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Original Research Article

Bacteriological Quality of Household Drinking Water and Water Disinfection Practices in Kinondoni Municipality, Tanzania

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ABSTRACT

Background: The bacteriological quality of household drinking water (HDW) and waterborne diseases are the main public health concerns in resource-limited countries, including Tanzania. Despite widespread use of water disinfection methods, prevalence rates of waterborne diseases like cholera, dysentery, and typhoid are still high.
Objectives: This study aimed to determine bacteriological quality of HDW used by residents of Kinondoni Municipality, in Dar-es-Salaam, and investigate on awareness and attitude towards commonly used HDW treatment methods.
Methodology: This was a cross-sectional study conducted from January to June 2016. Water samples were collected from HDW sources and subjected to presumptive coliforms count followed by *Escherichia coli* confirmation. Interviews were used to investigate residents' awareness and attitude towards HDW treatment and storage practices (HTSP).
Results: Regression analysis predicted effects of isolated bacteria on incidences of water-borne infections. Neither types of isolated bacteria nor bacterial counts had significant associations with the prevalence of water-borne infections (p= 0.86). Prevalence of water-borne infections among household members had no associations with water storage means (p= 0.44). Combination of chemical disinfectants and filtration was the most effective water treatment methods. The most frequently isolated coliforms were *Pseudomonas aeruginosa* (45%) and *Klebsiella* (25%). Over 50% of water samples exceeded acceptable limits of coliform bacteria counts.
Conclusion: High levels of coliform counts were revealed in HDW that could be attributed to poor storage and non-use of treated drinking water. Boiling of HDW killed all coliform bacteria. Satisfactory awareness of the importance of water disinfection was noted among the residents.

Keywords: household water contamination, coliform bacteria, disinfection methods

INTRODUCTION

"Access to safe drinking water is essential to health, a basic human right and a component of effective policy for health protection". [1] Inadequate supply of good quality drinking water and poor sanitation are among the major causes of morbidity and mortality worldwide. The WHO estimates that over 66% of waterborne disease-related deaths per year are due to diarrheal diseases caused by waterborne microorganisms. The most affected are children less than five years of age and the poorest households or communities. [2,3] The millennium development goals aimed to half a proportion of the world population without access to safe drinking water by 2015. To date, huge disparities remain, particularly in developing countries. The lowest levels of coverage are found in 48 countries designated as the least developed countries, where less than 50% of the population uses improved drinking water sources, and most of these are in Oceania and sub-Sahara Africa. [4]

The fact that microorganisms are easily dispersed, exhibit physiological diversity, and tolerate harsh conditions, they are ubiquitous and may contaminate and multiply in water. The presence of waterborne intestine pathogens (bacteria, viruses, and protozoa) in household water supplies represents a potentially significant human health risk. [5-7] Coliform bacteria are a group of microorganisms found in the environment as well as in the intestines of mammals. They are usually harmless, but their presence indicates that the microbiological quality of drinking water is of concern. [5] Some members of coliforms bacteria include *Escherichia, Serratia, Enterobacter, Proteus, Klebsiella, Citrobacter, Yersinia, Hafnia, and Enterobacter* species. *Escherichia coli* is the only member that is found in the intestine of mammals including humans; thus it presence indicates recent fecal contamination and the possible presence of other waterborne pathogens. Drinking water is an important vehicle for waterborne infections such as cholera, dysentery and typhoid fever. [8] Waterborne diseases are among the leading public health problems in Kinondoni Municipality, and their modes of transmission are closely associated with poor environmental management, inadequate supply of clean water and sanitation problems. [9] Moreover, poor sewerage and overcrowding increase the risk of waterborne infections transmission, either by virtual presence of a large number of the bacteria in surrounding or drinking water contamination.

About 20% of community diarrhoeal diseases are due to insecure drinking water; [8] particularly in developing countries where drinking water is harvested from rain by collecting on precarious surfaces and then kept in household storage vessels or tanks. Hence, drinking water either becomes contaminated during collection or storage. [8-10] A study conducted in Bangladesh, Ethiopia, and Zambia revealed that majority of water sources are contaminated with faecal coliforms bacteria. [10-12] Despite efforts of supplying clean and treated potable water, campaigns on water treatment at household levels as well as the construction of wastes disposal systems; a number of waterborne disease outbreaks are being reported in Dar es Salaam City, and Kinondoni Municipality is the worst affected municipality.

HTSP has shown to be a useful preventive measure to lick microorganisms that sneak into portable water pipe system through leakages or unsafe sources, particularly when is properly done. Analysis for fecal coliform bacteria provides a sensitive, although not the most rapid indication of microbial contamination of drinking-water supplies; especially if factors such as growth media, incubation conditions, and sampling time are maintained constant in order to avoid variability of the findings. [12-13] Therefore, this study intended to determine the bacteriological quality of HDW by performing bacteriological tests on the drinking water samples collected from each household using standard procedures, and assess the knowledge and attitudes towards HTSP among the residents. Throughout this document, the words ‘water treatment’ and ‘water disinfection’ will be used interchangeably, though water treatment consists of removing organic materials, particles, bacteria, and other contaminants, and water disinfection refer to killing or/and inactivation of microorganisms. [14]

MATERIALS AND METHODS

Study areas and population

The Kinondoni Municipality has 10 wards (sub-administrative areas) and is one of the 7 Municipalities of Dar es

Salaam City; the later is the most important commercial city in Tanzania. Kinondoni Municipality has a total area of 531square kilometers with over 1,800,000 residents, of those 927,000 (51.5%) are females. It is surrounded by other 4 municipalities of Dar es Salaam City/Region and the 3 belong to the Coast Region. [15]

Study design and sampling procedures

This was a cross-sectional study aimed to assess knowledge and attitudes towards on HTSP among Kinondoni Municipal residents. Face to face interviews guided by a semi-structured questionnaire were conducted to collect the information on the above-mentioned aspects. All members of the households within Kinondoni Municipality and residents over 17 years of age willing to participate were eligible. Persons who had not been residing in the Municipality for the past six months and households that used commercially available drinking water (pre-packaged) were excluded from the study. The purposeful random sampling technique using the Stat Treck Random Number Generator software was employed for selection of 10 households from each of the 10 administrative wards, where the face to face interviews and HDW samples collection were conducted.

Face to face interviews: investigated variables

Among several investigated variables include the following key aspects: whether any member of the household had ever experienced incidences of waterborne-related diarrheal diseases, what kind of drinking water sources each household used, whether the used water sources were safe or no, and what methods were used for HDW treatment. Respondents were also asked whether the HDW treatment methods used were effective or not; and if the methods were effective, what could have been the causes of the cited incidences of diarrheal diseases in the community or among the household members. To instigate further on the water safety used by respondents, they were asked to give opinions on what they thought were the safest HDW sources and whether there was a possibility of the drinking water to be contaminated during storage or use and what were the potential contaminants. To enquire about how they take care of their storage water tanks, respondents were asked if they had ever cleaned the water tanks. Participants were also requested to state factors that might affect the HWTS practices.

Water samples collection

After each interview, sterile 50 ml caped-bottles were employed for water samples collection from each household. Collection time, its declared source, and the name of ward/locality were noted on each sample's bottle. The HDW samples were later taken to the Pharmaceutical Microbiology Laboratory for bacteriological analysis within 6 hours of collection.

Isolation and identification of bacteria

Each of the collecting bottles was externally swabbed with 70% ethanol prior to opening; then a 100ml aliquot was drawn and spread plated on Nutrient agar (Himedia, India) plate. Following a 24 hour-incubation at 37ºC, the total viable counts (TVC) were performed and expressed as colony forming unit per millimeter (cfu/ml). Another aliquot of the same HDW sample was subjected to presumptive coliforms test by inoculating it into MacConkey's broth-containing Durham tube. Each of the tubes was incubated at 37°C for 24-48 hours for total coliform detection and 44.5°C for 24-48 hours for fecal coliform in accordance with the WHO guidelines. [16] A loopful of culture from a positive Durham tube test was streak plated on Eeosin methylene blue and/or MacConkey agar (Oxoid, UK) plates and confirmed using both colony morphology and biochemical tests as per standard bacteriological procedures. [17]

Statistical data analysis

Two samples of HDW were collected from each participating household and analyzed in duplicate for statistical purpose and consistency of results. Therefore the reported numerical data were expressed as means. Statistical data analysis (means and variance) for bacterial viable counts (cfu/ml) were performed using the computer package SPSS version 20 (Chicago, IL). Differences of the aerobic total viable counts, total coliform and fecal coliform counts among water sources or/and households were compared with respect to The WHO acceptable limits [1,16] and analyzed by the T-test; and the differences were considered statistically significant when $p<0.05$.

Ethical consideration

Each participant was provided with a clear explanation of the study's objectives prior to the interview and both verbal and written consents were also sought. Participants were vividly explained that they could ignore any question or withdraw from the study at any given point in time. For confidentiality, names of respondents or any personal particulars were not disclosed.

RESULTS

Demographic characteristics of the participants

A total of 100 Kinondoni household residents participated in this study. Of those, 93% were females. The respondents' ages ranged from 18-65 years of age with median of 34 years. About 48% of the participants had primary education level and 13% had no formal education. The size of households' members ranged from 1-20 (Table 1). No significant differences ($p>0.05$) with regard to ages of participants were observed between females and males.

Table 1: Demographic characteristics of the respondents in relation to HDW treatment practices.

Variables		Disinfect drinking water		p-values
		NO	YES	
Gender	Females	41	52	0.388
	Males	4	3	
Age groups	18-29	17	9	0.100
	30-39	10	14	
	40-49	8	16	
	>50	10	10	
Education levels	Not formal	7	6	0.262
	Primary	20	28	
	Secondary	13	19	
	Vocational	0	1	
	College	5	1	
Family size	1-5	23	28	0.740
	6-10	18	23	
	11-15	3	4	
	16-20	1	0	

Sources of HDW, isolation and identification of bacteria

All participating households used tap water as their main sources of HDW, though only a few (4%) admitted to have been using rain water as well. Of 100 HDW samples, 76% exceeded the permissible limits of bacterial counts for HDW, [13] as well as shown in Table 2. The most frequently isolated bacterial species was *Pseudomonas aeruginosa* (45%) and a mixture of coliform bacteria was detected in 16 (16%) HDW samples.

Table 2: Isolated coliform bacteria from domestically treated drinking water

Detected bacteria	Drinking water disinfection methods							Total
	None	Boiling (B)	Filtration (F)	Chemicals (C)	B+F	B+C	F+ C	
Acceptable levels	6	3	1	3	5	5	0	24
E. coli	1	0	0	2	0	0	1	4
K. pneumoniae	8	7	5	1	1	0	0	22
P. aeruginosa	25	8	7	1	3	1	0	45
E. coli & K. pneumoniae	2	0	0	0	0	0	0	2
E. coli & P. aeruginosa	1	0	0	0	0	0	0	1
Klebsiella & P. aeruginosa	2	0	0	0	0	0	0	2
Total	45	18	13	7	9	7	1	100

Of 45 drinking water samples obtained from respondents who did not treat the drinking water, 38 (84.4%) exceeded the permissible levels of microbial contents, of which *Pseudomonas aeruginosa* and *E. coli* were also present (Table 2).

Awareness and attitude towards drinking water disinfection practice

Majority (98%) of the households were using public pipe -tap water and only 2% used both well and rain waters. Only 55(55%) respondents treated the drinking water, though 3 of them had no trust in the disinfection methods. Reasons given for not treating the drinking water include financial constraints thus unable to buy fuel and charcoal for boiling water. When asked whether the sources of water used were safe, 30% (n=30) said the sources were insecure and 16% were uncertain. Of those who said the water sources were not safe, 46.7% (n=14) disinfected the drinking water prior use. Two thirds (65%) of interviewees had no reliable sources of water. About 77% (n=77) cited tap water as the most secure source of HDW. The most common methods of water disinfection used were by boiling (18%), filtration (15%) and use of chemical disinfectants (6%) or combination of the methods as shown in Table 3.

Table 3: Isolated coliform bacteria from HDW and their respective total viable counts

Water treatment methods	Total bacteria viable counts (cfu/ml)					Total
	<100	101-200	201-400	401-500	>500	
None	7	1	6	2	29	45
Boiling	3	0	2	0	13	18
Filtration	1	1	1	0	12	15
Chemicals	3	0	2	1	0	6
Boiling & Filtration	5	0	1	0	3	9
Boiling & Chemicals	5	0	0	0	1	6
Filtration & Chemicals	0	1	0	0	0	1
Total	24	3	12	3	58	100

Boiling drinking water proved to be more effective in eliminating fecal coliform bacteria (*E. coli)* as shown in Table 3. No statistical significant differences were observed in respect to total viable counts from drinking water between households that have had incidences of waterborne-diarrheal illnesses and those which had none (X^2 = 42; p=0.163).

A total of 72 (72%) respondents had no water storage tanks; from those, 39(54.2%) of the water samples revealed total bacterial counts greater than 500cfu/ml as compared to 19(67.8%) out of 28 interviewees with water storage tanks. Even tough, the same number of respondents (67.8%) of those who had storage water tanks, claimed to disinfect drinking water. For those who had water storage tanks cited dusts, dirt storage containers and aged water (staying for long time) as major causes of diarrheal related diseases. About 35% of the participants could not identify the appropriate water storage vessels among the tracer items. The interviewees cited bad taste and water appearance, possible microbial contamination and adverse effects due to chemicals used for HDW treatment as reasons for reluctance to use treated drinking water. Chemical water disinfection together with filtration yielded the least number of viable counts (1-200cfu/ml) as compared to the other methods (Table 3). Regarding the possibility of water contamination during storage, 61% of were affirmative, and of those, 41 (67.2%) had water storage facilities.

Analysis of other investigated variables

Household members with secondary and vocational training education were less likely to suffer from water-borne diseases with odd ratios (OR) of 0.116 (p=0.023) and 0.143 (p=0.046) compared to those without formal education. The use of water storage tank, size of household members, bacteria coliform counts and type of isolated bacteria had no associations with incidence of waterborne infections (p>0.05). Moreover, water scarcity was not statistically significant predictor of family members to had have suffered from water-borne diseases (OR=3.474; p=0.103). Having water tank reserve and tendency for water treatment led to 0.3 folds (p=0.05) decrease in incidences of water-borne infections among household members. Of 100 interviewed households, 67% had water storage tanks and about 18 % (n=12) of these had suffered from waterborne diarrheal-related infections. Adult members of the interviewed households were 6.135 times less likely to suffer from waterborne-related disease as compared to children less than 5 years old (p> 0.01).

DISCUSSION

Dar es Salaam's urban settlement is increasing especially in unplanned areas, where houses are built without regulated domestic water supply or appropriate sewerage. Currently, a significant part of the existing drainage system is old, undersized or partially blocked. This has exposed most of the city residents to incessant flooding during heavy rain seasons accompanied with cholera and other waterborne outbreaks. [18-19] Although ground water is the main water source in most major cities, including in Kinondoni Municipality, because of reliability, abundance, and be cost-effective, may become contaminated during rain seasons. [16,18,20-21] Our findings showed that about 65% of the residents had no reliable sources of HDW. As several pathogens are transmitted through contaminated drinking-water and can lead to severe or life-threatening diseases such as typhoid, cholera and infectious hepatitis. [22] Most of the pathogenic bacteria transmitted by the faecal-oral route, drinking-water is their main vehicle of transmission. Thus improved quality and availability of good quality water, waste disposal and general hygiene are all imperative in reducing waterborne and faecal-oral diseases transmission. [22]

Bacteria are usually the group of pathogens that is most sensitive to inactivation by disinfection. However, only 55% of the respondents treated their drinking water; while 35% of them were unable to describe how to properly keep their HDW storage vessels. Partly this could explain the high incidences of waterborne disease outbreaks in the municipality, because poor storage can considerably affect the microbiological water quality. Evidences indicate that non–use of treated HDW and poor storage is associated with increased incidences of diarrheal diseases. [3,21,23-24] Other opportunistic microorganisms present in the environment may get access to water and food stuffs, and cause diseases in susceptible individuals such as infants, the elderly or patients with severe burns or patients with secondary immunodeficiency syndrome or those undergoing immunosuppressive therapy. [25] The observed high coliform counts (>500cfu/ml) in more than 50% of the tested HDW samples is of serious health concerns; since individuals ingesting or in contact with such high microbial counts, can contract infections such as that of skin, ear, nose and other mucous cavities. [16] Some of the recovered bacteria from HDW, including *Klebsiella pneumoniae* and *P. aeruginosa*, which usually don't represent major health problems in healthy individuals. Occasionally, *Klebsiella pneumoniae* can become pathogenic because of its ability to produce a thermal stable enterotoxin, and being one of the major causes of urinary tract infections, second only to *E. coli*. Not only that *P. aeruginosa* may cause several infections, but also is an opportunistic pathogen. *Pseudomonas aeruginosa* biofilms cause persistent infections in individuals with health problems. [26] *Pseudomonas aeruginosa* that was isolated in most of water samples, its presence can be associated with complaints about odor, bad taste, and turbidity. [26-28] Besides, some respondents were reluctant to use chemicals for water disinfection, because of the unpleasant taste and appearance changes that may be due to presence of bacteria, and water contamination in storage vessels as result of multiple uses. Likewise, one study showed that chloramines, chlorine-based disinfectants, undergo nitrification that affects water quality as result of variations in the biofilm microbial community. [26-27,29-30] Drinking water contamination with both *P. aeruginosa and K. pneumoniae* might be minimized by water disinfection; [16] particularly by water boiling, as showed to be very effective method of killing *E. coli*, because no such bateria were found in boiled drinking water. The present study showed that water chemical disinfection in conjunction with boiling was the most effective water treatment approach. Nevertheless, another study has raised concern on the use of chemicals for treating HDW since the inactivation of microorganisms increases with increasing disinfectant exposure time and concentration of disinfectant; such that is a product of concentration and contact time (CT). However, the formation of undesired disinfection by-products also increases with CT. [29]

The high prevalence of waterborne disease outbreaks in the municipality coincides with the high level of bacterial loads in HDW observed in this study. The presence of coliforms in HDW witnessed in the study area can be due to contamination of drinking water sources, inefficient water plant treatment and/or poor storage. [10,12] Our findings are in conformity with studies conducted in Zambia, which showed that about 80% of urban and 97.6% of rural households had drinking water contaminated with coliforms; [31] and another in India indicating rate of HDW contamination of 78%. [6] We have shown that neither types of isolated bacteria nor their observed counts had significant association with incidences of water-borne infections in the study area, which might be because of time limitation and/or failure to follow up the interviewees for longer period. Use of inappropriate HDW storage containers, such as large open-mouth vessels by most respondents could have significantly led to the observed high total coliform counts in domestically treated drinking water.

CONCLUSION

Slightly more than half (55%) of the residents were aware of the importance of appropriate HTSP. High level of bacterial contamination of drinking water was noted that may contribute to the high prevalence of waterborne disease outbreaks in the municipality. High total coliform counts in drinking water were revealed that were partially attributed to poor storage and non-use of treated drinking water. Household water treatment by boiling was the most useful means for fecal coliform elimination. We suggest that HTSP can improve drinking water quality and prevent diseases if used correctly and consistently. The use of wide-open mouth containers for water storage could also contribute to contamination of stored drinking water. The residents should be educated on proper HTSP to prevent microbial water contamination thus reduce the incidences of waterborne outbreaks. The government should strive to increase accessibility of improved drinking water to her citizens in line with the millennium development goals.

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