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Sustainable wastewater management for underdeveloped communities – a hands-on method for qualitative and quantitative analysis of greywater

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Abstract: The quantity of greywater produced in urban areas of Dhaka city in Bangladesh is around 96–112 litres per capita per day which is 60%–70% of the average water supplied. This huge amount of greywater could be recycled via a separate distribution system to meet water demand for greywater toilet systems, gardening and irrigation. The quality parameters of collected greywater samples ranged for pH between 6.67 to 7.92, conductivity between 548 to 999 μS-cm^{-1}, turbidity between 54 to 435 NTU, colour between 28 to 367 (Pt-Co Unit), BOD$_5$ between 60 to 299 mg-L^{-1} and COD between 135 to 751 mg-L^{-1}. It is estimated that an annual savings of 59 million Taka (about 728,300 USD based on $1 = 81 Taka as of 4/13/2017) could be achieved in a chemical and purification process if greywater is recycled for this community. This practice of recycling greywater is a step toward sustainable wastewater management for underdeveloped communities struggling with capital and dwindling freshwater sources.

Keywords: greywater; recycle; underdeveloped communities; sustainable; reuse.

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1 Introduction

Water scarcity is a burning issue in today's world where millions of people lack access to freshwater (WHO/UNICEF, 2014) and a growing population rate puts 700 million people at a level far below the water stress level of 1,700 m^3 per person per year (Qu et al., 2013). The expensive and energy-consuming water treatment processes make it difficult for the developing and underdeveloped countries to be able to afford and produce a huge amount of freshwater. Therefore, wastewater recycling and treatment concepts (Gupta et al., 2012) and novel technologies for desalination of saltwater are being extensively studied by researchers throughout the globe (Ahmed and Tewari, 2016). The concept of reusing wastewater is helpful to meet the growing water demand if the water quality standards are met with an energy efficient treatment technology.

Greywater is a component of domestic wastewater which is free from human and animal excretion wastes. Typically, it consists of wastewater from bathing and domestic cleansing activities such as laundering, cleaning of kitchens and cleaning floors. Greywater makes up a good portion of domestic wastewater. In a study (Vakil et al., 2014) on Indian urban households, greywater was found to be 80% of total wastewater with the main contribution (44%) from the kitchen. The average production of greywater in Greek households was 82.6 ± 49.3 litre per capita per day (lpcd) with the major contribution from bathtub and laundry (Antonopoulou et al., 2013). The reuse of greywater results in reduction of freshwater usage and the associated cost, but there are some challenges that need to be addressed:

1 availability of inexpensive technology for treating greywater

2 access to this inexpensive technology and its relative ease of applicability by common people with little to moderate technical knowledge (Ammari et al., 2014).

The motivation behind reusing greywater is to reduce the use of freshwater being wasted for non-potable activities like toilet flushing, gardening and irrigation. Reuse of greywater may have some unwelcomed consequences and thus, needs special attention in designing such water reuse systems.

In a study conducted at Hong Kong International Airport (Leung et al., 2012), integration of seawater and greywater reuse for toilet flushing resulted in 52% of freshwater savings. At the same time, the application of seawater for toilet flushing resulted in an increased salinity level of sewage by 20%–30%, thus affecting the wastewater recycling process. Greywater contains pathogenic microorganisms (NSW, 2000) which makes it hazardous for human health if consumed. The presence of suspended solids in the wastewater from kitchen wastes may also produce problems like clogging of conduits and odour. Use of greywater poses greater probability of skin infection by *S. aureus* while probability of risk caused by *P. aeruginosa* was low in a study (Maimon et al., 2014). This study also emphasised the treatment of greywater and a professionally designed greywater reuse system to lower the risks. In another study (Zimmerman et al., 2014), assessing human mitochondrial DNA as a molecular marker proved the presence of *staphylococcus*, *corynebacterium*, and *propionibacterium* bacteria in greywater.

Gardening and irrigation, in contrast to toilet flushing, require a wide range of issues to be addressed because soil characteristics and plant growth are affected by greywater quality. Reichman and Wightwick (2013) showed that the use of greywater containing detergent has a negative impact on plant biomass of radish and lettuce. This greywater had high concentration of Na which affected the uptake of Ca, Mg, and K. Also, a higher amount of salt present in greywater affected soils adversely and altered physical properties such as hydraulic conductivity. The plants grown in soil irrigated with greywater containing higher amounts of Cu and Fe, are unlikely to cause a risk to human health according to this work. Soil pH was increased which could have negative impacts on availability of phosphorus (P) and micronutrients. The effect of greywater application on soil pH and electrical conductivity (EC) level was examined in a study (Pinto et al., 2010) by assessing three cases:

1. applying greywater only
2. applying freshwater and greywater alternately
3. applying freshwater only.

Using only greywater for irrigation increased soil pH and EC levels which was indicated by poor plant growth. However, using freshwater and greywater alternately has shown similar pH and EC levels in plants as in the case of using freshwater only. Therefore, this study suggested that using freshwater and greywater alternately should be a viable option. One of the problems associated with the use of greywater for irrigation is oil and grease accumulated in the soil because this significantly hampers the transmission of water through soil (Travis et al., 2008). Another issue that needs to be addressed while using greywater for irrigation is P concentration, since many household items have high P content. A study investigated four parcels of land for around five years and observed the level of P in the soil (Turner et al., 2013). They reported a saving of 1.6 million litres of freshwater by using greywater for irrigation in the first four years but also mentioned a higher risk level due to the presence of P.

Some of the researchers have focused on the treatment of greywater for its reuse as it is evident that there are problems associated with the use of greywater for irrigation. Also, human health risk exists due to the presence of harmful pathogens and bacteria in greywater. Therefore, though greywater is technically less contaminated than municipal wastewater, reusing it onsite requires a treatment technology that is economic and user friendly. Dalahmeh et al. (2014) compared performance of bark, charcoal, and sand filters by varying hydraulic loading rates (HLR) and organic loading rates (OLR) and observing the changes in removal of 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total N and total P. The results indicate that sand filters can be replaced by bark filters for low HLR conditions, but charcoal filters provide the best result in all combinations of loading of HLR and OLR. Since, in the case of low HLR, both bark and charcoal filters provide good results, cost and ease of availability of the materials can be the decisive factors when choosing either of these filter mediums. Another study (Ammari et al., 2014) used a vertical flow bioreactor to recycle greywater. Their system significantly improved greywater quality as it removed 97% of BOD_5, 94% of COD, 100% of PO_4, 90% of TSS, 19% to 66% of NO_3, 45% of chloride ions, and 55% of sulphate ions. They were also able to increase DO by 98%. This treated water may be recommended for irrigation, but due to a lower reduction of organisms with this method this water is not suitable for domestic reuse as there is a greater chance of direct human contact. A pilot scale study (Karabelnik et al., 2012) used filter systems having oil shale ash (an industrial by-product) and filtralite (inert ceramic particles with a dense shell surrounding a porous core, a commercially trademarked product) as filter media. Crushed filtralite particles in the range of 4–10 mm provided the best results in terms of COD removal while oil shale ash provided better performance in phosphate removal. The filters with vertical flow removed a high percentage of TSS, organic matter, total nitrogen, and total P. They recommended filtralite as filter material for vertical flow and shale ash for horizontal flow configurations. Use of an electrochemical reactor to treat greywater achieved about 70% removal of COD and 99.9% removal of pathogens with energy consumption of 0.3 $kWh\text{-}m^{-3}$ (Vakil et al., 2014). Jabornig and Favero (2013), treated greywater with a moving-bed biofilm membrane reactor to combine the lower space requirements of an activated sludge membrane bioreactor and the reduced investment cost of biofilm membrane reactors to further reduce the investment and maintenance cost. The effluent quality meets NSF/ANSI 350 guidelines for water reuse and the energy consumption could be lowered to 1.26 $kWh\text{-}m^{-3}$ with a stable flux of 5–10 $Lm^{-2}h^{-1}$. The photo-fenton process was used in one study by Teodoro et al. (2014) to inactivate severe skin infection causing *pseudomonas aeruginosa*. They found that a higher concentration of H_2O_2 leads to a more efficient system compared to pH adjustments with low H_2O_2. A study on sewer systems (Penn et al., 2013) compared system performance for a particular population with no greywater reuse, greywater for toilet flushing only and greywater for flushing and irrigation. In each case, they observed flow rate, velocity and proportional depths at different times of day in addition to the pollutant concentrations. They found that volumetric flow rate, flow velocities, and flow depths in sewers reduced with greywater reuse suggesting smaller diameters being sufficient for future sewer systems with reuse of greywater in toilet flushing and irrigation. However, if all the houses use greywater only for toilet flushing and no greywater is being reused for irrigation, the pipe diameters of sewers cannot be changed as the flow velocity, volumetric flow rate and flow depth remained the same. COD and

TSS peaked during morning hours and NH_4^+, N and PO_3-P exhibited a peak during the night indicating a pattern of the use of water and ensuing wastewater discharge.

A recent study conducted in Syria (Mourad et al., 2011) investigated the feasibility of greywater reuse in a Syrian city and proposed two treatment processes, i.e., artificial wetland (AW) and commercial bio-filter (CBF). This study, based on economic analysis, suggests that AW has a significantly lower payback period (three years) than CBF (52 years). Therefore, the AW was a good option to conserve treated supply water. Their study also showed a 35% savings in freshwater supply if greywater is reused for toilet flushing. Matos et al. (2014) discussed how water reuse and greenhouse gas emissions are related. In their work, greywater reuse systems emitted between 123.7 kg and 575.6 kg of CO_2 per day which is much lower than the emission from wastewater reuse systems which is between 329.6 kg and 4,879.2 kg of CO_2 per day. Also, greywater reuse systems used only 11.8% to 37.5% of the energy used by wastewater reuse systems. These results suggest that greywater recycling reduces greenhouse gas emissions and it also reduces energy requirements.

There is a severe scarcity of freshwater in Bangladesh. Surface water pollution, growing population, lack of infrastructure (Ahmed and Rahman, 2000), groundwater depletion (Rahman and Mahbub, 2012) are some of the factors that contribute to this scarcity. A huge demand for irrigation and a growing population makes efficient water management necessary in context geographical location and availability of water resources. Production of Boro rice in Bangladesh requires 11,500 m^3 of water per hectare per year (Biswas and Mandal, 1993; Chowdhury, 2012). The main source of irrigation water is a man-made canal that is connected with a nearby river. But in the dry season (November–May) these rivers encounter a shortage of water-flow as the rainfall amount drastically reduces (Ahmed and Roy, 2007). In recent years, agricultural activities increased three times and consequently increased the cultivated lands of Boro rice from 1,168,000 to 4,068,000 hectares (Rahman and Parvin, 2009). The successful reuse of greywater could help in fulfilling the growing demand for freshwater and compensate for the huge irrigation water demand. In current study, the focus is on quantifying and characterising the greywater generated from Bangladeshi households and other sources to pave a way for a viable treatment process. The research contributes to efficient and sustainable water management practices by helping in minimising the growing water demand in Bangladesh and other such underdeveloped communities across the world.

2 Materials and methods

2.1 Quantification of greywater produced

The basic approach in quantifying the volume of greywater generated for activities considered in this study is based on two variables – the flow rate and the duration of the activity. The basic experimental determination of flow rate when faucets are open completely or at full force was done using a bucket with known volume, V and measuring the time, T, needed to fill up the bucket for each faucet while open at full force. The determination of actual full force flow rate, Q, was done using the basic relationship in equation (1) provided below.

$$Q = V/T \tag{1}$$

Once full force flow rates were determined for various faucets, a group of 10 to 15 people was observed for time spent by each individual using different faucets and their particular purpose. The volume of water used by each person was calculated by simply multiplying the full force flow rate, Q, by the time, T, of use. Several volume values were calculated and their average was used to arrive at an experimental lpcd value for an activity.

It is not realistic to assume that all faucets are opened fully when being used by every user and for that reason a reduction factor was used in the estimation of volume of greywater generated to eliminate overestimation. For example, people may use a faucet at full force while taking shower, but they may not use it at full force while washing dishes in the kitchen to avoid water spills and splashes. Sometimes, low pressure at a faucet makes people use it at full force. But in this study, all of the faucets were found delivering water at a reasonable pressure. A reduction factor was determined by observing five different people while using a faucet for a particular purpose and measuring the flow rate. The average flow rate calculated in this way was divided by the actual full force flow rate and this ratio was used as a reduction factor in calculating the usage volume for a particular purpose. Table 1 lists the reduction factors we used in our water quantity (volume) calculation.

2.2 Quality analysis

The quality analysis of all the samples was done in the Environmental Engineering Laboratory of the Bangladesh University of Engineering and Technology (BUET). For measuring pH, the USEPA 150.1 method was followed using a HACH pH metre. Turbidity was measured in *nephelometric turbidity units (NTU) using the* USEPA 180.1 method and using a HACH 2100P turbidimeter and colour was measured in Pt-Co units using the USEPA 110.2 method using a HACH DR4000U spectrophotometer. Conductivity was measured using a HACH conductivity metre in S-cm^{-1} units. The COD was measured using the USEPA 410.4 method by heating a COD vial in a HACH COD reactor and recording final measurements with a HACH DR2010 spectrophotometer. The BOD$_5$ was measured using the Winkler method.

Table 1 Reduction factors

Purpose	*Reduction factor*
Hand wash and brushing	0.8
Floor wash	1
Bathing	1
Clothes wash	1
Toilet flush (blackwater)	1
Kitchen (wash water)	0.65
Gardening	0.7
Bathroom wash	1

3 Results and discussions

3.1 Quantification of greywater and potential savings by reuse

There were three groups in this study. Two of the groups worked on quantifying and analysing greywater from two different student dorms (Titumir Hall and Nazrul Hall) and another group worked on greywater from households. All groups followed the same methods and procedures. Table 2 shows actual figures of water consumption for different purposes from these two studies and also the generation of greywater. Most of the consumed water resulted in to greywater except for the water used for toilet flushing and gardening. The total number of residents were 24 and 30 in Titumir Hall and Nazrul Hall, respectively.

Table 2 Consumption of water for different purposes in dorms and greywater generation

Type of use	*Actual generation (lpcd)*	
	Titumir Hall	*Nazrul Hall*
Hand wash and brushing	6	16.52
Floor wash	11	13
Bathing	49	46.7
Clothes wash	17	14
Kitchen (wash water)	18	12.7
Total greywater generation	*101*	*102.92*
Toilet flush (blackwater)	15	21.58
Gardening water	15	18.5
Total water consumed (including greywater)	*131*	*143*

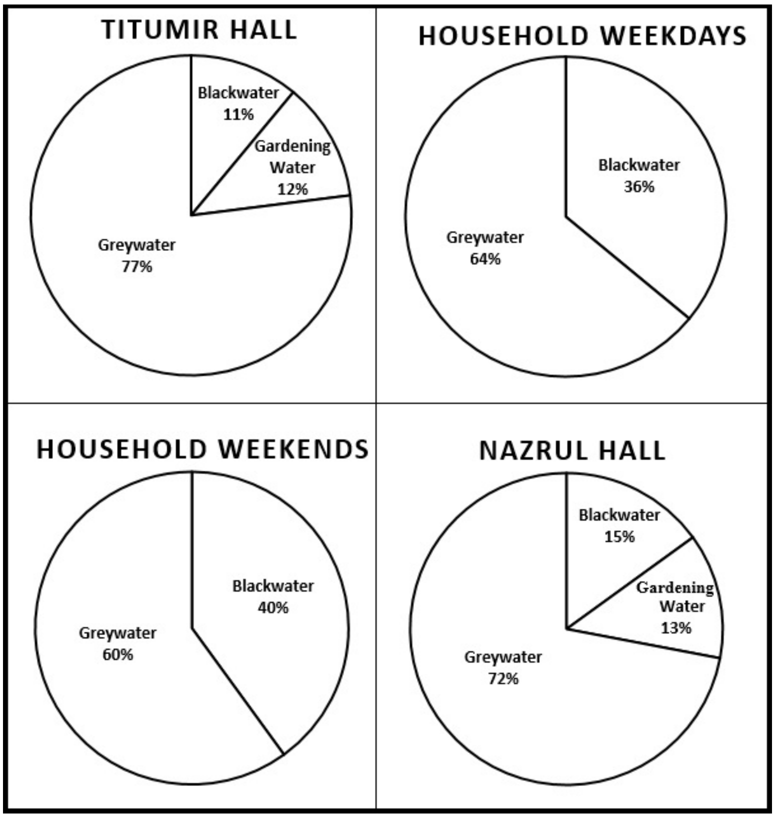
Table 3 Consumption of water for different purposes in households and greywater generation

Type of use	*Actual generation (lpcd)*	
	Weekdays	*Weekends*
Clothes wash	27	27
Bathing	30	30
Utensils wash in kitchen	24	24
Floor wash	15	15
Hand wash	8	11
Ablution	8.75	12.5
Bathroom wash	8	8
Total greywater generation	120.75	127.5
Toilet flushing	68.25	84
Total water consumed (including greywater)	*189*	*211.5*

The group focusing on quantifying greywater from households used a slightly different approach by dividing usages based on time of the week. Their results presented in Table 3, show water consumption for different purposes and greywater generation data from five different households each having a single family with five members. This group also defined the water consumption patterns on weekdays as well as during weekends as this pattern varied on weekends. In households, greywater generation peaked on weekends due to washing clothes and other weekly cleaning activities. However, these criteria were ignored by the other two groups because of the more uniform water consumption pattern in student dorms throughout the week. This uniform pattern was assumed based on the interviews of the students in which most of them stated that during weekends they were busier because of their projects, assignments and outdoor activities. Thus, their laundry and other weekly cleaning activities were taken care of during the week depending on free time.

The greywater generation rates from resident dorms are 77% and 72% (greywater generation/total water consumption × 100%) of total water consumption respectively for Titumir Hall and Nazrul Hall. Although these percentages are slightly higher than the household generation rates which are about 64% on weekdays and about 60% on weekends (Figure 1), the actual values are lower due to low blackwater generation in dorms. This wide variation is due to a large number of non-functioning auto-flushing toilets resulting in lower actual generation of blackwater from resident halls. This lower generation is attributed to manual flushing by buckets of water.

Figure 1 Percentage of greywater production from different sources



Actual values of greywater generation (total wastewater generation minus water used for toilet flushing and gardening) rates are 101 lpcd for Titumir Hall, 102.92 lpcd for Nazrul Hall, 120.75 lpcd for households on weekdays, and 127.50 lpcd for households on weekends.

These rates show little variation in terms of their respective percentages. In fact, thousands and thousands of households in Dhaka city lack modern facilities. Flushing systems in these households are either not working properly or are not installed at all. (Ahmed and Rahman, 2000) Therefore, blackwater generation would be much lower in percentage and in turn greywater generation would be higher if compared to the data from other cities around the world. The household generation rates are congruent to similar studies done in India (Vakil et al., 2014).

Dhaka Water Supply and Sewerage Authority (DWASA) serves 15 million people by supplying 2,420 million litres of water each day at an average rate of 161.33 lpcd (DWASA, 2014). The total water consumption rate found in each case by our study is near this value. Meeting this amount of water demand costs DWASA a total of around 5,000 million Takas (about 67 million USD based on \$1 = 81 Taka as of 4/13/2017) of which 147 million Takas (1.96 million USD) was used for chemical and purification activities. Estimation of savings in total operating cost and total cost would require a more rigorous economic analysis which is beyond the scope of this research. However, if greywater (which is more than 96 lpcd or 60% of total water supplied) can be reused to supplant water demand because of toilet flushing activities resulting in blackwater. Same could be done with gardening water demand (for non-edible purpose). It may save up to 59 million Taka (about 728,300 USD) annually only on chemical and purification activities before trading off this amount to meet the costs for greywater storage, supply system installation, maintenance and possible treatment options as and when needed.

3.2 Greywater characteristics

This study also focuses on finding the greywater quality parameters such as pH, conductivity, turbidity, colour, BOD_5 and COD of all the samples categorised based on their usage. Table 4 provides the data that was collected and compared with values from similar studies from Indian households assuming that sociocultural and economic similarities between the two countries might reflect in the water quality as well.

In addition to the data presented in Table 4, in case of Nazrul Hall, the collected water samples from different activities were mixed in proportions and were analysed. The results are compared with published values of similar usage and are presented in Table 5. The presented data in Table 4 shows that the pH of the samples varied from 6.67–7.92. Among bathing, washing and laundry water, the last one is found to be slightly basic based on pH which may be due to the presence of detergent, soap and other basic/alkaline substances. Table 5 shows the pH of combined greywater samples being 6.99. It is close to other reported values such as Bangladesh guidelines [i.e., Environmental Conservation Rules (ECR), 1997] (Bangladesh, 1997) and World Health Organization (WHO, 2004) guidelines. According to them, the potable water pH should be between 6.5 and 8.5. A pH of 6.99 makes greywater suitable for specific reuse as suggested in this study. Conductivity data was taken only in the case of Nazrul Hall. Mixed greywater samples show a conductivity value of 780 S-cm^{-1} which is close to the average range reported in the literature and as presented in Table 5. Higher conductivity indicates the presence of dissolved salts in greywater which requires removal before reuse.

Turbidity of the samples varied between 55 and 435 NTU which is significantly higher than standard values of 10 NTU (Bangladesh, 1997) and 5 NTU (WHO, 2004) which necessitates the process of treatment before using the water for irrigation. The laundry water shows most turbidity which may be attributed to the presence of dust, mud, soaps, detergent, oil and grease and other organic and inorganic substances present in the used clothing. For the presence of some substances, it can be concluded that the true colour, BOD_5 [Figure 2(a)] and COD [Figure 2(b)] are also high for laundry water.

According to the Bangladesh ECR (1997), the maximum limit for any wastewater discharge in irrigated lands BOD_5 is 100 mg-L^{-1}. Mixed greywater samples show BOD_5 of 198 mg-L^{-1} whereas all other samples have BOD_5 in between 62 and 369 mg-L^{-1}. Therefore, some treatment for greywater is necessary for most greywater samples and mixed samples before reuse.

Table 4 Comparison results for three types (bathing, washing and laundry) of greywater with reported literature values

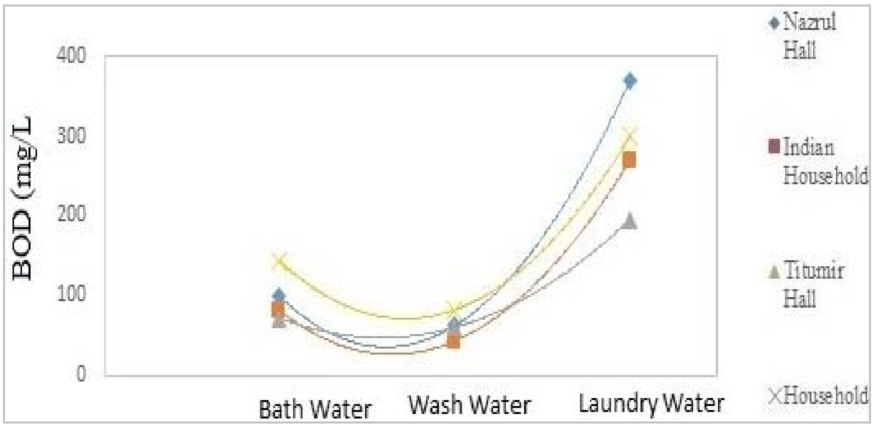
Bathing water				
Parameters	*Nazrul Hall*	*Titumir Hall*	*House-hold*	*Indian house-hold**
pH	6.82	6.77	7.05	7.5
Conductivity (μS/cm)	548.33	-	-	-
Turbidity (NTU)	80.83	85	133	-
Colour (Pt-Co)	90.67	128	52	-
BOD_5 (mg/L)	99	72	143	81
COD (mg/L)	187	430	423	461
Floor washing water				
Parameters	*Nazrul Hall*	*Titumir Hall*	*House-hold*	*Indian house-hold**
pH	6.85	6.92	7.17	7.5
Conductivity (μS/cm)	586.33	-	-	-
Turbidity (NTU)	54.67	95	62.5	-
Colour (Pt-Co)	28.67	41	210	-
BOD_5 (mg/L)	62	60	82	43
COD (mg/L)	186	135	289	225
Laundry/clothes washing water				
Parameters	*Nazrul Hall*	*Titumir Hall*	*House-hold*	*An Indian house-hold**
pH	7.07	7.92	6.67	9.4
Conductivity (μS/cm)	999	-	-	-
Turbidity (NTU)	165	435	342	-
Colour (Pt-Co)	247.33	520	367	-
BOD_5 (mg/L)	369	195	299	269
COD (mg/L)	505	865	751	824

Note: *Vakil et al. (2014)

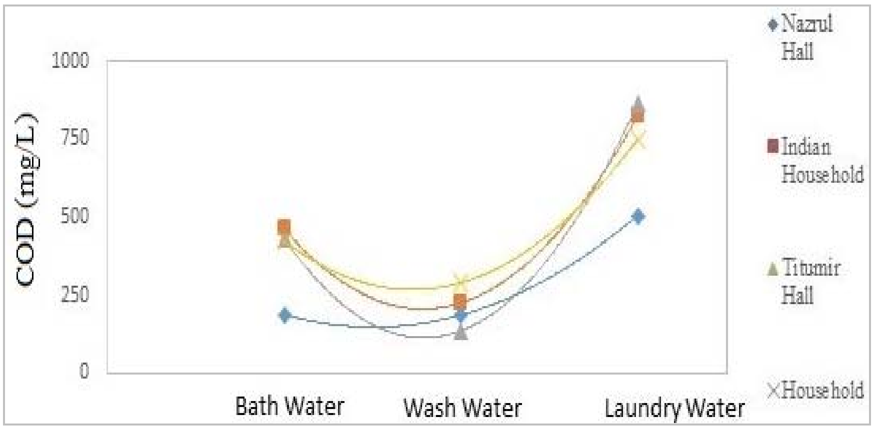
Table 5 Comparison results of combined greywater with reported literature values

Parameters	*Nazrul Hall*	*(Ammari et al. 2014)*	*(Jabornig and Favero, 2013)*	*(Dalahmeh et al. 2014)*
		Sample 1–2		
pH	6.99	5.44	8.41	6.98–8.80
Conductivity (µS/cm)	780	805–3,840	439	-
Turbidity (NTU)	105	-	133	-
Colour (Pt-Co)	130	-	564	-
BOD_5 (mg/L)	198	600–1,710	168	126–490
COD (mg/L)	317	816–2,560	240	420–1,450

Figure 2 (a) Variation of BOD_5 for different types of greywater from different sources (b) Variation of COD for different types of greywater from different sources (see online version for colours)



(a)



(b)

The BOD_5 and COD values from our tests are similar to the values from Indian households, but are much lower than the values obtained from other published works (Tables 4 and 5).According to USEPA guidelines for water reuse (USEPA, 2012) the maximum limit for turbidity and BOD_5 for allowable greywater reuse is 10 NTU and 25 mg-L^{-1} respectively, which requires all of the samples of this study to undergo some form of treatment to meet the guidelines.

4 Greywater reuse and sustainability

Ensuring sustainable development in terms of water and wastewater management in communities with severe scarcity of freshwater and economic burden due to expensive treatment options is a challenging issue. Greywater and recycled wastewater reuses has emerged as a viable solution for societies facing such issues. It also clearly reduces the use of natural resources by using the same water for at least two different purposes. Several researchers have developed checklists so that an applied water management solution can be identified as being sustainable or not. In general, for a water management system to be considered as sustainable the following criteria should be fulfilled:

1 ensure a safe and healthy environment

2 improve health and hygiene

3 benefit sociocultural or human resources

4 save natural resources

5 provide economic benefit (Hellström et al., 2000).

Health and hygiene risks are minimised if greywater is used in toilet flushing or if it is used in irrigation following standard guidelines. In another study (Anderson, 2003), the author listed a number of cases where greywater reuse brought benefits to the community in terms of resource conservation and economic savings. For example, the Monterey Regional Water Pollution Control Agency (MRWPCA) in California, USA, was able to build up a scheme to use 20 Mm^3/yr of recycled water for irrigation and that reduced local groundwater depletion and subsequent saltwater intrusion. In Mexico City, 90% of the wastewater was recycled to irrigate the lands in the Valley of Mexico and the Mezquital Valley, where lack of rainfall and poor soil quality prevailed. This irrigation work resulted in increased crop yields. In desert areas like Tel Aviv in Israel, 60% of the wastewater is reused to meet irrigation demands. This helped to mitigate the regions total water need that exceeded the available freshwater resources. A study in Harare in Zimbabwe (Madungwe and Sakuringwa, 2007) also reported that reuse of greywater resulted in cost savings due to a lower amount of freshwater treatment expenses and a lesser load on the waste disposal system. Even in highly populated cities like Beijing, China (Zhang et al., 2009) greywater reuse has been proved to be much more appropriate than rainwater harvesting in the case of mitigating water demand for toilet flushing.

5 Conclusions

This study explored the economic potential of greywater in reducing gross production cost of supply water. Since greywater is more than 60% of the total household wastewater produced, reusing it can save around 59 million Taka or 786,000 USD per year in Dhaka city. The reuse can be mainly in two forms. One of them is toilet flushing. In this case, a careful design and maintenance of the distribution system of greywater is required to avoid water clogging issues and to eliminate human contact. Human exposure to this water may be hazardous due to the presence of harmful bacteria. Another form of reuse can be irrigation, but greywater must undergo some treatment to meet the irrigation water quality criteria. Extended research work is needed to develop a suitable treatment model for reusing greywater. Also, a social awareness and scientific approach are both necessary to popularise greywater reuse among people and motivate them to reuse greywater. Official collection of greywater for treatment and resupplying to residents would require detailed planning by appropriate authorities. Important consideration is the groundwater table with respect to water cycle. Other vital environmental issues are frequency and percentage of collection of greywater from sewer lines to be reused and percentage of greywater that should be allowed to discharge to the natural water receiving bodies.

The social and economic similarities and dis-similarities has to be taken in to consideration if the results of this study to be applied to communities that are located in a different geographical region as their water consumption habits and the need for the water conservation will be different. It will change the reduction factors used in this study. The application of reduction factors is unique to this paper. In the methodology for quantification, the volumetric flow rate delivered by each faucet were multiplied with time of average usage to get the quantity of water used for a specific purpose.

The method of quantification presented in this paper has its unique advantages over other quantification methods. This method is not capital intensive as it will not require installation of greywater collection systems and the meters that need to be installed for the quantity measurement. Installing greywater collection systems and metres could be difficult and too expensive depending up on availability of space and financial situation of a community. Once a community is studied extensively, a general factor could be derived for estimation of greywater generation based on the used quantity of potable water. This method could be used as a verification for indirect approach of quantification of greywater, where generally it is assumed that a certain percentage of the potable water quantity used results in greywater generation. The combined effect of users' behaviour and the type of plumbing on greywater quantification will be more accurate over time in case of the method presented in this paper. As, in this direct method, changes in types of plumbing, living standards, users' types will be documented regularly and more accurately, resulting in more accurate greywater quantification.

In an ideal case, an isolated small community or a smart city testbed with greywater collection and treatment system can be used primarily to observe the effect of residents' daily activities and life style on quantification of greywater generation. Also, it would allow their perception and the feeling of disgust towards reusing greywater to be changed. It would provide a better controlled environment for the real-time data collection and analysis for savings in energy and other costs. However, underdeveloped countries and communities often lack infrastructure like smart city testbeds. The hands-on methodology discussed here could be employed to understand the greywater generation and characteristics for a sustainable future in an economical way.

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