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Can you taste it? Taste detection and acceptability thresholds for chlorine residual in drinking water in Dhaka, Bangladesh

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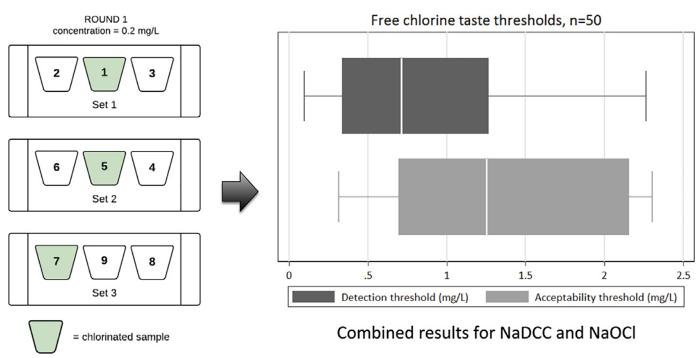
HIGHLIGHTS

- A typical Dhaka resident could detect the taste of free chlorine at 0.71 mg/L or higher.
- Taste sensitivity was similar for sodium hypochlorite and sodium dichloroisocyanurate.
- Among adults, drinking water taste was acceptable up to 1.25 mg/L free chlorine.
- Doses used for point-of-use chlorine products are likely too high for acceptability.

GRAPHICAL ABSTRACT



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ABSTRACT

Chlorination is a low-cost, effective method for drinking water treatment, but aversion to the taste or smell of chlorinated water can limit use of chlorine treatment products. Forced choice triangle tests were used to evaluate chlorine detection and acceptability thresholds for two common types of chlorine among adults in Dhaka, Bangladesh, where previous studies have found low sustained uptake of chlorine water treatment products. The median detection threshold was 0.70 mg/L (n = 25, SD = 0.57) for water dosed with liquid sodium hypochlorite (NaOCl) and 0.73 mg/L (n = 25, SD = 0.83) for water dosed with solid sodium dichloroisocyanurate (NaDCC). Median acceptability thresholds (based on user report) were 1.16 mg/L (SD = 0.70) for NaOCl and 1.26 mg/L (SD = 0.67) for NaDCC. There was no significant difference in detection or acceptability thresholds for dosing with NaOCl versus NaDCC. Although users are willing to accept treated water in which they can detect the taste of chlorine, their acceptability limit is well below the 2.0 mg/L that chlorine water treatment products are often designed to dose. For some settings, reducing dose may increase adoption of chlorinated water while still providing effective disinfection.

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1. Introduction

Chlorination has long been promoted as a low-cost, effective method for drinking water treatment (Mintz et al., 2001; Mintz et al., 1995). Advantages of water treatment with chlorine include low cost, rapid disinfection, and the ability to treat without electricity or fuel. A cost-effectiveness analysis of household-based water interventions in Africa and Asia found that chlorination was more cost effective than SODIS, filtration, and flocculation/disinfection (in addition to boiling, these are the most commonly promoted household water treatment methods besides chlorination) (Clasen et al., 2007). Perhaps most importantly, in contrast to non-chemical treatment methods, chlorine residual protects against microbiological contamination between treatment and end use (Wright et al., 2004). Thus, chlorine is widely used in piped water systems, where free chlorine residual can be crucial for maintaining water quality throughout distribution systems, especially in situations of intermittent supply (Kumpel and Nelson, 2014; Lee and Schwab, 2005). The consequent health benefits of chlorination have been demonstrated. A review of household chlorine treatment interventions found a 29% decrease in risk of child diarrhea (Arnold and Colford, 2007). These effects work at scale as well; the significant health gains observed in the U.S. at the beginning of the 20th century have been attributed in part to the introduction of chlorination in piped water systems (Cutler and Miller, 2005). Due to its widespread and long history of effective use, scaling up chlorination could be a useful strategy for working toward Sustainable Development Goal 6, which includes universal access to safe drinking water.

Chlorine does have disadvantages and is not appropriate for all situations. Chlorine may react with organic matter or bromide to produce disinfection byproducts (WHO, 2000). These resulting compounds, for example trihalomethanes (THMs) and bromate, are regulated due to their health risks (Murray et al., 2012; WHO, 2005). Additionally, chlorine has limited efficacy against protozoan pathogens, such as *Cryptosporidium* spp., an important cause of child diarrhea (Korich et al., 1990; Kotloff et al., 2013; Liu et al., 2016). However, chlorine remains an appropriate treatment option for many settings. In Kenya, chlorine treatment of a variety of sources, including extremely turbid waters, were found not to exceed World Health Organization (WHO) limits for THMs (Lantagne et al., 2008). Of the 6 pathogens identified as the top causes of child diarrhea in a multi-country study, chlorine is effective against 5 (*Shigella* spp., rotavirus, adenovirus 40/41, ST-ETEC, and *Campylobacter* spp.) (Liu et al., 2016; WHO, 2011).

Chlorine water treatment faces barriers to acceptability, as has been reported in numerous field trials of household water chlorination products (Freeman et al., 2009; Luby et al., 2008; Luoto et al., 2011; Olembo et al., 2004). Household water chlorination methods require individuals to consistently and correctly treat their own water in order to realize health benefits (Brown and Clasen, 2012; Enger et al., 2013). Barriers to point-of-use chlorination include the financial and time costs of usage, as well as taste and smell (Luby et al., 2008; Luoto et al., 2011). Currently, data on the influence of taste and smell aversion on adoption rates of household chlorine products (including tablet, liquid, and powder options) are non-standardized and inconclusive. For example, 84% of users reported improved taste after treatment in an evaluation of a flocculant plus chlorine disinfectant in rural Guatemala (Luby et al., 2008). In contrast, an evaluation of a similar product in Dhaka, Bangladesh, reported that 57% of users disliked the taste and/or smell (Luoto et al., 2011). A study of a liquid sodium hypochlorite (NaOCl, the active ingredient in household bleach) product in Kenya reported that 15% of individuals who never used the product cited taste as a barrier to use (Freeman et al., 2009). Among individuals in Zambia who used sodium hypochlorite and stopped, 32% cited smell and 18% cited taste as the reason for discontinuing use (Olembo et al., 2004).

Few studies have explored how chlorine dose may be associated with taste or smell complaints, as these are often merely noted in larger discussions of compliance. Our review of the literature did not identify any studies that have precisely determined doses that can optimize acceptability of chlorination in low-income settings. However, the evidence from Guatemala suggests that reducing chlorine dose can lead to increased use of a chlorine product (Chiller et al., 2006). An intervention using a flocculant-disinfectant formula with a lower chlorine dose compared to a previous higher-dosing intervention found a much higher proportion of households with chlorine residual in stored water, indicating increased use. This suggests there may be scope for adjusting dosing to improve uptake, without compromising water quality (Chiller et al., 2006).

The WHO has established dosing guidelines for disinfection efficacy. They recommend a minimum free chlorine residual of 0.2 mg/L and a maximum of 5.0 mg/L; the recommended minimum increases to >0.5 mg/L during possible waterborne disease outbreaks (WHO, 2011). In a study of various water sources, a dose of 1.875 mg/L ensured a minimum safe residual after 24 h of storage in low turbidity waters (<10 NTU) (Lantagne, 2008). For waters with turbidity 10–100 NTU, the required dose increased to 3.75 mg/L (Lantagne, 2008). WHO guidelines also address the concentration and contact time required for chlorine to inactivate specific waterborne pathogens (WHO, 2011). In line with these guidelines, household water treatment products are generally designed to deliver approximately 2 mg/L of chlorine under non-emergency conditions. Doses are not typically set for ensuring acceptability of chlorinated water by users.

The data that identify concentration thresholds at which individuals can even detect chlorine indicate substantial geographic variation. For example, evidence from the United States, France, and Spain suggest that taste sensitivity to free chlorine may be associated with the chlorine residual concentration typical in a country's municipal water supplies (Piriou et al., 2015, 2004). The detection threshold among consumers in the U.S. was found to be 0.8–1.1 mg/L and in France to be 0.2 mg/L (Mackey et al., 2001; Piriou et al., 2004). The data from low-income settings are less precise. Results from focus groups conducted in Ethiopia and Zambia suggest detection thresholds between 1.0 mg/L and 2.0 mg/L (Ethiopia) and 0.2 mg/L and 1.0 mg/L (Zambia) (Lantagne, 2008). In these same focus groups, concentrations of 3.0 mg/L in Ethiopia and 2.0 mg/L in Zambia were considered unacceptable (Lantagne, 2008). In a small trial in Bangladesh, only 3 of 30 volunteers were able to consistently differentiate samples containing 1.0–1.7 mg/L free chlorine from chlorine-free samples; this was the identification rate expected from random guesses (Flanagan et al., 2013). In double-blind taste tests in Cambodia, researchers found a preference for unchlorinated water over chlorinated water at 0.5 mg/L, although there was inconsistency in preference over increasing concentrations (Jeuland et al., 2015). These studies indicate detection thresholds in settings where household treatment is promoted are likely below the 2 mg/L dose products are generally designed for; however, there appears to be some margin of acceptability above detection. Dosing acceptability has yet to be explored in-depth.

In Dhaka, Bangladesh, >3 million residents live in informal settlements and receive intermittent piped water supply through shared municipal water points (Angeles et al., 2009). This intermittency negatively impacts water quality, placing residents at greater risk for waterborne illness (Ercumen et al., 2015a; Kumpel and Nelson, 2014). Studies in Dhaka, conducted by the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b), have found low sustained use of household chlorine water treatment products (Luoto et al., 2011; Pickering et al., 2015). In Dhaka the most common options that have been promoted are various brands of liquid sodium hypochlorite (NaOCl) and chlorine tablets such as sodium dichloroisocyanurate (NaDCC, the active ingredient in Aquatabs® chlorine tablets). (It should be noted that not all products that have been studied are widely available for local purchase.) Some evidence suggests that NaDCC may be more acceptable to end users than sodium hypochlorite (Clasen and Edmondson, 2006). In a small trial in Dhaka, Bangladesh, overall user satisfaction with smell was lower in the group receiving water treated with sodium