

# Feasibility Study of Treatment Technologies for Greywater to Enhance Water Security

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## Abstract

Greywater can be viewed as an important resource which could be diverted for variety of application to water starved areas. With the increased challenges of freshwater availability, reliable alternatives like treated greywater need to be searched upon. Its constant availability throughout the year with low organic content makes it quite suitable and cost feasible for recycling and also a good source of water for augmenting water supply. Various Greywater treatment methods such as physical, biological, chemical, constructed wetland and combined treatment have been analysed in this paper for both Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) removal efficacy. Also the feasibility aspects of these technologies in terms of effluent generation, space consumption, financial viability, expertise required have been analysed with reuse perspective and it was found that the relatively simpler technologies like physical treatment and constructed wetlands are cost effective in treating greywater and are suitable for reuse in landscaping and flushing. Complex technologies like chemical and biological treatment technologies generate treated effluent suitable for stringent reuse applications. Social acceptance and awareness are some of the other aspects which need to be considered for enhancement of usage of such technologies.

**Keywords:** Greywater, Blackwater, Treatment, Reuse, Feasibility

## INTRODUCTION

World is facing a global challenge in the form of freshwater availability due to various reasons including increased urbanization. It is estimated that by the year 2025 about one third to half of the global population will face water shortage (Juan et al. 2016). It is expected that the per capita availability of freshwater in 2025 would reduce to 1,500 cubic meters per year from 2,200 cubic meters in 1997 and 5,300 cubic meters in 1955 (Mehta 2012). This calls for immediate attention to augment the freshwater supply by focusing the reuse of rainwater, storm water and recycling domestic wastewater using various technologies. Depending on the source of generation and characteristics of wastewater generated, domestic wastewater can be segregated into two groups i.e. greywater (GW) and blackwater (BW). GW is the wastewater generated from bathroom, laundry and kitchen (Guidance Manual 2007) while BW is wastewater from water closet flushing. Based on strength of GW generated, it is further segregated as light GW generated from shower, washbasin, floor cleaning and dark GW generated from kitchen sink and laundry/washing machines. It is a widely accepted fact that GW recycling is feasible and reusing GW may supplement up to 50% of freshwater demand (Kundu et al. 2015). The large

unremitting accessibility of GW with low organic content leads to the possibility of treating it with ease at a lower cost, making it most suitable for recycling.

Even though reuse of GW can contribute to sustainable water management, GW treatment and reuse schemes have not been actively considered by water managers so far. The primary reason for this is the availability of limited information on quantification and characterization of GW (Vakil et al. 2014). Other issues, like use of GW with or without treatment, indoor or out-door reuse (Ling and Benham 2014), cost of treatment and reuse infrastructure (Nnaji et al. 2013) and social acceptance (Odeh 2003) are also associated with reuse of treated GW.

The paper presents an overview of GW treatment options by describing the various feasibility factors for treating GW as a source of water supply. The purpose is to enhance understanding about suitability of available water technologies for various specific purposes as per the user requirements.

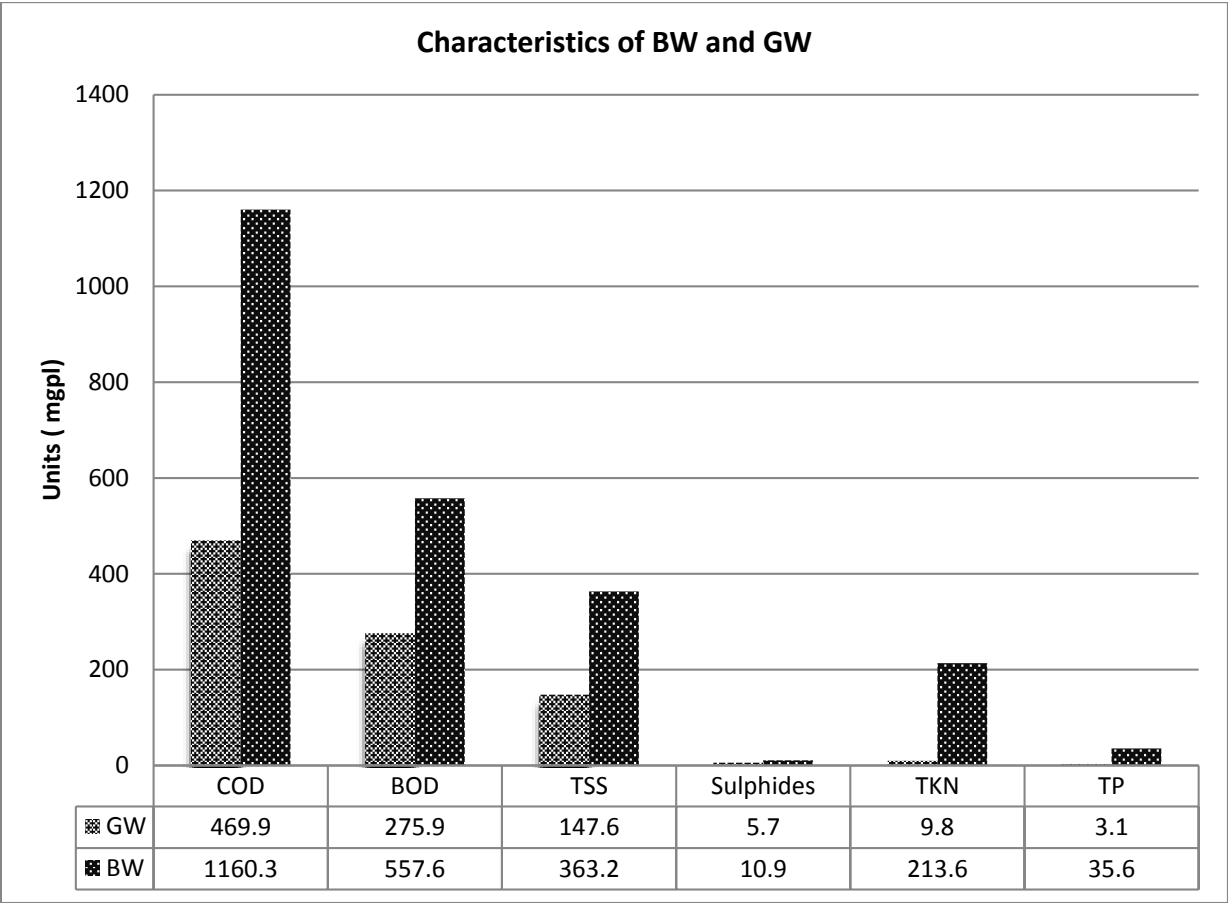
## MATERIALS AND METHODS

For the purpose of this study, a number of research papers have been referred to understand various aspects of GW treatment technology. The data provided in these published studies about various characteristics of the studied treatment technologies have been compiled and analysed using exploratory statistical methods to generate graphs which have been interpreted and explained. Further, a comparative analysis of these technologies for reuse has been performed. A conceptual framework has been developed to understand the water resource supply in cities for different purposes, its first usage, treatment technologies available, and potential options for reuse of treated water. The feasibility aspects of the studied technologies have been analysed with reuse perspective.

## RESULTS

### Augmenting Water Availability - GW as a Resource

The physical, chemical and biological parameters of GW generated have wide variation depending on the source of its origin. Treating GW is relatively easier and economical compared to treat the entire domestic wastewater generated (Vakil, et al 2014). The figure 1 gives a comparative insight into the major physico-chemical characteristics of GW and BW to further validate this.



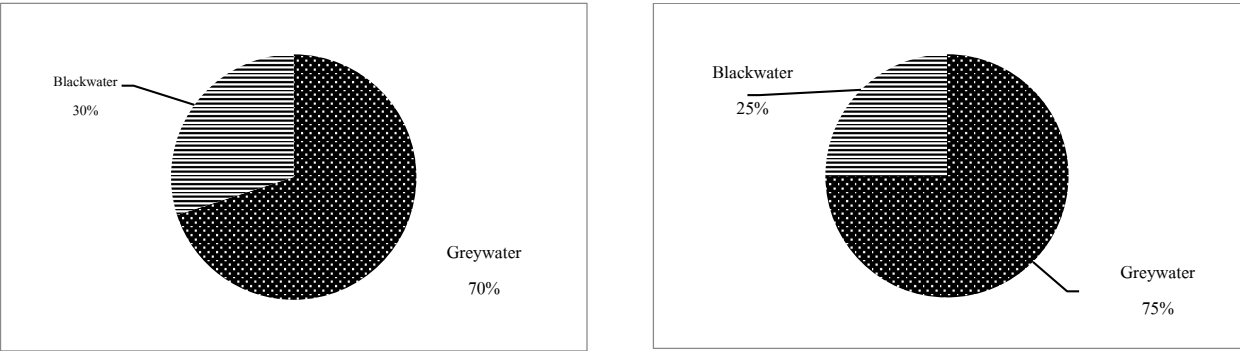
**Figure 1:** Characteristics of BW and GW;

(Source: Vakil et al., 2014, Jamrah and Ayyash, 2008, Shamabadi et al., 2015, Ushijima et al., 2013, Pidou et al., 2007)

It can be clearly seen from the figure 1 that constituents load for GW is less than half that of BW indicating the degree of treatment required for GW would be significantly lesser than that of BW. Characterization of GW has mostly been done based on physico-chemical parameters. About 70-77% of the total consumed water converts to GW (Kujawa et al. 2006; Ghaitidak et al. 2013). The

indoor domestic water consumption in developed countries comprises of 30-70% of total urban water demand of which 60-70% is transformed into GW and remaining 30-40% forms BW (Friedler et al. 2006).

In India, a fast developing economy, the generation of GW in urban areas is best explained vide the figures 2(a) and 2(b):



**Figure 2a and b:** Estimation of GW and BW generation in major Indian cities

Figure 2(a) shows the quantification of GW and BW generation estimated for major Indian cities using Indian Standards (IS):1172, 2007for Code of basic Requirement for Water Supply, Drainage and Sanitation and Manual on Sewerage, 2013 while figure 2(b) shows GW as estimated from water consumption pattern of Indian cities reported by Shaban (2008). From both these figures, it can be interpreted that the GW generation in urban Indiais about 70-75% of total water consumption. This indicates availability of large source of water with persistent supply round the year.

Comparative Analysis of GW Treatment Technologies for Reuse

Treatment methods investigated to treat GW may be categorized as physical, biological, chemical, constructed wetlands and combined treatment. Various studies have been examined to develop an understanding on the treatment of GW and BOD and COD removal to compare the treatment efficacy of these technologies. Removal has been categorized as low: < 61%, Moderate: 61–80%, High: >80% for ease of understanding in figure 3(a) and figure 3(b) showing BOD and COD removal respectively. After a detailed literature review, only those type of studies have been considered which provide comparative data for removal of both BOD and COD.

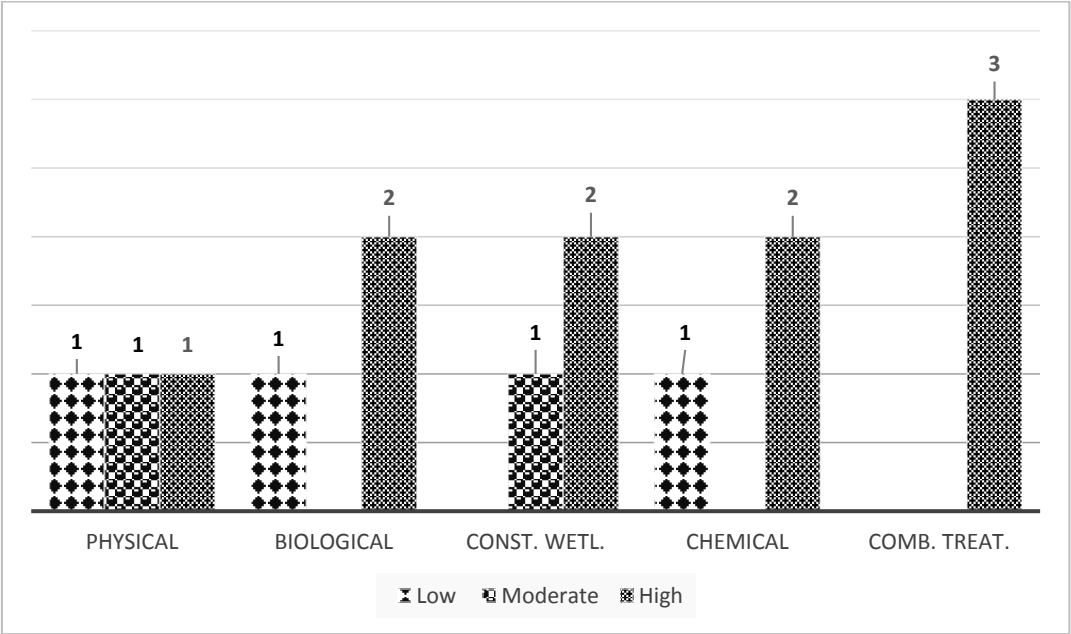


Figure 3a: Variation in BOD removal using different technologies

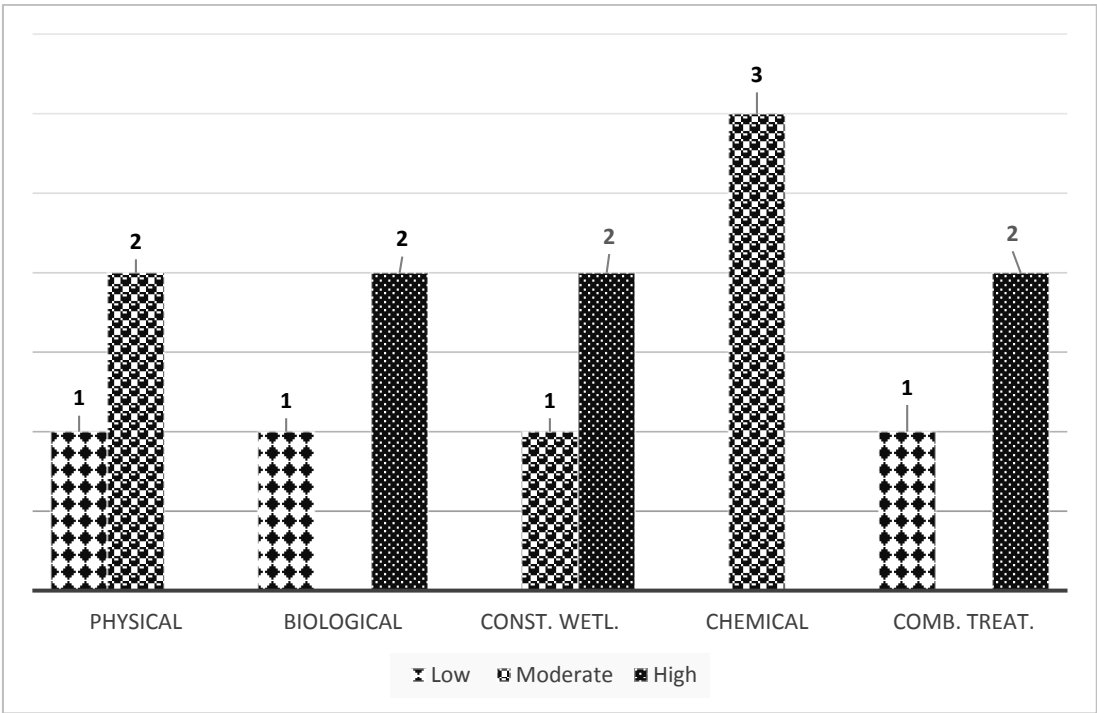
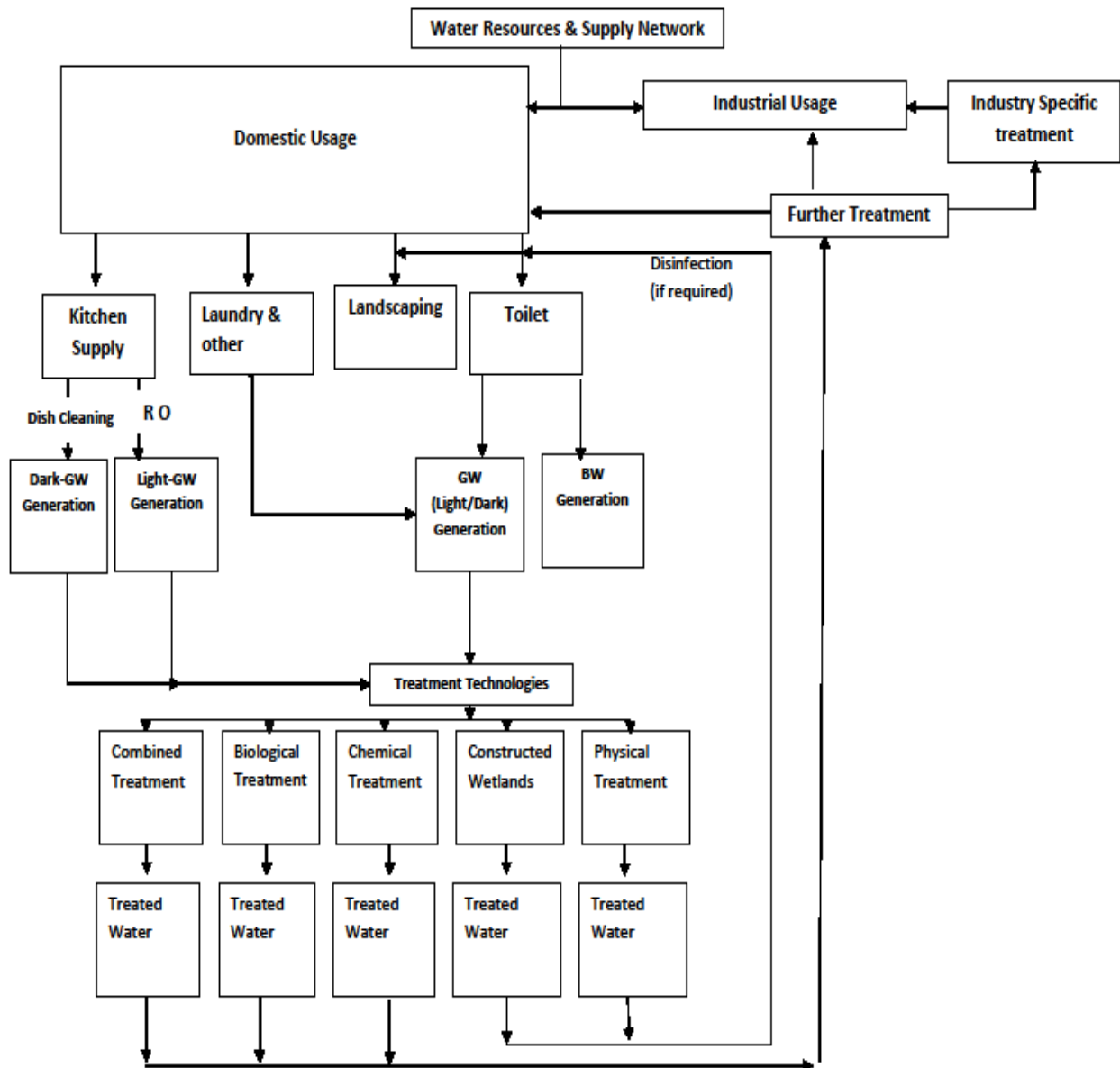


Figure 3b: Variation in COD removal using different technologies

It is seen from the figures that BOD removal by Physical method is low while for biological, constructed wetland and chemical method, it is low to moderate. Highest degree of BOD removal can be achieved by combining various individual treatment methods to form a treatment scheme. However, for highest level of COD removal is achieved by chemical methods while rest all methods can successfully remove low to moderate level of COD. Annexure gives further details on the various treatment methods examined for this study.

From this consultative process, it can be seen that GW available can be treated by various techniques for reuse for various purposes in the urban areas of India.

A conceptual framework has been developed, refer to figure 4 which shows the water resources and supply network as the starting point of the whole chain. Supplied water can be broadly categorized for domestic and industrial usage. Since domestic usage is the main source of generating GW, it is further categorized into Kitchen supply and other. The GW (light and dark) generated from these sources can be treated using multiple treatment technologies. The effluent generated can be reutilized as per the quality requirement for the specific usage.



**Figure 4:** Conceptual framework for reusing GW as a resource in urban areas

In the above figure reuse of treated effluent has been considered based on feasibility parameters like quantity and quality of effluent generation, space availability and techno-commercial aspects. The feasibility parameters have been further explained as below:

#### **Effluent Generation**

Most of the treatment technologies generate treated effluent of acceptable quality for reuse purposes. However, for specific reuse additional treatment like equalization tank, disinfection etc. may be required. In addition to the above analysis, it may be needed to consider the peak and off-peak load impact of GW on efficiency of such technologies. In case of constructed wetlands, it could be the seasonal variations which can reduce its efficiency due to heavy siltation during rainy or post-rainy season leading to high turbidity or it can enhance its treatment capacity due to availability of diluted effluent. Similarly, incase of chemical treatment, the frequent variation in load of GW generated may result in varying quantity of chemicals to be used if adequate equalization of GW generated is not proposed.

It may be mentioned that almost the entire quantity of raw GW taken for treatment is available for reuse in all the treatment technologies but for Constructed Wetland, very little water is left for reuse after treatment.

#### **Space Availability**

Constructed wetland is the most suitable GW treatment technology for rural areas where plenty of land is available for such treatment processes. Using raw GW for irrigation in rural areas may have adverse health effects in addition to clogging of irrigation facilities.

In urban areas, often there is a gap between supply and demand of freshwater which increases the feasibility of reusing GW after treatment for various purposes such as landscaping, flushing, fire- fighting, recreation, street washing etc. Physical treatment with disinfection, if required, is a more suitable technology for smaller sub-urban areas like in colonies, buildings etc. However, for large residential and industrial complexes chemical, biological or combined treatments are more suitable.

#### **Expertise Required**

The treatment technologies like physical treatment and constructed wetland are relatively simpler techniques and therefore its implementation is relatively easier. Their operation does not require skilled manpower. However, for all the remaining treatment options in-depth technical knowhow is required for its implementation and operation. Thus, physical treatment and constructed wetlands, being simpler treatment technologies, are more suitable for areas which have ample land at inexpensive rates or such places where there is shortage of skilled persons or have financial limitations due to which affordability of skilled staff is not possible.

#### **Financial Viability**

Cost can be a major criteria often considered to implement a treated GW reuse. In marginalized communities, affordability of constructed wetland and physical treatment technologies can derive out the maximum cost-benefit ratio. However, construction cost for wetland can be of concern in some areas owing to its high area requirement. In case of commercial interests, distance and infrastructure development for reuse could be significant financial criteria.

From the above analysis, it can be seen that not only different technologies with varying components provide treatment of different level but also that simple technologies like physical treatment and constructed wetlands are more suitable for treating light GW whereas complex treatment systems like biological and chemical treatment technologies can be comfortably used for treating both light and dark GW. Combined treatment technologies can be tailor-made to suit the requirement and resource availability of user.

A treated effluent user can select from the mentioned technologies as per their specific requirements and considering the various constraints.

#### **DISCUSSION**

Different GW treatment technologies produce results satisfying varying requirements on different scales. The considerations for feasibility could be monetary, space availability, technical expertise required etc. User can make a choice to maximize the utility while optimizing the resources available.

Any use of treated GW has to consider socio-economic acceptance in addition to the environmental and technical aspects as reuse of GW may not be very acceptable in certain socio-cultural contexts where GW is considered dirty. Reuse of raw GW for unrestricted irrigation practices should be discouraged as it may provide nutrients for plant but in repeated application may enhance soil salinity in addition to clogging of soil pores and irrigation network. Further, investigations to study the effect of GW irrigation on soil salinity and ground water table is required.

In developed countries or metros of fast developing economies like India, the GW generation may be as huge as 70-75% of total water supplied. Thus, it may be beneficial to develop guidelines for using treated GW in urban India. There are guidelines for reuse of GW in various parts of world like Hongkong (Technical specification, 2015), USA (Yu et al. 2013), Singapore (Public Utility Board, Singapore), Israel and Spain (Jeong et al., 2016)

Some countries like USA (Yu et al. 2013), Australia, Korea, Japan and Cyprus even have incentive programs to promote and popularize reuse of treated GW (Lucy et al. 2010). So there is an acute need to develop policy to popularize reuse of treated GW among users. It is also important to have a paradigm shift in attitude of water managers and consumers for social acceptability of GW as a source of water.

#### **REFERENCES**

- [1] Abdel-Shafy, H. I., Al-Sulaiman, A. M., & Mansour, M. S. (2015). Anaerobic/aerobic treatment of greywater via UASB and MBR for unrestricted reuse. *Water Science and Technology*, 71(4), 630-637.
- [2] Abdel-Shafy, H. I., El-Khateeb, M. A., Regelsberger, M., El-Sheikh, R., & Shehata, M. (2009). Integrated system for the treatment of blackwater and greywater via UASB and constructed wetland in Egypt. *Desalination and Water Treatment*, 8(1-3), 272-278.
- [3] Albalawneh, A., Chang, T. K., & Alshawabkeh, H. (2017). Greywater treatment by granular filtration system using volcanic tuff and gravel media. *Water Science and Technology*, 75(10), 2331-2341.
- [4] Allen, L., Christian-Smith, J., & Palaniappan, M. (2010). Overview of greywater reuse: the potential of greywater systems to aid sustainable water management. *Pacific Institute*, 654.

- [5] Friedler, E., & Hadari, M. (2006). Economic feasibility of on-site greywater reuse in multi-storey buildings. *Desalination*, 190(1-3), 221-234.
- [6] Public Utility Board, Singapore, (n.d.), Guidelines for Treated Greywater Quality-For Recycling of Greywater for Toilet Flushing, General Washing, Irrigation and Cooling Tower Make Up Water; National Water Agency, Singapore. Website: <https://www.pub.gov.sg/Documents/greywaterRequirements.pdf>
- [7] Govahi, S. (2014). Studying of treatability of Gray Water Using Slow Sand Filter. *Bull. Env. Pharmacol. Life Sci*, 3, 214-218.
- [8] Gross, A., Shmueli, O., Ronen, Z., & Raveh, E. (2007). Recycled vertical flow constructed wetland (RVFCW)—a novel method of recycling greywater for irrigation in small communities and households. *Chemosphere*, 66(5), 916-923.
- [9] Guidance Manual-Greywater reuse in rural schools (January 2007), National Environmental Engineering Research Institute and United Nations Children's Fund Website: <http://indiawastemanagementportal.org/wp-content/uploads/2014/09/Grey-water-Treatment-Plants-in-Ashram-Schools-Madhya-Pradesh.pdf>
- [10] Indian Standard (IS):1172, reaffirmed 2007(2007). Code of basic Requirement for Water Supply, Drainage and Sanitation. Revision 4<sup>th</sup>, Bureau of India Standards, New Delhi
- [11] Jamrah, A., & Ayyash, S. (2008). Greywater generation and characterization in major cities in Jordan. *Jordan Journal of Civil Engineering*, 2(4), 376-390.
- [12] Jefferson, B., Laine, A., Parsons, S., Stephenson, T., & Judd, S. (2000). Technologies for domestic wastewater recycling. *Urban water*, 1(4), 285-292.
- [13] Jeong, H., Kim, H., & Jang, T. (2016). Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainable wastewater reuse in South Korea. *Water*, 8(4), 169.
- [14] Juan, Y. K., Chen, Y., & Lin, J. M. (2016). Greywater Reuse System Design and Economic Analysis for Residential Buildings in Taiwan. *Water*, 8(11), 546.
- [15] Kujawa-Roeleveld, K., & Zeeman, G. (2006). Anaerobic treatment in decentralised and source-separation-based sanitation concepts. *Reviews in Environmental Science and Bio/Technology*, 5(1), 115-139.
- [16] Kundu S., Khedikar I. P. and Sudame A. M. (2015). Laboratory Scale Study for Reuse of Greywater. *IOSR Journal of Mechanical and Civil Engineering*, 12(3), 40-47
- [17] Lamine, M., Bousselmi, L., & Ghrabi, A. (2007). Biological treatment of grey water using sequencing batch reactor. *Desalination*, 215(1), 127-132.
- [18] Ling, E., & Benham, B. L. (2014). Greywater Reuse. Website: [http://pubs.ext.vt.edu/content/dam/pubs\\_ext\\_vt.edu/BSE/BSE-114/BSE-114.pdf](http://pubs.ext.vt.edu/content/dam/pubs_ext_vt.edu/BSE/BSE-114/BSE-114.pdf)
- [19] Mehta, P. (2012). Impending water crisis in India and comparing clean water standards among developing and developed nations. *Archives of Applied Science Research*, 4(1), 497-507.
- [20] Merz, C., Scheumann, R., El Hamouri, B., & Kraume, M. (2007). Membrane bioreactor technology for the treatment of greywater from a sports and leisure club. *Desalination*, 215(1-3), 37-43.
- [21] Nnaji, C. C., Mama, C. N., Ekwueme, A., & Utsev, T. (2013). Feasibility of a Filtration-Adsorption Grey Water Treatment System for Developing Countries. *Hydrol Current Res S1: 006*. doi: 10.4172/2157-7587. S1-00 6 Page 2 of 6 Hydrol Current Res ISSN: 2157-7587 HYCR, an open access journal Water Resources Research and North America by a variety of manufacturers [6]. *Berlin, Germany*, a, 60.
- [22] Nnaji, C. C., Afangideh, B. C., & Ezech, C. (2016). Performance evaluation of clay-sawdust composite filter for point of use water treatment. *Nigerian Journal of Technology*, 35(4), 949-956.
- [23] Pathan, A. A., Mahar, R. B., & Ansari, K. (2011). Preliminary study of greywater treatment through rotating biological contactor. *Mehran Univ Res J Eng Technol*, 30, 531-538.
- [24] Pidou, M., Memon, F. A., Stephenson, T., Jefferson, B., & Jeffrey, P. (2007, September). Greywater recycling: treatment options and applications. In *Proceedings of the Institution of Civil Engineers: Engineering Sustainability* (Vol. 160, No. 3, pp. 119-131). ICE Publishing.
- [25] Pidou, M., Avery, L., Stephenson, T., Jeffrey, P., Parsons, S.A., Liu, S., Memon, F.A. and Jefferson, B. (2008). Chemical solutions for greywater recycling. *Chemosphere*, 71(1), 147-155.
- [26] Shaban, A. (2008, June). Water poverty in urban India: a study of major cities. In *Seminar Paper UGC Summer Programme June-July*.
- [27] Shamabadi, N., Bakhtiari, H., Kochakian, N., & Farahani, M. (2015). The investigation and designing of an onsite grey water treatment systems at Hazrat-e-Masoumeh University, Qom, IRAN. *Energy Procedia*, 74, 1337-1346.
- [28] Travis, M. J., Wiel-Shafran, A., Weisbrod, N., Adar, E., & Gross, A. (2010). Greywater reuse for irrigation: effect on soil properties. *Science of the Total Environment*, 408(12), 2501-2508.
- [29] Ushijima, K., Ito, K., Ito, R., & Funamizu, N. (2013). Greywater treatment by slanted soil system. *Ecological Engineering*, 50, 62-68.
- [30] Vakil, K. A., Sharma, M. K., Bhatia, A., Kazmi, A. A., & Sarkar, S. (2014). Characterization of greywater in an Indian middle-class household and investigation of physicochemical treatment using electrocoagulation. *Separation and Purification technology*, 130, 160-166.
- [31] Yu, Z. L., Rahardianto, A., DeShazo, J. R., Stenstrom, M. K., & Cohen, Y. (2013). Critical review: regulatory incentives and impediments for onsite graywater reuse in the United States. *Water Environment Research*, 85(7), 650-662.
- [32] Zipf, M. S., Pinheiro, I. G., & Conegero, M. G. (2016). Simplified greywater treatment systems: Slow filters of sand and slate waste followed by granular activated carbon. *Journal of environmental management*, 176, 119-127.

**Annexure I**

**Table 1** Treatment technologies for reuse of treated GW

<b>Physical Treatment</b>		
Filtration	Slow sand filter of effective fine sand size of 0.3 mm and depth of 400 mm	COD : 71.85% BOD: 89%
	Slate waste filter	COD: 60% BOD: 51%
	Volcanic turf media	COD: 65% BOD: 73%
<b>Biological Treatment</b>		
Rotating Biological Contractors	Single stage, tank volume 54 l, hrt 1.5 h, disc was submerged by 40%, disc of textured plastic having surface area of 9.7785 m <sup>2</sup>	BOD: 52.42% COD: 60.36%
Membrane Bioreactors	UF membrane of 0.1 micronmeter, and 400 cm <sup>2</sup> area, average hrt 13 hrs	COD: 86.24% BOD: 93.22%
Sequential Batch Reactor	Reactor dia. 19 cm, total volume 11 l, mechanical agitation 30 rpm, air flow 5l/min, hrt 0.6 day	COD: 88.24% BOD: 92.78%
<b>Constructed Wetland</b>		
Constructed Wetland	RVFCW, 8 cm organic soil, Hydrocotyleleucocephala and cyperus papyrus	BOD: 99.22 COD: 82.16
	RVFCW, bed depth 0.5 m and recycling rate 390L/h	BOD: 99.85% COD: 81.29%
	Phragmitesaustralissp, 5 days hrt, wetland dimension 1.1m x 1.0 m x 0.4 m P	BOD : 70.3% COD: 65.9 %
<b>Chemical Treatment</b>		
Chemical Treatment	Coagulation flocculation using alum	BOD : 88.28 % COD: 63.72 %
	Coagulation flocculation using ferric chloride	BOD : 85.37 % COD: 63.59 %
	Magnetic ion exchange resin	COD: 65.61% BOD: 76.44%
<b>Combined Treatment</b>		
Combined Treat.	Coagulation + sand filter + GAC	BOD: 92.85% COD: 94.87%
	Filtration followed by Adsorption	BOD: 85.68% COD: 57.09
	UASB as primary treatment unit and Horizontal sub surface flow of a constructed wetland as a polishing unit	COD: 87.7% BOD : 89.5%

Source: (Saeed et al. 2014;Mariah et al. 2016; Albalawneh et al. 2017; Pathan et al. 2011; Merz et al. 2007; Lamine et al. 2007; Travis et al. 2010; Gross et al. 2007; Abdel-Shafy et al. 2009; Pidou et al. 2008; Jefferson et al. 2000; Nnaji et al. 2016; Abdel et al. 2009)