to a field. Chi-square contingency analysis was used when the independent variable was categorical, for example lining and use. A two sample *t* test was used in the case of distance to toilet, distance to fields and number of household members. A logistic regression analysis using the generalized linear model was also used to consider contamination against all the other variables. The R statistical analysis package was used to perform all the tests.

Results

A GPS unit was used to record the locations of the 36 wells. Figure 1 shows the results coded by several of the well characteristics. The locations of the nearest toilets were also recorded and nearby fields, which could be used for open defecation, marked. In total, 33 of 36 wells had toilets within 50 m of the well, and only 9 out of 36 were protected with a lining. The key findings of this analysis are summarized in Table 2, with additional test results listed in supplemental Table 1 in the Electronic supplementary material.

Microbiological results The presence of fecal coliform in water is conclusive evidence of fecal pollution and an indicator of the presence of other microbes (WHO 2008). None of the 36 samples tested positive for the presence of *E. coli*, but 22 samples tested positive for the presence of fecal coliform, with 18 out of these 22 samples having greater than ten counts of fecal coliform per 100 ml (Table 1). One-third of the protected wells tested positive for fecal coliform, and 70% of unprotected wells tested positive. The 16 wells reported as not used for drinking had fewer positive for microbial contamination than the 20 wells reported to be used as drinking water sources (50% of non-drinking water wells versus 70% of wells used for drinking water).

The mapping of well location and contamination gives the appearance that several different household characteristics might be predictors of contamination. Statistical analysis was performed to determine if any of these associations can be considered significant. The lowest *p* value for any of these tests was 0.06 for the distance from a field, which is above the usual significance level of 0.05. This was not a quantity originally collected and was calculated afterwards from georeferenced satellite imagery and the GPS coordinates of each well. All other tests had much larger p-values, indicating there was no significant association between contamination and household characteristics. A logistic regression analysis using the generalized linear model was run for groupings of variables, and the only variable that was indicated as significant was distance from a field. What initially appears interesting, such as less contamination of non-drinking water sources, cannot be trusted as being a true and statistically significant difference. However, the small sample size requires a conservative interpretation of this result.

Chemical results In assessing the quality of drinking water, the WHO (WHO 2008) and the US Environmental Protection Agency (EPA) (EPA 2009a, b) provide standards for several physiochemical parameters, including pH, turbidity, TDS, electrical conductivity, calcium (Ca^{2+}), ferrous iron (Fe^{2+}), fluoride (F^{-}), magnesium (Mg^{2+}), manganese (Mn), nitrate-nitrogen (NO_3^{-}-N), nitrite (NO_2^{-}), phosphate (PO_4^{2-}), sulphate (SO_4^{-}), and sulphite (SO_3^{-}).

The F^{-} concentrations ranged from 0.1 to 1.4 mg/l, with all 36 samples within the recommended range. The concentrations of NO_2^{-} ranged from 0 to 1.10 mg/l and for NO_3-N ranged from 0.9 to 28.0 mg/l. All samples were within WHO recommendations (3 mg/l for NO_2^{-} and 50 mg/l for NO_3^{-}-N) for both NO_2^{-} and NO_3^{-}-N. However, by the stricter EPA standards (1 mg/l for NO_2^{-} and 10 mg/l for NO_3^{-}-N), two samples exceeded recommended NO_2^{-} concentrations and 11 samples had excessive NO_3^{-}-N concentrations. Similarly, the concentration of manganese ranged from 0 to 0.91 mg/l, with only one sample exceeding WHO standards but 13 failing to meet EPA guidelines.

We also measured the concentration of Ca^{2+}, Fe^{2+}, Mg^{2+}, PO_4^{2-}, SO_4^{-}, and SO_3^{-}. These chemicals have no direct health concern but affect the taste and appearance of the water when present at high levels. All samples tested had values within the recommended limits or, in the absence of recommended concentrations, at very low levels. The concentrations of Ca^{2+} and Mg^{2+} determine the

Table 2 Physicochemical properties and levels of some trace metals in underground water samples

Sample	Turbidity (NTU)	TDS (mg/l)	F$^-$ (mg/l)	Mn (mg/l)	NO$_2^-$ (mg/l)	NO$_3^-$-N (mg/l)	pH[c]
1	6.8±0.06[d]	78.3±0.06	0.85±0.01	0.01±0.00	0.001±0.00	2.20±0.06	6.6±0.06
2	*0.7±0.06*	*248.3±0.06*	*1.0±0.06*	*0.91±0.01[d]*	*0.05±0.01*	*6.7±0.06*	*5.8±0.06*
3[e]	1.4±0.58	140.0±0.58	0.65±0.01	0.04±0.03	0.01±0.00	3.0±0.58	5.8±0.06
4[e]	*2.4±0.06*	*36.3±0.06*	*0.54±0.01*	*0.01±0.00*	*0.03±0.01*	*0.9±0.06*	*5.9±0.06*
5	*3.0±0.58*	*290.0±0.58*	*1.2±0.06*	*0.2±0.06[f]*	*0.08±0.01*	*8.4±0.06*	*5.7±0.06*
6	*1.6±0.06*	*55.5±0.06*	*0.55±0.06*	*0.00±0.00*	*0.00±0.00*	*1.5±0.06*	*5.5±0.06*
7	*2.6±0.06*	*386.0±0.58*	*0.62±0.01*	*0.2±0.01[f]*	*0.34±0.01*	*12.0±0.58[f]*	*5.4±0.67*
8	*1.7±0.06*	*352.0±0.06*	*1.4±0.01*	*0.2±0.01[f]*	*0.06±0.01*	*10.5±0.06[f]*	*5.8±0.06*
9	0.3±0.58	19.5±0.58	0.15±0.06	0.00±0.00	0.00±0.00	0.5±0.06	5.6±0.06
10[e]	0.9±0.06	91.0±0.06	0.95±0.06	0.02±0.02	0.00±0.00	4.4±0.58	5.3±0.58
11[e]	3.3±0.06	292.0±0.01	0.65±0.06	0.01±0.01	0.03±0.01	2.2±0.06	5.1±0.06
12[e]	0.5±0.58	25.7±0.06	0.17±0.06	0.00±0.00	0.00±0.00	1.0±0.58	5.9±0.58
13[e]	5.3±0.06	103.0±0.58	0.95±0.01	0.01±0.01	0.04±0.01	3.2±0.06	5.5±0.06
14[e]	*2.9±0.06*	*110.0±0.06*	*0.85±0.06*	*0.01±0.01*	*0.02±0.01*	*2.5±0.06*	*5.3±0.06*
15	1.5±0.06	24.4±0.01	0.10±0.01	0.01±0.01	0.03±0.01	2.0±0.06	5.2±0.58
16	4.2±0.58	24.3±0.06	0.11±0.58	0.02±0.02	0.03±0.01	2.4±0.06	5.4±0.06
17[e]	0.27±0.06	259.0±0.05	1.10±0.01	0.20±0.01[f]	0.34±0.01	17.0±0.58[f]	5.9±0.58
18[e]	1.1±0.06	381.0±0.06	1.20±0.01	0.28±0.01[f]	0.09±0.01	14.0±0.06[f]	5.7±0.58
19	*2.8±0.58*	*639.0±0.06[f]*	*1.40±0.06*	*0.35±0.01[f]*	*1.10±0.01[f]*	*25.0±0.58[f]*	*6.0±0.06*
20	1.0±0.06	48.6±0.01	0.85±0.01	0.21±0.02[f]	0.01±0.01	11.0±0.58[f]	6.3±0.06
21[e]	*0.5±0.01*	*163.0±0.01*	*0.75±0.01*	*0.21±0.02[f]*	*0.01±0.01*	*9.4±0.25*	*5.6±0.06*
22[e]	0.6±0.01	29.8±0.58	0.22±0.03	0.01±0.01	0.01±0.01	2.0±0.06	5.5±0.01
23[e]	*1.1±0.01*	*467.0±0.06*	*0.95±0.06*	*0.25±0.06[f]*	*0.03±0.01*	*19.0±0.06[f]*	*5.6±0.06*
24	*0.7±0.01*	*35.7±0.06*	*0.12±0.01*	*0.01±0.01*	*0.00±0.00*	*1.3±0.06*	*5.5±0.06*
25[e]	*2.0±0.02*	*14.3±0.01*	*0.65±0.01*	*0.00±0.00*	*0.01±0.01*	*2.4±0.06*	*5.7±0.01*
26[e]	0.5±0.01	181.0±0.01	0.96±0.01	0.01±0.01	0.02±0.02	17.0±0.06[f]	5.7±0.06
27[e]	*0.3±0.01*	*254.0±0.06*	*1.20±0.58*	*0.01±0.01*	*1.07±0.06[f]*	*28.0±0.06[f]*	*5.8±0.06*
28	*1.0±0.01*	*52.1±0.58*	*0.25±0.58*	*0.00±0.00*	*0.02±0.06*	*6.0±0.06*	*5.9±0.01*
29[e]	1.0±0.01	43.9±0.06	0.95±0.01	0.01±0.01	0.01±0.01	8.6±0.58	5.7±0.01
30[e]	*2.3±0.06*	*585.0±0.58[f]*	*1.25±0.01*	*0.21±0.02[f]*	*0.01±0.01*	*21.4±0.67[f]*	*5.8±0.06*
31[e]	*0.5±0.01*	*397.0±0.67*	*0.90±0.01*	*0.15±0.01[f]*	*0.06±0.06*	*17.0±0.06[f]*	*5.9±0.01*
32[e]	0.5±0.01	51.6±0.62	0.21±0.01	0.00±0.00	0.08±0.06	6.3±0.06	5.7±0.01
33[e]	1.9±0.58	159.0±0.58	0.55±0.01	0.05±0.01[f]	0.02±0.02	3.4±0.01	5.4±0.06
34[e]	0.3±0.06	244.0±0.58	0.62±0.01	0.02±0.02	0.02±0.02	3.2±0.01	5.6±0.06
35[e]	3.1±0.58	80.1±0.01	0.85±0.01	0.00±0.00	0.01±0.01	2.0±0.01	5.5±0.06
36	7.1±0.58[d]	47.9±0.01	0.95±0.01	0.01±0.01	0.01±0.01	1.4±0.01	5.8±0.06
Limit[a, b]	<5[a, b]	–[a]/<500[b]	1.5[a]/4[b]	0.4[a]/0.05[b]	3.0[a]/<1[b]	<50[a]/<10[b]	6.5[a, b]–9.5[a]/8.5[b]

Entries set in italics indicated that the well was not used for drinking purpose. See supplemental Table 1 in the Electronic supplementary material for details, such as well use, counts of fecal coliform, protected by lining or not

[a] Values obtained from WHO guideline for drinking water quality (2008)

[b] Values obtained from US EPA primary and secondary water regulations (2009)

[c] No health-based guideline values was proposed, only recommended optimal values

[d] The value is higher than the WHO and US EPA recommendation

[e] The well was contaminated with fecal coliform

[f] Concentration is higher than US EPA regulation but not the WHO value

water hardness. Hard water (a combined concentration of Ca^{2+} and Mg^{2+} above 200 mg/l) can cause the deposit of calcium carbonate scale after water is heated; soft water (<100 mg/l) has a lower buffering capacity. All but one of the samples tested were soft water.

Physical characteristics Although pH has no direct impact on consumers and WHO does not issue a value for pH health-based guideline, the pH of water does affect the effectiveness of water disinfection and clarification, and inappropriate levels can cause corrosion of water mains and pipes in household water systems. Failure to minimize corrosion can result in the contamination of drinking-water and adverse effects on its taste and appearance. The EPA recommends a pH of 6.5 to 8.5 (WHO 2008; EPA 2009b). The pH of the water samples from Kulanda Town ranged from 5.1 to 6.6, with all but one sample outside the recommended range.

Turbidity values are associated with the cloudiness and color of water. A high level of turbidity caused either by particulate or inorganic matter can stimulate the growth of microorganisms and lower the effectiveness of disinfection processes. Both the WHO and the US EPA recommend a turbidity of less than 5 NTU for drinking water (WHO 2008; EPA 2009b). The turbidity values of the water samples measured ranged from 0.3 to 7.1 NTU, and all but two wells were within acceptable limits (Table 1). Statistical tests were performed with the various well characteristics but no significant correlations were found.

TDS include inorganic salts, such as calcium, magnesium, potassium, and organic matter that are dissolved in water. The concentration of TDS in drinking water can vary based on local geology and geography. No TDS guidelines are provided by WHO, but the US EPA suggests 500 mg/l as the upper acceptable value (EPA 2009b; WHO 2008). The TDS ranged from 14.3 to 639.0 with all but two of the water sources in the acceptable range. Electrical conductivity, which is affected by the presence of inorganic dissolved solids, was also measured and had a range from 39.1 to 1,281.0 μs/cm. As expected, higher TDS values correlated with higher EC values (supplemental Table 1 in the Electronic supplementary material). No significant correlations with well characteristics were found.

Discussion

Across all of Sierra Leone, only 6% of households obtain drinking water from a pipe borne water supply system. In Bo district, only 1% of households obtain drinking water from a pipe borne water supply system, and about 54.5% of households obtain drinking water from protected or unprotected wells (Muana and Gegbe 2006). This study conducted a quality assessment of the main water resources in Kulanda Town, Bo, Sierra Leone. Only 38.9% of the water sources met the WHO microbial drinking water safety requirements (WHO 2008; EPA 2009a, b). Only 30% of the wells that were reported to be used as drinking water sources were found to be safe. Physicochemical contamination is much less of a concern to this population since the majority (91.7%) of the water sources met the WHO physicochemical guidelines (WHO 2008). In combination, only 25.0% of all water resources and 20.0% of the designated drinking water sources meet the WHO safe drinking water criteria for microbial and physicochemical contamination (EPA 2009a).

Microbial contamination is the greatest health risk associated with drinking water (Cabral 2010). The presence of fecal coliform in the majority of the water samples is alarming because it suggests that other potentially harmful pathogens may also be present in the water (WHO 2008; EPA 2009a). A detailed statistical analysis was carried out to determine if any characteristics of the wells were accurate predictors of contamination. None of the variables was significant, including the distance from the nearest toilet, which in other studies has been found to be a major source of fecal coliform in drinking water. It is also suggested that a deep well can protect against potential pollutions from surface discharges, however, we did not find any correlation regarding the well depth and coliform count. Information from more wells would be required to determine whether the correlation would become significant or stay non-significant. It is possible in a future study to achieve this in Bo by including sections neighboring Kulanda town over a several-month time period since the water quality may vary between dry and wet seasons, as rainfall can lead to heavy microbial contamination (Howard et al. 2003). Another consideration after the data collection was completed is that the distance to the closest toilet may not have been the correct datum to collect. It may have been more appropriate to determine the distance between a well and several toilets, as the wells are surrounded by homes, to see if wells with several potential contamination sources near them have a higher incidence of contamination. There are 97 homes, with most having a toilet, but only 36 wells.

Stricter US EPA standards were also used to evaluate the water quality. Only 41.6% of water sources met the US EPA physicochemical guidelines, mainly due to the high concentration of manganese (Table 1) (EPA 2009a, b). However, due to the presence of the microbial hazards in the majority of the water sources, physicochemical contamination is much less of a public health priority. Similarly, only 19.4% of all water resources and 20.0% of the designated drinking water sources meet the EPA safe drinking water criteria for microbial and physicochemical contamination.

The acidity of the water sources in Kulanda Town is similar to other water sources in Africa, including Uganda (Haruna et al. 2005; Bordalo and Savva-Bordalo 2007) and Guinea-Bissau (Haruna et al. 2005; Bordalo and Savva-Bordalo 2007). But studies from Ghana (Adomako et al. 2008; Fianko et al. 2010a, b; Nartey et al. 2004), Nigeria (Ejechi et al. 2007; Jaji et al. 2007; Nduka and Orisakwe 2011; Omezuruike et al. 2008), South Africa (Zamxaka et al. 2004), and Tanzania (Shayo et al. 2007) indicated that acidic water is not uniformly found throughout the continent. Water with acidic pH can cause corrosion of the metal pipes used with wells and can release those minerals into wells, potentially causing serious health problems (WHO 2008). Since the majority of the water sources in Kulanda Town are not connected to a tap, this is not a concern at the moment. However, the acidity of the water will need to be taken into account when implementing water policy to increase the accessibility of pipe borne water supply system in the future.

Conclusions

The information on water quality of the region will provide critical information for setting priorities for developing water treatment methods and directing the limited resources available to gain the maximal benefits. This study, along with other water quality assessments in Africa, indicates that moderate to heavy fecal contamination is the greatest health risk associated with drinking water (Bordalo and Savva-Bordalo 2007; Quagraine and Adokoh 2010; Howard et al. 2003; Omezuruike et al. 2008; Ayanlaja et al. 2005; Zamxaka et al. 2004; Clasen and Bastable 2003; Shayo et al. 2007) while physiochemical contamination is a less important consideration. Greater attention should be given to implementing methods to reduce fecal contamination. Inexpensive methods of water treatment, such as boiling water or adding bleach, and raising awareness of the importance of digging toilets further away from wells will greatly improve the drinking water safety in Bo, Sierra Leone as well as in other developing countries in a similar situation.

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Conflicts of interest None declared.

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