Investigating the presence of enteric bacteria and their antibiotic resistance in drinking water samples of slum households in port city Chattogram, Bangladesh

Sidratun Nur Chowdhury, Nazifa Rafa, Sayed Mohammad Nazim Uddin and A. K. M. Moniruzzaman Mollah

ABSTRACT

Globally, unsafe water supplies due to contamination with fecal coliforms are major issues in urban slums. To determine the presence of microbial risk, water samples were collected from three slums in the port city Chattogram and the most probable number (MPN) method was used to test for the presence of fecal coliform. All of the samples tested positive by the MPN test. The highest count was 1,100 MPN/100 mL and the lowest count was 7.2 MPN/100 mL. Water stored in containers was prone to being more contaminated than water collected directly from the source. To understand the antibiotic resistivity of the coliform bacteria isolated from the water samples, antibiotic susceptibility was evaluated using the Kirby-Bauer disc method for six antibiotics. All the bacteria were 100% resistant to penicillin-G and ampicillin, and 91.7% showed resistance to amoxicillin and mecillinam. An integrated approach to water, sanitation, and hygiene education must be undertaken when providing sustainable interventions in slums.

Key words | antibiotic resistance, *E. coli*, fecal coliform, sanitation, slums, water

Sidratun Nur Chowdhury
Nazifa Rafa
Sayed Mohammad Nazim Uddin (corresponding author)
Environmental Sciences Program,
Asian University for Women,
Chattogram,
Bangladesh
E-mail: *sayed.uddin@auw.edu.bd*

A. K. M. Moniruzzaman Mollah
Science and Math Programs,
Asian University for Women,
Chattogram,
Bangladesh

HIGHLIGHTS

- Microbial risks were assessed in the context of a dynamic port city in the global south.
- Safe drinking water and a more hygienic environment have become crucial to improve the standards of living of slum dwellers.
- Projects for slum development should not only focus on the water quality but also include improving the sanitation, environment, and hygiene practices in the slums.

INTRODUCTION

Globally, millions of people do not have access to an adequate supply of safe drinking water, which is universally recognized as a basic need. The consumption of contaminated water causes over one-third of deaths in low-income countries (WHO, 1997 cited in Zuthi *et al.* 2009). As of 2017, 2.2 billion people lack safely managed water services, with 579 million depending on unprotected and untreated water sources (UNICEF/WHO 2019). In addition, 4.2 billion lack safely managed sanitation and 3 billion lack access to basic handwashing facilities (UNICEF/WHO 2019), contributing to 10% of the global disease burden, mainly diarrhea (Mara *et al.* 2010).

The spread of many infectious waterborne diseases such as cholera, typhoid, hepatitis, polio, schistosomiasis, etc.,

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has been attributed to unsafe water sources contaminated with human excreta and the lack of adequate personal and domestic hygiene. Urban slum-dwellers are very vulnerable to these diseases because they do not have access to safe drinking water, sanitation, or proper drainage or garbage collection systems, thereby exposing them to different pathogens and making them susceptible to different waterborne and infectious diseases, injuries, and respiratory problems (Vlahov *et al.* 2007; Firdaus 2012; Katukiza *et al.* 2014). Most slums have unsanitary latrines that are each shared by many households. In addition, indiscriminate waste disposal, latrines being constructed too close to water pipelines, or open defecation near water supply can cause contamination of water sources. Water contamination can also occur during water collection, transportation, and storage if proper hygiene is not maintained. Inadequate water supply and sanitation facilities are the leading cause of mortality and morbidity in slums (Mara *et al.* 2010). In 2000, more than 650 million residents of informal settlements had inadequate water supply and approximately 850 million residents lacked proper sanitation, with younger children often suffering from waterborne diseases due to not getting access to good quality water and sanitation (Sverdlik 2011). Slum-dwellers, for example, those in India (Firdaus 2012), Kenya (Corburn & Hildebrand 2015), and Nigeria (Ayeni 2014), live in poor quality housing and lack access to clean, safe water and sanitation facilities. As a result, in slums, the prevalence of dysentery, diarrhea, and gastroenteritis are high, especially in immunocompromised groups (Alirol *et al.* 2011).

The main cause of the waterborne disease is water contamination by human or animal excreta. Therefore, an important part of the evaluation of water quality lies in the investigation of the presence of microorganisms, which are explicitly found in excreta or feces, in water samples. The three most common indicators used to assess fecal contamination in water are *Escherichia coli*, total coliform bacteria, and thermotolerant bacteria. Of the three aforementioned indicators, the presence of *E. coli* is often dubbed as the 'more precise indicator of fecal pollution' and the presence of *E. coli* notifies on the possibilities of the presence of other enteric pathogens (WHO 2017). Several studies have found the presence of *E. coli* and coliform bacteria in water from sources like taps as well as household storage systems in slums of countries like Malawi (Zeleza-Manda 2009), India (Palit *et al.* 2012; Subbaraman *et al.* 2013), and Kenya (Kimani-Murage & Ngindu 2007; Opisa *et al.* 2012). The aforementioned studies associate the observed fecal contamination with the lack of water treatment before storage, unsafe or unprotected sources, improper waste and excreta management and improper water handling, hygiene practices, and sanitation.

Inadequate water, sanitation, hygiene (WASH), and unsafe disposal of waste from health care facilities have been linked to the spread of antimicrobial-resistant infections, placing people at risk of serious infections that are hard to treat (UNICEF/WHO 2019). In countries and areas where WASH is inadequate and infectious disease risks are high, prophylactic use of antibiotics is more common, which further gives rise to antimicrobial resistance (AMR) (UNICEF/WHO 2019). AMR is a major factor determining clinical unresponsiveness to treatment and rapid evolution to sepsis and septic shock and, therefore, has emerged as a global health concern in the last couple of years. Drug-resistant microbes could reverse the progress made in the decline in global mortality rates in the last 15 years, particularly in maternal mortality rates in low and middle-income countries (WHO 2015). In addition to posing risks to the public health, AMR is a hindrance to the world's pursuit of sustainable development as it compromises the world's food security, threatens economic growth, and has negative implications on the environment (Jasovský *et al.* 2016). Due to overuse in the agricultural, poultry, and the healthcare sector, antibiotics are introduced into the natural environment, mostly via waste products from these sectors, which lead to the development of antibiotic-resistant microbes in water and soil.

Multi-drug resistant *E. coli* are now widespread in water supplies around the world, thus, becoming a well-known global issue in the health sector, but even more so for developing nations. 49.48% of the *E. coli* isolates collected from drinking water sources from different districts in Ghana showed high resistance patterns, exhibiting the most resistance to penicillin (32.99%), cefuroxime (28.87%), erythromycin (23.71%), and tetracycline (21.45%), while displaying susceptibility to nitrofurantoin (93.8%), cefotaxime and amikacin (91.75%), gentamicin (90.7%), nalidixic acid (89.65%), ciprofloxacin (74.2%), chloramphenicol (69.07%), pipemidic acid (65.97%), and cefuroxime (52.58%) (Odonkor

& Addo 2018). Another study in Hangzhou city in China showed that most of the isolates collected from drinking water sources were resistant to tetracycline, followed by ampicillin, piperacillin, trimethoprim/sulfamethoxazole, and chloramphenicol (Chen *et al.* 2017). Antibiotics that have been rendered useless due to the proliferation of resistant microbes compounds on nations' health budgets and reduces productivity and household earnings, thereby causing losses in GDP (Jasovský *et al.* 2016).

In Bangladesh, the problem is acute too. The lack of proper regulations and surveillance, financial incentives, low awareness regarding antibiotic consumption, and lack of trained healthcare professionals are some of the reasons why antibiotics are unsystematically and carelessly used in the country (Ahmed *et al.* 2019; Matin *et al.* 2020). Slum-dwellers, one of the poorest and marginalized communities in Bangladesh, are at high risk of contracting diseases caused by antibiotic-resistant microbes. According to the Bangladesh Bureau of Statistics (BBS), around 2.23 million people live in slums all over the country (BBS 2015). Most of the water sources in slums become contaminated and unsafe because of poor infrastructure, low water, and sanitation levels, high population density, and lack of adequate personal and domestic hygiene (Katukiza *et al.* 2014). Slums are also often located near polluted water bodies, swamps, or putrid drainage canals. These account for the poor environment and health of slum dwellers. Fecal contamination of water is a major concern in the slums. Issues pertaining to unsafe and unprotected water sources, as well as poor hygiene practices, cause a high prevalence of waterborne illnesses in slums. However, very little research has been conducted that inquires into the presence of enteric pathogens in water in slums, let alone the assessment of their antibiotic susceptibility. Nevertheless, a study tested for water samples collected across Dhaka city, including from a large slum (Talukdar *et al.* 2013). Water supplied by the municipal authority was the only source of water for the population living in the study area. The study revealed that around 80% of the samples were contaminated with *E. coli*, with counts being more than 100 CFU/mL, and many of the *E. coli* isolates were multi-drug resistant, which is a source of alarm for the general public health.

Chattogram, being the commercial capital and one of the port cities of Bangladesh, has a dense urban population, and the urban slums of the city are the most vulnerable to water contamination. The quality of water distributed and the status of sanitation facilities in the slum areas are not regularly monitored. A study in Chattogram by Zuthi *et al.* (2009) found that some of the samples of water collected from Madarbari and Kapasgola were contaminated with uncountable total coliforms, compromising the safety of the people. More recent studies have assessed the quality of commercially supplied drinking water, which have also revealed poor quality due to the presence of coliform bacteria, which have shown resistance to enrofloxacin (100%), cephradine (100%), gentamycin (92.59%), ceftriaxone (3.70%), ampicillin (81.48%), colistin-sulphate (74.02%) and amoxicillin (70.30%) (Ahmad *et al.* 2018). However, a huge gap still remains regarding the current condition of the microbial safety of drinking water in the slums of Bangladesh, as well as an assessment of the microbial risk they pose because of their antibiotic resistivity. Therefore, this study aims to address this gap by evaluating the microbiological quality of water samples collected from urban slums in the port city context, obtaining an insight into the contamination pathways of fecal coliform bacteria, and analyzing the antibiotic sensitivity of bacteria inoculated from the collected water samples.

METHODOLOGY

Sample area

Water samples were collected from three slum areas within Chattogram city: Sholoshohor (Latitude: 22.369596, Longitude: 91.829029; near Sholoshohor railway station), Motijhorna (Latitude: 22.347859, Longitude: 91.816998; in Lalkhan Bazar), and Jhautola (Latitude: 22.358311, Longitude: 91.808442; near Khulshi). In Motijhorna, a deep tubewell, and in Jhautola and Sholoshohor, municipal water pipelines provided drinking and nonpotable water to the slum dwellers. The water that is supplied via municipal waterlines, provided by the Chattogram Water and Sewerage Authority, is treated in the Mohora Water Treatment Plant before distribution. For both government-supplied water and water obtained from deep tubewell, no further treatment is undertaken before use or consumption by slum dwellers. Boiling is done by very few, and very rarely.

On inspection of the settlements, some common scenarios regarding water and sanitation facility usage were observed. Because households do not possess toilets or water taps in their homes, about 10–15 people share one latrine, and one tap, where people queue up to collect water in containers. All of the families stored the water in containers in their houses, where potentially the members of the household, about four to five people, are the only people to come into contact with the water. The slums also have poor sanitation facilities, where latrines were observed to be in very unhygienic states. In addition, the drains that go through the slums are situated right beside houses and are clogged with waste. A walk through the slums confirms that solid and liquid waste is dumped indiscriminately and is often dumped directly into the clogged drains. Overall, the slums were in poor condition in terms of living standards.

Sample collection

Water samples were randomly collected from each slum on 18th May 2019 in sterilized 500 mL plastic bottles. Samples 1–5 were collected from Motijhorna, 6–10 were collected from Sholoshohor, and 11–12 were collected Jhautola. Only samples 3 and 6 were collected from the water sources (deep tubewell and municipal water supply, respectively), while the remaining were collected from household storage containers. The sample size was subject to time and resource constraints. The samples were transported to Asian University for Women (AUW) research lab within 2 h of collection. Then, they were stored at 2 °C in the freezer for 24 h for further analysis.

Coliforms quantification using the MPN method

Most probable number (MPN) test was performed 24 h after sample collection to quantify the coliform population present in the samples. MPN test was used in a similar study for testing for the presence of enteric pathogens in Kenya (Kimani-Murage & Ngindu 2007). The procedure outlined by Pepper *et al.* (2011) was followed.

The MPN test for coliforms consists of three steps: a presumptive test, a confirmation test, and a completed test.

For the presumptive test, lactose broth was prepared, autoclaved at 121 °C, and taken into test tubes. In each test tube, a Durham tube was placed inverted to collect gas. A set of tubes of lactose broth was inoculated with samples of diluted water. For each sample, nine test tubes were used. 0.1 mL, 1 mL, and 10 mL of sample were poured into the test tubes. Three test tubes were used for each dilution. In addition, three tubes were maintained as control, and they did not contain any sample water. All the tubes were incubated at 35 °C for 24 h in a shaking incubator. After 24 h, the gas formation was observed as a bubble at the peak of the inverted Durham's tube (Figure 1(a)). The controls did not show any bubble formation after incubation.

For the confirmative test, 330 mL of eosin methylene blue (EMB) agar was prepared and autoclaved. Then, one lactose broth tube that was tested positive in the presumptive test was selected for each sample and was streaked on EMB agar plates. The plates were incubated for 24 h at 35 °C. After the incubation period, the plates were observed for coliform growth (Figure 1(b)). However, because this study attempts to specifically look into the presence of

Figure 1 | (a) (Left) Coliform positive test tube with gas bubble and (Right) coliform negative test tube with gas bubble, (b) coliform colonies on EMB agar.

E. coli as it is the most preferred indicator organism, Endo agar was not used to detect for the presence of other lactose fermenting (coliform) colonies, as suggested by the protocol.

The completed test consists of using gram staining to identify the bacteria. As EMB agar, which contains methylene blue that inhibits the growth of gram-positive bacteria was used, the completed test was not done for this experiment.

Antibiotic susceptibility test using the kirby-bauer disc method

The Kirby-Bauer disc method was performed 24 h after sample collection to measure the effectiveness of the antibiotics against bacterial isolates. This method uses antibiotic discs to test resistivity and the inhibition zones are measured. The zones are termed as susceptible (S), intermediate (I), or resistant (R).

20 mL of peptone water broth was prepared and autoclaved. Then, about 1 mL of the broth was transferred to 12 test tubes each. 1 mL of each of the samples was then transferred to the test tubes and incubated for 24 hours at 35 °C in a shaking incubator. Using an inoculation loop, the samples were taken from the test tubes and streaked onto EMB agar plates and incubated for another 24 h at 37 °C. Using a micropipette, 0.3 mL of sterile distilled water was taken into a microfuge tube. For 12 samples, 12 microfuge tubes were arranged. After the incubation, a single colony was selected from the agar plates and transferred into the microfuge tube using an inoculation loop. A vortex mixer was used to mix the solution.

Twelve nutrient agar plates were prepared. 0.1 mL of suspension was taken from the tube and was evenly spread onto the Agar plate. The plate was then left to dry for 2–3 min. To the plate, six antibiotic discs: co-trimoxazole (25 μg/disc), penicillin-G (10 units), ampicillin (25 μg/disc), amoxicillin (30 μg/disc), mecillinam (10 μg/disc), and tetracycline (30 μg/disc), were placed at an even distance. The discs were placed using a flame sterilized forceps. The plates were then incubated at 37 °C temperature for five days. Then, the inhibition zone of the antibiotic disc was measured with a ruler and the results were recorded.

RESULTS AND DISCUSSION

MPN test

According to WHO drinking water guidelines, fecal coliform (*E. coli* or thermotolerant coliform bacteria) should not be detectable in any water source that is for drinking purposes (WHO 2017). However, according to the results of the MPN test (Table 1), all the samples collected for the study showed the presence of coliform bacteria and tested positive for either *E. coli* or thermotolerant coliform bacteria (*Enterobacter*). This means that all the samples were contaminated with fecal coliforms, possibly *Enterobacter aerogenes* and *E. coli*. *Enterobacter spp.* are opportunistic pathogens that can cause gastrointestinal infections, urinary tract infections (UTIs), skin and soft tissue infections, respiratory infections, and CNS infections (Fraser & Sinave 2019). *E. coli* can cause bacterial infections such as cholecystitis, bacteremia, cholangitis, UTI, and traveler's diarrhea, and other clinical infections such as neonatal meningitis and pneumonia (Madappa & Go 2019). To measure the prevalence of the diseases caused by fecal coliform in the slum populations of Chattogram, further research is required.

As mentioned in the Methodology section, the source of the water from Motijhorna is from deep tube wells, and the water sources for Sholoshahor and Jhautola were municipal water supply. Samples 3 (11 MPN/100 mL) and 6 (15 MPN/100 mL) were taken from the water sources – deep tube well and municipal water supply, respectively. Because the residents did not have water taps in their homes, and because each tap was shared by 10–15 people, there is an increase in the likelihood of contamination if hygiene is poorly maintained by residents. The presence of fecal coliforms in sample 3 could denote an intrusion of wastewater from pit latrines into the groundwater. The presence of fecal coliform in sample 6 could be a sign of contamination of municipal water supplies, as in the study done in Dhaka (Talukdar *et al.* 2013). However, the relatively low colony-forming unit (CFU) count in both source samples could indicate that the sources were contaminated during water collection due to poor personal/domestic hygiene practices.

According to Table 1, the highest count was found in samples 4, 8, 11, and 12, with the values 1,100 MPN/100 mL, 53 MPN/100 mL, 210 MPN/100 mL, and 93

Table 1 | Results of MPN test

Sample source (Household container/Water source)-Sample No.	Presumptive test				Confirmative test	
	Number of test tubes giving a positive reaction			MPN/100 mL	Bacteria colony color on EMB agar	Possible bacteria
	10 mL	1 mL	0.1 mL			
Motijhorna (Household container)-1	1	2	3	24	Purple	*Enterobacter* spp.
Motijhorna (Household container)-2	2	2	0	21	Dark blue with a metallic green sheen	*E. coli*
Motijhorna (Water source)-3	1	1	1	11	Purple	*Enterobacter* spp.
Motijhorna (Household container)-4	3	3	2	1,100	Purple	*Enterobacter* spp.
Motijhorna (Household container)-5	2	2	2	35	Dark blue with a metallic green sheen	*E. coli*
Sholoshohor (Water source)-6	1	2	1	15	Dark blue with a metallic green sheen	*E. coli*
Sholoshohor (Household container)-7	1	1	0	7.3	Purple	*Enterobacter* spp.
Sholoshohor (Household container)-8	2	3	3	53	Dark blue with a metallic green sheen	*E. coli*
Sholoshohor (Household container)-9	1	1	1	11	Purple	*Enterobacter* spp.
Sholoshohor (Household container)-10	1	0	1	7.2	Dark blue with a metallic green sheen	*E. coli*
Jhautola (Household container)-11	3	2	2	210	Purple	*Enterobacter* spp.
Jhautola (Household container)-12	3	2	0	93	Purple	*Enterobacter* spp.

MPN/100 mL, respectively. Sample 4 had the highest MPN/100 mL count, perhaps, because the household where the sample was collected from had very poor domestic hygiene practices. Both the samples from Jhautola displayed MPN count>100 MPN/100 mL. Samples 7 (7.3 MPN/100 mL), 9 (11 MPN/100 mL) and 10 (7.2 MPN/100 mL) had the least MPN counts, with sample 10 having the lowest count. This can be due to comparatively better sanitation and hygiene practices in households.

To explore the exact reasons behind such counts, a study needs to be undertaken that explores the features (protected/unprotected) and water quality of the water sources, as well as the hygiene practices at the households to understand the route of fecal coliform transfer.

Antibiotic susceptibility test

The analysis of the extent of antibiotic susceptibility was done according to the guidelines given by the Clinical and Laboratory Standards Institute (CLSI 2014) (shown in Table 1 in Supplementary Materials). According to the ISO 20776–1 standard (2006), which is valid all over the world, a bacterial strain is said to be S (susceptible) to a given antibiotic when it is inhibited *in vitro* by a concentration of this drug that is associated with a high likelihood of therapeutic success, and R (resistant) when it is inhibited *in vitro* that is associated with a high likelihood of therapeutic failure (DIN Deutsches Institut für Normung 2006). The susceptibility to a given antibiotic is said to be intermediate when the strain is inhibited *in vitro* that is associated with an uncertain therapeutic effect. Table 2 and Figure 2 show the results of the antibiotic susceptibility test.

Motijhorna (samples 1–5)

Samples 1 and 4, which were found to contain *Enterobacter* spp. isolates obtained from water collected from households displayed resistance against all six of the antibiotics tested, except sample 4 which showed susceptibility against tetracycline (TE). Sample 3, also determined as having *Enterobacter* spp. isolates, which was collected from the water source, the deep tubewell, was susceptible only to co-trimoxazole (CoT) and TE. The *E. coli* isolates in samples 2 and 5, obtained from water collected from household containers, displayed susceptibility only to CoT and TE.

Sholoshohor (samples 6–10)

The *Enterobacter* spp. isolates (samples 7 and 9, both obtained from household containers) showed susceptibility

Table 2 | Antibiotic susceptibility test

Sample no. (Potential bacteria type)	Co-Trimoxazole (COT 25)	Penicillin-G (P 10)	Ampicillin (AMP 25)	Amoxicillin (AMX 30)	Mecillinam (MEC 10)	Tetracycline (TE 30)
	Inhibition zone (R = resistant/I = intermediate/S = susceptible)					
1 (*Enterobacter* spp.)	7 mm (R)	7 mm (R)	7 mm (R)	7 mm (R)	7 mm (R)	7 mm (R)
2 (*E. coli*)	20 mm (S)	7 mm (R)	10 mm (R)	7 mm (R)	13 mm (I)	25 mm (S)
3 (*Enterobacter* spp.)	20 mm (S)	7 mm (R)	7 mm (R)	7 mm (R)	7 mm (R)	20 mm (S)
4 (*Enterobacter* spp.)	10 mm (R)	7 mm (R)	7 mm (R)	8 mm (R)	7 mm (R)	25 mm (S)
5 (*E. coli*)	20 mm (S)	7 mm (R)	7 mm (R)	7 mm (R)	7 mm (R)	20 mm (S)
6 (*E. coli*)	19 mm (S)	7 mm (R)	8 mm (R)	7 mm (R)	8 mm (R)	29 mm (S)
7 (*Enterobacter* spp.)	24 mm (S)	7 mm (R)	7 mm (R)	7 mm (R)	8 mm (R)	20 mm (S)
8 (*E. coli*)	10 mm (R)	7 mm (R)	10 mm (R)	15 mm (S)	7 mm (R)	20 mm (S)
9 (*Enterobacter* spp.)	17 mm (S)	7 mm (R)	7 mm (R)	7 mm (R)	7 mm (R)	21 mm (S)
10 (*E. coli*)	17 mm (S)	7 mm (R)	7 mm (R)	10 mm (R)	7 mm (R)	25 mm (S)
11 (*Enterobacter* spp.)	15 mm (R)	7 mm (R)	7 mm (R)	13 mm (R)	7 mm (R)	10 mm (R)
12 (*Enterobacter* spp.)	10 mm (R)	7 mm (R)	8 mm (R)	7 mm (R)	7 mm (R)	20 mm (S)

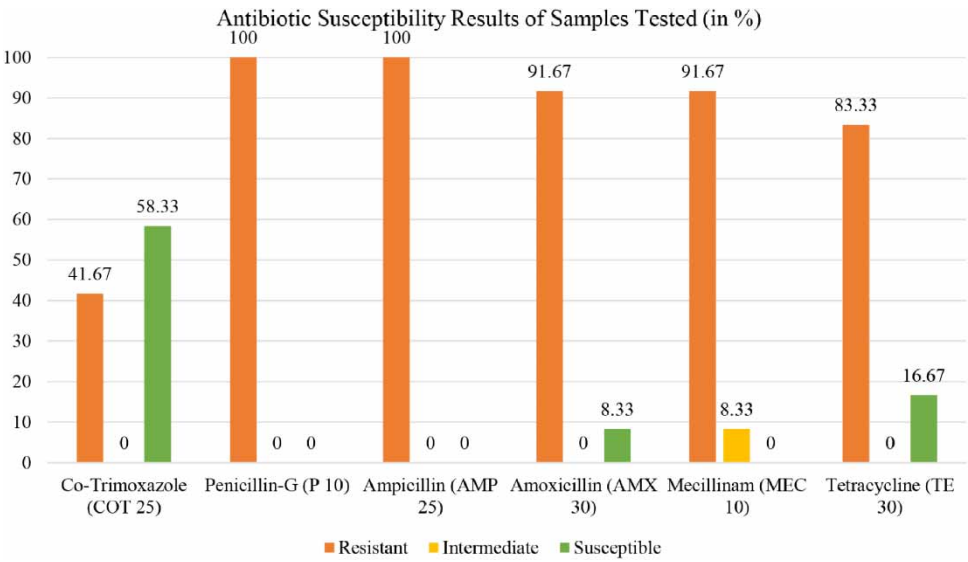

Figure 2 | Antibiotic susceptibility results of samples tested (in %).

against CoT and TE only. *E. coli* isolates from sample 6 collected from municipal water pipes and sample 10 collected from a household container also showed the same susceptibility trend. *E. coli* isolate from sample 8 was inhibited by TE and amoxicillin (AMX).

Jhautola (samples 11–12)

Enterobacter spp. isolates found in samples 11 and 12 collected from household containers showed resistance to all the antibiotics, except for sample 12's isolate which was susceptible to TE.

From Table 2 and Figure 2, it is clear that CoT and TE had the largest inhibition zones for most of the bacteria isolates, and were more effective in killing the bacterial isolates than the other antibiotics. For CoT, 41.7% of the isolates (samples 1, 4, 8, 11, and 12) showed resistance. For AMX, ampicillin (AMP), penicillin (P), and mecillinam (MEC), the resistance of the isolates is very high. All bacterial isolates showed 100% resistance to AMP and

P. 91.7% of the isolates showed resistance to AMX and MEC. TE was the most effective of all the drugs, having only 16.7% of the isolates exhibit resistance (shown by samples 1 and 11). The results of the bacterial isolates from samples 1 and 11 were of concern as it was susceptible to all of the antibiotics.

Samples 2, 5, 6, 8, and 10 were *E. coli* isolates. They usually showed similar patterns in antibiotic resistivity. Only sample 2 showed susceptibility to MEC. All of them showed resistance against AMP, AMX, and P, except for sample 8, which showed susceptibility to AMX. The aforementioned samples were susceptible to CoT and TE. AMP and AMX are commonly used to treat *E. coli* but these isolates are highly resistant to those antibiotics, which can imply that these bacteria have developed genes that are resistant to the antibiotics or that a more concentrated amount is needed to kill them. So these antibiotics will no longer be able to cure diseases caused by these bacteria.

Enteric pathogens found in water samples collected from slums in Dhaka city were also found to be resistant against AMP, AMX, and vancomycin (Nur *et al.* 2017). It also seems that the resistivity of *E. coli* to AMP has been observed worldwide (Christabel *et al.* 2012; Chen *et al.* 2017). In a study done in the Kibera slum in Nairobi, Kenya, 188 isolates of enteric pathogens were drawn from environmental samples and the characterization of their antibiotic susceptibility showed 56.79% resistance to AMP, as well as other antibiotics like trimethoprim+ sulphamethoxazole (29.63%), augmentin (27.16%), tetracycline (18.52%), streptomycin (13.57%), chloramphenicol (7.41%), nalidixic acid (4.94%), and gentamycin (2.47%) but none for ciprofloxacin (Christabel *et al.* 2012). Further tests can determine the resistance of the *E. coli* isolates from water supplies in slums to antibiotics like ciprofloxacin, nitrofurantoin, and cephalosporins, to which fecal coliforms have been found to be susceptible. These antibiotics could not be tested due to their unavailability in the lab.

FUTURE DIRECTIONS AND RECOMMENDATIONS

As mentioned previously, this study was heavily subjected to time and resource constraints, which contributed to the relatively uneven and small number of water samples from the different slums and a lack of multiple sampling which could have increased the reliability of the results. The study also failed to inquire into the causes of source contamination and was unable to explore the isolates' resistivity to other important antibiotics. Future studies could look into the correlation between water source type and antibiotic resistivity. The findings should have been complemented with a more comprehensive insight into the sanitation and hygiene practices of the slum dwellers as well as an understanding of the prevalence of waterborne and WASH-borne illnesses in the population and their correlation to the type of bacteria prevalent. Antibiotic consumption patterns of the study population should also be assessed to better understand the potential causes of the development of such resistant microbes in the slums. In addition, further tests and utilization of polymerase chain reaction (PCR) could give more accurate identifications of the other different kinds of pathogens that may have been present in the water. Further research can be done based on this study. Coliform growth can be affected by seasons and climate, so samples collected in different seasons can help understand how the seasons impact the contamination level. Also, a comparative study can be done with the water samples collected from formal settlements situated around the slum areas to understand if the water quality from the municipal water supplies is better in the households than the slum areas to see whether the contamination of water sources was solely due to the environment and hygiene practices at the slum. In addition, molecular studies that look into the genes responsible for antibiotic resistance and the mode of transfer of resistance can be conducted for isolates from urban slums, as in Christabel *et al.* (2012), for better environmental monitoring.

As sustainable interventions, successful community WASH projects, as in the case slum communities of central Uganda undertaken by Musoke *et al.* (2018), can be applied. The project implemented community interventions like home improvement campaigns, clean-up exercises, water quality assessment, promotion of drinking safe water through household point-of-use chlorination, promotion of handwashing, and support towards solid waste management, and school interventions like health clubs and platforms with 'talking compound' messages (Musoke

et al. 2018). It also involved the training of youth and community health workers. Employment of such projects can result in increased usage in piped water, reduction in the use of unprotected water sources, reduction in indiscriminate disposal of solid waste, and increased satisfaction with solid waste management services (Musoke et al. 2018).

Intensive behavioral change in hygiene practices is recommended as their current practices make the slum dwellers more susceptible to water-borne diseases. According to some informal interviews taken from the slum dwellers, most families in the slums do not boil or filter the water collected from the source. To further minimize the risk of diseases from stored water, all potable water should be treated either by boiling, filtration, or chlorination. Appropriate handling, and covering the water containers with lids are also important to reduce contamination (Palit et al. 2012). In addition, households in the slums of the study area did not have toilets in their homes, so each latrine was shared by 10–15 people. The drains that go through the slums were also very close to the houses. Solid and liquid wastes are dumped haphazardly and often collect in the already clogged drains. Thus, projects for slum development should not only focus on the water quality but also include improving the sanitation, environment, and hygiene practices in the slums.

Safe drinking water and a more hygienic environment have become crucial to improve the standards of living of slum dwellers. The government and non-governmental organizations (NGOs) should work together for this cause to achieve equitable living standards for all.

CONCLUSION

Regardless of the limitations faced by the study, the findings were successful in presenting the current condition of microbial quality of the water supplies in the slums of Chattogram, and the resilience of these microbes under commonly used antibiotics. Microbial tests of water samples collected revealed the presence of enteric pathogens in all of the samples studied. Two samples showed an MPN count of more than 100 MPN/100 mL, where the highest count observed was 1,100 MPN/100 mL. The lowest count found was 7.2 MPN/100 mL. The isolates exhibited high resistance against ampicillin, amoxicillin, penicillin, and mecillinam, where all isolates showed resistance against ampicillin and penicillin. Co-trimoxazole and tetracycline were the most effective in inhibiting bacterial growth. Considering the above discussions, the water samples collected from the slum areas are contaminated with fecal coliforms and are not safe for drinking without treatment. Results show that water from the source is comparatively less contaminated than water stored in containers, so it is highly likely that the unsanitary environment of the slums and the hygiene practices of the residents have contributed to the contaminations.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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