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Development of Low-cost indigenous filtration system for urban sullage: assessment of reusability

Tajuddin Sikder[1,2,3*], Zakir Hossain[3], Priangka Bhattacharya Pingki[3], Jussi Dayna Biswas[3], Mostafizur Rahman[1], Shakhaoat Hossain[2], Takeshi Saito[4] and Masaaki Kurasaki[1]

Abstract

Treated sullage water could be the answer to urban water scarcity. In this study, urban sullage water was subjected to various tests to determine a number of physiochemical parameters, heavy metal content and coliform count. Obtained results were compared with the Dhaka Water and Sewerage Authority (DWASA) water samples. The sullage water was then treated using a proposed filtration system with indigenous gravel-coal-sand filter. The pH, chlorine (Cl^-) and phosphate (PO_4^{3-}) of the sullage water, DWASA water and treated sullage water were found to be within the allowed limit set by Bangladesh Drinking Water Quality Standard. The nitrate (NO_3^{1-}), BOD, DO, coliform and phosphate (PO_4^{3-}) of the sullage water exceeded both the Bangladesh and WHO standard. The amount of toxic heavy metals, lead, cadmium, chromium, mercury and arsenic, were determined to be below the standards. The results indicated that sullage water is not safe and the treated one is safe from toxic heavy metals for household use. The significant portion of treated water can be reutilized which is equivalent of 29 % savings from the annual DWASA water bill. The quality of the treated sullage water revealed that it can be reused for cleaning, washing, bathing in household activities along with other agricultural and industrial purposes.

Keywords: Indigenous technology, Water pollution, Pollution remediation, Filtration

Introduction

Water is a finite resource, which makes up 75 % of the total volume of the earth. The earth's water resource is 97.5 % saline and only the remaining 2.5 % is potable, about which 2/3 is ice. Thus, approximately 0.83 % water is normally useable and available in ground and surface [1–3]. During the last 100 years, it has been observed that usage of water increased at the rate of double than the growth rate of the population. It is projected that water usage will increase more than 50 % from 2007 to 2025 in developing countries whereas in developed country, it will increase 18 % in the same period [3–7].

In Bangladesh, groundwater, which is naturally contaminated with arsenic, is the major source of drinking water for the majority of the population. On the other hand, surface water is polluted with industrial and domestic waste which requires treatments. Dhaka, the capital city of Bangladesh, has more than 45,000 people per square kilometer. In addition, about 1418 new comers add up to the Dhaka City population each day [8]. Open areas have reduced from 26 % to 8 % from the year 1989 to 2010. On top of that, wet areas around the river and river basin area in Dhaka City decrease gradually due to unplanned urbanization. Also, the recharge area for ground water replenishment decreases significantly.

The intensity of river water pollution in Dhaka and the addition of new pollution parameters in each year hinder the city from changing to surface water source from ground water source. Already 82 % of water supply in Dhaka has been generated from groundwater through 659 deep tube-wells and the rest of 18 % is supplied

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* Correspondence: sikder@juniv.edu; sikder@ees.hokudai.ac.jp
[1] Graduate School of Environmental Science, Hokkaido University, 060-0810 Sapporo, Japan
[2] Department of Public Health and Informatics, Jahangirnagar University, Dhaka 1342, Bangladesh
Full list of author information is available at the end of the article

from surface water. The water table in the city area has sunk by 50 m in the past four decades, and the closest underground water is now over 60 m below ground level in dry summer period. Now, deep tube-wells fail to draw groundwater, and it makes huge public chaos due to unavailability of water supply. The average water usage in a city like Dhaka is estimated around 140 l per person per day, by which only 30 l of these is used for drinking, cooking, toilet and urinal purposes. The remaining 110 l is mainly considered as 'sullage' which can be described as wastewater that arises as a by-product of daily human activities such as showering, washing dishes, and doing the laundry. It's estimated that up to 80 % of all household wastewater is sullage. As such, we focused on the reuse of the said 110 l of water hoping that it will contribute in resolving the water crisis of Dhaka [9–11].

In the south-western coastal belt of Bangladesh, a lot of Pond Sand Filters (PSF) has been constructed. Locally known as "sweet water ponds", these serve as a fresh water filter. In these systems, the collected rainwater is treated primarily with coconut fibers followed by sand to remove impurities [12, 13]. In line with the current water crisis, we hypothesized that a technology similar to this can be applied to treat sullage water. Upon treatment, this can be reused in Dhaka hoping to mend the water crisis that the city is going through. In this study, a small scale research was done to determine the efficiency of this indigenous technology in treating sullage water in Dhaka. Its effectiveness in terms of water quality, cost effectiveness and restoring ground water table were investigated to qualify the competence of the system proposed.

Materials and methods

The whole experiment was divided into two parts. First, a laboratory-based filter was prepared and tested, and then the system was applied in the actual filter.

Development of laboratory-scale filter

The filter was composed of a five feet long pipe, a smooth cloth, a funnel and a water pot to collect water as shown in Fig. 1. The sorbent, which is the active component of the column, is typically a granular material made of solid gravel particles (2–4 mm), fine sand (0.10–0.25 mm), coarse sand (0.5–1.0 mm) and coal (Fig. 1a-d). No external pressure and solvent were given to the column, and the flow relies on the force of gravity to allow the sample to pass through the column. First, the bottom of the pipe was bound with a smooth cloth to stop the components from flowing out of the pipe. A funnel was also attached to that end of the pipe to direct the flow of the water. Then, the pipe was filled with fine sand followed by coarse sand, gravel and coal (Fig. 1e). The upper most region (~1 ft) was kept empty for the sullage sample. The flow rate of the sullage was calculated to be 11.5 L/h.

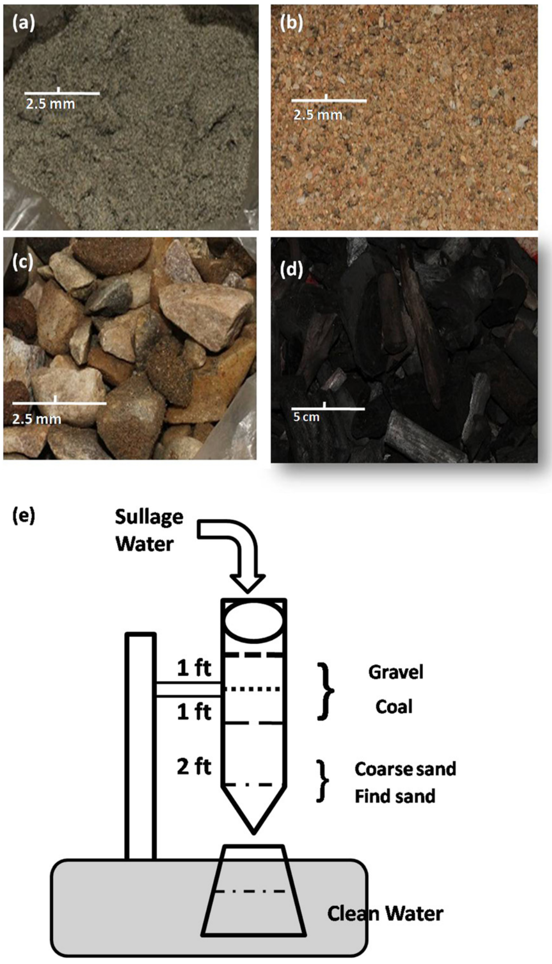

Fig. 1 Photos of indigenous filter materials and components (**a**) Fine sand; (**b**) Coarse sand; (**c**) the Gravel or jhama bricks; (**d**) Coal; (**e**) Flow chart of the laboratory scale filter and filtration

Development of real-scale filter

The real-scale filter for sullage water treatment was developed based on PSF technology. A two-story residential building at Kakrail, Ramna, Dhaka-1000 was chosen for the research work. Two types of filter media were used. To conduct a rapid filter, jhama brick chips (gravel) was used and found very effective in treating color, odor, etc. (Fig. 2). The second filter, the slow sand filter (SSF), was used to remove bacteria. The removal of bacteria starts by the sticking of the jelly-like floc to the grain of sand where bacteria can adhere and be trapped. After which, a biological jelly forms around each grain where biological activities carry out. Due to the large intervals of wash-up of this jelly, almost all of pathogenic type bacterial load retained on it. It was found that SSFs are very efficient in removing the bacterial contents of

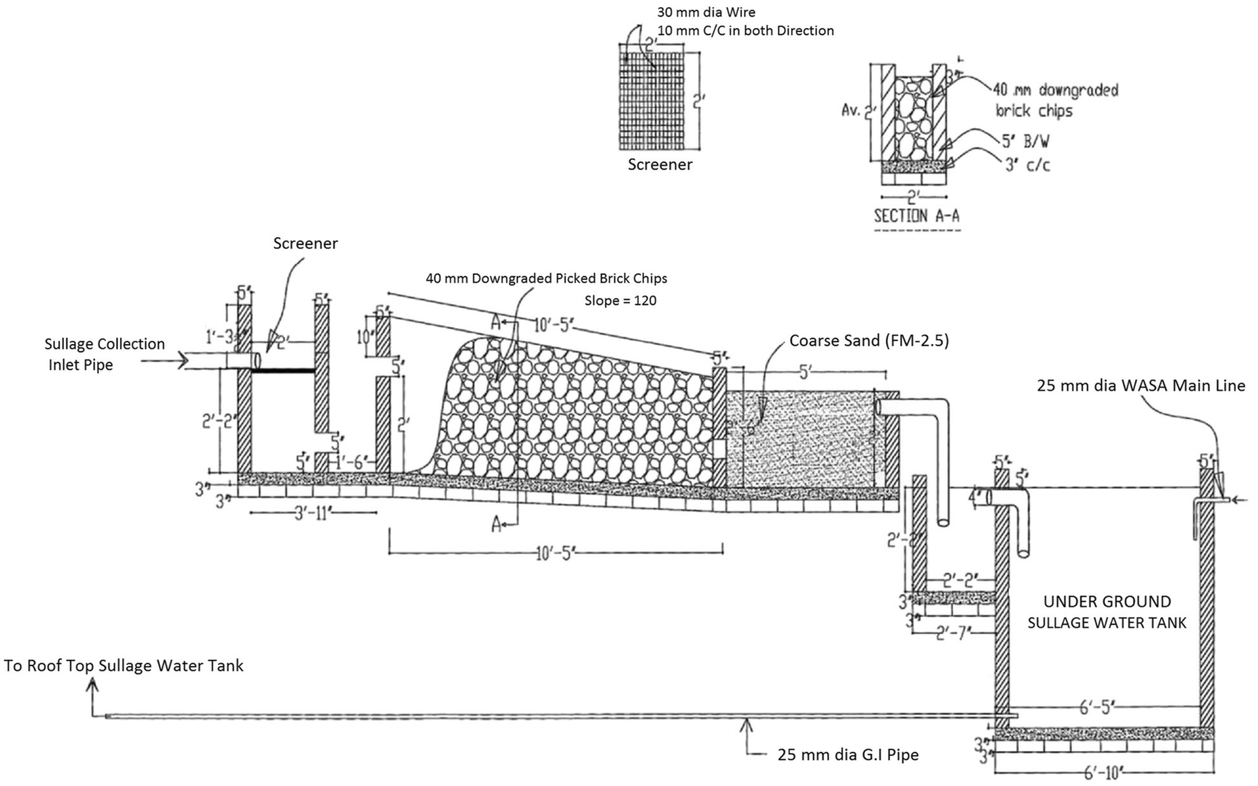

Fig. 2 Different treatment stages of sullage with an indigenous gravel-sand-coal based real-scale filter

the treated water. In the three treatment beds, 40 mm downgraded brick chips, coarse sand and fine sand beds were taken initially.

Treatment procedure through the real-scale filter

First, the sullage was allowed to pass through 40 mm downgraded picked jhama brick chips. Then, it passed through a coarse sand (minimum fineness modulus - 2.5 mm) filter media followed by a 2-m long fine sand (fineness modulus - 1.0 mm) filter media (Fig. 2). A gradient was maintained to keep the constant water flow. To make it cost-effective and low maintenance, the fine sand layer can be removed from the filter. The treated water was stored into a tank from where the samples were collected for laboratory tests. The stored water was then pumped to the roof tank and can now be used as needed (Fig. 3). The produced sullage was passed through a screener to a smaller sedimentation tank.

Determination of water quality parameters

The physicochemical parameters (pH, Cl^-, PO_4^{3-}, NO_3^-, DO and BOD) in sullage water, treated water and the supplied water of DWASA were measured at Bangladesh Council of Scientific and Industrial Research (BCSIR) and Bangladesh University of Engineering and Technology (BUET). The pH, TDS, DO and total suspended solid (TSS) were measured using a Portable Multi Parameter Meter (sensION™156). The PO_4^{3-} was measured with a UV-Spectrophotometer (UV-1650PC). Ammonium molybdate solution was prepared and mixed with ammonium metavendate solution followed by dilution with the sample to prepare 1 mL for PO_4^{3-} detection. An Ion Chromatograph (IC) with a UV/Visible absorbance detector was then used to measure NO_3^-. The eluent (1.0 L) was prepared by using 1.8 mM Sodium Carbonate and 1.7 mM Sodium Bicarbonate. Then, the eluent was subjected to Ion Chromatography after 100 times dilution with deionized water. The Cl^- and BOD levels were measured using standard laboratory method. The detection limits were 0.02 mg/L(PO_4^{3-}), 0.1 mg/L (Cl^-), and 1 mg/L (NO_3^-) [10, 11]. Internal quality control was used in the measurement of the physicochemical parameters and dissolved metals in the samples from each region. Analytical quality control was confirmed by doing replicate analysis of the samples. Three replicates of each sample were prepared, and their physicochemical parameters were analyzed simultaneously.

For the dissolved metal analysis, water samples were filtered to remove the insoluble materials followed by acidification with grade conc. HNO_3 for 1.5 h. The treated samples were transferred into a volumetric flask to analyze metal ions with Atomic Absorption Spectrometer (AAS) (Graphite Furnance: EL02096439). Atomic Absorption

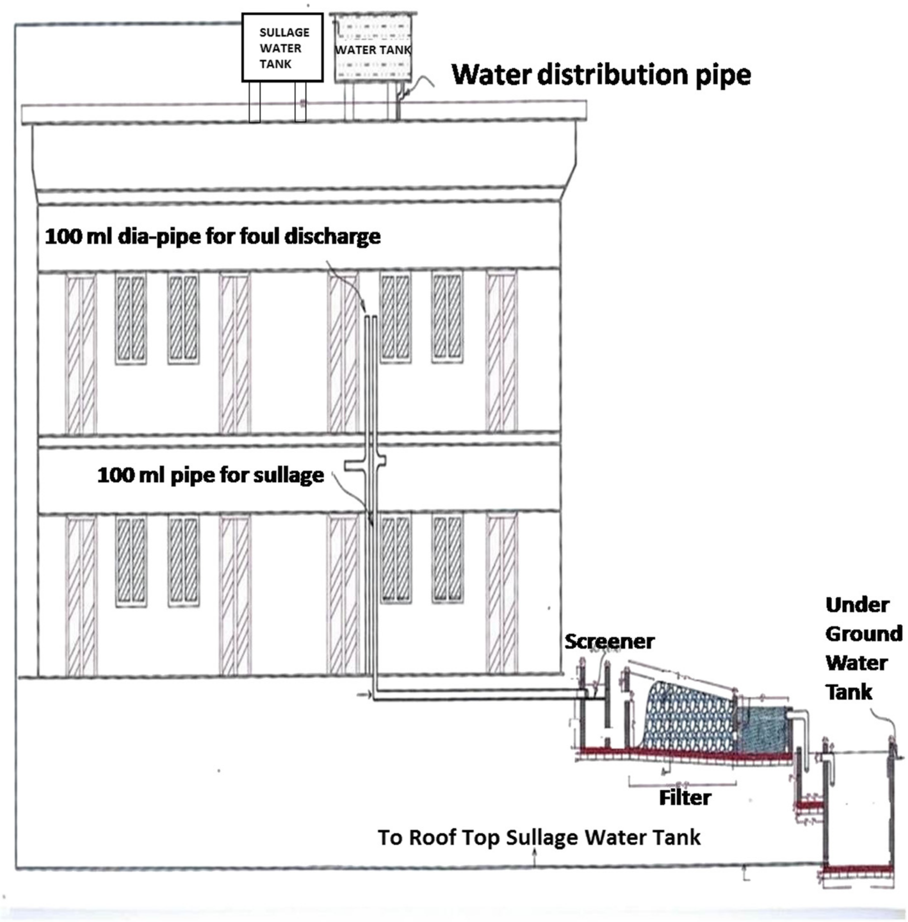

Fig. 3 Sullage collection, filtration and restoration system from a two-storied residential building in Dhaka city, Bangladesh

Spectrometer VGA (Vapour Generation Accessories: EL02096755) was used to measure Hg^{2+}. The concentrations of dissolved metals were detected at the ng/ml (ppb) level. The detection limits of AAS were 0.03 ng/mL (Cr), 0.03 ng/mL (Cd), 0.005 ng/mL (As) and 0.005 ng/mL (Pb). Standard solutions were prepared from 1000 mg/L stock solutions of different metals of interest by dilution with distilled water [10, 11]. The glass wares were washed with nitric acid followed by distilled water. All the experiments were carried out in triplicate. The results were reproducible within an error limit of ±5 %.

Total coliform was measured with Membrane Filter Coliform Count (MFCC), whereas, Membrane Filter Fecal Coliform Count (MFFCC) and the multiple-tube procedure by standard method were used for the detection of fecal coliforms. The confirmatory total coliform test is run at an elevated temperature (44.5 °C) to separate the fecal from the non-fecal strains. The MFFCC technique employs an M-FC Broth base medium and an incubation temperature of 44.5 °C (±0.5°) in a water bath for 24 h (±2). After incubation, the blue fecal colonies are counted [14]. The microbial tests were conducted in the Microbiology Department, Stamford University Bangladesh.

Results and discussion

Water quality analysis on laboratory scale

To understand the quality of DWASA, sullage and treated sullage water in this study, turbidity, pH, electrical conductivity, total suspended solid, total dissolved solid, turbidity, pH, BOD, DO, nitrate, phosphate, chlorine, Cd, Cr, Pb, As, Hg, total coliform and fecal coliform were determined for WASA water, sullage water and treated sullage water.

DWASA water quality

Water samples were collected from DWASA water supply and measured for physical qualities, chemical contents, and microbiological counts. The test results showed good water quality except for the presence of total coliform, which should be absolutely zero for drinking water. The residents of Dhaka rely mainly on the DWASA water supply for drinking. As such, a 2.3×10^4total coliform present in their water system pose a danger to the health of these people. Previously, some other researchers also conducted fecal coliform tests from DWASA water samples where they found fecal coliform in significant amounts in 89 out of 90 samples. In addition, the BOD and DO of the DWASA water exceeded both the Bangladesh and WHO standards whereas PO_4^{3-} and NO_3^- exceeded only the WHO standard (Table 1) [13, 15, 16]. Therefore, proper monitoring and assessment of the biological indicators in drinking water throughout Dhaka is highly and immediately recommended.

Sullage water quality test analysis

Sullage water samples were collected and subjected to various tests to determine its quality. The test results are highly close to the Bangladesh standard for drinking water except for BOD, DO, PO_4^{3-}, NO_3^- and coliform. On the other hand, pH and Cl^- were within the permissible limit (Table 1). The values of both total and fecal coliforms were significantly high and can potentially cause water borne diseases. The total coliform count of more than 0.24 million per milliliter in sullage was needed to be treated [13, 15, 16]. Elevated level of PO_4^{3-} (5.56 mg/L) was found in sullage water since the majority of the water originates from the kitchen dirt and washings. Furthermore, BOD level increased to 5.28 mg/L as expected and DO decreased drastically to 0.98 mg/mL, which must be adjusted before reuse.

Treated sullage water quality test analysis

The results of the measured parameters of sullage water treated with the proposed filtration system were found acceptable for reusing in daily life activities. Initially, the target was to pass the drinking water standard after sullage water treatment. By using this low-cost effective indigenous filtration system, all measured parameters were within the allowed limit of the Bangladesh standard for drinking water. It was found that every pollutant of concern in both DWASA and sullage water drastically decreased and was successfully filtered by the indigenous Gravel-Coal-Sand based filter chamber. Surprisingly, the level of PO_4^{3-} dropped to 0.97 mg/L, which is below the Bangladesh standard but still remains above the WHO standard. On the other hand, BOD value slightly decreased to 4.88 mg/L from 5.28 mg/L. This problem can be solved by increasing more retention time for necessary atmospheric oxidation or by adding required amount of coagulants and flocculent [17].

Analysis of heavy metals

Heavy metals are major source of pollution in natural water. They are considered highly toxic to aquatic organisms since they are non-biodegradable and, hence, are accumulated in organisms [18, 19]. Heavy metals affect kidney and liver by changing their physiological activities [20]. Pb, Cr, Cd, Hg and especially, As were expected to be present in low levels in the DWASA water as well as in the sullage water. In both cases, the heavy metal concentration was found below the Bangladesh and WHO standards. The results indicated that sullage water is less safe, and the treated one was safer from toxic heavy metals for household use.

Water quality analyses on real-scale

The results obtained from the laboratory scale filtration system were compared with the real-scale filter where the sullage was collected from a two-story building. In case of laboratory filter, it was able to decrease the BOD, DO,

Table 1 Comparative water quality analysis of sullage, treated water, Dhaka WASA and Bangladesh Standard for drinking water in laboratory-scale filter system

Water quality parameters	Unit	Dhaka WASA	Sullage	Treated water	Bangladesh standards for drinking water	WHO standards for drinking water
pH	-	6.58	6.52	7.10	6.5-8.5	6.5-8.5
NO_3^{1-}	mg/L	4.89	13.89	<3.0	10	0.45
PO_4^{3-}	mg/L	0.25	5.56	0.97	6	0.01
BOD_5	mg/L	0.68	5.28	4.88	0.2	0.2
DO	mg/L	7.02	0.98	5.96	6	6
Cl^-	mg/L	Nil	Nil	Nil	0.2	0.2
Pb^{2+}	mg/L	<0.01	<0.01	<0.01	0.01	0.01
Cr^{6+}	mg/L	<0.005	<0.005	<0.005	0.05	0.05
Cd^{2+}	mg/L	<0.001	<0.001	<0.001	0.005	0.003
Hg^{2+}	mg/L	<0.001	<0.001	<0.001	0.001	0.001
As	mg/L	<0.005	<0.005	<0.005	0.05	0.01
Total coliform	Number/100 mL	2.3×10^4	2.45×10^5	0	0	0
Fecal coliform	Number/100 mL	0	0	0	0	0

PO_4^{3-}, NO_3^- and coliform values below both Bangladesh and WHO standard. In real filter, these parameters along with TDS and TSS were tested (Table 2). The measured water quality parameters for treated sullage water were within the allowed limit of Bangladesh standard for drinking water. TSS concentration drastically decreased to 14 mg/L, which is slightly higher than the standard value of 10 mg/L [21]. Unfortunately, high level of TSS was also found in the DWASA water. The nitrate concentration was reduced dramatically in real-scale filter and the value was found to be below both Bangladesh and WHO standard (Table 2). The reduction of NO_3^-(0.42 mg/L) was significantly high in real-scale filter in comparison with the laboratory scale (<3.0 mg/L). On the other hand, the decrease in PO_4^{3-} was lower in the real-scale filter though it is still below the Bangladesh standard value. The significant result obtained from this real-scale filter was the reduction of the BOD value to 0.14 mg/L lower than both Bangladesh and WHO standard [15, 16]. In case of total and fecal coliform, the results were similar to the laboratory scale. All water quality parameters assessed in this study especially, NO_3^{1-}, PO_4^{3-}, DO, Cl^-, coliforms and the heavy metals are appropriate to express the exact water quality which can be used for expected purposes. It is evident from this study that DWASA water is almost equivalent with the treated sullage in terms of water quality. So, this study will surely provide significant insights to the policy makers.

The settling sank down at the bottom where the sludge was collected. The treated sullage water was directed to the underground water tank followed by the collection into the main storage tank. Remarkably, four consecutive tests done in different times showed no coliform in the treated sullage water samples. Furthermore, other tested parameters were also within the allowed limit.

The U.S. Environmental Protection Agency (USEPA) has promulgated treatment technologies for total suspended solids for municipal wastewater treatment plants. The USEPA recommended that municipal wastewater treatment plants must treat water to bring TSS levels to 30 mg/L as a monthly average and 45 mg/L as a weekly average [22]. Treatment typically consists of settling prior to discharge. Settling allows solids to sink to the bottom from where they can be removed. The retention time for both laboratory scale and real-scale filter was considered to calculate the flow rate of sullage water through the filter. There was no similarity of flow rate found in both cases, thus, only the real-scale flow rate was considered justifiable. The total water filtered by the real-scale filter was 920 L, and the obtained water after filtration was around 850 L after 20.5 h. More than 5 % of water was lost during the filtration process. Thus, the flow-rate was calculated as 41 L/h indicating a highly efficient sullage water treatment system using the indigenous gravel-sand-coal based filtration system. The gradient was always maintained to keep this flow-rate constant. The kinetics and isotherm of the filtered materials were already well known and were not calculated in this study.

It is assumed that separation occurs due to the difference in the degrees of attraction between the sorbent particles and the targeted pollutants. This water filter uses two different techniques to remove dirt. Physical filtration to remove larger impurities that usually works as a glorified sieve. Chemical filtration on the other hand involves passing water through the active gravel-coal-sand material that removes impurities chemically as water pass through them. So, this filter could be the easiest and safest way to treat sullage water and to make it reusable for daily purposes like bathing, washing, cleaning, and watering public parks, areas surrounding public buildings, large apartment complexes and condominiums. For industrial usage such as cooling process, water for textiles, paper and other chemical industries, the treated sullage water can also be reused.

Economic savings from the proposed filtration system

Water saving analysis

It was evident from the results discussed above that treated sullage water can be reused for daily activities except for drinking and cooking. Reusing the treated sullage water can give financial benefits to the users. On average, an adult utilize 140 L of water per day in Dhaka [13].

Table 2 Comparative water quality analysis of sullage, treated water, Dhaka WASA and Bangladesh Standard for drinking water in real scale filter system

Water quality parameters	Unit	Dhaka WASA	Concentration present in sullage	Concentration present after treatment	Bangladesh standard for DW	WHO Standards for drinking water
TDS	mg/L	465	667	523	1000	500
TSS	mg/L	419	522	14	10	10
NO_3^{1-}	mg/L	4.89	13.89	0.42	10	0.45
PO_4^{3-}	mg/L	0.25	5.56	2.28	6	0.01
BOD_5	mg/L	0.68	5.28	0.14	0.2	0.2
Total coliform	Number/100 mL	2.3×10^4	2.45×10^5	0	0	0
Fecal coliform	Number/100 mL	0	0	0	0	0

From this 140 L, 30 L is attributed for drinking and toilet/urinal purposes while the remaining 110 L is being used for other daily life activities. Approximately 5 % of the water, around 5.5 L, is lost by evaporation, washing filter media and etc. Thus, the remaining water, after considering drinking, toilet/urinal purposes, and water loss, equates to 104.5 L. Therefore, approximately 75 % [(104.5/140)×100 = 74.64 %] of water can be reused.

Cost analysis

The cost of the real-scale filtration system for sullage water was calculated for a two-story residential building at Dhaka and a tentative projection of financial benefits were shown. The building was the residential space for 12 people using DWASA water & sewerage disposal system. The constructed filter bed was targeted to last for 10 years. The capital cost for the construction of a complete filter bed system for 10 years was 25,000.00 Taka (USD 313). Therefore, the capital cost per annum is only 2500.00 Taka (USD31.3). The operation and maintenance cost were determined to be 6000 Taka per year (USD 75/year). This was based on bimonthly filter media washing and weekly cleaning of screener and scum from the sedimentation tank and others.

For a two-story building with 12 residents, the average DWASA bill payment for the water supply and sewerage system is around 12,000.00 Taka per year (USD 150/year). Thus, the monthly average is around 1000.00 Taka (USD 12.5).

Direct economic benefit for 12 members by reutilization of treated sullage water per year is calculated as follows: {payment of DWASA bill/year - (construction cost of the filter/year + operation and maintenance cost/year)}. Accordingly, total savings is (12000 – 2500 – 6000) = 3500.00 Taka (USD 44), which corresponds to a total of 29 % savings off from the DWASA bill.

Conclusion

It is concluded that the sullage water was contaminated with PO_4^{3-}, NO_3^- and coliform, with high levels of BOD and DO. Results of this research work indicated that the installed indigenous gravel-coal-sand based filter system was capable to entrap effectively the above pollutants from the sullage. About 75 % of water can be stored back to the tank for reutilization while having 29 % savings from the annual DWASA water bill. The results indicate that sullage water is not safe, and the treated sullage water is safe from toxic heavy metals. Using this proposed sullage water treatment filtration system; water can be saved and reused. As a result, ground water extraction can be reduced to 26 %, raising the water table justifiably. The treated sullage water can be suggested for household use, agricultural and industrial purposes cost-effectively. The experimental results suggested that this filtration system can be used for metallic elements, fecal coliforms, BOD, nitrate and phosphate removal for both industrial and residential area. However, one major challenge to overcome is cultural acceptance. Reuse of treated sullage water for daily household purposes is still a new idea and it may take time for people to be open about doing it. Moreover, chlorination of treated sullage water will be needed to remove any further mystification.

Competing interests

The authors have declared no conflict of interest.

Authors' contributions

TS supervised the whole work both in laboratory and in real scale, analyze the data and drafted the manuscript. ZH performed the real scale experiment, designed the treatment system, draw the figures and took part in the manuscript wirte up. PBP conducted the laboratory scale experiment and drafted the manuscript. JDB also supervised the work and drafted the manuscript. MR, SH, and TS participated in the editing of the manuscript. MK co-operated to carry out the English Language editing.

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Author details

[1]Graduate School of Environmental Science, Hokkaido University, 060-0810 Sapporo, Japan. [2]Department of Public Health and Informatics, Jahangirnagar University, Dhaka 1342, Bangladesh. [3]Department of Environmental Science, Stamford University Bangladesh, Dhaka 1208, Bangladesh. [4]Faculty of Health Sciences, Hokkaido University, 060-0812 Sapporo, Japan.

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