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Towards safely managed drinking water supply in the hard-to-reach areas in Bangladesh: modified biosand filters and safe storage

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ABSTRACT

Despite attaining the Millennium Development Goal water target on "access to improved water sources", Bangladesh is lagging the new Sustainable Development Goal target for "safely managed drinking water services". Sufferings are mainly prevalent in many pockets of hazard-prone hard-to-reach (HtR) areas. This study aims at the development of a household water treatment technology, that is, modified biosand filter (MBSF) to strengthen safely managed drinking water supply in these areas. The MBSFs were developed using locally available materials to treat surface water and then tested for performance evaluation in the laboratory. Pond water was taken as feed water and several water quality parameters such as turbidity, ammonia, nitrate, phosphate, fecal and total coliforms were monitored. The results indicated an average of 99.4% of turbidity and 3.2-log of total coliforms removal. The chlorine disinfection results revealed the microbial safety of the stored filtrate over the 24 h. The MBSFs could provide 24–36 L safe water per day at household premises that might be adequate for a large representative household. Moreover, it would cost US$ 10.5 that would be largely affordable by low-income HtR people. Overall, this simple technology could have greater sustainability potentials and appropriateness to strengthen safely managed drinking water supply in the hazard-prone HtR areas of Bangladesh.

Keywords: Modified biosand filter; Hazard-prone hard-to-reach areas; Point-of-use; Safely managed drinking water

1. Introduction

Bangladesh has gained a significant access to improved water sources over the last few years and achieved the Millennium Development Goal (MDG) water target by 2015. Today, about 98% of the population have easily accessible improved water sources [1]. However, when considering Sustainable Development Goal (SDG) water target, only 39% population have access to 'safely managed water' mainly due to *E. coli* and arsenic contamination [2]. Furthermore, entirely equitable access to clean water exists as a major challenge due to geophysical and socioeconomic characteristics for the country. Specifically, there exist many pockets of areas (i.e., coastal, chars [estuary], haors [wetland], hilly and forest areas) where water supply coverage is not adequate due to little infrastructural development and poor road communication network. These areas have been identified and termed as hard-to-reach (HtR) areas which occupy 25% areas of the total geography and home of 28.62 million people [3,4]. Besides, these HtR areas experience the frontline pain of frequently occurring natural disasters and has become the most vulnerable to climate change phenomena (i.e., cyclones, tidal surges, floods, salinity intrusion, waterlogging) that exacerbates the water crisis.

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Moreover, extreme poverty in these areas hinders access to water supply services. The traditional water sources, that is, surface water use is hindered by fecal contamination and groundwater use is limited mainly due to arsenic and salinity contamination in these HtR areas [2–4]. Therefore, the vulnerable people are forced to drink untreated contaminated water that may have numerous direct and indirect impacts on health. Thus, it is apparent that development of safely managed drinking water supply for hazard-prone HtR condition has become an urgent need.

In regions where, centralized water supply systems are not available or reliable, then point-of-use (POU) implied 'Household Water Treatment and Safe Storage (HWTS)' can be the appropriate alternative that includes filtration and chlorination. Promisingly, biosand filter (BSF), an advanced version of slow sand filter (SSF) has been termed to be one of the most efficient, low-cost and accessible POU/HWTS technologies all over the world and evident in Asia, Africa and South America. Studies have addressed the BSF sustainability in many other developing countries [5–8]. Sobsey et al. [9] documented that BSFs continued water supply services for 8 years long in the 85% households in Cambodia and Dominican Republic. Duke et al. [10] found 5 years longevity of BSFs with the average filter age being 2.5 years in 107 households in Haiti. Thus, the BSF is expected to be accessible, affordable and sustainable technology for safely managed drinking water supply in these HtR areas of Bangladesh.

Hence, the main objective of the study is to develop a low-cost POU/HWTS device, that is, modified biosand filter (MBSF) using locally available materials, enhance performance in surface water treatment and further to describe the appropriateness of the technology to strengthen safely managed drinking water supply services in the hazard-prone HtR areas of Bangladesh.

2. Methodology

2.1. Filter design

BSF is an intermittently operated advanced version of SSF employed with biological process, that is, biologically active layer in SSF. In the early 1990s, Dr. David Manz at the University of Calgary adapted the BSF for household use with intermittent operation [11]. The current BSF designs were modified using locally available materials (plastic container, sponge [foam] sheets, sand from crushed rock, gravel, adsorption materials-brick-chips and charcoal, pond water etc.) following the 'Center for Affordable Water and Sanitation Technology (CAWST)' manual version 10 [12]. The two BSF designs (MBSF–01 and MBSF–02) and an SSF were tested in the laboratory (Fig. 1). The designs were selected to improve the technical performance with appropriateness prospectus for hazard-prone HtR areas in terms of safely managed drinking water supply, low cost and technological simplicity, and applicability even during disaster period.

2.2. Filter construction, installation and operation

Two MBSFs along with one SSF as control filter were constructed for laboratory-scale evaluation. The used plastic containers specifications were diameter: 41.2 cm (top) and 31.7 cm (bottom), 48 cm length and 3.7 cm thickness. First, the containers and filter materials were properly prepared. The control SSF was constructed at the first step. The SSF filtration media were given as per design specifications (3 cm deep underdrain gravel [12 mm–6 mm diameter of the gravel size] layer; 3 cm of separating gravel [<6 mm diameter of the gravel size] layer and 30 cm sand [screened through 1 mm mesh size] layer in succession were placed). For the MBSFs, 3 cm deep underdrain gravel (12–6 mm diameter of the gravel size) layer and 30 cm sand (screened through 1 mm mesh size) layer were used. The modifications were done through addition of 3 cm of brick-chips layer (<6 mm diameter) and 3 cm of charcoal layer (<6 mm diameter) respectively, in MBSF–01 and MBSF–02 replacing the separating gravel layer of SSF (Fig. 1). Additionally a 1 cm thick sponge foam layer was placed on sand layer. Sponge foam sheet was set as a platform to facilitate the schmutzdecke (i.e., the biologically active layer formed at the top surface of the sand bed in SSF/BSF [12]) formation, provide mechanical filtration and prevent algal growth at the top of the sand layer in the MBSFs. The outlet pipe height for

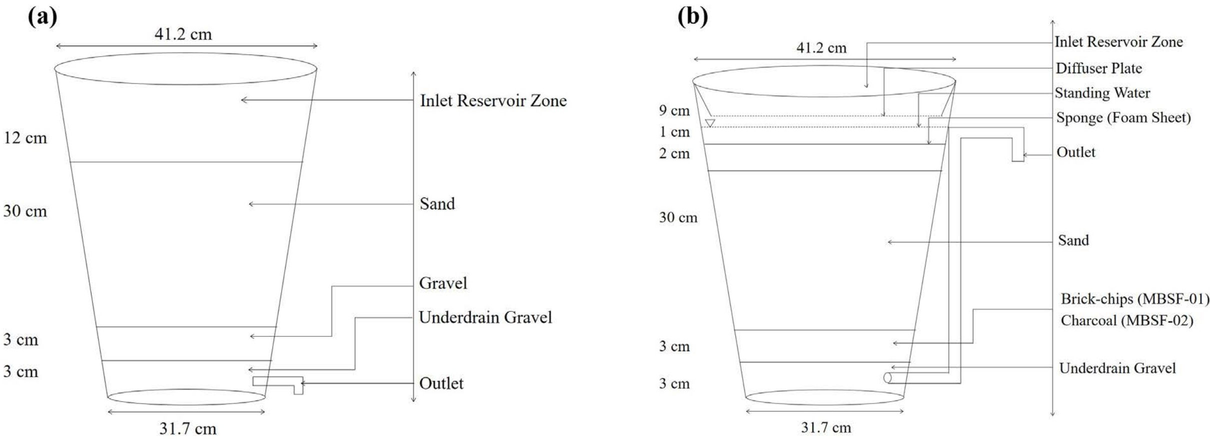

Fig. 1. Schematic layouts of the filters: (a) control SSF and (b) MBSF–01 and MBSF–02 were differentiated through brick-chips and charcoal uses, respectively, following the layouts.

the MBSFs was extended above the sand layer to maintain a 3 cm standing water depth. A diffuser plate was made to place on the top mainly to spread water poured into the filter evenly over the surface of the sand and minimizing disturbance of the schmutzdecke. The filters had a reservoir volume of 15, 12 and 12 L, respectively, for the SSF, MBSF–01 and MBSF–02. Each filter was charged twice daily with 6 h pause period. A controlled flow rate of 50 mL/min was given to the filters for the entire period of the experiment to expect that lower filtration rate can result in improved performance [13].

2.3. Analysis

Pond water was used as the feed water. The feed water quality analysis was started prior to the filter operation to know the feed water quality before application in the filters. The filtrate quality tests were started after 3 weeks as to the filter ripening occurs through biolayer grow up [12]. As a result, time (days) counting after the 3 weeks of filter operation was started to represent the results. Water quality parameters including turbidity, ammonia, nitrate, phosphate, fecal coliforms and total coliforms were monitored (n = 36) for both feed and filtrate during the filters operation period (i.e., 120 d after the 3 weeks of ripening). Disinfection through chlorination was tested for stored filtrate using commercially available bleaching powder. pH was recorded using MARTINI instruments, PH 56 PHWP (Milwaukee, Hungary). Electrical conductivity (EC) and total dissolved solids (TDS) was recorded using HACH Sension 156 multi-parameter meter. HACH portable 2100Q turbidity meter was used to measure turbidity. Ammonia, nitrate, phosphate and free chlorine were measured using HACH DR/2700 Spectrophotometer. Microbial concentrations were measured according to the standard methods '9222 Membrane Filter Technique for Members of the Coliform Group' from the 'Standard Methods for the Examination of Water and Wastewater (22nd edition, 2012)'. '9222D Thermotolerant (Fecal) Coliform Membrane Filter Procedure' and '9222B Standard Total Coliform Membrane Filter Procedure' were applied. m-ENDO and m-FC agar were used for total coliforms and thermotolerant (Fecal) coliform analysis, respectively [14]. All the SSF and MBSF filtrates were sampled within maximum two hours after pouring the feed water (approximately 3–5 L of filtrate had been discharged) for testing the physical, chemical and microbiological quality. After collection, all the samples were placed in refrigerator at 4°C, and time differences between the samples collection and analysis were no longer than three to four hours for all the parameters analysed. Procedural blank tests were carried out during each experiment. Additionally, laboratory measures were taken to avoid any possible external contamination during sample processing and analysis.

Statistical analysis was performed using Microsoft Excel 2016.

3. Results and discussion

3.1. Feed water characteristics

The laboratory analysis revealed that the pond water was highly fecal contaminated (Table 1). The total coliforms concentration ranged 1,200–3,000 CFU/100 mL and fecal coliforms concentration ranged 280–420 CFU/100 mL that might create higher microbial health risks. Turbidity values were higher ranging from 198 to 268 NTU. All other tested physical and chemical water quality parameters value remained within the drinking water guideline value (Table 1).

3.2. Performance evaluation of MBSFs

3.2.1. Turbidity

Feed water and filtrate turbidity are shown in Fig. 2. The MBSFs were found to perform higher turbidity reduction consistently over the length of the experiment run. The mean turbidity of the filtrate was recorded to be 0.8 NTU for MBSF–01 and MBSF–02, which was slightly higher than control SSF performance (Table 1). The MBSFs achieved 99.4% turbidity removal on an average which was higher than the values documented in other studies for BSF use with high turbid water [8,10].

Although there was found a noticeable difference in removing turbidity between the MBSFs at the initial period of the filter operation, both MBSFs performed equally better

Table 1
Summary of feed and filtrate data for the course of the experiment

Parameters	Feed water (mean ± SD)	SSF (mean ± SD)	MBSF–01 (mean ± SD)	MBSF–02 (mean ± SD)
pH	7.99 ± 0.19	8.07 ± .14	7.94 ± .18	7.97 ± .17
Electrical conductivity (EC) (μS/cm)	433 ± 8	412 ± 11	417 ± 7	415 ± 11
Total dissolved solids (TDS) (mg/L)	281 ± 5	268 ± 6	271 ± 4	270 ± 6
Turbidity (NTU)	227 ± 19	2.08 ± 0.86	1.16 ± 1.19	1.11 ± 0.91
Ammonia (mg/L)	0.33 ± 0.05	0.11 ± 0.05	0.06 ± 0.04	0.10 ± 0.04
Nitrate (mg/L)	1.03 ± 0.16	0.9 ± 0.2	1.1 ± 0.1	0.9 ± 0.2
Phosphate (mg/L)	1.38 ± 0.44	0.52 ± 0.05	0.41 ± 0.09	0.46 ± 0.09
Fecal coliforms (CFU/100 mL) (Min.-Max., Median)	359 ± 44 (280–420, 360)	1.94 ± 1.79 (1–11, 2)	0.39 ± 0.9 (0–5, 0)	0.42 ± 1.08 (0–6, 0)
Total coliforms (CFU/100 mL) (Min.-Max., Median)	2,057 ± 593 (1,200–3,000, 1,800)	1.81 ± 2.59 (1–16, 1)	0.47 ± 1.46 (0–8, 0)	0.56 ± 1.48 (0–7, 0)

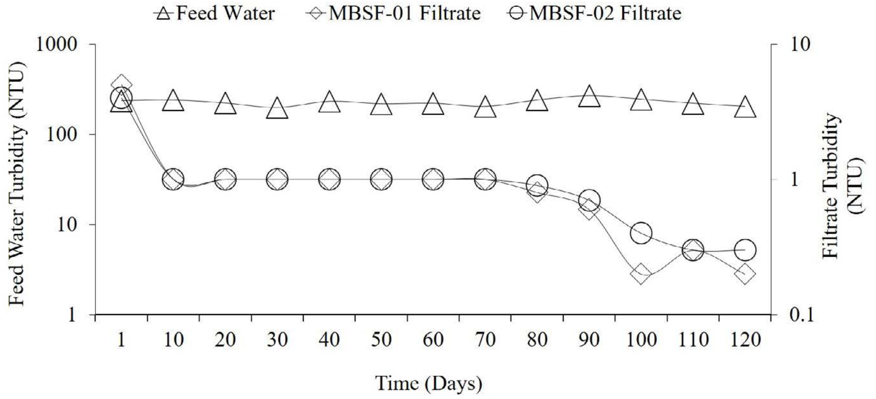

Fig. 2. Feed water and filtrate turbidity over the length of the MBSFs runs.

with consistency over the period from the 10th d. The used adsorption materials brick-chips and charcoal in the MBSFs as an additional layer did not make any noticeable difference between the filters in question. However, for turbidity removal, adsorption process plays the most important role as it takes place under physicochemical and molecular forces, which cause bridging between particles and influence the particle charge on electro kinetic forces. These make the attachments between sand grains and the particles and thus turbidity reduction efficiency increased highly in the filtrate. Hence, the higher turbidity reduction was facilitated by adsorbing materials (charcoal and brick-chips) in the MBSFs. Moreover, the lower filtration rate might result in increased contact time and enhanced suspended particle settling onto sand grains and thus higher turbidity removal was found [11,15,16]. Moreover, no noticeable changes were seen to the outflow rate due to high turbidity. This might be happened due to uniform flow rate set up.

3.2.2. Ammonia and nitrate

In this study, it can be noted that ammonia decreases from feed water to filtrate (Fig. 3). The average feed water ammonia concentration was 0.33 mg/L whereas in filtrate it was 0.06 and 0.10 mg/L, respectively, for the MBSF–01 and MBSF–02 over the study period (Table 1). Among the filters, MBSF–01 achieved the better ammonia removal efficiency ranging from 59% to 98% whereas MBSF–02 reached up to 90% removal, and no noticeable differences were observed in the average removal efficiency between the MBSF units indeed. Overall, this reduction might happen due to ammonification in the biological layer and adsorption materials induced filtration process inside the MBSFs, as charcoal adsorptive removal for ammonia has been found. On the contrary, previous studies showed increasing concentrations of the ammonia in the effluent. Chiew et al. [17] showed that ammonia concentration occasionally exceeded

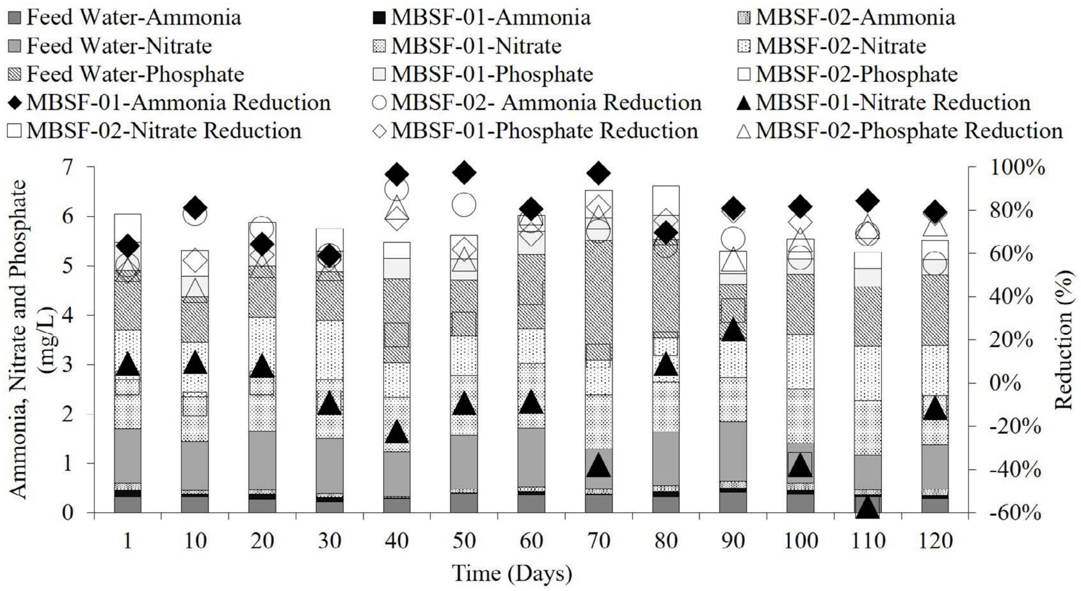

Fig. 3. Feed water and filtrate ammonia, nitrate and phosphate concentration and their removal performance by the filters over the experiment period.

10 mg/L in BSF effluent when treating raw groundwater. Ammonification has been resulted in 30 mg/L as reported by Murphy et al. [18] during BSF field studies in Cambodia. However, charcoal and brick-chips seem to be potential to solve the reported ammonification issues which are required for further investigation to optimize the ammonia adsorption by charcoal and brick-chips in MBSFs. However, based on results, the performance efficiency was observed as MBSF–01 > MBSF–02 > Control SSF.

On the other hand, conventional BSFs have been proved to be inferior in nitrate removal from water. In this study, feed water nitrate concentrations ranged from 0.7 to 1.2 mg/L with an average of 1.0 mg/L. In Fig. 3, it can be noted that the filters demonstrated a discontinuous trend of increasing and decreasing in nitrate concentration from feed water to filtrate, simultaneously. Nitrate removal performance of MBSF–01 (–57% to 25%) and MBSF–02 (–57% to 42%) is similar with other observations [13,17,18]. MBSF–02, modified with charcoal layer, was found better in nitrate removal than the MBSF–01. Hence the sequence of performance showed that MBSF–01 has higher rate of nitrification than MBSF–02. It is likely that simultaneous nitrification–denitrification might be occurring inside the MBSFs. Also, it can be thought that ammonification did not occur inside the filter consistently up to 90th d. We hypothesized that maturation of the MBSFs may have correlation with ammonification and nitrification occurrence. Furthermore, as water proceeds through the filter and ultimately 'pauses' for a period until the filter is refilled, the water at the bottom of the filter becomes lower in oxygen content, and thus provides ideal conditions for denitrification to occur [18,19]. However, in this study, this is too far to exceed the WHO guideline value of 50 mg/L for nitrite [20]. Further studies are required for determination of ammonification and nitrification in MBSFs.

3.2.3. Phosphate reduction

Feed water phosphate concentrations were found ranging from 0.93 to 2.42 mg/L with an average of 1.39 mg/L. As shown in Fig. 3, phosphate concentrations decreased through the filters from feed water to treated water. The MBSF–01 achieved 57%–81% whereas MBSF–02 had 43%–81% reduction in phosphate concentrations during study period. The MBSFs performed better than control SSF, and MBSF–01 was found to be efficient than MBSF–02 in removing phosphate from feed water (Table 1, Fig. 3). Charcoal has been found evident for adsorptive removal of phosphorous from aqueous solution [21]. Hence the adsorption materials (brick-chips and charcoal) played important role in removing phosphate by the MBSFs in this study.

3.2.4. Total and fecal coliforms reduction

As can be seen in Table 1 and Fig. 4, the MBSFs achieved 2.5-log to 3.6-log reduction of total coliforms compared with 2.3-log reduction in the SSF. The highest removal of total coliforms was recorded in MBSFs between 50th and 120th d of the experiment period based on the value of 0 CFU/100 mL that revealed 100% reduction. A declined trend can be found between 60th to 70th d and 100th to 120th d. This might happen due to initial lower microbial concentration in feed water than the other days. On the contrary, the fecal coliforms

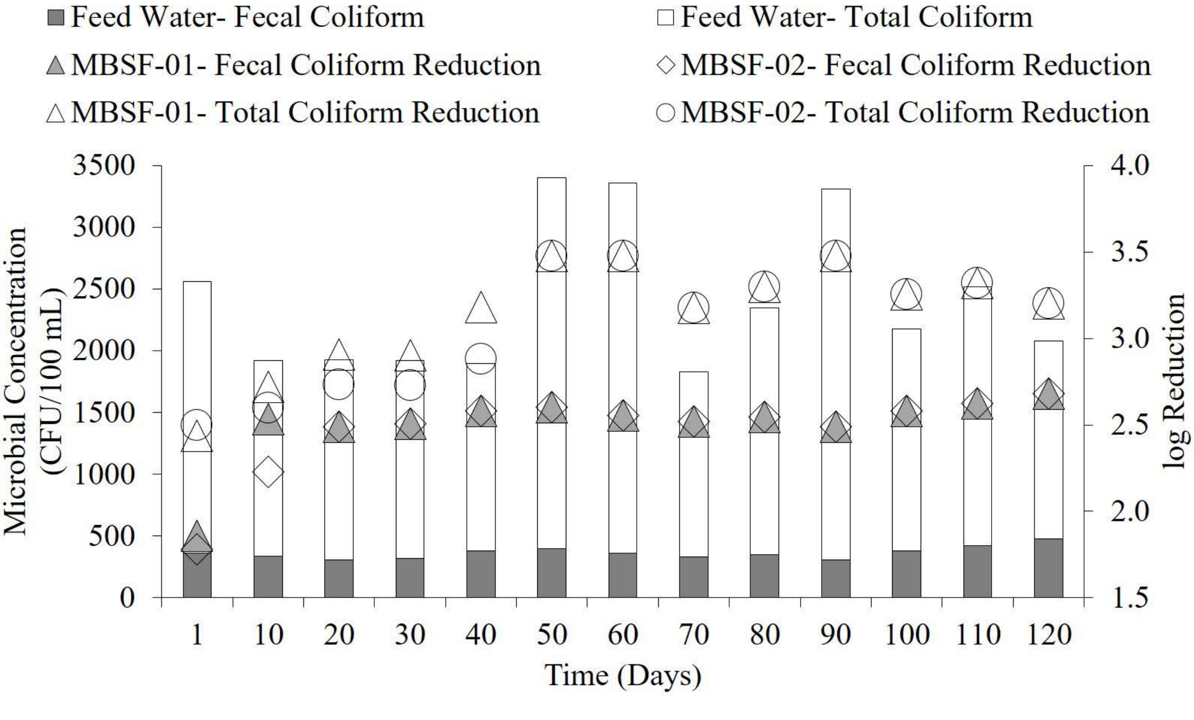

Fig. 4. Fecal and total coliforms in feed water and MBSFs filtrate, and reduction performance of the MBSFs. Bacterial concentration over the length of the filter runs are shown plotting on a logarithmic scale and the reduction is shown as log reduction value based on the calculation of initial (feed) concentration and the final (filtrate) concentration.

concentration was also found to be reduced by at least 2-log by the MBSFs with the average value of 2.5-log removal. The reductions were higher in comparison with the typical range of 93% to 99% found in other studies [8,10,13,16].

Besides, both filters performed equally better and additional layer of charcoal and brick-chips could accelerate the higher microbial reduction in the filtrate through enhancing adsorption. Also, as discussed earlier, lower filtration rate has been observed to be resulted in increased bacterial removal, potentially due to enhanced particle settling onto sand grains, the increased contact time, and the bacteria and the sand media/biolayer functioning [11,13,16]. Thus, an optimum combination of lower filtration rate and two times pouring of water with 6 h pause period enhanced the microbial contaminant removal performance by the MBSFs. Furthermore, the fair degree of consistency in achieving higher microbial contamination reduction efficiency indicates that filter maturation had occurred during the study period.

3.3. Chlorination of MBSFs filtrate for safe storage

Total coliforms and fecal coliforms were found in the filtrate occasionally (Table 1). Further to that it can be subjected to recontamination occurrence during collection, storage and household use where water is safe even at the source. So, it is required to be protected by residual disinfection and/or improved storage [22,23]. In this regard, disinfection through chlorination was tested to inactivate the residual microbial concentration and secure the stored filtrate over 24-h period applying free chlorine dose of 2.0 mg/L [20].

Fig. 5 shows that the free chlorine concentration decreased over 24-h time due to chlorine demand. At the initial dose of 2.0 mg/L, free chlorine concentration was found greater than 1.5 mg/L after the 30 min and 0.3 mg/L at the 24-h level that maintained the WHO and CDC SWS recommended guidelines of having 0.2–0.5 mg/L free chlorine to protect the stored water adequately from recontamination [20,24]. In addition, total coliforms concentration of the treated water after chlorination in comparison with control tests (without chlorination) was measured over time. The results showed 0 CFU/100 mL for chlorinated stored MBSFs filtrate while all the control tests were found having total coliforms concentration at the 24 h' level that might be due to regrowth of microbials or recontamination (Table 2). So, the chlorine disinfection after MBSFs filtration was effective in this study to provide microbially safe (0 CFU/100 mL) water. The initial dose of 2.0 mg/L showed the satisfactory level of free residual chlorine over the 24-h level to secure the stored water. Besides, the uses of sand filtration prior to disinfection lead to reduce microbial contaminants, chlorine demand effectively and provides valuable insight of more consistent free chlorine residual concentrations over time [25].

3.4. MBSFs cost analysis

The POU/HWTS should be cheap and widely available for the low-income people in the HtR areas. The initial construction cost for MBSF–01 and MBSF–02 was approximately US$ 10.50. Besides, the economic years of MBSFs was supposed to be 2.5 years for calculation as per previous other studies conducted by Sobsey et al. [9] and Duke et al. [10]. The overall cost-analysis was done based on filter construction, maintenance and disinfection, and cost per litre water has been estimated US$ 0.0007 (Table 3).

3.5. Potential public health risk reduction

Clasen [6] and Hunter et al. [26] indicated that inadequate access to safe drinking water is associated with both waterborne as well as several non-diarrheal and non-infectious diseases. Health authorities say that microbiologically safe water plays an important role in preventing outbreaks of waterborne diseases. Several household water treatment and safe storage technologies, such as BSF and chlorine disinfection, have been documented for their ability to reduce diarrheal disease and improve microbial water quality against waterborne diarrheal disease [7]. From Table 1, it can be noted that the MBSFs reduced a greater number of total coliforms and fecal coliforms in the filtrate that resulted in improved drinking water quality. Table 2 shows

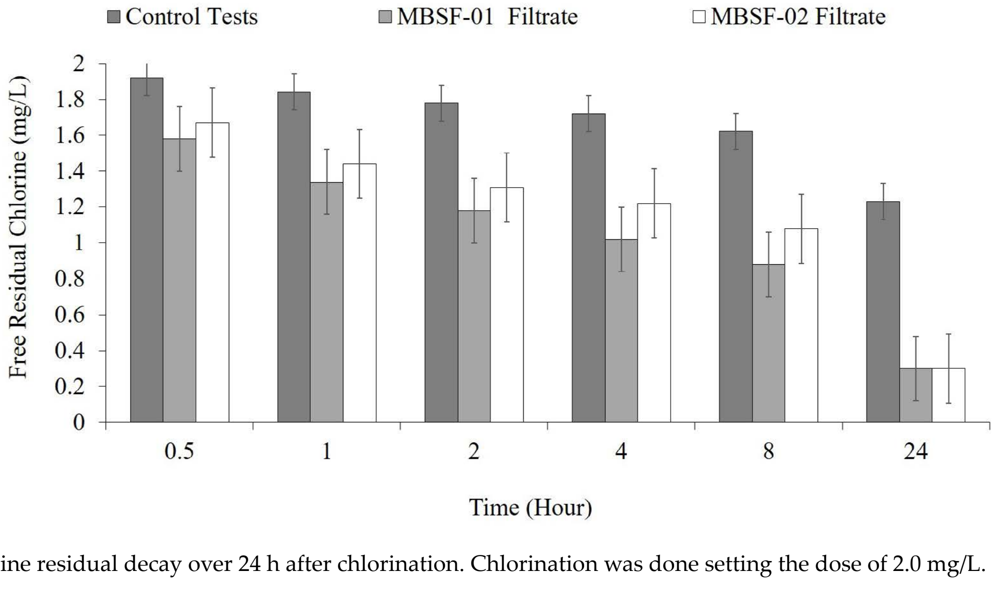

Fig. 5. Free chlorine residual decay over 24 h after chlorination. Chlorination was done setting the dose of 2.0 mg/L.

Table 2
Total coliforms concentration of the treated water after chlorination in comparison with control tests (without chlorination) over time

Time	MBSF–01 filtrate disinfection	MBSF–01 filtrate (control test)	MBSF–02 filtrate disinfection	MBSF–02 filtrate (control test)
0 min	1 ± 1	1 ± 1	1 ± 1	1 ± 1
30 min	0 ± 0	2 ± 1	0	3 ± 1
24 h	0 ± 0	14 ± 3	0	28 ± 8

that chlorine disinfection after filtration was effective to provide microbiologically safe water (0 CFU/100 mL). Thus the MBSFs and safe storage techniques resulted in microbially safe drinking water supply provision. Hence, the techniques could be applicable to promote public health through health risk reduction potentials from ingestion of contaminated water. Thus, overall, the MBSFs and safe storage technique would be translated into improved public health outcome for the climate vulnerable hazard–prone HtR population and to achieve SDG water target 'safely managed water' supply.

3.6. Appropriateness of MBSFs in HtR areas

Centralized water supply systems are generally difficult to introduce in the HtR areas due to being remote locations, poor infrastructural development and road communications, financial scarcity and lack of skilled professionals. Thus, not only from technological feasibility but also from applicability and accessibility context, the decentralized household solutions, that is, MBSFs seem to be effective alternatives in these HtR cases [27,28]. Besides, the existing water supply systems (community-based pond sand filters,

Table 3
Cost analysis of MBSFs

Outline of the cost				
Items	Description	Unit	Quantity	Cost (US$)
(a) MBSF packing materials				
Plastic bucket	50 L volume	Nos.	1	07.5
Sand	Grain size <1 mm	cft	2	0.625
Foam (sponge)	Thickness (1 cm)	m^2	0.5	0.55
Brick-chips	Size <6 mm (¼″)	cft	0.5	0.125
Brick-chips	Size 12 mm (½″)–6 mm (¼″)	cft	0.5	0.125
Charcoal	Size <6 mm (¼″)	cft	0.5	0.0625
Charcoal	Size 12 mm (½″)–6 mm (¼″)	cft	0.5	0.0625
Subtotal a				09.05
(b) Fittings and construction				
Pipe	Diameter - 12 mm (½″)	ft	3	0.1875
Glue	Water soluble	Nos.	1	0.1875
Thread tape		Nos.	1	0.25
Tap		Nos.	1	0.4375
PVC (U-Shape)	Diameter - 12 mm (½″)	Nos.	2	0.075
Water seal		Nos.	1	0.25
Subtotal b				01.45
(A) Total MBSF unit packing material and construction costs (a + b)				10.5
(c) Possible maintenance costs in 2.5 years				
Sand				0.625
Miscellaneous (packing and fittings)				0.975
Subtotal c				01.56
(B) Total maintenance cost in 2.5 years (c)				1.6
(C) Disinfection (chlorination) costs in 2.5 years				3.90
Total cost in 2.5 years (A + B + C)				16.00
Total cost/day				0.017
Total cost/day/litre of water				0.0007

Table 4
Appropriateness of the MBSFs in the hazard-prone HtR areas of Bangladesh

Features	Appropriateness
I. Technical Features	- Efficient to provide adequate water - Usable for drinking, washing and cooking, food preparation and personal hygiene for a family - Small device, technically simple and easy operation and maintenance - Low-cost (US$ 10.5), made of locally available materials that may promote system sustainability
II.SDG Safely Managed Uses	- Fecal and prior chemical contamination free improved drinking water quality - Safe storage and no risk of recontamination - Household level availability and affordability - Continuity potential of service ranges from 1 to 8 years
III. Applicability and suitability	- Treatment of surface water (pond water, river water, harvested rainwater). - Hazard-prone HtR areas, even functional during disaster or emergency periods. - Easy to install at household, schools, community places, disaster shelter centers. - Saves required time and remove distance difficulties to fetch water.
IV. Economic strength	- Largely affordable by low income group - A new business plan can be formulated, and local industry can be built up - Potential for socio-cultural acceptability, dissemination, socio-economic development and women empowerment
V. Expected outcome	- Improved public health outcome - Strengthening safely managed drinking water - Application potentiality in other developing countries

rainwater harvesting systems, solar desalination plants, etc.) in the many HtR areas such as char, coastal, etc. are often found inefficient to meet drinking water quality standard, scattered and dysfunctional, very insignificant in comparison with availability and affordability, inaccessible due to time and distance difficulties and disaster induced inaccessibility [29,30,31–33]. Thus, MBSFs as an individual technology and/or combination with existing community-based systems could be suitable as well as a matter of preference for year-round safely managed drinking water supply in the HtR areas. The appropriateness prospectus has been shown in Table 4.

4. Conclusion

The MBSFs were constructed with locally available materials and has been found to be low cost, technically simple, easily applicable and usable during emergency such as disaster periods. The MBSFs were found to be effective at reducing turbidity (>99%), fecal (2.0 to 2.5-log reduction) and total coliforms (2.5–3.6 reduction) from surface water. The recommended chlorine dose of 2.0 mg/L was efficient to protect stored filtrate over 24 h. Overall, the techniques might satisfy the new SDG dimensions for safely managed water supply services. Thus, the MBSF technology seems to be the prospective and suitable solution with sustainability potentials as an individual technique or in a combination with existing supply systems for the climate vulnerable hazard-prone HtR populations. Also, the current design can easily be added as new BSF system as well as applicable in the other developing areas around the world. Further studies are recommended for suitability assessment of pilot-scale application, long-term performance evaluation and sustainability assessments.

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