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Research Paper

Evaluation of WASH indicators associated with diarrhoeal disease among under-five children in an urban slum pocket, Mumbai city, India: a community-based repeated cross-sectional study

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ABSTRACT

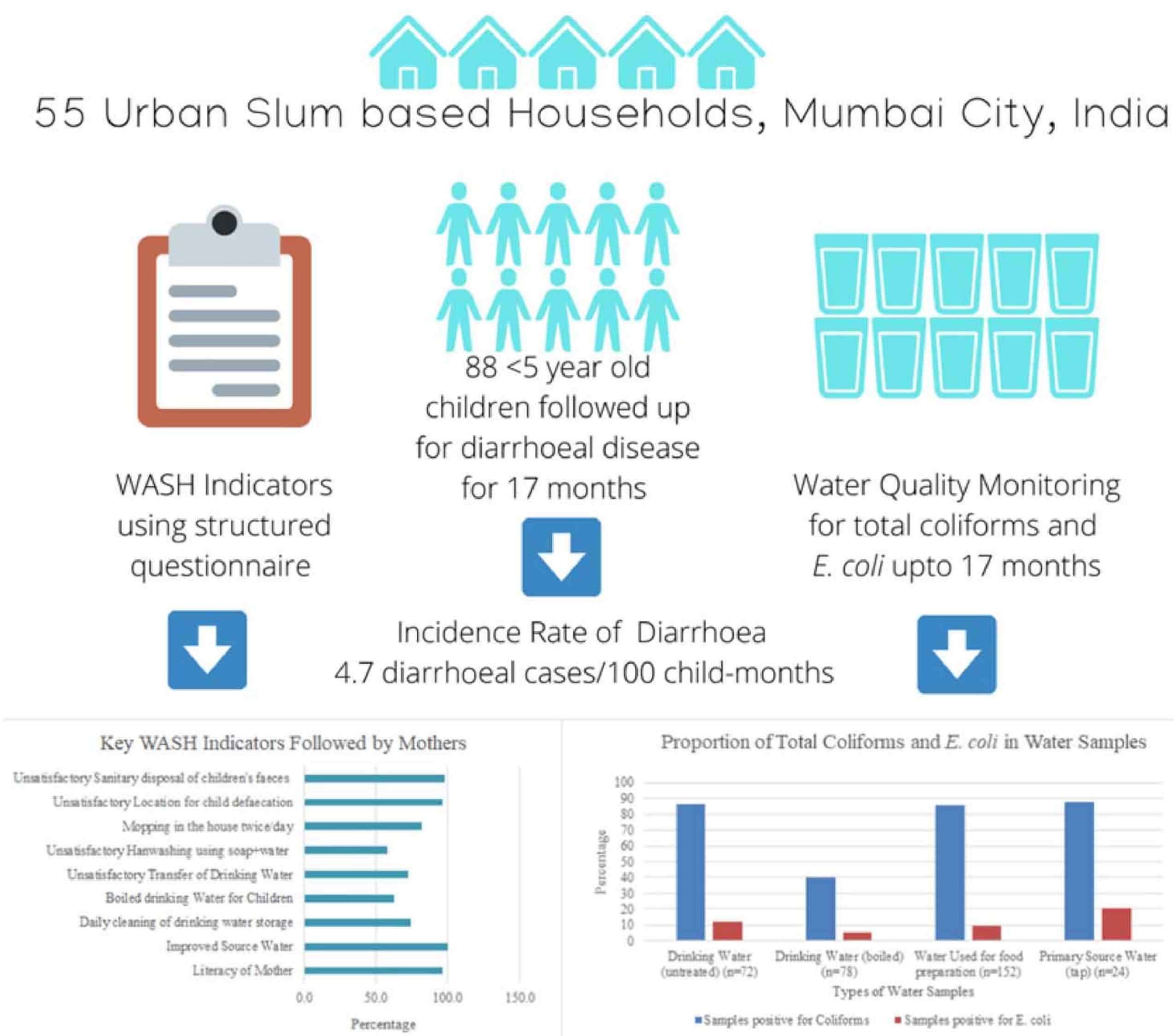
Water, Sanitation and Hygiene (WASH) practices are important factors in preventing diarrhoea. The objectives of this study were to assess the behaviour of the mothers of under-five children with regard to WASH practices, water quality, incidence rate of diarrhoea and the WASH predictors responsible for diarrhoea and water contamination, using multivariate regression analysis. The present study was conducted in households (n=55) having under-five children ($n = 88$) based in an urban slum pocket of Mumbai city, India. Key satisfactory practices included (percent household following them in parenthesis) boiling of water (63.6%) and daily cleaning of storage containers (74.5%). Households followed unsatisfactory practices during water transfer (72.7%), handwashing (58.2%), defaecation location (96.4%) and disposal of children's faeces (98.2%). The incidence rate of diarrhoea among <5-year-old children was 4.7 diarrhoeal episodes/100 child months. 86 and 39.7% of untreated and boiled drinking water samples had coliforms, while 12.5 and 5.1% had *E. coli*, respectively. Untreated drinking water and water sourced from shared taps were significantly associated with the incidence of diarrhoea ($p < 0.05$), and inconsistent in-house treatment of water was significantly associated with the presence of coliforms in drinking water ($p < 0.05$). The study results suggest that WASH advocacy and an improvement in sanitation-related infrastructure for the slum population can reduce diarrhoeal incidence.

Key words: children, diarrhoea, households, urban slum, WASH, water quality

HIGHLIGHTS

- Diarrhoeal incidence and microbial water quality were linked to WASH practices in the urban slum pocket of Mumbai city.
- Households fell short on the following parameters: the water transfer process, children's defaecation and safe faeces disposal practices.
- The study findings suggest improvements in WASH practices, point-of-use water quality and safety.
- WASH awareness, improved hygiene and sanitation infrastructure in slums are recommended.

GRAPHICAL ABSTRACT



1. INTRODUCTION

The World Health Organization (WHO) emphasises water, sanitation and hygiene (WASH) practices to be the most basic needs for overall development (Patel *et al.* 2020). The global importance of adequate WASH for development, poverty reduction and health is reflected in the Sustainable Development Goals (SDGs), wherein SDG6 targets improved WASH, i.e., 'Ensure access to water and sanitation for all' (WHO 2019).

According to the global health estimate report, in India, diarrhoea was the top cause of death among children aged between 1 and 4 years in 2015 (48.4 deaths per 100,000 live births) and in 2019 (37.8 deaths per 100,000 live births) (Global Health Estimates 2020). In low- and middle-income countries, diarrhoea is attributed to 54–65% of all deaths due to the inadequate access of safe drinking water (35%), poor sanitation (31%) and poor hygiene (12%), which result in 829,000 deaths annually (WHO 2019).

The national-level data on the prevalence of diarrhoea among under-five children in 649 and 668 surveyed households based in Mumbai and Mumbai suburban city were found to be 6.2 and 5.5%, respectively (IIPS 2015).

Diarrhoeal disease burden is influenced by health-related behaviours and prevalent risk factors in the environment where people live. (Ali *et al.* 2018). Factors contributing to the occurrence of diarrhoea among under-five children in low–middle-income countries (India, Cambodia, Nepal and Nigeria) and low-income countries (Ethiopia, Uganda and Yemen) are a complex mix of socio-economic, environmental and behavioural factors, which is compounded by a lack of easy access to clean water and awareness towards WASH practices (Shrestha *et al.* 2013; Bin Mohanna & Al-Sonboli 2017; Getachew *et al.* 2018; Musoke *et al.* 2018; Yaya *et al.* 2018; Edward *et al.* 2019; Melese *et al.* 2019).

Several studies on different aspects of WASH have been conducted in urban and rural settings in India in the past few years by Kundu *et al.* (2018) (Delhi), Quazi *et al.* (2019) and Reddy *et al.* (2017) (Andhra Pradesh, Uttarakhand and West Bengal), Bauza *et al.* (2019) (rural Odisha), Mohd & Malik (2017) (Bangalore) and (Subbaraman *et al.* 2013; Devansh Jalota 2014; Singh *et al.* 2019) (Mumbai). Most of these studies either focused on the behavioural knowledge of mothers on WASH practices or only on microbial water quality assessment.

The WASH-based studies reported in the past have found shortcomings in the behaviour of primary care-givers with regard to treatment, storage and handling of in-house drinking water (Bhattacharya *et al.* 2011; Sileshi Asfaw *et al.* 2016; Mohd & Malik 2017). A study conducted in a slum community based in Kampala, Uganda, observed that three-fourths of the study population did not maintain a safe water chain, which included practices of preventing water contamination from source to consumption such as during collection, handling, transportation, storage, treatment and consumption (Ssemugabo *et al.* 2019).

To identify the risk factors associated with diarrhoeal disease burden in urban slums, an integrated study of water quality and behaviour of the households with regard to WASH practices is essential, as both are interdependent with respect to water safety and health.

The main objectives of the present project were to study and evaluate the behaviour of mothers of under-five children with regard to WASH practices, such as water handling and general hygiene. An analysis of this behaviour was used to understand the impact of WASH practices on the microbial quality of drinking water in the household and the occurrence of diarrhoeal disease among children of this age group.

This study tried to establish the baseline data in the area of WASH research. The study is expected to help in planning and implementing effective WASH-related intervention strategies to bring out overall health and hygiene improvements such as improving water quality and reducing waterborne infections among the slum-based population.

2. MATERIALS AND METHODS

2.1. Study design and period

A community based cross-sectional study was conducted in the months of February and March 2017 using a structured questionnaire to understand the behaviour of mothers with regard to WASH practices. An assessment of the microbial quality of stored and source water and diarrhoeal incidence rate among under-five children was determined using a repeated cross-sectional study from March 2017 to July 2018.

2.2. Study setting and population

Mumbai is one of the largest and densely populated metropolitan cities in the western coast of India and is the capital of the state of Maharashtra. It has two districts, namely, Greater Mumbai and Mumbai suburban. The Municipal Corporation of Greater Mumbai (MCGM) has divided the entire city into 24 wards for administrative purposes (Risbud 2001).

An urban slum pocket named 'Waghariwada' based in Wakola area, Village Santacruz East, which falls under the H East administrative ward of Mumbai suburban district of Mumbai city, India, was selected for the study. In the identified slum pocket, households having under-five children were the final unit of sampling covering a total area of 24,386 m^2 (Figure 1). Mothers and under-5-year children were the population under study.

2.3. Sample size and sampling procedure

The sample (household) size was considered to be 50 households +10% non-respondent (55 households) using non-probability-based purposive sampling in the present study, with the aim of multiple sampling of in-house stored water for water quality assessment. Among the six slum pockets based in the Wakola area, Santacruz East, 'Waghariwada' having 1,663 households was randomly selected. This area was divided into five sub-clusters, with 300–350 households in each cluster. From the five sub-clusters, giving equal weightage to each, 103 households having under 5-year children were identified.

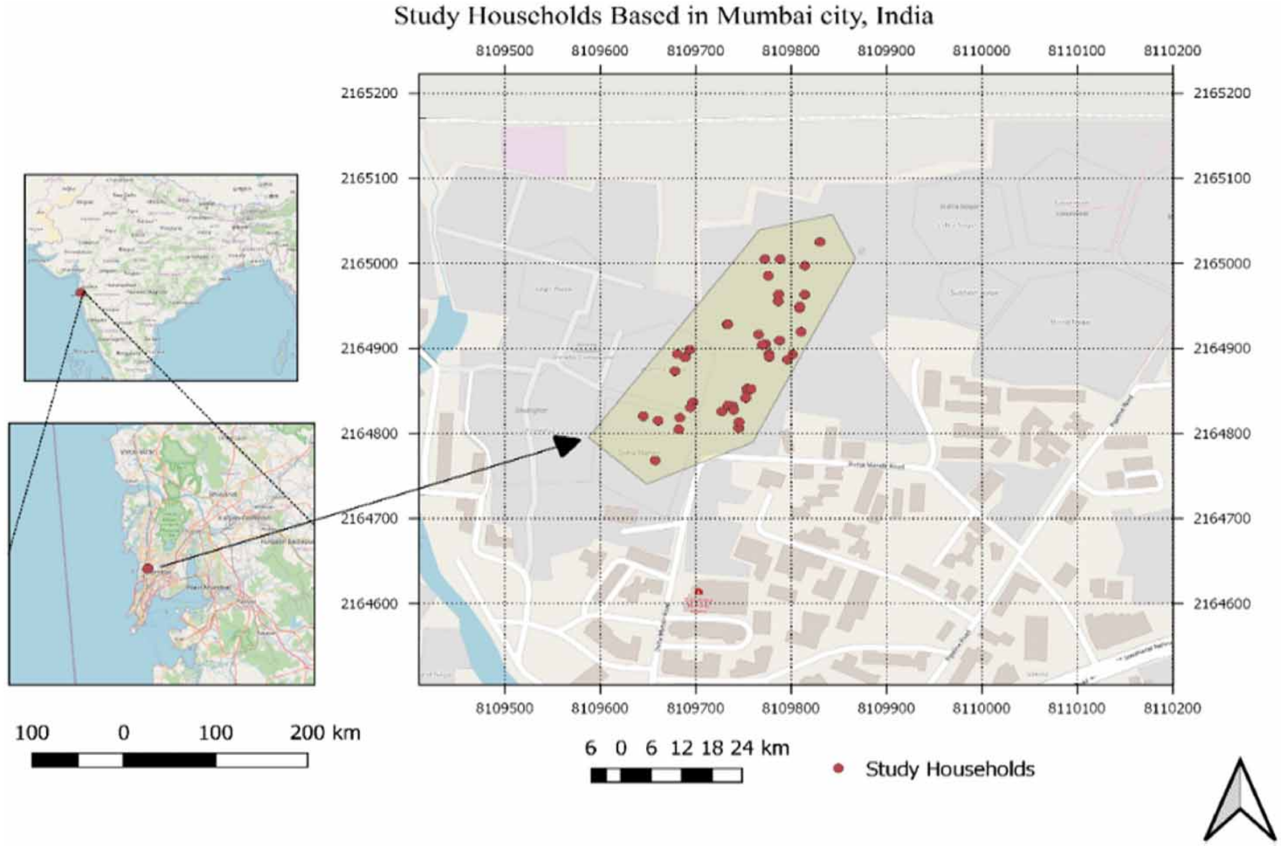


Figure 1 | Study households based in an urban slum pocket, Mumbai city, India.

Thereafter, they were screened for the remaining two criteria required for study participation. Finally, 55 households were selected for the study based on overall selection criteria that were as follows:

Inclusion criteria:

- Households having child/children aged between 6 months and 2 years.
- Families anticipating to stay for 3 years from the start of the study.
- Willingness to respond to the WASH questionnaire and consent to provide water for sampling and monthly data on diarrhoeal episodes in children as per the study plan.

Participation in the study was totally on a voluntary basis, and study participants were free to opt out of the study at any point of time during the study period. An upper age limit of 2 years was selected based on the study duration of 17 months, which required multiple water sampling (three times) from households and monthly follow-up on diarrhoea.

2.4. Operational definitions

Diarrhoea is defined as the passage of three or more loose or watery stools in a 24-h period (Hunter *et al.* 2011) as reported by mothers monthly at the time of data collection.

Satisfactory transfer of water: Use of tap/spigot, long ladle or direct pouring to transfer water for drinking purpose.

Unsatisfactory transfer of water: Use of glass, i.e., dipping the glass or any other similar utensil into a storage container for transferring drinking water.

Satisfactory practice for child defaecation: Defaecation in a potty chair or toilet, and vice versa is unsatisfactory.

Satisfactory sanitary disposal of child faeces: Use of the toilet/latrine by children; discarding of faeces into the toilet/latrine.

Unsatisfactory sanitary disposal of child faeces: Discarding of faeces into the drainage line inside the '*mori*' (a small bathroom in the house) and faeces thrown into garbage or into open drainage.

Satisfactory handwashing practices: Handwashing using soap and water before cooking food, eating, and breast-feeding the child and after visiting the toilet and cleaning the child post defaecation were considered to be the most important tasks and categorized as satisfactory and unsatisfactory if vice versa.

2.5. Data collection tools

The data collection tool was a structured interview questionnaire to evaluate the behaviour of mothers with regard to WASH practices, whereas templates were prepared to note monthly follow-up on diarrhoea among study children in the households. Both data were filled in by the data collector who was a trained master's degree holder and who was supervised by a doctoral degree holder.

2.6. Data collection

A structured questionnaire (WHO/UNICEF 2006; CDC 2008) comprising socio-demographic characteristics such as age and education of mothers, and WASH indicators such as primary water sources, water storage, usage and handling practices, hygiene and sanitation practices and mothers' awareness on diarrhoea, was prepared. Water-related practices focused on the material used for storage of water, cleaning frequency, the methods used for the transfer of water for drinking purpose and in-house treatment of water, if any. Hygiene and sanitation practices covered (a) handwashing using soap and water for seven different tasks, namely, after returning home, before cooking food before eating, before breast-feeding the child, after mopping, after visiting the toilet and after cleaning the child post defaecation, (b) material used for handwashing, (c) frequency of mopping and material used for mopping and (d) existing toilet facilities for children and methods of disposal of the child's faeces.

The mother's understanding of diarrhoea was assessed by asking if she had heard the term 'diarrhoea' and about her knowledge of the symptoms of diarrhoea.

Data on diarrhoea among children from all the study households were collected using a 1-month recall period, for up to 17 months. Thus, at the end of each month, mothers were asked if 'any children had suffered from diarrhoea during the previous month'.

A total of 302 samples of in-house stored water intended for drinking by children were collected, including untreated ($n = 72$) and boiled ($n = 78$), and water used for food preparation ($n = 152$). Sampling was done thrice at an interval of 4–5 months during March 2017 to July 2018. Mothers who were giving their children 'boiled water for drinking' were boiling water on a daily basis, especially in the morning. When the boiled water was to be sampled from such households, they were informed 1/2 days prior to boiling the water in larger quantities and to keeping the water available for collection on sampling day. To determine water quality at the source, 24 samples were collected from two identified sources/taps (piped water into yard/plot) at an interval of 1 month. 1.5 L samples were collected in a sterile container containing sodium thiosulphate (100 mg/L), in order to inactivate residual chlorine present in the chlorinated water samples (Liguori *et al.* 2010).

All samples were transported to the laboratory (situated 8.6 km from the study site) within 2 h of collection, refrigerated and processed within 6–24 h of collection (WHO 1997). The water samples were analysed for total coliforms and *E. coli* by the membrane filtration technique as per APHA, 2005 (9222B), using 0.45 μm pore size (Merck Millipore) membrane filters that were placed on HiCrome Chromogenic Coliform Agar (HiMedia Laboratories Pvt. Ltd, Mumbai, India) recommended by ISO 9308-1:2014. The plates were incubated at 37 °C for 24 h. Blue-violet colonies that appeared on the plates were counted as *E. coli*, whereas total coliform colonies included all colonies coloured from pink to red as well as *E. coli*. In each batch of water sample, standard *E. coli* ATCC 10536 and *Klebsiella pneumoniae* ATCC 10031, one of the members of the coliform group and sterility control of media were run. Total coliforms and *E. coli* were enumerated as Colony Forming Units (CFU)/100 ml.

2.7. Data quality control

The responses obtained from mothers through structured questionnaires, data on diarrhoea and microbial water quality assessments were transferred to an Excel spreadsheet manually and were verified twice with the original data sheets before data analysis.

2.8. Data analysis

The behaviour of mothers with regard to WASH practices was evaluated using the statistical software SPSS version 23.0. The frequencies and percentages of socio-demographic characteristics, WASH variables and knowledge on diarrhoea were obtained using descriptive analysis. WASH variables such as transfer of water for drinking purpose, overall handwashing using soap and water, location of child defaecation and disposal of the child's faeces were dichotomized into satisfactory and unsatisfactory as described under operational definitions.

The incidence rate of diarrhoea among <5-year-old children was calculated during the study period as per the formula mentioned below (Hunter *et al.* 2011). If the same child had diarrhoea twice or thrice during the study period, they were treated as different cases for the calculation of the incidence rate (Ali *et al.* 2018).

$$\text{Incidence rate} = \frac{\text{The number of new events in a defined population over a defined period of time}}{\text{Total person} - \text{time at risk during the defined period of time}}$$

The frequencies and percentages of positive samples for coliforms and *E. coli* in various types of water samples were calculated using an Excel spreadsheet.

A generalized linear model of the Poisson log link function with the logarithm of the child-month follow-up as an offset variable was used to estimate the incident rate ratio (IRR) to determine the association between the outcome/dependent variable, i.e., the incidence of diarrhoea among under-5 children, and independent predictors, namely, socio-demographic characteristics such as the age and education of mothers, mothers' understanding of diarrhoea, and WASH indicators such as improved source of water, frequency of cleaning storage container meant for drinking and cooking, in-house treatment of water, transfer of water, overall handwashing practices, frequency of mopping, location for child defaecation and sanitary disposal of children's faeces, and coliforms and *E. coli* in drinking water. Bivariate models between outcome and one independent variable were run to obtain crude IRRs at 95% confidence interval. For a multivariate Poisson regression model, variables with p values <0.2 were included to obtain adjusted IRRs. P values <0.05 were considered as statistically significant.

The association of the dependent/outcome variable, i.e., the 'presence of coliforms and *E. coli* in drinking water', with independent predictors such as socio-demographic characteristics and WASH indicators mentioned in the above paragraph was determined using logistic regression analysis. The independent variable 'treatment of water' was categorized based on the actual boiling history of the samples collected for microbial analysis. These indicators were investigated using bivariate logistic regression analysis to obtain a crude odds ratio with 95% confidence intervals. The variables with $p < 0.2$ were subjected to a multivariate logistic regression model with 95% confidence interval and P values <0.05 were considered statistically significant. The final model was checked for goodness-of-fit using the Hosmer and Lemeshow test and was found to be fit ($p>0.05$) (Mshida *et al.* 2017; Getachew *et al.* 2018; Kundu *et al.* 2018). The dependent variable (coliform/*E.coli* occurrence) was dichotomized as 'yes' for coliforms and *E. coli* if found to be present in at least one out of three drinking water samples from a household and vice versa.

2.9. Ethical clearance

A detailed study plan including study protocols and informed consent forms was reviewed and approved by the Bhavan's College Institutional Ethics Committee (BC/IEC/2016/01/part 2). The study group (mothers of <5-year-old children) was informed in the local Indian language (Marathi/Hindi) about the study procedure and duration following which consent was obtained from them. Data collected from the study group were kept confidential and households had the right to withdraw from the study at any time. Necessary permissions were obtained from the Public Health and Hydraulic Engineering Department of H East ward of the Municipal Corporation of Greater Mumbai in April 2016.

3. RESULTS AND DISCUSSION

3.1. Socio-demographic characteristics

The study involved a total of 55 households comprising 253 individuals (mean 4.6 ± 2.3 persons/house) and 88 <5-year-old children (mean 1.6 ± 0.97 children/house). As shown in Table 1, the highest proportion of mothers of <5-year-old children were in the age group of 25–34 years (32 (64%)), followed by 14 (28%) between age 18 and 24 years, and 4 (8%) were above 35 years. No response on age was obtained from five mothers.

Table 1 | Socio-demographic characteristics of study participants in an urban slum, Mumbai city, India

Variables	Category	Frequency (*n*)	Percentage
Age of mothers (NR = 5)	18–24 years	14.0	28.0
	25–34 years	32.0	64.0
	>35 years	4.0	8.0
Educational status of mothers	No education	2.0	3.6
	10th grade	18.0	32.7
	12th grade	28.0	50.9
	Graduate	7.0	12.7

The literacy rate of the mothers was found to be quite good with seven (12.7%) graduates, 28 (50.9%) 12th grades and 18 (32.7%) 10th grades, and only two (3.6%) mothers could not read and write.

3.2. WASH indicators

3.2.1. Source of water supply

In Mumbai city, drinking water is distributed through a complex water distribution network, i.e., piped water. Thus, the primary source of drinking water in the slum pocket as per WHO's definition was an improved source of water, i.e., piped water to plot (collected either from an installed tap or a handpump) and/or into dwellings; this water was chlorinated and supplied daily for 2 h in the wee hours of the day. Based on the socio-economic conditions of the study households and the capability to buy/own taps, it was found that only 7.3% of the households were receiving water into their dwellings (taps fitted inside the houses) as well as in the plot (taps fitted outside the houses) and 9% received water through handpumps. In contrast, 29.1% of the households had to share taps, and this sharing was between a minimum of two and six households. The largest percentage, i.e., 32.7% households, received water at the yard from the tap fitted at an average distance of 5 m from their house. Figure 2 shows the distribution of the primary source of drinking water.

3.2.2. In-house water treatment, handling and storage practices

Table 2 provides details of the frequencies and percentage of water treatment and the storage and handling practices followed by the households. Although slum households were receiving improved and chlorinated drinking water in their plots/dwellings, the percentage of mothers who were giving boiled water to their children at the time of response was found to be 63.6%, which indicates that mothers were aware of the advantages and benefits of boiling. The use of cloth/strainer to filter water was practised by 20% of mothers under the assumption/misunderstanding that they were getting clean/safe water. The remaining 16.4% of mothers followed no in-house water treatment.

The behaviour of mothers with regard to the transfer of water for drinking was largely unsatisfactory, wherein most households (72.7%) were dipping glass (or similar utensil) directly into the storage container, which is a completely unhygienic practice with a high probability of finger dipping in clean water along with glass. Similar findings were reported in Andhra Pradesh, India, for household water transfer practices (Reddy *et al.* 2017). The remaining 27.3% households either used a long ladle or poured water or had a tap fitted to the container to withdraw water for drinking.

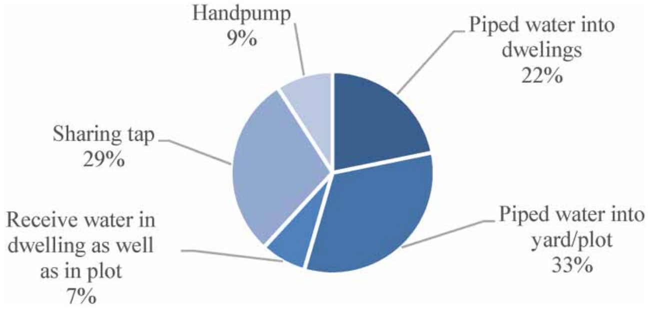


Figure 2 | Source of supply water received by study households in an urban slum, Mumbai city, India.

Table 2 | Water storage, usage and handling practices followed by mothers in an urban slum, Mumbai city, India

Characteristics	Category	Number (*n*)	Percentage
Water treatment at home	No treatment	9.0	16.4
	Strain using cloth/net	11.0	20.0
	Treated 'boiled'	35.0	63.6
Transfer of water for drinking	Satisfactory	15.0	27.3
	Unsatisfactory	40.0	72.7
Material used for storage of drinking water	Steel	17.0	30.9
	Plastic	6.0	10.9
	Earthen pot	5.0	9.1
	Cooper	1.0	1.8
	Multiple storage containers (>1) (steel/plastic/copper/aluminium/alloy/earthen pot/purifier)	26.0	47.3
Material used for storage of water used for food preparation	Steel	42.0	76.4
	Plastic	4.0	7.3
	Multiple storage containers (>1) (steel/plastic/copper/aluminium/alloy)	9.0	16.3
Frequency of cleaning storage for drinking water	Daily	41.0	74.6
	2–3 days	13.0	23.6
	Weekly	1.0	1.8
Frequency of cleaning storage container for food preparation	Daily	38.0	69.1
	2–3 days	15.0	27.3
	Weekly	2.0	3.6

Figure 3 | Various types of storage containers among study households in an urban slum, Mumbai city, India.

Given the constraints of not having 24×7 running water, multiple containers were used for the storage of water for drinking and cooking purposes, storage that included stainless-steel tank/pots, earthen pots, aluminium, alloy or plastic. (Figure 3).

The frequency of daily cleaning of storage containers for drinking and food preparation was observed to be reasonably good, i.e., 74.5 and 69.1% households followed this practice. The percentage was found to be higher than that in the study reported by Mohd & Malik (2017) in Bangladesh, which was 53.8 for daily cleaning of drinking water storage containers.

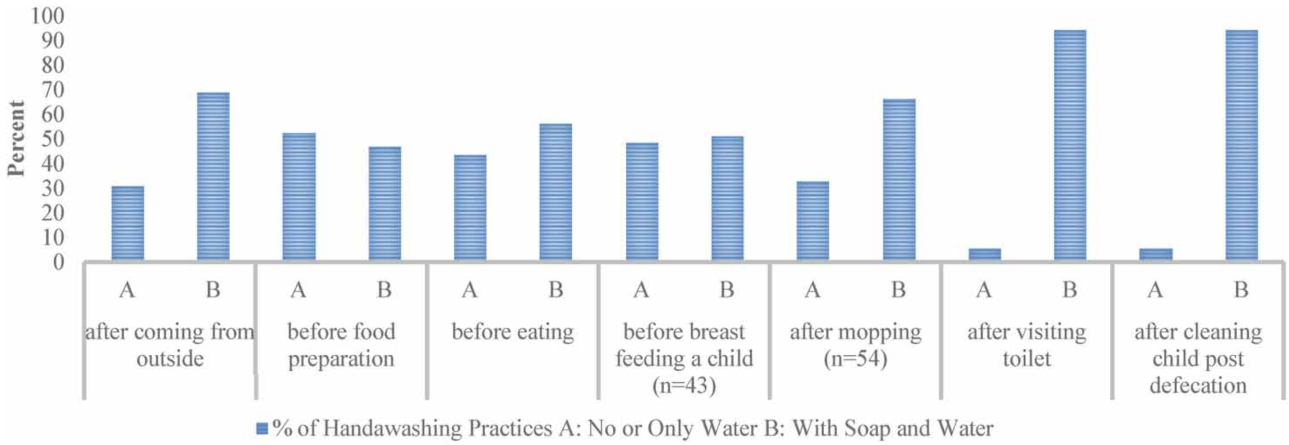


Figure 4 | Handwashing practices followed by the mothers of <5-year-old children in an urban slum, Mumbai city, India.

3.2.3. Hygiene practices and sanitation

Handwashing practices followed by the mothers of <5-year-old children in the urban slum pocket for seven different tasks as captured in the questionnaire are represented in Figure 4. The behaviour of mothers with regard to handwashing using soap and water after visiting the toilet as well as cleaning the child post defaecation was observed to be highly positive (94.5%). Similar observations were reported (89–100%) in an urban slum in Latur, Maharashtra (Quazi *et al.* 2019), but the frequency was that the same practice was reported to be lower in Kolkata-based (66–70%) and in Ethiopia-based (62–78%)-based studies (Ali *et al.* 2018; Melese *et al.* 2019). In another post-defaecation handwashing study, Mohd & Malik (2017) reported frequencies to be 93.8% in Bangalore city, which is similar to our observations; however, washing hands after cleaning children post defaecation was reported to be considerably low (33%). In this study, the rate of handwashing before cooking food and eating was found to be between 47.3 and 56.3%, respectively, which is slightly higher (40–43%) than that in a Kolkata-based study (Ali *et al.* 2018), while the study based in Latur showed a higher frequency at 70–98% (Quazi *et al.* 2019).

Besides the above findings, 58.2% households that followed less than five tasks of handwashing were categorized under unsatisfactory practices. Such observations confirm that, though there is a fair degree of awareness, behaviour varies with the individual and is entirely dependent on their perception and understanding of WASH practices.

In households with very young children, adequate floor cleaning is essential. The study observed this behaviour of mothers to be quite satisfactory as the frequency of cleaning and disinfection of the floor was over 96% with a similar proportion of households using either disinfectant or detergent powder while mopping. The bulk of the households (81.8%) mopped the floors twice a day.

One of the most critical WASH practices in limiting pathogen transfer is managing child defaecation practice and sanitary disposal of the faeces. The main concern here, like in most slum areas, was a lack of in-house toilet facility. It was difficult for the mothers to access community toilets for their children due to distance, discomfort, crowding and most importantly, poor sanitation and hygienic conditions around such toilets. Therefore, defaecation of children was managed within the household via different practices such as diaper (12.7%), pants (16.4%), paper (40%), on the floor (16.4%) and mixed practices (10.9%). Such unsatisfactory defaecation practices further led to extremely unsanitary disposal of faeces, wherein 58.2% of households disposed of faeces along with household garbage, 18.2% used the in-house bathroom drain to drain off the faecal matter and 21.8% followed both methods. Only one household (of 55) followed the practice of disposing the child's faeces in the community latrine, which, according to WHO's definition, is sanitary disposal practice, including the use of toilet/latrine by child, whereas unsanitary practices include putting/rinsing faeces into the drain and into garbage or leaving it in the open.

In comparison with these observations, in another study conducted in a rural area of Odisha, 60% of the households used floor and cloth, while 35% used the toilet for children's defaecation (Bauza *et al.* 2019). Mohd & Malik (2017), in a Bangalore-based study, reported that 57.7% of the households followed satisfactory faecal disposal practices.

The above observations warrant not only educating households on better handling of defaecation and faecal disposal practices, but also emphasizing the need for creating good infrastructure in crowded localities by the authorities concerned for achieving better sanitary conditions. This will go a long way in reducing enteric infections not only in young children, but also in the population at large.

3.2.4. Understanding of the mother's knowledge of diarrhoea

The participant mothers were asked, 'Have you heard the term diarrhoea?' A total of 34 (61.8%) said 'yes', and when asked, 'What are the symptoms of diarrhoea?', 19 of them provided the expected answer, i.e., loose motion, sometimes accompanied by vomiting, fever, stomach pain, etc. Overall, this indicates that 36 of 55 (65.4%) mothers had no understanding of the symptoms associated with diarrhoea.

3.3. Incidence rate of diarrhoeal disease

Diarrhoeal disease among children during the study period was measured as the incidence rate. The follow-up period of 17 months started with 88 children and ended with 83 children, which totalled to 1,411 months of follow-up. During this period, 66 cases of diarrhoeal disease were recorded. The incidence rate of diarrhoea was 0.047 diarrhoeal cases/child months (95% confidence interval, CI = 0.030–0.063) or 4.7 diarrhoeal cases/100 child months.

The geospatial tool of the global health data exchange (https://vizhub.healthdata.org/lbd/diarrhoea) (Troeger *et al.* 2020) reported an incidence rate of diarrhoea of 0.055/child month and 0.054/child month among under-5 children in Mumbai city for the entire slum pocket under study in the years 2017 and 2018, respectively. These figures are slightly higher than those observed in the present study. This could be attributed to the larger geographical area covered in the global health report of around 2,600 under-5 children, as against a much smaller sample size (88 under-5 children) covered under this study.

Thus, the low incidence rate of diarrhoea among the study children could be attributed to the supply of chlorinated water through the municipal pipeline distribution system, a high (63%) proportion of mothers giving boiled water to their children and handwashing (94.5% of mothers) with soap and water after performing the two most important tasks , i.e., after visiting the toilet and cleaning the child post defaecation. Most (81.8%) households mopped the floor twice a day. Nevertheless, there is a need to enhance hygienic conditions and practices to further reduce the burden of diarrhoea.

3.4. Water quality monitoring

For water quality monitoring, out of 55 households, there were six non-respondents due to relocation/migration and one household that was unwilling to remain in the study, reducing the total number of households to 48 towards the end.

As per WHO (2011), total coliforms and *E. coli* should not be detectable in the water intended for drinking. Figure 5 shows a proportion of coliforms and *E. coli* present in various types of water samples from the households.

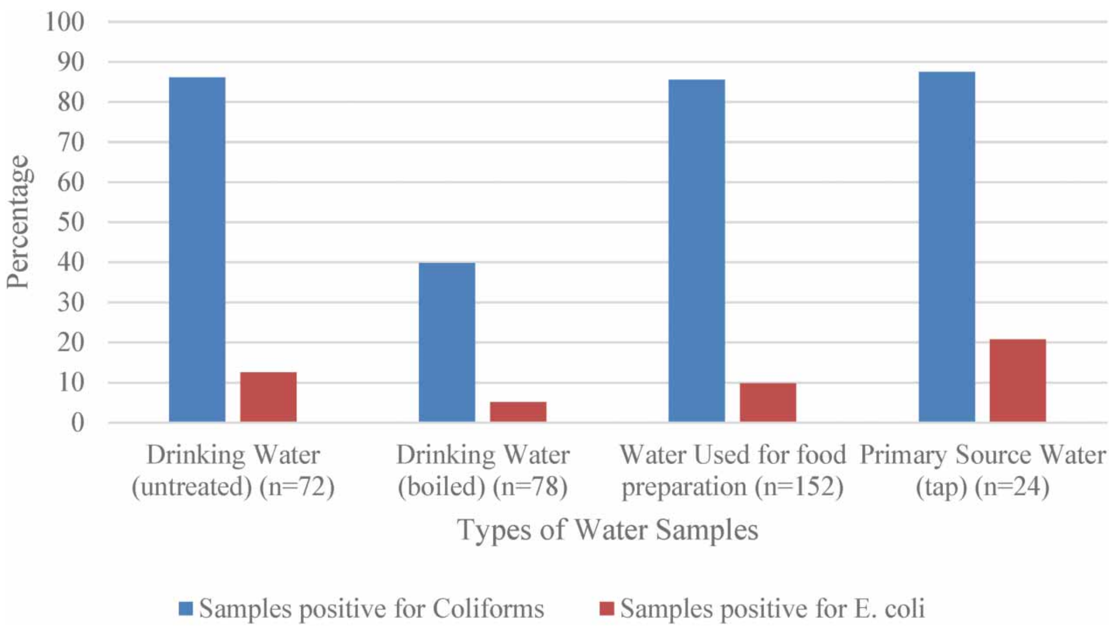


Figure 5 | Proportion of total coliforms and *E. coli* in various types of water samples from study households in an urban slum, Mumbai city, India.

86 and 12.5% samples of untreated drinking water were tested positive for total coliforms and *E. coli*, respectively. A study conducted in similar settings in Mumbai but in non-notified slums reported lower coliforms (76%) and higher *E. coli* (43%) in stored drinking water (Subbaraman *et al.* 2013). Edessa *et al.* (2017) and Soboksa *et al.* (2020) reported higher levels (>90% and 30–70% coliforms and *E. coli*, respectively) in drinking water in studies conducted in Ethiopia.

Although boiled water was expected to be free of coliforms, 39.74 and 5.13% samples were tested positive for coliforms and *E. coli*, respectively. A study from an urban slum based in Uganda reported a much higher content, i.e., 61% boiled water samples contained *E. coli* (Musoke *et al.* 2018). The presence of coliforms and *E. coli* in boiled water indicates the possibility of recontamination, especially during storage, due to unsatisfactory water handling/transfer from the storage container since a high proportion of mothers (72.7%) were dipping glass to withdraw water for consumption. The other contributing factors for high counts could be inconsistency in boiling with respect to inadequate temperature/time, as expected with this practice (rolling boiling).

Thus, two simple practices, namely, boiling water adequately and handling it hygienically thereafter, could be the easiest ways to improve the quality of point-of-use water. The potential reasons for high coliforms and *E.coli* in source tap water could be due to the receipt of contaminated water (due to disruption in the distribution pipeline) or intermittent water, which can cause an ingress of contaminated water and may elevate the risk of waterborne disease (WHO 2011; Bivins *et al.* 2017).

Furthermore, if the water quality with respect to faecal indicator bacteria/*E. coli* is pathogenic, it could cause diarrhoeal infections in children in significant proportions. In addition, it is also necessary to understand the prevalence of enteric pathogens other than routine bacteria, virus or protozoa, which are also known to contribute to waterborne diarrhoeal disease.

3.5. Predictors of diarrhoea among <5-year-old children

The crude and adjusted IRRs with 95% CIs of the incidence of diarrhoea among under-5 children for WASH variables using the multivariate generalized linear model of Poisson log link function are represented in Table 3.

The incidence of diarrhoea was 1.71 times significantly higher among households that were accessing water from taps on a sharing basis as compared to those receiving piped water inside their dwellings or had their own taps just outside their dwellings (IRR: 1.71, 95% CI = 1.02–2.87, $p = 0.043$). Thus, this parameter is a significant predictor responsible for diarrhoea.

From this outcome, one can infer that households getting water directly as compared to sharing from a common source plays an important role in maintaining the integrity of water quality. As observed, the generally poor hygienic conditions around the areas of shared taps, the low position of these taps, the wet floors of these areas, narrow lanes, crowding at the taps and the transportation of water in open receptacles could be the factors leading to an increase in the microbial loads of the above-tested samples.

Providing untreated drinking water to children as compared to boiled water was 2.24 times significantly associated with the incidence of diarrhoea among under-5 children (IRR: 2.24, 95% CI: 1.24–4.0, $p = 0.008$). Similar findings have been reported by Soboksa *et al.* 2020.

Table 3 | Predictors of diarrhoeal disease among <5-year-old children in an urban slum, Mumbai city, India

Characteristics	Category	Crude IRR (95% CI) ($n = 55$)	Adjusted IRR (95% CI) ($n = 55$)
Source water	Piped water inside dwellings/also access to tap into yard	1[a]	1[a]
	Sharing of tap in the yard	1.81 (1.10–2.98)*	1.71 (1.02–2.87)*
	Handpump	0.89 (0.32–2.52)	0.91 (0.32–2.63)
Treatment of water	Boiling	1[a]	1[a]
	Use of strainer/cloth	1.44 (0.75–2.76)	1.51 (0.77–2.96)
	No treatment	2.45 (1.42–4.21)*	2.24 (1.24–4.0)*
Handwashing practices (overall)	Satisfactory	1[a]	1[a]
	Unsatisfactory	1.60 (0.94–2.69)	1.11 (0.62–1.99)

IRR, incident rate ratio; CI, confidence interval.
[a]Reference category.
*Significant association at $p < 0.05$.

Although important, as several studies have established a significant association between childhood diarrhoea and handwashing practices (Melese *et al.* 2019; Soboksa *et al.* 2020), the data in the present study could not be significantly associated with the incidence of diarrhoea using multivariate analysis. The likely explanation for this difference could be the smaller sample size ($n = 55$) in the present study as compared to that in other published studies, wherein the sample size ranged between 390 and 550 households, and also the selection of handwashing tasks, which were not exactly the same.

Other WASH variables, namely, transfer of water, frequency of cleaning water storage for drinking, frequency of mopping, disposal of the child's faeces, etc., were also found not to be significantly associated with diarrhoea. The mother's age and education and understanding of diarrhoea was also not significantly associated with the incidence of diarrhoea among<5-year-old children.

Due to the low case value in bivariate analysis, the association between sanitary disposal of child faeces (due to the lack of in-house toilets) and diarrhoea could not be assessed in this study. However, diarrhoea was prevalent among children from 30 households that were following unsatisfactory faeces disposal practices. A study by Bawankule *et al.* (2019), using the data of the National Family Health Survey 2015–2016, found that the absence of exclusive places for children's defaecation and the subsequent unsafe faeces disposal more likely puts children at a higher risk of bloody diarrhoea.

3.6. Predictors of the presence of coliforms/*E. coli* in drinking water

The two independent variables, namely, the education of mothers and the treatment of drinking water sampled for microbial analysis were subjected to the multivariate logistic regression analysis (Table 4). As captured in the questionnaire, 63% households were giving boiled water to their children; however, during sampling for water quality, the in-house treatment of water/boiling was found to be inconsistent. The odds of the presence of coliforms in the drinking water were likely to be 27.98 times significant among households that were not giving treated water (boiled water) to their children on a regular basis (AOR: 27.98, 95% CI: 2.56–306, $p = 0.006$). It was also observed that coliforms were detected in all households (28.3%) that were giving their children untreated drinking water, but a statistically significant association could not be computed due to the low case value. This clearly indicates that in-house treatment, i.e., boiling, could be effective in controlling/eliminating the pathogenic bacteria.

With reference to the predictors responsible for the presence of *E. coli* in drinking water samples, four independent variables were subjected to the multivariate logistic regression analysis. The presence of *E. coli* in drinking water was 3.44 times more likely associated with unsatisfactory overall handwashing practices (AOR: 3.44, 95% CI: 0.43–27.2) as observed with the significant predictors for diarrhoea, and the presence of *E. coli* was 4.49 times (AOR: 4.49, 95% CI: 0.41–49.4) and 2.43 times (AOR: 2.43, 95% CI: 0.25–23.7) more likely associated with the provision of untreated and inconsistent treatment of water, respectively. But these predictors too were statistically non-significant (Table 5).

One of the most important WASH indicators, namely, water transfer practices (where 72% households were found to transfer drinking water by directly dipping glass/fingers in storage containers), could be the likely reason for microbial

Table 4 | Variables related to the presence of coliforms in water samples in an urban slum, Mumbai city, India

Characteristics	Category	Presence of coliforms ($n = 53$)		Crude odds ratio (95% CI)	Adjusted odds ratio[a] (95% CI)
		Yes (%)	No (%)		
Education	Graduate	5 (9.4)	2 (3.8)	1[b]	1
	12th grade	18 (34.0)	9 (17.0)	0.8 (0.13- 5.0)	2.70 (0.17–44)
	10th grade	16 (30.2)	1 (1.9)	6.4 (0.47–86.3)	9.57 (0.3–310)
	No education	2 (3.8)	0 (0.0)	–[c]	–[c]
Treatment of sampled water for analysis	Boiled	8 (15.1)	11 (20.8)	1	1
	Untreated	15 (28.3)	0 (0.0)	–[c]	–[c]
	Inconsistent[d]	18 (34)	1 (1.9)	**24.8 (2.71–225.6)***	**27.98 (2.56–306)***

CI, confidence interval.

[a]The Hosmer and Lemeshow test for the goodness-of-fit, $p = 0.97$.

[b]Reference category.

[c]Low case value.

[d]Inconsistent water treatment, i.e., households were sometimes giving boiled or untreated water to child.

*Significant association at $p < 0.05$.

Table 5 | Variables related to the presence of *E. coli* in water samples in an urban slum, Mumbai city, India

Characteristics	Category	Presence of *E. coli* ($n = 53$)		Crude odds ratio (95% CI)	Adjusted odds ratio[a] (95% CI)
		Yes (%)	No (%)		
Education	Graduate	4 (7.5)	3 (5.7)	1[d]	1
	12th grade	2 (3.8)	25 (47.2)	0.06 (0.008–4.79)*	0.11 (0.01–1.21)
	10th grade	4 (7.5)	13 (24.5)	0.23 (0.04–1.5)	0.11 (0.01–1.21)
	No Education	2 (3.8)	0 (0.0)	–[b]	–[b]
Source water	Piped water inside dwellings/also access to tap into yard	10 (18.9)	22 (41.5)	1	1
	Piped water into plot/sharing from plot	2 (3.8)	14 (26.4)	0.31 (0.06–1.65)	0.08 (0.006–1.16)
Treatment of sampled water for analysis	Boiled	2 (3.8)	17 (32.1)	1	1
	Untreated	6 (11.3)	9 (17)	5.67 (0.94–34.0)	4.49 (0.41–49.4)
	Inconsistent[c]	4 (7.5)	15 (28.3)	2.27 (0.36–14.19)	2.43 (0.25–23.7)
Handwashing practices (overall)	Satisfactory	2 (3.8)	20 (37.7)	1	1
	Unsatisfactory	10 (18.9)	21 (39.6)	4.76 (0.93–24.5)	3.44 (0.43–27.2)

CI, confidence interval.
[a]The Hosmer and Lemeshow test for the goodness-of-fit, $p = 0.75$.
[b]Low case value.
[c]Inconsistent water treatment, i.e., households were sometimes giving boiled or untreated water to child.
[d]Reference category.
*Significant association at $p < 0.05$.

contamination of water, though it could not be established as a significant predictor for diarrhoea as well as the presence of coliforms/*E. coli* in drinking water.

Other variables, namely, age, education, frequency of cleaning of storage of drinking water, sanitary disposal of children's faeces, etc., were not found to be significantly associated with the presence of coliforms/*E. coli*.

3.7. Study limitations

A small group of households ($n = 55$) selected using non-probability-based purposive sampling could be considered as a study limitation. However, the study group was purposefully kept small in order to closely study and identify the status of WASH indicators in the identified slum pocket, coupled with multiple assessments of microbial quality of stored water and diarrhoeal disease incidence rate among <5-year-old children, which might be a possible bias in the study. Other variables/indicators that may also contribute to the diarrhoeal disease incidence rate are socio-economic status, occupation of the father, nutritional and vaccination status of children (Melese *et al.* 2019; Jeyakumar *et al.* 2021) were not included in the study.

4. CONCLUSION

The study findings demonstrate a high diarrhoeal incidence rate and unsafe point-of-use water quality. Although some of the WASH practices followed by mothers in the study group were encouraging, the overall WASH practices were inadequate, especially during the transfer of drinking water, handwashing, children defaecation process and safe management of faeces.

Households using shared taps to access source water and providing untreated water to children had a high incidence of diarrhoeal disease in the slum pocket, which is a complex settlement with limited WASH infrastructure.

This was supported by findings obtained from a water quality analysis, wherein the presence of coliforms in drinking water was associated with households that were inconsistent in providing boiled water to children. Thus, in-house treatment of drinking water such as boiling would be a cost-effective method for slum settings following appropriate practices of safe storage and handling.

It was observed that, in India and Botswana, the diarrhoea mortality rate was reduced by 21.8 and 39.2% between 1990 and 2017 by improving sanitation and increased access to safe water, respectively (Troeger *et al.* 2020). Such improvements indicate that the principles of WASH, when implemented totally, i.e., making clean water available, along with required sanitation infrastructure and awareness on hygiene, adequate training and monitoring, would play a combined role in reducing the incidence rate of diarrhoea.

The authorities/policymakers are required to actively work towards UN SDG6 for 100% access to safe water, adequate hygiene and sanitation for all by the year 2030. Besides, India is implementing the Swachha Bharat Mission (Urban), which targets the elimination of open defaecation and brings out behavioural change and awareness towards healthy sanitation practices. This would require extending the focus on improving hygiene and sanitation infrastructure for slums, including safe faeces disposal and its management.

One also needs to use technological advancements to map aetiologies for gastro-intestinal infections beyond regular bacterial pathogens (viral, protozoan and emerging pathogens) to devise strategies for preventive and therapeutic actions for reducing enteric diseases. Water quality monitoring regimes need to be reviewed to include indicators other than *E. coli* that are more persistent in the environment. These microbial assessment plans, coupled with WASH awareness, would enable taking a holistic approach towards the prevention and treatment of diarrhoeal disease, which would subsequently lead to a reduction in disease burden among<5-year-old children in slum settings.

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DATA AVAILABILITY STATEMENT

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

REFERENCES

Ali, F., Singh, O. P., Dutta, A., Upadhyay, M. B. & Bhaumik, D. 2018 Do community level interventions work in the same way on incidence and longitudinal prevalence of diarrhoea among under five children in rural and urban slum settings? Insights from Stop Diarrhoea Initiative in India. *Journal of Global Health Reports* **2**. https://doi.org/10.29392/joghr.2.e2018003.

Bauza, V., Reese, H., Routray, P. & Clasen, T. 2019 Child defecation and feces disposal practices and determinants among households after a combined household-level piped water and sanitation intervention in Rural Odisha, India. *American Journal of Tropical Medicine and Hygiene* **100** (4), 1013–1021. https://doi.org/10.4269/ajtmh.18-0840.

Bawankule, R., Shetye, S., Singh, A., Singh, A. & Kumar, K. 2019 Epidemiological investigation and management of bloody diarrhea among children in India. *PLoS ONE* **14** (9), 1–22. https://doi.org/10.1371/journal.pone.0222208.

Bhattacharya, M., Joon, V. & Jaiswal, V. 2011 Indexed in: Index Medicus (IMSEAR), INSDOC, NCI current content, database of alcohol & drug abuse, national database in TB & WATER HANDLING AND SANITATION PRACTICES IN RURAL COMMUNITY OF MADHYA PRADESH: a KNOWLEDGE, ATTITUDE AND PRACTICE STUDY. *Indian Journal of Preventive & Social Medicine* **42** (1). Available from: http://medind.nic.in/ibl/t11/i1/iblt11i1p93.pdf

Bin Mohanna, M. & Al-Sonboli, N. 2017 Prevalence of diarrhoea and related risk factors among children aged under 5 years in Sana'a, Yemen. *Hamdan Medical Journal* 29–33. https://doi.org/10.7707/hmj.711.

Bivins, A. W., Sumner, T., Kumpel, E., Howard, G., Cumming, O., Ross, I., Nelson, K. & Brown, J. 2017 Estimating infection risks and the global burden of diarrheal disease attributable to intermittent water supply using QMRA. *Environmental Science and Technology* **51** z(13), 7542–7551. https://doi.org/10.1021/acs.est.7b01014.

Cdc, U. 2008 *A Guide to Conducting Household Surveys for Water Safety Plans*. Cdc, p. 25. Available from: https://www.cdc.gov/nceh/ehs/gwash/publications/guide_conducting_household_surveys_for_water_safety_plans.pdf (accessed 4 October 2016).

Devansh Jalota, A. B. 2014 Community-based water quality improvement in a rehabilitated slum building. *Journal of Pollution Effects & Control* **03** (01). https://doi.org/10.4172/2375-4397.1000132.

Edessa, N., Geritu, N. & Mulugeta, K. 2017 Microbiological assessment of drinking water with reference to diarrheagenic bacterial pathogens in Shashemane Rural District, Ethiopia. *African Journal of Microbiology Research* **11** (6), 254–263. https://doi.org/10.5897/ajmr2016.8362.

Edward, A., Jung, Y., Chhorvann, C., Ghee, A. E. & Chege, J. 2019 Association of mother's handwashing practices and pediatric diarrhea: evidence from a multi-country study on community oriented interventions. *Journal of Preventive Medicine and Hygiene* **60** (2), E93–E102. https://doi.org/10.15167/2421-4248/jpmh2019.60.2.1088.

Getachew, A., Guadu, T., Tadie, A., Gizaw, Z., Gebrehiwot, M., Cherkos, D. H., Menberu, M. A. & Gebrecherkos, T. 2018 Diarrhea prevalence and sociodemographic factors among under-five children in rural areas of North Gondar Zone, Northwest Ethiopia. *International Journal of Pediatrics*, 1–8. https://doi.org/10.1155/2018/6031594.

Global Health Estimates 2020 Deaths by Cause, Age, Sex, by Country and by Region, 2000-2019. *World Health Organization, Geneva, 2020*. Accessed at https://www.who.int/data/gho/data/themes/mortality-and-global-health-estimates/ghe-leading-causes-of-death, 18 August 2021.

Hunter, P. R., Resebro, H., Cameron, J., Hunter, P., Jagals, P. & Pond, K. 2011 *Defining the Current Situation-Epidemiology. Valuing Water, Valuing Livelihoods: Guidance on Social Cost-Benefit Analysis of Drinking-Water Interventions, with Special Reference to Small Water Supplies*. World Health Organization/IWA Publishing, London, pp. 75–100. https://doi.org/10.4324/9781351041942-3.

Indian Institute for Population sciences 2015 *National Family Health Survey – 4 2015-16. State Fact Sheet, Maharashtra*, pp. 1–6. Available from: http://rchiips.org/nfhs/FCTS/MH/MH_FactSheet_519_Mumbai.pdf (accessed 15 May 2019).

Jeyakumar, A., Godbharle, S. R. & Giri, B. R. 2021 Water, sanitation and hygiene (WaSH) practices and diarrhoea prevalence among children under five years in a tribal setting in Palghar, Maharashtra, India. *Journal of Child Health Care* **25** (2), 182–193. https://doi.org/10.1177/1367493520916028.

Liguori, G., Cavallotti, I., Arnese, A., Amiranda, C., Anastasi, D. & Angelillo, I. F. 2010 Microbiological quality of drinking water from dispensers in Italy. *BMC Microbiology* **10** (19), 1–5. https://doi.org/10.1186/1471-2180-10-19.

Kundu, A., Smith, W. A., Harvey, D. & Wuertz, S. 2018 Drinking water safety: role of hand hygiene, sanitation facility, and water system in semi-urban areas of India. *American Journal of Tropical Medicine and Hygiene* **99** (4), 889–898. https://doi.org/10.4269/ajtmh.16-0819.

Melese, B., Paulos, W., Astawesegn, F. H. & Gelgelu, T. B. 2019 Prevalence of diarrheal diseases and associated factors among under-five children in Dale District, Sidama zone, Southern Ethiopia: a cross-sectional study. *BMC Public Health* **19** (1), 1–10. https://doi.org/10.1186/s12889-019-7579-2.

Mohd, R. & Malik, I. 2017 Sanitation and hygiene knowledge, attitude and practices in urban setting of Bangalore: a cross-sectional study. *Journal of Community Medicine & Health Education* **07** (04). https://doi.org/10.4172/2161-0711.1000540.

Mshida, H. A., Kassim, N., Kimanya, M. E. & Mpolya, E. 2017 Influence of water, sanitation, and hygiene practices on common infections among under-five children in Longido and Monduli Districts of Arusha, Tanzania. *Journal of Environmental and Public Health*. https://doi.org/10.1155/2017/9235168.

Musoke, D., Ndejjo, R., Halage, A. A., Kasasa, S., Ssempebwa, J. C. & Carpenter, D. O. 2018 Drinking water supply, sanitation, and hygiene promotion interventions in two slum communities in Central Uganda. *Journal of Environmental and Public Health*. https://doi.org/10.1155/2018/3710120.

Patel, S. K., Pradhan, M. R. & Patel, S. 2020 Water, sanitation, and hygiene (WASH) conditions and their association with selected diseases in urban India. *Journal of Population and Social Studies* **28** (2), 103–115. https://doi.org/10.25133/JPSSv28n2.007.

Quazi, S., Wadde, S. K. & Nagaonkar, A. S. 2019 Hand washing practices amongst mothers of under-fives in an urban slum. *International Journal of Community Medicine and Public Health* **6** (11), 4748. https://doi.org/10.18203/2394-6040.ijcmph20195050.

Reddy, V. B., Kusuma, Y. S., Pandav, C. S., Goswami, A. K. & Krishnan, A. 2017 Water and sanitation hygiene practices for under-five children among households of Sugali Tribe of Chittoor District, Andhra Pradesh, India. *Journal of Environmental and Public Health*. https://doi.org/10.1155/2017/7517414.

Risbud, B. N. 2001 *Mumbai, India*. Available from: https://www.archidev.org/IMG/pdf/Mumbai_DPU_.pdf (accessed 15 May 2019).

Shrestha, S., Aihara, Y., Yoden, K., Yamagata, Z., Nishida, K. & Kondo, N. 2013 Access to improved water and its relationship with diarrhoea in Kathmandu Valley, Nepal: a cross-sectional study. *BMJ Open* **3** (6). https://doi.org/10.1136/bmjopen-2012-002264.

Sileshi Asfaw, H., Abate Reta, M. & Getnet Yimer, F. 2016 High enteric bacterial contamination of drinking water in Jigjiga city, Eastern Ethiopia. *Ethiopian Journal of Health Development* **30** (3), 118–128.

Singh, S., Mishra, S., Nadiadwala, F. & Rumane, N. 2019 A GIS based approach for drinking water management in urban slums. *Journal of Global Resources* **5** (01), 33–42.

Soboksa, N. E., Gari, S. R., Hailu, A. B. & Alemu, B. M. 2020 Association between microbial water quality, sanitation and hygiene practices and childhood diarrhea in Kersa and Omo Nada districts of Jimma Zone, Ethiopia. *PLoS ONE* **15** (2), 1–17. https://doi.org/10.1371/journal.pone.0229303.

Ssemugabo, C., Wafula, S. T., Ndejjo, R., Oporia, F., Osuret, J., Musoke, D. & Halage, A. A. 2019 Knowledge and practices of households on safe water chain maintenance in a slum community in Kampala City, Uganda. *Environmental Health and Preventive Medicine* **24** (1), 1–9. https://doi.org/10.1186/s12199-019-0799-3.

Subbaraman, R., Shitole, S., Shitole, T., Sawant, K., Obrien, J., Bloom, D. E. & Patil-Deshmukh, A. 2013 The social ecology of water in a Mumbai slum: failures in water quality, quantity, and reliability. *BMC Public Health* **13** (1), 1. https://doi.org/10.1186/1471-2458-13-173.

Troeger, C. E., Khalil, I. A., Blacker, B. F., Biehl, M. H., Albertson, S. B., Zimsen, S. R. M., Rao, P. C., Abate, D., Ahmadi, A., Ahmed, M. L. C. B., Akal, C. G., Alahdab, F., Alam, N., Alene, K. A., Alipour, V., Aljunid, S. M., Al-Raddadi, R. M., Alvis-Guzman, N., Amini, S. *et al.* GBD 2017 Diarrhoeal Disease Collaborators 2020 Quantifying risks and interventions that have affected the burden of diarrhoea among children younger than 5 years: an analysis of the Global Burden of Disease Study 2017. *The Lancet Infectious Diseases* **20** (1), 37–59. https://doi.org/10.1016/S1473-3099(19)30401-3.

WHO 1997 *Water Sampling and Analysis*. *Analysis*, Jan/Feb 19, pp. 51–72. Available from: https://www.who.int/water_sanitation_health/dwq/2edvol3d.pdf (accessed 18 July 2016).

WHO 2011 *Guidelines for Drinking-Water Quality*. WHO. Available from: http://apps.who.int/iris/bitstream/handle/10665/44584/9789241548151_eng.pdf?sequence=1 (accessed 15 May 2019).

WHO 2019 *Safe Water, Getter Health. 2019 Update*. World Health Organization, Geneva. Licence: CC BY-NC-SA 3.0 IGO. Photographs. Available from: https://apps.who.int/iris/bitstream/handle/10665/329905/9789241516891-eng.pdf (accessed 23 September 2020).

WHO/UNICEF 2006 *Core Questions on Drinking-Water*. World Health Organization, p. 25. Available from: https://www.who.int/water_sanitation_health/monitoring/oms_brochure_core_questionsfinal24608.pdf (accessed 4 October 2016).

Yaya, S., Hudani, A., Udenigwe, O., Shah, V., Ekholuenetale, M. & Bishwajit, G. 2018 Improving water, sanitation and hygiene practices, and housing quality to prevent diarrhea among under-five children in Nigeria. *Tropical Medicine and Infectious Disease* **3** (2), 1–11. https://doi.org/10.3390/tropicalmed3020041.

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