Point-of-use chlorination of turbid water: results from a field study in Tanzania

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ABSTRACT

Household-based chlorine disinfection is widely effective against waterborne bacteria and viruses, and may be among the most inexpensive and accessible options for household water treatment. The microbiological effectiveness of chlorine is limited, however, by turbidity. In Tanzania, there are no guidelines on water chlorination at household level, and limited data on whether dosing guidelines for higher turbidity waters are sufficient to produce potable water. This study was designed to assess the effectiveness of chlorination across a range of turbidities found in rural water sources, following local dosing guidelines that recommend a 'double dose' for water that is visibly turbid. We chlorinated water from 43 sources representing a range of turbidities using two locally available chlorine-based disinfectants: WaterGuard and Aquatabs. We determined free available chlorine at 30 min and 24 h contact time. Our data suggest that water chlorination with WaterGuard or Aquatabs can be effective using both single and double doses up to 20 nephelometric turbidity units (NTU), or using a double dose of Aquatabs up to 100 NTU, but neither was effective at turbidities greater than 100 NTU.

Key words | chlorination, diarrhea, household water treatment and safe storage, point of use, turbidity

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INTRODUCTION

The goal of extending household connections to a safe water supply remains elusive in many settings. Simple and effective household water treatment and safe storage (HWTS) has been proposed as a practical interim strategy to prevent waterborne diseases by reducing exposure to diarrheagenic microbes in drinking water (Mintz *et al.* 1995; Semenza *et al.* 1998; Quick *et al.* 1999, 2002; Clasen & Cairncross 2004; Luby *et al.* 2004; Crump *et al.* 2005; Chiller *et al.* 2006; Clasen *et al.* 2006). Among the technologies that have been shown to be effective in improving microbial point-of-use (POU) drinking water quality are boiling, chlorination, various forms of filtration, and solar disinfection (Conroy *et al.* 1999; Quick *et al.* 2002; Clasen *et al.* 2006; Brown *et al.* 2008; Jain *et al.* 2010). These and other HWTS strategies are the focus of extensive laboratory and field-based research and development.

Chlorination is among the most widely practiced means of treating drinking water, principally in disinfection of piped water supplies, for which it has been used since at least the 1890s (Turneaure & Russell 1901). Globally, the use of chlorine has contributed to important health gains resulting from reduced exposure to bacteria, viruses, and protozoa that are present in waters contaminated with fecal waste (Gala-Gorchev 1996). In wealthier countries, chlorination, together with filtration and other sanitary improvements, has virtually eliminated waterborne diseases such as cholera, typhoid, dysentery, and hepatitis A.

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As an intervention in Tanzania, widespread water chlorination at the household level began in 2002 when Population Services International launched two chlorine products: WaterGuard (1.25% sodium hypochlorite aqueous solution) and Aquatabs (tablet containing 67 mg of sodium isocyanurate (NaDCC)). Since then, some communities in Tanzania have used these products as one disinfection solution for drinking water at the household level. WaterGuard is packaged in a 150 mL bottle with a 3 mL cap. It is accompanied by written directions instructing users to add one full bottle cap (3 mL) of the solution (referred to as a single dose) to 20 L of clear water in a container with a lid that fits tightly, closing the lid and shaking slightly and waiting 30 min for water to become safe to drink. For turbid water, users are instructed to filter the water through a clean cloth, add two caps (6 mL) of chlorine solution (referred to as a double dose) in a 20 L container with a lid that fits tightly, close the lid, and shake slightly. After 30 min, instructions indicate that the water is safe to drink.

Like WaterGuard, Aquatabs generates hypochlorous acid upon contact with water (Clasen & Edmondson 2006). Instructions accompanying the product state that, for clear water, the user is to add one tablet of Aquatabs (referred to as a single dose) to 20 L of water and wait 30 min before consumption. For visibly turbid water, users are instructed to filter water through a clean cotton cloth before adding two tablets (referred to as a double dose) of Aquatabs to 20 L of water and waiting for 30 min before use. These simple, field-ready instructions suggest that POU chlorination is suitable for use even with higher turbidity waters. It is important to note that users will usually not be able to measure turbidity themselves.

The efficiency of chlorine disinfection is affected by organic and inorganic compounds present in turbid water. These compounds are known to exert a chlorine demand, presenting a challenge to maintaining a microbiocidal free available chlorine (FAC) residual in highly turbid waters (LeChevallier *et al.* 1981), and the chemical characteristics and effects of turbidity may vary widely across settings. Due to particle association, higher turbidity may also shield microbes from inactivation by chlorine (Crump *et al.* 2004). According to the World Health Organization (WHO) 'Guidelines for Drinking-water Quality' (WHO 2011), median turbidity should be below 0.1 nephelometric turbidity units (NTU) for effective disinfection.

There is some evidence, however, that POU chlorination may be suitable even for higher turbidity levels (Lantagne 2008), and some international organizations, governments, implementers, and researchers have recommended appropriate turbidity ranges for chlorinating water. Because measuring microbiological effectiveness is difficult, efficacy of POU chlorine-based disinfection is indicated by the maintenance of appropriate chlorine residue. The goal is to maintain a minimum FAC residue of 2.0 mg/L at 30 min after addition of sodium hypochlorite and thereafter, not less than 0.2 mg/L at 24 h (USEPA 2006; Lantagne 2008; WHO 2008; CDC 2009). This represents a range that has been shown to be both effective in killing bacteria and viruses while producing water that is not rejected by users due to excessive chlorine taste. It should be noted here that this normal range of FAC recommended to kill bacteria is not effective against *Cryptosporidium* spp. (Korich *et al.* 1990), one of the main etiological agents of severe diarrhea in children (Kotloff *et al.* 2013). The WHO (2008) recommends that free chlorine residue should not exceed 5 mg/L for taste acceptability reasons.

In Tanzania, there is no guideline value on turbidity for chlorination at household level. The Tanzania water quality standard sets limits and an allowable range of turbidity of between 5 and 25 NTU (TWQS 2009) for drinking water, based on organoleptic requirements. This study was designed to provide evidence-based practical guidance for proper dosing of chlorine at household level, where water treatment is required for prevention of waterborne diseases in rural water sources that are often of higher turbidity than in conventional systems. Specifically, our goal was to determine the maximum turbidity limit for household-level chlorination without pretreatment of water across rural areas in Tanzania.

METHODS

Study area description

This study was carried out in Kisarawe, one of the six districts of Pwani Region. It is bordered to the North by Kibaha District, to the East by Mkuranga District, to the South by Rufiji District, and to the West by Morogoro Region.

Baseline information

Baseline information on this study was sought as part of the Safe Water Project in Tanzania, a research collaboration supported by UNICEF among the Ministry of Health and Social Welfare; National Institute for Medical Research; Ardhi University and Muhimbili University of Health and Allied Sciences; University of California, Berkley; and London School of Hygiene and Tropical Medicine. We randomly selected households from two villages as part of the larger study of water quality, water treatment, and health. Using feedback from individual households and from village leaders, we assembled a list of available water sources used for drinking in the area. We analyzed the turbidity of the water sources onsite with the goal of including sources in each of the following categories of turbidity: <1, 1–5, 6–10, 11–20, 21–30, 31–50, 51–100, and >100 NTU. These turbidity ranges were selected with reference to the findings elsewhere that chlorination can be effective over a wide range of turbidity (Lantagne 2008; CDC 2009; WHO 2011). This study was designed to test chlorine dosing for water with turbidity even beyond 100 NTU because it is reported that people in some rural areas use water with turbidity above 100 NTU (Crump *et al.* 2004; Marobhe 2008; Lantagne & Clasen 2011). Only shallow wells (hand dug wells) were included in this study, the most common water source type in the study area. All water sources included in the study were tested at baseline for chlorine residue. Analyses for turbidity and chlorine were done using Turbidity and Free/Total Chlorine Meter; Hanna equipment, HI 93414, with a detection limit of 0.01 mg/L for chlorine and 0.1 NTU for turbidity (Adaptation of USEPA Method 108.1 and Standard Method 2130 B). Our sample included 43 water sources serving 292 households. Lower detection limits for chlorine were 0.01 mg/L and 0.1 NTU for turbidity.

Chlorine dosing of water samples

At each source, eight jerry cans were filled and transported to a predetermined field laboratory station where water was transferred to four new clean plastic buckets each of 20 L and four clay pots each with a capacity of 20 L. Clay pots which are hand-crafted from clay soil and fired in kilns at high temperature were ordered and purchased from local potters while plastic buckets were purchased from local shops in Dar es Salaam. Likewise, Aquatabs and WaterGuard were purchased locally from retail outlets. Both clay pots and jerry cans were used for chlorination to reflect the actual water treatment/storage containers used by many households in the study areas and to determine if the type of the container could affect the chlorine residuals at 30 min and 24 h contact time, other factors remaining constant.

The chlorine strength of sodium hypochlorite solution was analyzed at the Government Chemistry Laboratory Agency using a standard method developed by the Tanzania Bureau of Standards, TZS 784:2004 (TBS 2004). The chlorine strength of all batches of sodium hypochlorite solution was within the allowable 10% deviation from the labeled concentration for all samples (BP 2004). Aquatabs were not subjected to strength testing.

In this study, single dose refers to either one tablet of Aquatabs or one cap of WaterGuard liquid equivalent to 1.87 mg/L; double dose refers to two tablets of Aquatabs and two caps of waterGuard equivalent to 3.75 mg/L. These doses were chosen to reflect the actual practice of dosing water at the household level as instructed by manufacturers of the chlorine products and as recommended for turbid water chlorination (Lantagne 2008; CDC 2009).

Analyses for the total chlorine and FAC were done at 30 min and 24 h. Thirty minutes was chosen because in order for chlorine to be effective in killing pathogens in water it requires sufficient time (at least 30 min) to react with organic and inorganics present in water before it is available for disinfection (WHO 2011); 24 h was chosen because more than 24 h chlorine residue in water may be very small owing to decay of chlorine over time and the fact that many households will consume 20 L of water for not more than 24 h (CDC 2009).

Analyses of data

All data were double-entered in an Excel spreadsheet, compared and analyzed using Stata Release 11.0 (StataCorp., College Station, Texas). Because the turbidity levels tend to follow a skewed distribution, statistical analyses were performed after turbidity counts were transformed to their log 10 values and checked for normality before using statistical tests that assume a normal distribution of data. For this purpose only, turbidity values of 0 were assigned a value of 1 so as not to lose the data in the log transformation.

Mean, median, and range for turbidity and FAC were determined. A paired *t*-test was used to analyze turbidity counts of paired (time, container, and dose) water samples. A linear regression model adjusting for repeated samples within the same water sources was used to explore the possible associations between NTU values with dose and container characteristics at 95% significance level.

RESULTS

Water sources included in this study were those identified by local communities as used for drinking as the primary use. All water sources visited at baseline had turbidity >1 NTU. Consequently, the turbidity category <1 NTU was dropped from the study. Typical well depth was between 2 and 30 m. The wells were unlined, uncapped and without pumps. No FAC residue was detected in any water source at the point of collection. Clay pots, commonly known in the Swahili language as *Mtungi*, were the most commonly used storage containers for drinking water at household level.

Physico-chemical characteristics of water

The turbidity of water sources ranged between 3.3 to 350 NTU with geometric mean of 44.5 with standard of the average mean of 67.09. This and other characteristics of water are as shown in Table 1.

Mean FAC by turbidity category, time, and dose

The FAC concentrations for turbidity categories, time, and dose are summarized in Table 2. For category of turbidity 1–5 NTU, the overall mean FAC was 1.56 and 0.75 mg/L at 30 min and 24 h, respectively, for the single dose; and for the double dose it was 2.08 and 1.13 mg/L. For the water turbidity category of 6–10, the mean FAC was 1.45 and 0.67 mg/L at 30 min and 24 h, respectively, for the single dose and 1.67 and 1.02 mg/L for the double dose. The mean of FAC was least for the turbidity category 51–-100 NTU. No FAC was detected in the category of >100 NTU for single or double dose chlorination after 30 min contact time.

Aquatabs

When water treated with Aquatabs was analyzed, it was found that for the category of 1–5 NTU, the FAC was 1.56 and 0.74 mg/L at 30 min and 24 h, respectively, for the single dose (Table 2). However, for the double dose it was 2.03 and 1.12 mg/L at 30 min and 24 h, respectively. For the water with turbidity category of 6–10 NTU, the mean FAC was 1.44 and 0.67 mg/L at 30 min and 24 h, respectively, for the single dose and 1.78 and 1.11 mg/L for the double dose. The category of turbidity 11–20 NTU had the following mean FAC: 1.03 and 0.18 mg/L for single dose at 30 min and 24 h, respectively, and 1.69 and 0.96 mg/L for double dose at 30 min and 24 h, respectively. The category of turbidity >100 NTU had the lowest mean FAC with only 0.09 mg/L when applied as a double dose after 30 min (Table 2).

Waterguard

For water treated with WaterGuard, in the category of turbidity 1–5 NTU, the FAC was 1.56 and 0.77 mg/L at 30 min and 24 h, respectively, for the single dose and for

Table 1 | Physico-chemical source water characteristics

Parameter	Mean	Median	Range	Std. average mean
Turbidity (in nephelometric turbidity units)	44.5 (geometric)[a]	59	3.3–350	67.09
pH	7.2	7	5.7–10.3	1.03
Total dissolved solids (mg/L)	343.5	300	30–940	269.7
Conductivity (mS/cm)	709	610	60–2,100	560.8
Temperature (°C)	29.6	29.3	26.6–32.3	1.5

[a]Used here because the turbidity values were skewed.

Table 2 | Comparison of FAC after treating with WaterGuard or Aquatabs

		Single dose						Double dose					
		30 min			24 h			30 min			24 h		
NTU	**N**	**WG**	**AQ**	**Overall mean**	**WG**	**AQ**	**Overall mean**	**WG**	**AQ**	**Overall mean**	**WG**	**AQ**	**Overall mean**
1–5	3	1.56	1.56	1.56	0.77	0.74	0.75	2.14	2.03	2.08	1.14	1.12	1.13
6–10	2	1.45	1.44	1.45	0.68	0.67	0.67	1.55	1.78	1.67	0.93	1.11	1.02
11–20	3	0.78	1.03	0.91	0.38	0.18	0.28	1.34	1.69	1.52	0.62	0.96	0.79
21–30	5	0.12	0.29	0.21	0.02	0.04	0.03	0.72	1.04	0.89	0.39	0.40	0.39
31–50	7	0.03	0.23	0.13	0.01	0.04	0.02	0.71	1.04	0.88	0.27	0.39	0.33
51–100	14	0.02	0.17	0.09	0.00	0.03	0.01	0.56	1.03	0.79	0.13	0.37	0.25
>100	9	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.00	0.00	0.00	0.00

NTU = nephelometric turbidity units; WG = WaterGuard liquid; AQ = Aquatabs; N = number of water sources; FAC = free available chlorine.

the double dose it was 2.14 and 1.14 mg/L (Table 2). For the water turbidity category of 6–10 NTU, the mean free chlorine was 1.45 and 0.68 mg/L at 30 min and 24 h, respectively, for the single dose and 1.55 and 0.93 mg/L for the double dose. The category of turbidity 11–20 NTU had the following mean free chlorine residuals: 0.78 and 0.38 mg/L for the single dose at 30 min and 24 h, respectively, and 1.34 and 0.62 mg/L for the double dose at 30 min and 24 h, respectively. The category of turbidity >100 NTU had the lowest FAC residue with only 0.01 mg/L when used as a double dose for 30 min (Table 2).

The result of the linear regression analysis is shown in Table 3. The effectiveness of Aquatabs and WaterGuard was compared by measuring the amount of FAC remaining after adjusting for contact time (30 min, 24 h), dose of chlorine used (single, double), container type (plastic, clay pot), and the level of turbidity (NTU).

The results show that, after adjusting for dose, time, and container type, the amount of FAC remaining was strongly associated with the level of turbidity in both chlorine type ($p < 0.001$). The amount of FAC remaining decreased with increasing turbidity levels, and the decreasing rate was higher in Waterguard compared with Aquatabs. The mean FAC difference between water with turbidity (>100 NTU) and (1–10 NTU) was −1.40 mg/L, (95% CI: −1.45, −1.34) in WaterGuard and −1.34 mg/L (−1.70, −0.97) in Aquatabs.

Container type was not significantly associated with the amount of free chlorine that remained in both chlorine types ($p = 0.818$ for WaterGuard and 0.128 for Aquatabs). Dose applied and time were strongly associated with the amount of FAC that remained in each chlorine type ($p < 0.001$). On average, the FAC remaining after 24 h was less than that after 30 min. A mean difference of −0.27 (−0.35, −0.19) was observed in WaterGuard and −0.41 (−0.55, −0.30) in Aquatabs. When different doses were applied under fixed time and level of turbidity, the mean FAC difference was higher in Aquatabs (0.46 mg/L (95% CI: 0.32, 0.60)) than in WaterGuard (0.31 mg/L (95% CI: 0.20, 0.42)).

DISCUSSION

Chlorine is a strong water disinfectant, capable of killing most bacterial and viral pathogens associated with diarrheal

Table 3 | Comparison of FAC after treating with WaterGuard or Aquatabs and the corresponding *p* values and 95% CI (detection limit = 0.01 mg/L)

Indicator variables	WG: Coefficient (95% CI)	*p* values	AQ: Coefficient (95% CI)	*p* values
Container				
Clay pot	1	0.818	1	0.128
Bucket	0.03 (−0.01,0.07)		−0.02 (−0.04,0.01)	
Time				
30 min	1	< 0.001	1	< 0.001
24 h	−0.27 (−0.35,− 0.19)		−0.41 (−0.55,− 0.30)	
Dose				
Single dose	1	< 0.001	1	< 0.001
Double dose	0.31 (0.20,0.42)		0.46 (0.32,0.60)	
NTU categories				
1–5	1		1	< 0.001
6–10	−0.25 (−0.41, − 0.09)	< 0.001	−0.11 (−0.49,0.25)	
11–20	−0.61 (−1.06, − 0.18)		−0.40 (−0.86,0.61)	
21–30	−1.09 (−1.17, − 1.00)		−0.92 (−1.29,− 0.55)	
31–50	−1.15 (−1.41, − 0.89)		−0.94 (−1.52, − 0.55)	
51–100	−1.23 (−1.30, − 1.16)		−0.96 (−1.34, − 0.59)	
>100	−1.40 (−1.45, − 1.34)		−1.34 (−1.70, − 0.97)	
Random effects	SD(T) = 0.15 SD(ϵ) = 0.29		SD(T) = 0.25 SD(ϵ) = 0.36	

NTU = nephelometric turbidity units; WG = WaterGuard liquid; AQ = Aquatabs; FAC = free available chlorine; SD = estimates of the standard deviation of the random effects terms and of the error terms.

diseases (AWWA 1979; EPA 1999; Rice *et al.* 1999; LeChevallier & Au 2004). Nevertheless, its effectiveness as a microbiocidal agent is affected by turbidity. Turbidity is a major challenge for HWTS chlorination for two reasons. First, high levels of turbidity are common. In this study it was found that people use water for drinking with turbidities as high as 300 NTU, similar to ranges reported previously (Gadgil 1998; Crump *et al.* 2004; Marobhe 2008; Kotlarz *et al.* 2009; Lantagne *et al.* 2010; Schafer *et al.* 2009). Second, householders may not be able to judge the level of turbidity in their water before chlorination.

Our results suggest that the amount of FAC declined significantly with increased turbidity and contact time. These findings reveal the effect of turbidity on chlorine available for disinfection.

The amount of FAC provided by double dose at 30 min of contact time was slightly higher than the recommended value of ≤2 mg/L owing to taste and odor to consumers who may reject the treated water and drink untreated water if chlorination is the only available means of water treatment (Lantagne 2008; CDC 2009). The FAC provided by a double dose was significantly higher ($p < 0.01$) compared with that provided by single dose. A single dose may be effective to a maximum of 50 NTU, since measurable FAC remains at 30 min, but this may not be sufficient contact time for achieving a high microbial reduction. Our data suggest that water chlorination can be effective using both single and double doses up to 20 NTU. Use of a double dose of Aquatabs continues to be effective up to 100 NTU. Above that level no FAC was detected in treated water, even after 30 min contact time. This finding is similar to the study by Lantagne (2008), who recommended not chlorinating water with turbidity higher than 100 NTU.

When Aquatabs were evaluated separately, the minimum required FAC was attained within 30 min across all turbidity ranges except where water had turbidity >100 NTU. Furthermore, a double dose of Aquatabs attained the minimum required FAC at 24 h storage time, again with the exception of turbidity >100 NTU. This was not the case with WaterGuard, which when used as a single dose achieved the minimum required FAC with water of up to a maximum turbidity of 20 NTU both at 30 min and 24 h. A double dose of WaterGuard resulted in attaining the minimum required FAC in turbidity range up to 100 NTU after 30 min contact time. However, after 24 h storage the required FAC residue could be attained for water with turbidity not exceeding 50 NTU. Whether used as single or double dose, Aquatabs was able to attain the minimum required FAC concentration at higher turbidity compared with WaterGuard.

This difference may be attributable to the decline in strength of chlorine liquid owing to frequent opening of the bottle, allowing volatilization of chlorine and reduction in concentration; also, exposure to the sun may result in degradation due to free radicals. Once a bottle of WaterGuard liquid was opened, the same was used to chlorinate water for 2–3 days before switching to another bottle. This was done on purpose to imitate exactly how householders would act. Furthermore, it is also known that the concentration of sodium hypochlorite undergoes a disproportionate reaction where it reacts with itself in both a reduction and oxidation reaction (Clasen *et al.* 2006). This is a mechanism where degradation occurs. It is highly dependent on light (UV), pH, initial available chlorine concentration, and temperature (Hoffman *et al.* 1981; Gordon & Bubnis 1996; Gordon *et al.* 1997). The Aquatabs were removed from the packaging and used immediately. Similarly, chlorine residues were found to decay with time. The amount of FAC remaining after 30 min contact time was significantly high as compared to 24 h ($p < 0.001$). Similarly, the study by the Centers for Disease Control and Prevention in Busia, Kenya revealed a decline in FAC with time (CDC 2009).

Concerning the type of container used, plastic bucket or clay pot, results reveal that the container type had no effect on FAC ($p > 0.05$) when chlorination was done in either container. A similar study was done by Ogutu *et al.* (2001) to compare the drinking water quality in clay and plastic vessels, and the results indicated that jerry cans and clay vessels all achieved adequate FAC to disinfect turbid, contaminated source water in laboratory and household level settings.

While protecting against microbial contamination is the top priority, there are concerns that dosing turbid waters (containing ammonia and organic nitrogen compounds) may result in formation of potentially carcinogenic disinfection by-products. However, studies have revealed formation of trihalomethane levels that did not exceeded WHO guidelines (Lantagne 2001; Lantagne *et al.* 2008, 2010). A report by the International Programme on Chemical Safety (IPCS 2000) strongly cautions that the health risks from these by-products at the levels at which they occur in drinking water are extremely small in comparison with the risks associated with inadequate disinfection. For the same reason, the US Centers for Disease Control and Prevention (2001) concludes that in populations in developing countries, the risk of death or delayed development in early childhood from diarrhea transmitted by contaminated water is far greater than the relatively small risk of bladder cancer in old age.

Among the limitations of the study is that it was done during the dry season only, between July and October 2012. Although turbidity is known to be high during the rainy season (N'Diaye *et al.* 2014), the study was probably not affected by turbidity values because we were able to get water sources with turbidity as high as over 100 NTU as could be the case if the study was to be done during the rainy season.

Although we are ultimately concerned with microbial safety of drinking water, the study did not actually measure microbial indicators or pathogens in chlorinated water; instead, we measured FAC as an intermediate indicator of disinfection effectiveness recommended for assessing potability of water (CDC SWS Project 2000; WHO 2008). It was therefore assumed that chlorine residue after some contact period (in this case 30 min and 24 h) means that the dosing was effective and that we can assume microbes were inactivated. On the other hand, since high turbidity in water interferes with disinfection because of the shielding effect on microbes as they are particle associated, and that since the study did not measure microbial counts, it is not possible to conclude that the chlorine doses tested here were effective for the inactivation of pathogens, especially for the more resistant ones such as *Cryptosporidium*.

It is important to note that although household water treatment improves water quality and thus may reduce diarrheal diseases significantly in settings where disease is waterborne (Fewtrell *et al.* 2005; Clasen *et al.* 2006), diarrheal diseases are transmitted via multiple pathways and water quality interventions may not always be sufficient to prevent exposure and disease.

CONCLUSION

Major findings from this study are: (1) treatment of water using regular chlorine sources available to households in Tanzania (WaterGuard and Aquatabs) effectively attained minimum required FAC for water of turbidity up to 20 NTU; (2) application of a double dose of WaterGuard and Aquatabs (as recommended by product manufacturers) for more turbid water achieved the required FAC for a wider range of water turbidity up to 50 NTU; and (3) the use of Aquatabs attained the required residual chlorine for water of higher turbidity (100 NTU). These results suggest that POU chlorine disinfection can be effective across a wide range of raw water turbidities.

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