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Greywater reuse: a sustainable solution for water crisis in Dhaka, Bangladesh

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ABSTRACT: Dhaka is one of the most densely populated cities in the world. Due to rapid population growth and unplanned urbanization, the scarcity of water is one of the major concerns. The reuse of greywater is an attractive solution to minimize the deficit between demand and supply of water in Dhaka city. Everyday a significant amount of greywater is produced from different sources. Greywater from different sources and different locations of Dhaka city were characterized. A lab scale treatment system was run to treat greywater from mosque. The main goal of this paper is to propose some efficient, cheap and sustainable greywater treatment systems for households and mosque. The treated greywater can be used for non-potable use purposes such as irrigation, toilet flushing, car washing and dust control as well as to recharge the aquifers.

1 INTRODUCTION

Due to the scarcity of fresh water all over the world, balancing the supply and demand of fresh water has always been a great challenge. The recycle and reuse of wastewater is considered as a strategy of water demand management (WDM) system. Reuse of wastewater minimizes the demand for the freshwater (Redwood 2007). Greywater reuse in many parts of the world, including both industrial and developing countries, has gained significance for last few decades. Many investigations have been conducted on domestic greywater quality analysis, treatment and reuse in the EU, USA, Middle-east countries, Japan and Australia. Greywater treatment systems have been successfully implemented in the US, Japan and Australia to reclaim greywater for non-potable uses. With the technological advancement and public acceptance, greywater seems to be a potential source of water saving (Al-Jayyousi 2003).

Traditionally, greywater is defined as non-industrial wastewater generated from domestic processes such as dish washing, laundry and bathing. Essentially, any water, other than toilet wastes, draining from a household is greywater. Greywater is a major fraction of domestic wastewater which is generally less polluted than other types of wastewater. Former studies reported that the amount of greywater produced in household is 55% - 65% of the total amount of wastewater (Burnat et al. 2007). Greywater generated from sinks, baths, showers, or washing machines can be treated onsite or offsite for non-potable use purposes such as irrigation, toilet flushing, car washing, dust control, soil compaction, in construction works and in industrial processes like cooling boilers and other appliances (Almeida et al. 1999, Butler et al. 1995, Funamizu et al. 2001). Reuse of greywater in toilet flushing and gardening can save 31-54% of potable water in households (Christova-Boal et al. 1996).

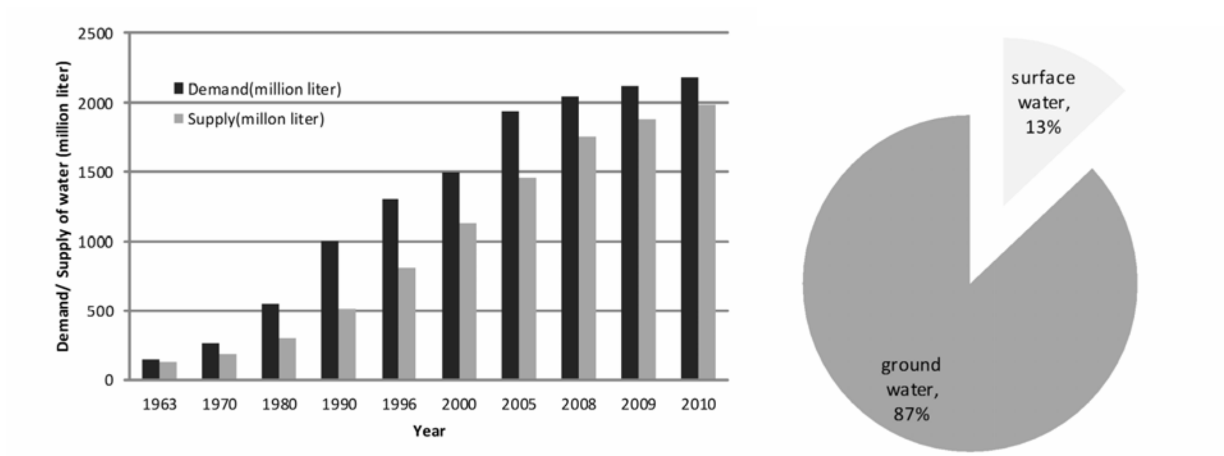
Bangladesh is a developing country. Dhaka, the capital city of Bangladesh, is considered as one of the most densely populated cities in the world. The city covers a total area of 360 km^2 (139 sq. mile). The population of Dhaka (areas under the jurisdiction of the Dhaka city corporation) stands at approximately 7.0 million. The city, in combination with localities forming the wider metropolitan area, is home to an estimated 14.6 million populace as of 2010 census. The population growth rate is estimated to be 4.2% per year which is one of the highest rates amongst Asian cities. Considering this birth rate and rural-urban population migration, estimated projected rate of growth is over 5.6 %, by the year of 2015 (Biswas et al. 2010). Population growth usually increases demand for water in all sectors of economy: agricultural, industrial and domestic. Due to rapid population growth, unplanned urbanization, surface water pollution and continuous ground water extraction, water resources are already being pushed to the limits of sustainability in Dhaka. To deal with this complicated situation, some innovative measures should be taken to minimize the use of potable water. Recycle and reuse of greywater, rainwater harvesting during monsoon are good options for saving fresh drinking water. However, wastewater treatment and reuse is not common in Bangladesh. To save fresh drinking water, greywater reuse for non-potable purposes is the main concept of this paper.

The main objective of this paper is to propose some efficient, cheap and sustainable greywater treatment systems for greywater generated from households and mosque. To shed light on the main objective, these relevant topics will be discussed along with the rationale of this study.

2 THE PRESENT SCENARIO OF WATER AVAILABILITY IN DHAKA CITY

Dhaka is surrounded by the distributaries of the two major rivers, the Brahmaputra and the Meghna. Although, there are several rivers, lakes and canals in Dhaka, the availability of surface water to feed this vast population is not sufficient. The water bodies are experiencing acute pollution due to the disposal of industrial and municipal wastes without proper treatment. Groundwater is the sole source of water supply for this mega city. Due to the continuous extraction of ground water, depending on the locations in Dhaka, the ground water table is continuously declining at an average rate of 2 to 3 m per year since the year of 1986. Recently the ground water table has lowered significantly in some places and the dearth of potable water causes intolerable miseries to the city dwellers. In addition, the imbalance between the extraction and recharge of groundwater raises the probability of land subsidence which could be catastrophic for the existence of the city (Akther et al. 2009).

Dhaka experiences a hot, wet and humid tropical climate. The city is within the monsoon climate zone, with an annual average temperature of 25 °C. Nearly 80% of the annual average rainfall of 1,854 mm (73 in) occurs between May and September [Biswas, et al., 2010]. The aquifer of this city is basically recharged by direct rainfall, river water, and floods through direct infiltration and percolation. But due to unplanned urbanization, the recharge area of the city is decreasing significantly with time. In summer, scarcity of water is acute at many places of Dhaka city. It is becoming worsened due to frequent load shedding and fall in groundwater level. During dry season ground water table moves downward from -45 to -54 m depth from the sea level due to continuous extraction of ground water (Akther et al. 2009).



(a) (b)

Figure 1. (a) Demand, supply and deficit of water, (b) Percentage of contribution of water sources in daily water supply in Dhaka.

The Dhaka Water Supply and Sewerage Authority (DWASA) is the only public utility to cater for potable water and sanitation services to about 90% of the urban people of Dhaka metropolitan area and Narayanganj district. Remaining 10% people get water from private deep tube wells. DWASA water supply system is mainly depended on ground water. As per June, 2009, DWASA supplies around 1990 million liter (ML) water daily against water demand of 2180 ML for approximately 14.45 million people. About 87% of the supplied water is abstracted from 560 deep tube wells and 13% is produced by treating the water of the river Buriganga and Shitolakhya through four surface water treatment plants (SWTP) situated in Dhaka (Saidabad & Chandighat) and Narayanganj (Godnail). The daily deficit of water supply is about 190 ML. DWASA is facing difficulties in maintaining the adequate level of water supply mainly due to rapidly growing demand and inadequate network to cope with the future demand. Moreover, the water supply distribution network is not modernized from time to time and the frequent use of unauthorized and faulty connections results in the contamination of water in its way to reach to the outlets and fixtures from the treatment plant (Annual report of Dhaka WASA, 2009-2010).

3 POTENTIAL OF GREYWATER REUSE IN DHAKA

Greywater is a major fraction of domestic wastewater which is about 75% (vol.) of the combined residential sewage [Eriksson, et. al., 2002]. Greywater might be generated from wash basins, sinks, baths, showers, or washing machines. The volume of greywater produced from single households, multi-storied buildings and community residences seems to be enough to recycle and reuse. Besides these domestic sources, the greywater generated from mosques is a potential source of greywater in Dhaka. Dhaka is said to be the city of mosques as there are several hundred mosques are available throughout the city. The main source of greywater from these mosques is the water that drains out during the ablution prior to the prayers that usually held five times a day. It really produces a significant amount of greywater which is far less inferior in quality compare to other types of wastewater.

Since greywater has low level of contamination, it has higher potential for treatment and reuse. When greywater is treated and reused either onsite or nearby, it has the potential to reduce the demand for water supply, reduce the energy consumption, and meet a wide range of socio-economic needs. By appropriately matching water quality to water need, the reuse of greywater can replace the use of potable water in non-potable applications. Treatment of greywater produced from mosque is much easier and cost-effective than households [Khatun et. al., 2011]. Simple and available low-cost treatment technology can be applied for treating greywater generated from mosque. Greywater reuse systems can be practiced individually on a small scale or by a community living in multi-storied buildings or by industrial entities on a large scale basis. Decentralized waste water reuse systems have been found to be widely practiced systems on the basis of economic feasibility rather than centralized system.

4 BENEFITS OF GREYWATER REUSE

Water recycling and reuse has become an attractive option for conserving and extending available water supply in many countries because of the limits of their readily available water supplies. Recycled water is being widely used for non-potable reuse purposes such as agricultural and landscape irrigation, golf courses and public parks irrigation, toilet flushing in the USA, EU, Australia and some Middle-east countries. Other non-potable urban uses of treated greywater can be in fire suppression, air conditioning, soil compaction and in construction works. High quality water does not required for such kind of non-potable uses.

Recycling of greywater will protect aquatic ecosystems by decreasing the diversion of freshwater, reducing the quantity of nutrients and other toxic contaminants entering waterways. It will reduce the need for water control structures. There are some other benefits of reusing of greywater. It reduces the total wastewater treatment costs as it lessens the organic and hydraulic loads of wastewater treatment plant (Eriksson 2002, Friedler et al. 2008). Reclaiming nutrients in greywater improves the soil quality. Greywater application in excess of plant needs is also a good way to recharge groundwater (Al-Jayyousi 2003). Highly treated greywater can be reused for aquifer recovery and storage. Water can infiltrated into the aquifer or directly injected in any season and can be extracted for irrigation during dry season. Besides groundwater replenishment, treated greywater can be used for salt water intrusion control in coastal areas and in subsidence control**.** High quality reclaimed water can be used for drinking purpose as well as for other potable reuse purpose such as blending in water supply reservoirs and groundwater (Metcalf & Eddy 2007).

5 CHALLENGES OF GREYWATER REUSE

There are several barriers which may impede the development of greywater recycling and reuse in Dhaka. These include limited human and financial resources, reliability of wastewater treatment, system energy demand, economic feasibility of the system, public perception and willingness, social and institutional acceptance, water right issues and political process, sufficient and consistent codes and guidelines etc. In Bangladesh, guidelines and standards for greywater reuse does not exist. Regulations and guidelines for grey water reuse mainly focus on the healthy and environmental impacts and are often established by local authorities. From aesthetic point of view, public acceptance for reusing recycled water can be a big challenge.

Greywater recycling system includes collection, storage, treatment and reuse. Recycling of greywater is based on exclusion of black water. For this purpose the plumbing systems should be modified so that the disposal of greywater and black water is facilitated through different pipes. In fact dual plumbing system is essential for successful implementation of greywater reuse schemes. Dhaka is an unplanned urbanized city. The major part of its urban development has been completed. Hence, implementation of a separate plumbing system for collecting greywater for treatment and reuse could be difficult. The costs of retrofitting an existing home with separate plumbing, storage and treatment unit could limit the attempt of wide-scale reuse of greywater in the country. These expenses mainly depend on the current regional cost of tap water and the availability of retrofitting incentives. Moreover, location of installation of a legal, properly designed grey water system can be an issue. If codes are vague or contradictory, or if permitting staff and contractors do not have knowledge and experience with grey water systems, the process of installing and permitting could be difficult. Possibly most important to the adoption of grey water reuse, is homeowners' acceptance. The willingness of homeowners to incur the expense associated with maintenance and installation of grey water systems is central to widespread voluntary adoption. To overcome these challenges, practical strategies should to be employed depending on the socio-economic condition for implementation of greywater recycle systems in Bangladesh.

6 CHARACTERISTICS OF GREYWATER

The quality of greywater varies from source to source. Former studies on source based characterization of greywater showed that greywater originated from different sources like bathroom, wash basin, laundry, kitchen sink varies in quality [Eriksson, 2002]. The kitchen grey water and the laundry grey water are higher in both organics and physical pollutants compared to the bathroom and the mixed greywater [Li, 2009]. The quality of greywater also varies from one household to another depending on the residents [Casanova, 2001]. The characteristics of greywater is influenced by many factors such as the quality of the water supply, number of residents, age distribution, financial condition and living standard, residents cultural habits, typical water usage pattern, type of household chemicals and personal care products, existing water supply system and infrastructure etc [Morel and Diener, 2006].

Table 1: Characteristics of grey water originated from different sources

Water Quality Parameters with unit	Bathroom[a]	Laundry[a]	Kitchen[a]	Mixed[a]	Wash basin[b]	Mosque[b]
pH	6.4-8.1	7.1-10	5.9-7.4	6.3-8.1	6.64-7.41	6.92-7.10
TSS (mg/l)	7-505	68-465	134-1300	25-183	7-445	5-146
Turbidity (NTU)	44-375	50-444	298	29-375	7.41-127	4.90-14.8
COD (mg/l)	100-633	231-2950	26-2050	100-700	85-2423	51-60
BOD (mg/l)	50-300	48-472	536-1460	47-466	28-500	1.0-21
TN (mg/l)	3.6-19.4	1.1-40.3	11.4-74	1.7-34.3	-	0.2-0.8[c]
TP (mg/l)	0.11->48.8	ND->171	2.9->74	0.11-22.8	0.66-1.43[d]	0.09-0.60[d]
Total coliforms (CFU/100ml)	$10\text{-}2.4\times10^7$	$200.5\text{-}7\times10^5$	$>2.4\times10^8$	$56\text{-}8.03\times10^7$	2800-TNTC	0-TNTC
Faecal coliforms (CFU/100ml)	$0\text{-}3.4\times10^5$	$50\text{-}1.4\times10^3$	-	$0.1\text{-}1.5\times10^8$	100-TNTC	0-TNTC

a: Li (2009); b: Khatun et al. (2011); c: Amonia (Total as NH_3-N) (mg/l); d: Phosphate (mg/l); TNTC: Too numerous to count; CFU: Colony forming units

Greywater may contain organic compounds, chemicals, suspended solids, heavy metals, nutrients and pathogens. Depending on the pollution loads, greywater can be divided into two categories- high load greywater and low load greywater. The greywater generated from kitchen sink, washing machine and dishwasher is high load greywater and the greywater originated from the bath, shower and wash basin is low-load greywater [Zavala, et. al., 2002; Terpstra, 1999; Friedler, 2004]. The amount of low-load greywater is 50–60% of the total greywater and less polluted [Almeida, et. al. 1999; Butler et. al., 1995]. Former study reported that the range of COD for low-load greywater and high load greywater are 210–501 mg/l and 1079-1815 mg/l and the TSS contents range 54–200 mg/l and 165–235 mg/l, respectively [Almeida, et. al. 1999]. Greywater quality varies in quality in a wide range depending on the usage patterns as well as depending on the sources and locations

[Khatun et al., 2011]. The greywater generated from mosque and community residences were found to be of low strength because the COD varied between 51-60 mg/l, 85-462 mg/l, respectively and TSS varied 5-146 mg/l and 16-132 mg/l, respectively. For residential apartments, COD and TSS concentrations were found to be in the range 106–2423 mg/l and 7–445 mg/l, respectively. The greywater produced from the wash basins of residential apartments range from low to high strength type.

Greywater quality can be analyzed by assessing three classes of attributes: physical, chemical and biological. Water quality parameters indicating physical properties are turbidity and solid contents; chemical properties are pH, nitrates, ammonia, total nitrogen (TN), total phosphorous (TP), biochemical oxygen demand (BOD) and chemical oxygen demand (COD) and microbiological properties are presence of coliform bacteria (Total and Fecal). Characteristics of greywater by different categories are summarized in Table 1.

7 GREYWATER TREATMENT PROCESSES

There is not a single treatment technology that can be applicable for all the countries in the world for the same reuse purpose. Adaptation of treatment technology depends on the weather and climatic conditions of the region and many other factors. The selection of greywater treatment system depends on the greywater quality (organic, solids and microbial fractions), context of use, availability of human and financial resources, space constraints, social and institutional acceptance, hygienic risks, public health impacts, environmental risks, system energy demand, economic feasibility of the system, guidelines and standards for waste water reuse of the country etc [Ramon, et al., 2004; Morel and Diener, 2006; Friedler, et al.,2006; Pidou, et al., 2007]. Since bacteriological quality of untreated greywater deteriorates rapidly with time, maximum storage period of 24 hours is recommended. From previous study chloramine was found to be the most effective disinfectant for long term storage periods as 7 days without any physical treatment. However, performing physical treatment (filtration) before using chemical disinfectant like chlorine was found to be essential for storing greywater for longer time. The reason behind it was the chemical reactions of chlorine with the impurities present in greywater [Tal, et al. 2011].

The recycling of low-load greywater is much easier and cost effective than other types of waste water. Simple low-cost treatment technologies can be applied for recycling it. Physical processes were preferred earlier. Now-a-days, combination of physical and chemical treatment or physical and biological treatment or combination of physical, chemical and biological treatment processes followed by disinfection unit is preferred. Formerly reported treatment processes used to treat greywater are listed herewith [Gross et al., 2007, E. Friedler et al., 2008, Skudi, et al., 2011]:

Physical*:* filtration using sand, gravel, charcoal, lime pebbles, naural zeolite, micro filtration (MF), ultrafiltration (UF), nano filtration (NF), reverse osmosis (RO).
Chemical*:* Coagulation, chlorination.
Biological*:* membrane bioreactors (MBR), biological aerated filters (BAF), SBR bioreactor.
Disinfection*:* chlorination, ozonation , UV irradiation.

Table 2: Greywater treatment processes

Type of processes	Reference	Process
Physical processes	Ramon et al. (2004)	Ultrafiltration (UF membrane of 400K Da, 200 KDa, 30 KDa)
	Prathapar et al. (2006)	Filtration+activated carbon+sand filter+disinfection
	Wabel (2011)	Sand filter+charcoal filter+UV disinfection
Chemical processes	Sostar-Turk et al. (2005)	Coagulation+sand filter+GAC
	Pidou et al. (2008)	Coagulation with aluminium salt
	Friedler et al. (2008)	Coagulation+sedimentation+UF+RO
	Skudi, et al. (2011)	Alum coagulation+quartz sand filtration
	Khatun et al. (2011)	Alum coagulation+chlorination+membrane filtration
Biological processes	Friedler et al. (2005)	Screen+RBC+sand filtration+chlorination
	Nolde (1999)	Sedimentation+RBC+UV disinfection
	Liu et al. (2005)	Membrane bioreactor (MBR)
	Gross et al. (2007)	Constructed wetlant

As direct filtration without any pretreatment causes organic fouling and inorganic scaling on the filter, it reduces the efficiency of the filter. Pretreatment of raw greywater has been found to be viable before applying membrane filtration. Effectiveness of several pretreatment processes such as coagulation, chlorination, coagulation and chlorination, coagulation and sedimentation had been examined [E. Friedler et al., 2008, Skudi, et al., 2011, Khatun et al., 2011].

A former study applied combined chemical and physical treatment processes to treat raw greywater originated from bathroom, kitchen and laundry for toilet flushing, mopping and laundry work. Chemical treatment included alum coagulation and pH adjustment using bicarbonate salts and physical treatment included filtration of alum treated water using Quartz sand and filtration of pH adjusted treated grey water using filter paper [Skudi, et al., 2011]. A simple greywater recycle system consists of sand and activated charcoal filters along with simple sterilization (Ultra violet unit) has been successfully tested in a big mosque of Saudi Arabia [Wabel, 2011].

A summary of the reported physical, chemical and biological treatment processes for greywater treatment and reuses is shown in Table 2.

8 EXPERIENCE OF GREYWATER REUSE IN BANGLADESH

The reuse of greywater is an attractive addition to water-management options for Bangladesh especially for Dhaka. In Bangladesh, a very little research work has been conducted on greywater. Recently a research work on greywater quality assessment and treatment has been reported (Khatun et al., 2011). The major findings of the research are- 1) A source based characterization of greywater of Dhaka city, 2) A raw estimation of the flow rates of greywater from different sources, 3) A simple, cost-effective combined treatment procedure (coagulation, sedimentation, chlorination and membrane filtration) for handling and reuse of greywater resulted from ablution in mosque.

The characteristics of greywater generated from three sources-mosques, residential apartments and community residences at different locations of Dhaka city were assessed. Based on the level of pollution the greywater generated from mosque and wash basins of community residences were found to be low strength type while greywater produced from wash basins of different residential apartments were found to be low strength to high strength type. Among all sources mosque was identified as the least contaminated source of greywater on the basis of data. The flow rates of greywater from different sources were estimated in liter per capita per day (lpcd) basis. The data showed that greywater generation rate varied during hours of the day as well as from source to source depending on the water usage pattern. The flow rates of greywater generated from wash basins from both residential apartments and community residences ranged from 13.5 lpcd to 28.5 lpcd. Greywater produced from mosque was selected for lab scale treatment. The effectiveness of greywater pretreatment processes- coagulation and chlorination prior to membrane filtration was assessed. Almost all the parameters exhibited significant improvements following treatment. The treated water quality met the Bangladesh Standards for drinking water (Table 3). It was suggested that the treatment procedures could be applicable for treatment of low load greywater and the treated water can be used for non potable use purposes in Bangladesh.

However, there were also some limitations. Limited number of greywater samples was analyzed. Extensive sampling from different sources is required to obtain a well established and indubitable characterization of greywater. Resources and time constraints were the most considerable limitation of the study. Moreover, there are no standards or guidelines for greywater reuse in Bangladesh.

Table 3. Result summary of Pretreatment of Greywater from Mosque

	Type of water	pH	Turbidity (NTU)	Color (Pt-Co unit)	TS (mg/l)	TDS (mg/l)	TSS (mg/l)	BOD_5 (mg/l)	COD (mg/l)	TC cfu /100 ml	FC Cfu /100 ml	Nitrogen-ammonia (mg/l)	Phosphate (mg/l)
Pretreatment	Raw greywater	6.83	10.5[a] 1.54[b]	76[c] 18[d]	447	428	19	26	50	TNTC	2650	0.312	0.711
	After Alum Coagulation	6.31	5.26[a] 1.34[b]	44[c] 18[d]	431	416	15	12	29	0	0	0.282	0.285
	After Chlorination	6.24	4.83[a] 1.18[b]	47[c] 12[d]	415	405	10	0	24	0	0	0.064	0.237
Membrane filtration													
Bangladesh standard (ECR, 1997)	Drinking water	6.5-8.5	10	15	-	1000	10	0.2	4	0	0	0.5	6

a. unfiltered b. filtered c. apparent d. true

9 PROPOSED GREYWATER TREATMENT SYSTEMS

The basic considerations for the selection of greywater treatment system are greywater quality, quantity of greywater, availability of human as well as financial resource, land availability, context of reuse and system energy demand in Bangladesh. As Dhaka is a capital of a developing country, it is more practical and wise to choose available and less contaminated greywater sources for treatment and reuse purpose. The greywater treatment system proposed here has chosen considering these criteria.

10 CONCLUSION AND RECOMMENDATIONS

Water shortage in Dhaka will be a key issue for its sustainable development in the future. Treated greywater can play a major role in substituting and supplementing DWASA's water supply. The potential of potable water savings can be substantial by using these proposed greywater treatment systems. It is clear that efficient, cheap, reliable and sustainable on-site greywater treatment system is indispensable in order to avoid technical problems and public health risk as well as promotion of public acceptance. There are numerous ways that water reuse can be implemented to supplement current water supplies. Bangladesh Govt. may launch water reuse projects through public utility departments such as the Water Administration and Sewerage Authority (WASA), the City Corporations, the Department of Public Health Engineering (DPHE) etc. Private organizations like operational and campaigning NGOs can work parallel. They can deal with water quality and water rights requirements for such projects, and address other important issues such as human health, environmental impacts, economics and project funding. To promote greywater reuse in the country, building codes should be modified, and standards and guidelines should be adopted. The standards should be realistic, enforceable, and sensible to public and environmental health.

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