Research Paper

Water source quality in Ahenema Kokoben, Ghana

Amadu Salifu, Helen M. K. Essandoh, Afsatou Ndama Traore and Natasha Potgieter

ABSTRACT

Regular monitoring of microbial quality of water used for drinking is an important aspect of public health. Microbiological quality, using a novel microbial water quality test kit – Compartment Bag Test (CBT; AguaGenX, LLC, Chapel Hill, NC, USA), and physical parameters (pH, dissolved oxygen, turbidity, temperature and electrical conductivity) of 94 different water sources used by communities in the Ahenema Kokoben area of Ghana for drinking were tested. Using the WHO drinking water quality risk categories for the presence of *Escherichia coli* indicator bacteria, only 56% (53/94) of the water sources were safe for drinking, while 29% (27/94) of the water sources were classified as high risk and unsafe for human purposes. Some of the physical parameters were also higher than guideline values and could have been a contributing factor to poor water quality. Overall, the CBT proved to be a reliable alternative to traditional and laboratory-dependent microbial drinking water quality tests which can be easily used by water authorities to make sure that water is safe to drink.

Key words | compartment bag test, drinking water quality, *E. coli*, Ghana

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INTRODUCTION

The provision of safe and accessible drinking water is an effective pathway to health promotion and poverty reduction. Globally, approximately 844 million people still lacked the basic drinking water services (an improved source within 30 minutes' round trip) at the end of 2015 (WHO/UNICEF 2017). In sub-Saharan Africa, 319 million people (the highest in the world) are without access to improved water sources (WHO 2015) even though the Millenium Development Goal (MDG) target on drinking water was met in 2010 (WHO/UNICEF 2014). It is also acknowledged in the water sector that even improved water sources do not reliably predict microbial safety of water (McMahan *et al.* 2011; Bain *et al.* 2014; Shaheed *et al.* 2014), but are rather '*technologies with a high level of probability to deliver safe and clean drinking-water*' (WHO 2012). The Sustainable Development Goals (SDGs), especially target 6.1, therefore, hope to achieve universal and equitable access to safe and affordable drinking water for all by 2030. The assessment of microbial quality of drinking water is the next big step in the quest to meet this target (Bain *et al.* 2012).

Major microbial threats are related to the consumption of water that is contaminated with faeces from either humans or animals (Dufour *et al.* 2012). Although long-term solutions will require improvement in water quality and sanitation infrastructures, a great deal can be achieved through more frequent and widespread water quality testing

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(WHO 2012; Launch 2017). There are, however, significant challenges in implementing efficient microbial water quality tests that are appropriate for low-resource settings such as rural and peri-urban Ghana (Bain *et al.* 2012; WHO 2012). Several portable test kits have been developed for microbial water quality analysis and include Enterolert®, Colisure®, Colilert®, m-ColiBlue®, ColiComplete® and PathoScreen. However, these kits are expensive, cannot quantify indicator bacteria, are time-consuming, or require a skilled technician or laboratory setting (Bain *et al.* 2012; Gronewold *et al.* 2017). The Compartment Bag Test (CBT) overcomes such shortfalls in microbial water quality testing (Stauber *et al.* 2014). The CBT quantifies *Escherichia coli* (*E. coli*) levels in a 100 mL sample – as recommended by WHO (WHO 2008) – using a chromogenic medium. It does not require electricity and provides built-in decontamination. It is affordable, portable and self-contained, and does not require a laboratory or specialist training. It allows for incubation at ambient temperatures (25–44.5 °C) (Stauber *et al.* 2014). The CBT is designed to be used completely on-site, eliminating the costs and associated delays for refrigeration, sample transportation, and laboratory sample analysis and processing. The CBT has been compared with laboratory membrane filtration (McMahan *et al.* 2011; Stauber *et al.* 2014) and a highly rated portable test such as Colisure/Colilert Quantity tray method (Knee *et al.* 2012) where it gave comparable results (statistically insignificant difference). The CBT has so far proved to give comparable results around the world including Ghana (McMahan *et al.* 2011; Weiss *et al.* 2013; Stauber *et al.* 2014; Heitzinger *et al.* 2015; Murcott *et al.* 2015), and the statistical basis for its design as well as the recommended interpretation of its results has been formally documented (Gronewold *et al.* 2017).

Ahenema Kokoben in Ghana is a low-resource/peri-urban setting where the microbial quality of drinking water is not monitored by the central government or its representation at the district level. The first and only attempt so far by the Government of Ghana at microbial water quality monitoring is through the Ghana Living Standards Survey (Ghana Statistical Service 2014b). There is no continuous or regular monitoring in Ghana to evaluate the safety of water sources for human consumption. The objective of this study was therefore to use a fast and affordable water quality test such as the CBT test to assess water sources in Ghana which could be an answer to regular water quality monitoring.

MATERIALS AND METHODS

Study area

Ahenema Kokoben (Figure 1) is a peri-urban community in the Atwima-Kwanwoma District of the Ashanti Region (Figure 2) of Ghana (Ghana Statistical Service 2014a; Ministry of Finance 2014) and home to approximately 7,166 inhabitants (Ghana Statistical Service 2012). It is ranked 202/216 in the district league table of poverty incidence in Ghana with a poverty incidence of 4.9 (Ghana Statistical Service 2015). It is popularly known as 'The Island City' because it is surrounded by two rivers: Akebosu to the north and Aboabo to the south. The district is located at the latitude of 6°24″ N and 6°43″ N and the longitude of 1°15″ W and 1°46″ W (Ghana Statistical Service 2014a; Ministry of Finance 2014). About 45% of the total drinking water in Ghana is produced from groundwater and most of the small towns, such as Ahenema Kokoben, depend on wells for their drinking water supply (Buamah *et al.* 2008).

Sample sources

Inventory of drinking water source points in the Ahenema Kokoben community yielded a total of 123 drinking water sources. Stratified randomisation, based on water source type (yard tap, communal tap, hand dug well, borehole and spring), was used to select a total of 94 (76%) of drinking water sources to be included in the study and tested for physical and microbial parameters. The water sources comprised of eight communal taps, nine yard taps, three boreholes, 47 hand dug wells, 25 tank water and two springs (Table 1).

Sample collection

The APHA/AWWA/WEF (1999) standard method for the examination of water and wastewater (1060A) general sampling protocols was used in this study. A sampling of water was done once off during 13 days which was spread over 4 weeks. Sterilised 100 mL glass bottles were used to

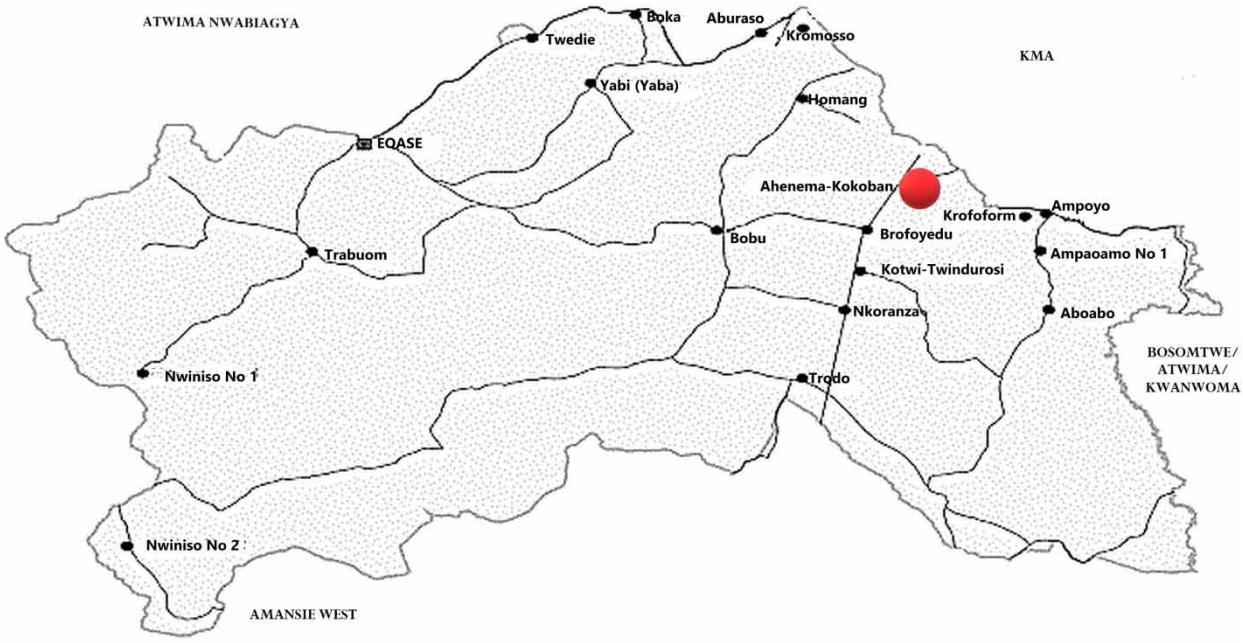

Figure 1 | Map of Atwima-Kwanwoma District (Ghana Statistical Service 2014a).

collect water samples which were then stored in an ice-chest stocked with crushed ice. The sample collection bottles were sterilised daily for re-use.

Sample testing

Physical parameter testing

Physical parameters were measured *in situ* during sample collection. They included temperature, pH, electrical conductivity (EC) and dissolved oxygen (DO). EC, pH and temperature were measured using a Eutect Multi-parameter Tester (PCSTEST35-01 × 441506/Oakton35425-01, Eutech Instruments®, Thermo Scientific Ltd, Oakton Instruments, USA). DO was measured using the Hach LDO (HQ30d), and turbidity was measured in the laboratory with a Turbidity meter (Hanna HI 93414, Hanna® Instruments, Limena, Italy). All equipment was calibrated following manufacturers' instructions.

Microbiological quality testing

The Aquagenx CBT (Aquagenx Chapel Hill, NC, USA) was used as per the manufacturer's instructions in an aseptic chamber in the Environmental Quality Engineering Laboratory of the Kwame Nkrumah University of Science and Technology. Water samples of 100 mL volume were emptied into the CBT bottles and the chromogenic medium was added. The bottles were mixed until the medium completely dissolved. This took about 15 min. The contents of the bottles were then emptied into the specially designed compartmentalised bags, making sure they were evenly distributed across all compartments. The bags were then incubated at 32 °C for 24–30 h in an incubator (Incubator Avantgarde.-Line, BD 115, Binder®, BINDER GmbH, Tuttlingen, Germany). The colour changes in the contents of the bags were noted and their corresponding MPN values read from a chart supplied by the manufacturer. Sterile distilled water samples were used for negative controls and sterile distilled water with pure *E. coli* culture was used as positive control.

Statistical analysis

Data entry was entered into Microsoft Excel spreadsheets where it was cleaned, and the Stata 14 statistical package was used for data analysis. The data were descriptive in nature including percentages, frequencies, and cross tables.

Figure 2 | District map of Ashanti Region, Ghana (Ghana Statistical Service 2015).

RESULTS AND DISCUSSION

Water source types

Water sources are grouped according to the WHO/UNICEF Joint Monitoring Programme groupings. The proportion of the various water source types is shown in Figure 3. Water storage tanks were the secondary sources and therefore not included in the WHO/UNICEF Joint Monitoring Programme classifications. The primary sources from which water tanks were filled were all improved sources (tap, borehole and dug well).

The trend (high patronage of groundwater) observed in Ahenema Kokoben is similar to what occurs in most peri-urban and rural communities in Ghana where there has been a shift from surface water to groundwater (hand-dug wells and boreholes) (Kortatsi *et al.* 2008). The majority of the drinking water sources in this study were from groundwater which is consistent with other studies in Ghana (Maxwell *et al.* 2012; Ghana Statistical Service 2014b; Ghana Statistical Service *et al.* 2015). There were '*tap water into premises*' but such dwellings were mostly gated and residents were absent during weekdays when samples were taken.

Quality of water sources

Physical characteristics

A summary of the physical characteristics of the 94 water sources is presented in Table 2. The Ghana Standard Authority (GSA)'s (Ghana Standards Authority 2013)

Table 1 | Description of water sources

Source type	Description of source type	Sample picture
Tap (yard and communal)	Both communal and yard taps were connected to the municipal water supply system which derives its source from the Barekese Dam in Kumasi. Supply is intermittent; households have to store water. Communal or public taps were shared by the whole community and were operated on a commercial basis. Yard taps were mostly shared by more than one household and located in the compound.	
Boreholes	Mostly communal or public because it is more expensive to construct. Communal boreholes were fitted with hand-pumps while privately owned ones had electric pumps.	
Hand-dug wells (protected and unprotected)	These were circular wells 5–20 m deep and may be lined or unlined. Water is generally drawn with a rope tied to a water collection bowl. The rope and the collection bowl are sometimes left outside the well or hung inside the well. Hand-dug wells are sometimes fitted with hand-pumps or electric pumps.	
Tank water	Water storage tanks were mostly employed to minimise the effect of intermittent water supply from the municipal water supply system or unreliable electricity. Water from the municipal water supply system is pumped or flows under gravity into tanks owned by households and private water vendors during periods of regular water supply. Water from hand-dug wells and boreholes, which are reliable sources, are also sometimes pumped into overhead storage tanks. Water from the tanks then flows under gravity.	
Springs	These are natural water bodies. Springs were not properly protected from animals. The natural vegetative cover was the only barrier to contamination. Bird droppings pose the greatest threat to the quality of these sources. Domestic animals such as goats and sheep rarely get to the springs.	

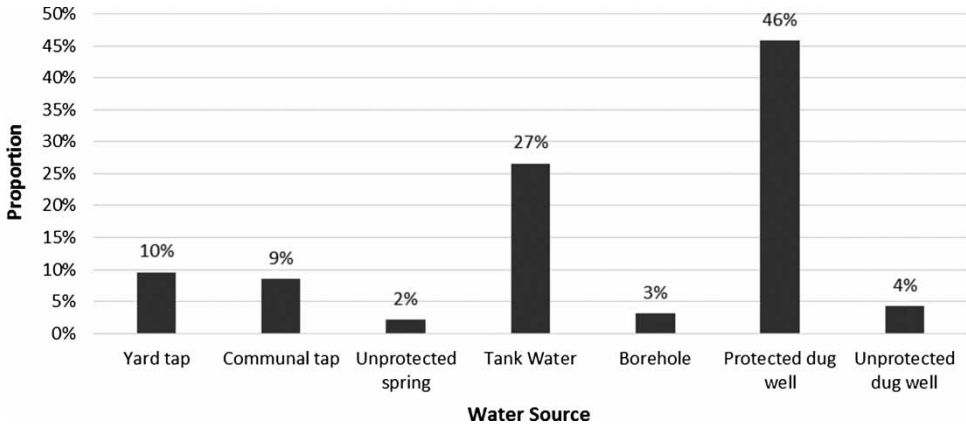

Figure 3 | Water source types in the study.

recommended that a minimum value for pH in water used for drinking purposes is between 6.5 and 8.5. In this study, the mean values for all sources were within the guideline values. There is no guideline value for temperature, although the GSA states that the temperature should not be objectionable to the consumer (Ghana Standards Authority 2013). In this study, the temperature of the water samples at the time of sampling ranged from 24.3 °C to 30.6 °C. Water temperature was determined by the following factors: (1) the time of sample collection; (2) the weather conditions at the time of sample collection; and (3) the type of water source. The time of sampling spun from mornings till noon which affected temperature readings. Water temperature from the sources at the time of sampling (24.3–30.6 °C) was suitable for *E. coli* activity and its possible growth (WHO 2003, 2004; Sakyi & Asare 2012).

No source water recorded an EC reading above the WHO/GSA guideline value of 1,000 μS/cm (Ghana Standards Authority 2013). Groundwater sources recorded high EC values probably due to the dissolution of elements which occur naturally in the earth into groundwater. Nkansah *et al.* (2010) who only looked at hand-dug wells in the Kumasi Metropolis of the Ashanti Region of Ghana also found all measurements meeting the WHO/GSA guideline value. No health-based guideline value is recommended for DO (WHO 2011). Yard tap, followed by communal tap and water tanks, had the highest DO (9 mg/L) and boreholes had the lowest DO of 3 mg/L. Tap water in the study area is from a central water treatment plant (Barekese Treatment plant), which improves DO content through aeration. Besides, raw water for the treatment plant is sourced from surface water which generally has relatively higher DO content than groundwater. Boreholes being narrow, are least exposed to atmospheric oxygen and hence generally have low DO. Unprotected dug wells are prone to the introduction of microorganisms which deplete the limited oxygen in water resulting in low DO content of such sources (Penn *et al.* 2009; Ukpaka 2013).

The GSA guideline for turbidity is 5 NTU (Ghana Standards Authority 2013). Turbidity in water is caused by the presence of suspended materials like clay, silt, and fine particles of organic and inorganic matter (Ukpaka 2013). In this study, maximum turbidity values recorded were 1.3 NTU for tap water and 18.1 NTU for unprotected dug wells. Unprotected dug wells had the highest mean turbidity (8.3 NTU), which is consistent with a study done by Sorlini *et al.* (2013). While water of high turbidity may not adversely affect health, it reduces the efficacy of disinfectants (Boamah *et al.* 2011). Higher turbidity values were most probably due to the wearing of the lining of the wells. Unprotected dug wells, additionally, could be contaminated due to debris carried by the wind (Dekker *et al.* 2015).

Microbial quality of water sources

The drinking water source test results from the CBT tests are shown in Table 3 and categorised following the WHO microbial water quality risk categories. A total of 56% (53/94) of the water sources tested were negative for any

Table 2 | Physical parameters of water sources

Water source	pH				Temperature (°C)				Electrical conductivity (μS/cm^{-1})				Dissolved oxygen (mg/L)				Turbidity (NTU)			
	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD	Mean	Min	Max	SD
Yard tap ($n = 9$)	7.3	6.6	7.9	0.5	27.1	26.1	28.3	0.7	151	136	169	11	7	6	9	0.7	0.9	0.5	1.3	0.3
Communal tap ($n = 8$)	7.1	6.8	7.4	0.2	28.3	26.6	30.6	1.4	152	143	165	8	7	7	8	0.3	0.8	0.4	1.5	0.3
Unprotected spring ($n = 2$)	7.5	7.5	7.5	0	25.9	24.9	26.8	1.3	212	165	258	66	3	1	6	3	9.3	0.98	17.7	11.8
Tank water ($n = 25$)	6.9	6.4	7.8	0.4	27.6	24.3	30.1	1.5	116	37	322	74	6	4	8	1	1.7	0.2	17.7	3.6
Borehole water ($n = 3$)	7.2	7	7.4	0.2	27.6	27.1	28.1	0.5	241	123	374	126	3	2	3	0.6	5.2	0.4	13.7	7.4
Protected dug well ($n = 43$)	6.8	5.7	7.7	0.49	27.4	26.5	28.6	0.5	152	39	557	108	4	2	6	0.9	1.7	0.1	8.3	1.8
Unprotected dug well ($n = 4$)	7.1	6.8	7.3	0.3	27.4	26.8	28.2	0.6	315	72	500	218	3	2	4	0.7	8.3	3	18.1	7.1

presence of *E. coli* bacteria and was categorised as safe according to the WHO/GSA standard of 0 MPN/100 mL for *E. coli*. Tap water (communal and yard) were generally safe (McGarvey *et al.* 2008). This was expected as the water treatment process at the Barekese Treatment plant includes a disinfection step which leaves the water with some residual chlorine. Chlorine residual in tap water aims at ensuring microbial safety at the point of use and contamination usually happens during transmission through pipe bursts and seepage through loose joints to consumers or at the point of collection of water (Shaheed *et al.* 2014). Tank water was generally safe to drink; however, some of the samples did have contamination which could have been due to water stagnation, sedimentation and poor pipes (Shaheed *et al.* 2014). The results further indicated that unprotected sources like springs and dug wells were most likely to be polluted due to contamination from household run-offs due to poor drainage systems and waste sewer systems, animal droppings, insect and rodents' faeces as well as debris carried by the wind (Dekker *et al.* 2015). Spatial plotting has shown that microbial contaminated and non-contaminated water sources were almost evenly distributed across the study area (Figure 4), blue icons show water sources which gave negative results for *E. coli* and the red icons denote sources which tested positive for *E. coli*). There was, however, a slight concentration of sources which tested positive for *E. coli* in the northern part of the area. The contamination did not happen with tap water found in that area but only in the groundwater sources. These sources were close to a polluted spring, which potentially contaminated the groundwater sources (US EPA 2002).

CONCLUSIONS

The CBT simplified the microbial water quality testing and was convenient and suitable in a low-resource setting. It was very easy to read MPN values off the chart provided by the manufacturers (Aquagenx, LLC, Chapel Hill, NC, USA). Colour change is just between two colours; yellow and blue/blue-green. The bright yellow and blue or blue-green eliminate difficulty that could be faced by colour-blind individuals. The study has shown that only 53 (56%)

Table 3 | Microbial quality of water sources using the WHO water quality risk categories

	WHO water quality risk categories			
Water source	**Safe 0 MPN/100 mL**	**Intermediate 1–10 MPN/100 mL**	**High risk 11–100 MPN/100 mL**	**Unsafe >100 MPN/100 mL**
Yard tap ($n = 9$; 10%)	8 (89%)	1 (11%)	–	–
Communal tap ($n = 8$; 9%)	7 (88%)	1 (13%)	–	–
Unprotected spring ($n = 2$; 2%)	–	–	1 (50%)	1 (50%)
Tank water ($n = 25$; 27%)	17 (68%)	2 (8%)	3 (12%)	3 (12%)
Borehole ($n = 3$; 3%)	2 (67%)	–	–	1 (33%)
Protected dug well ($n = 43$; 46%)	18 (39%)	9 (21%)	11 (26%)	5 (12%)
Unprotected dug well ($n = 4$; 4%)	1 (25%)	1 (25%)	1 (25%)	1 (25%)
Total = 94 (100%)	53 (56%)	14 (15%)	16 (17%)	11 (12%)

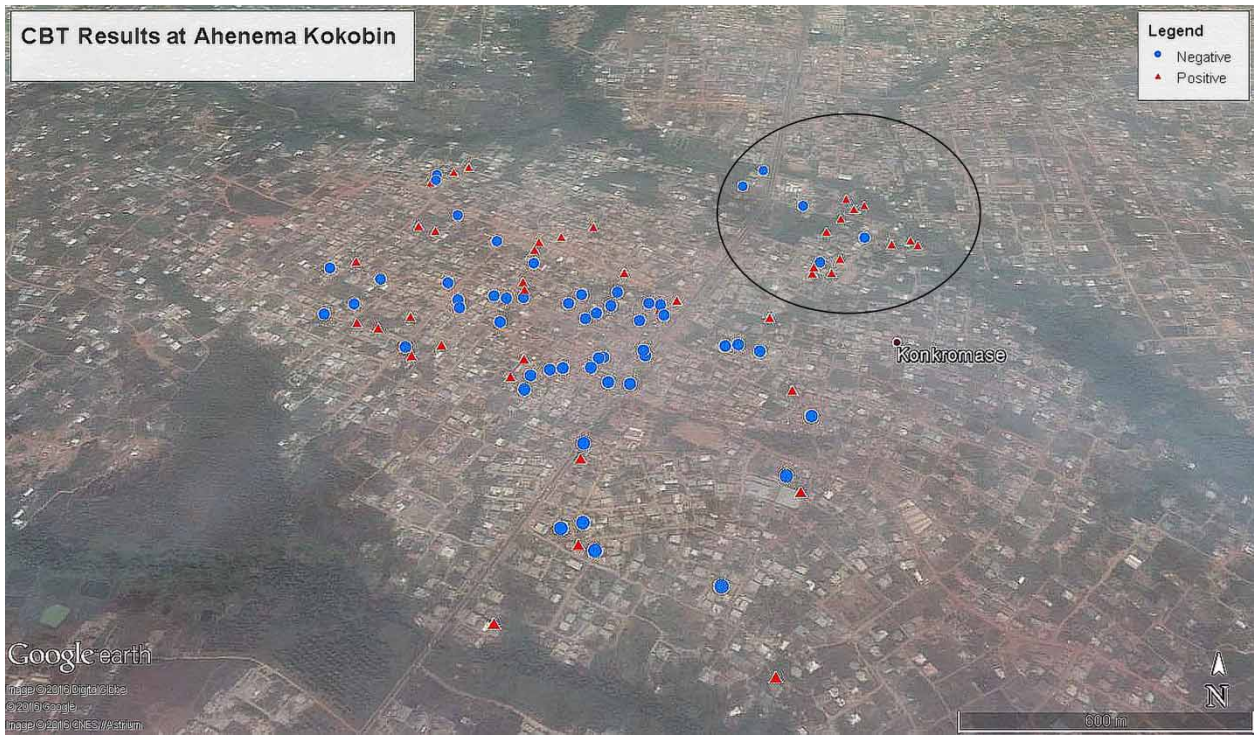

Figure 4 | Spatial distribution of microbial contamination of source water. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2019.048.

of the 94 water sources in the Ahenema Kokoben community were safe to drink which must be a concern for health authorities. To achieve the SDG, regular monitoring of microbial water quality is key to improving public health. Point-of-use technologies should also be employed to complement efforts in improvements in water quality at the source (Sobsey *et al.* 2008).

AUTHOR CONTRIBUTIONS

Amadu Salifu collected and analysed the water samples. Helen Essandoh trained and supervised Amadu Salifu. Afsatou Ndama Traore provided training of trainers on the CBT and Natasha Potgieter was the project leader. All authors contributed to the writing of the article.

CONFLICT OF INTEREST

None declared.

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