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A pilot scale study of greywater treatment using gravel sand followed by granular activated carbon

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Abstract

Greywater (GW) reuse can help reduce water footprint if used as an alternative source of water for non-potable use, but it requires careful treatment to remove the contaminants. Therefore, the objective of this study was to develop a simple treatment system with low-cost and low footprint. This study evaluated the performance of a treatment plant with flow rate of 1 m^3/day and organic loading rate of 0.32 kg COD/m^3.day for on-site treatment and reuse of water collected from wash basins and sinks, as a major source of GW. Gravel sand filter followed by granular activated carbon (GAC) were used as filter medias. Results showed that the removal efficiencies of TSS, COD and BOD concentration were reduced by an average of 53%, 57% and 47% respectively corresponding to 36 mg/L, 125.6 mg/L and 85.3 mg/L, respectively in the treated effluent. The treated effluent satisfied Nepal Water Quality Guideline for irrigation for parameters like EC, pH and TSS. However, the microbial removal efficiency was found to be low so, use of disinfectant is recommended. The cost-benefit analysis indicated payback after 500 m^3 of GW treatment and reuse, thereby reducing water demand with monetary benefits.

Keywords: Greywater; Treatment plant; Activated carbon

1. Introduction

The rapid population growth and consumerism lifestyle has increased pressure on water resources thus pushing them to their limit. Moreover, climate change and conflicting water usage practices has further escalated concern about water availability . Often it is assumed that water issues especially involve securing potable drinking water for water scare regions. But in fact, 70% of world's water is used for agriculture and therefore, problems concerning water scarcity mainly depend on agriculture and food production. Similarly, on one hand, global warming is expected to result in decreased water availability in semi-arid regions whereas on other, regions may face the problem of too much water and flood disasters [1].

In this context, sustainable ways of using water efficiently, promoting water saving measures and reusing treated wastewater (WW) as alternative source are gaining more importance. One of the promising measures being source separation, on-site WW treatment and reuse of greywater (GW), that have been continually practiced all over the world for a multiple purposes including; to increase water availability, tackle drought and water shortages, and support environmental and public health protection [2–4]. In addition, it reduces the load on WW treatment systems, support cities green infrastructure such as urban agriculture gardening and contribute to energy demand reduction [5].

In Asian countries, 72 to 225 litre/capita/day of GW is being generated with typical chemical oxygen demand (COD), biological oxygen demand (BOD) and total suspended solid (TSS) concentrations of 150-1270 mg/L, 129-688 mg/L and 85-1396 mg/L respectively [6,7].The major benefit of treating GW for reuse being it's substantial fraction (50-80% of each -household WW) and reliability when compared to other water management strategies such as rain harvesting which depend on climatic conditions [7]. However, due to high variability in quantity and quality of GW, the reuse of treated GW as an alternative water can be limited based on reuse application (e.g. toilet flushing, irrigation, service water, and so on). Its high variability is due to dependency upon source, living practises, geographical location, storage time, availability and consumption of water [2, 8].

A range of technologies have been used for GW treatment, which includes a simple physical and biological filtration systems such as sand filters and constructed wetlands (CW) to highly automated and energy-intensive systems that include combination of biological, physical and chemical treatment mechanisms [2]. Filtration, rotating biological contactors (RBC), membrane bioreactors (MBR), CW and up-flow anaerobic sludge blankets (UASB) are some of the most widely used treatment system in developing countries [7]. CW were effective in both low and medium strength GW but requires large land area [9], SBR [10] and UASB [11] were usually used for domestic WW or high strength GW and MBR [5] is good for urbanized area but relatively expensive compared to other technologies in terms of operation cost. All these WW treatment technologies are more applicable in large scale treatment plants and could be less practical for on-site treatment at the household levels [7].

This paper focuses on on-site treatment and possible reuse of GW in urban cities of developing countries. High value for space and only partial WW being treated in developing countries due to operational limitation like high cost, lack of skilled manpower and so on increases potential for on-site treatment plant. In this case, sand filter and GAC are focused due to their simplicity, cost-effectiveness and low area requirement. Slow sand filter, being practised since long time is capable of removing both physical and biological pollutants however the treatment efficiency can be limited. So, addition of adsorbent like GAC with sand filter can prove to be promising and robust technology increasing both efficiency

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*Corresponding author. Email: subodh.luitel@ku.edu.np and longevity of treatment plant. Dalahmeh et al. [12] conducted lab scale research using activated charcoal (AC) to treat artificial GW and found it to be suitable for use in small scale irrigation systems with respect to biological water quality parameters. Similarly, Parjane and Sane [13] used combination of coconut shell, sawdust, charcoal, bricks and sand as filter media to treat GW from residential bathroom and basins on lab scale and found it to have high potential for COD, TDS, TSS and total hardness removal. The study done by Noutsopoulos et al. [14] on mixed strength of GW anticipated that coagulation and sedimentation was needed prior to sand filtration and GAC filtration, later followed by disinfection in order to comply with criteria set in the Greek legislation for WW reuse for urban use (TSS < 2 mg/L, turbidity < 2 NTU, BOD_5 < 10 mg/L) and most of the international greywater standards (TSS < 5-10 mg/L, turbidity < 2-5 NTU) for toilet flushing and irrigation. Furthermore, Patel et al. [15] coupled various waste biomass derived AC with sand filter column on laboratory scale and found that under the optimum operating conditions, the percentage removal of COD and BOD are 97.83% and 95.83 % for sawdust AC, 91.85% and 90% for sugarcane bagasse AC, 95.30% and 93.33% for pine needles AC, respectively.

For use of treated GW in various non-potable purposes or safe disposal, it should meet appropriate water quality standards or guidelines to ensure its safe and sustainable reuse or disposal [2, 4, 16]. In Nepal, there is no specific law for GW but there is tolerance limit for industrial WW effluent to be discharged into inland surface water, 2011 and Water Quality Guidelines for irrigation purpose which has been taken as a reference while designing the treatment plant. In a study done by Rutkowski et al. [17] among 109 farmers in Nepal, 89% used WW for irrigation and at least 55% of them had personally experienced or have had a family member experience skin problem as a result of it. Similarly, Baidya and Dongol, [18] reported low potential for use of treated WW alone but very high potential for use of diluted WW along with its acceptability for use in irrigation. But as a result of adaption of such approaches, public health risks and pollution reduces significantly and furthermore, development of technologies are considered. To our best knowledge, most of the previous studies on GW treatment were done in laboratory scale and very limited studies have been done in pilot scale. In this context, the objective of this study is to develop a pilot scale GW treatment system using locally available materials and study the performance of the treatment plant for on-site treatment of GW generated from an organization.

2. Materials and methods

2.1. Design and operational considerations of pilot plant

A pilot scale greywater treatment plant (GWTP) was installed on premises of Himalayan Climate Initiative (HCI) with the treatment capacity of 1 m^3 of GW per day. HCI is a non-profit organisation having around 20 staffs producing 1000 L of GW per day due to use of fresh water for bathing, cleaning and washing excluding the GW generated from kitchen. The constructed GWTP consisted of settling tank, storage tanks and filtration tank as shown in Fig. 1.

A pilot scale greywater treatment plant (GWTP) was installed on premises of Himalayan Climate Initiative (HCI) with the treatment capacity of 1 m3 of GW per day. HCI is a non-profit organisation having around 20 staffs producing 1000 L of GW per day due to use of fresh water for bathing, cleaning and washing excluding the GW generated from kitchen. The constructed GWTP consisted of settling tank, storage tanks and filtration tank as shown in Fig. 1.

First, the generated GW passed through screen for retaining coarser solids followed by collection in sedimentation tank. Then, the GW was retained in sedimentation tank for 1-2 days and pumped to a tank placed at a height of 2 m above the ground at flowrate of 15 L/min. Further, the GW was passed through tank to filtration tank with help of gravity. The operational flow rate was maintained at 0.7 L/minute with use of manual ball valve and shower head. The shower head was used to distribute GW uniformly within the surface area of filter media and it required weekly maintenance to avoid clogging.

The filtration tank is designed with squared surface area of 1 m^2 so that it can be replicated on houses in urban area even with limited space. In addition, each media is kept in separate drawer to be easily cleaned and replaced after end use.

The locally available materials were used as filter media for the treatment plant as shown in Fig. 2. The first layer was of gravel (10-15 mm) of depth 10 cm followed by fine sand (0.5-1 mm) of depth 20 cm. Similarly, third layer consisted of gravel (2-5 mm) of depth 20 cm followed by activated charcoal layer of depth 10 cm. The final two layers consisted of gravel (2-5 mm) and gravel (10-15 mm) of depth 20 cm and 10 cm respectively. At last, filtered effluent was stored in a storage tank.

The design flow of primary influent is 1 m^3/day which gives HRT of 0.9 days or 21.6 hours for filter tank of volume 0.9 m^3 (1m×1m×0.9m). Similarly, it is operated at an organic loading rate of 0.32 kg COD/m^3.day (0.17 kg BOD/m^3 day) and hydraulic loading rate of 1 m^3/m^2.day. In order to attain continuous effective operation, the accumulated sludge and scum must therefore be emptied periodically. This should take place when accumulation of these materials exceeds 30 percent of the tank's liquid volume that is requiring approximately weekly maintenance [6].

2.2. Sampling and analyses

The source of the sample was GW generated from bathroom activities. The first sample collected from point S1 was taken into consideration for characterizing the quality of GW after sedimentation process. Therefore, there were altogether 6 samples from S1 and 5 samples from S2 taken on weekly basis after 2 weeks of installation of plant. The samples were collected in a sterilised plastic bottle and transported to laboratory for the analysis in ice box within the same day. All the analyses were carried out as per standard methods for the examination of water and WW [19].

3. Results and discussion

3.1. Greywater Characteristics

The characteristics obtained from GW at S1 i.e. after sedimentation process in this study is presented as average and standard deviation (SD) of the parameters shown in Table 1.

The average EC and pH value were found to be 652 μS/cm and 6.99 respectively. This pH value was neutral and likewise to assertion made by other studies compared in this research that pH of GW is usually between range of 6.5 to 8.0. Similarly, it was observed that average TSS concentration was similar to weak strength domestic WW however, average concentrations of both COD and BOD were similar to medium strength domestic WW [24].This low strength of TSS could be due to sedimentation process which reduced TSS value.

TSS concentration in this study was in similar range compared to other studies except to Abdel-Shafy et al., and Parjane and Sane, where TSS concentrations were slightly higher. Similarly, both COD and BOD concentrations were lower compared to GW collected from residential houses in research of Abdel-Shafy et al., but higher compared to GW collected in Zipf et al., and Couto et al.,. BOD/COD ratio was more than 0.5 showing results for good biodegradability as stated by Li et al. [2] that all kinds of GW shows readily biodegradable quality in terms of BOD/COD ratio.

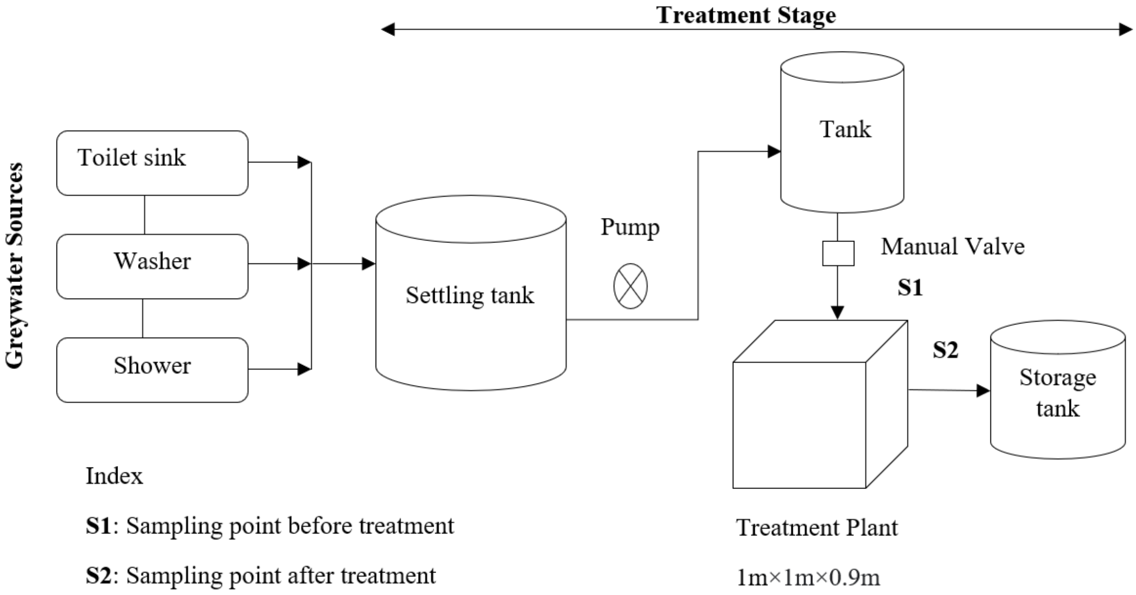

Figure 1: Schematic diagram of greywater treatment plant

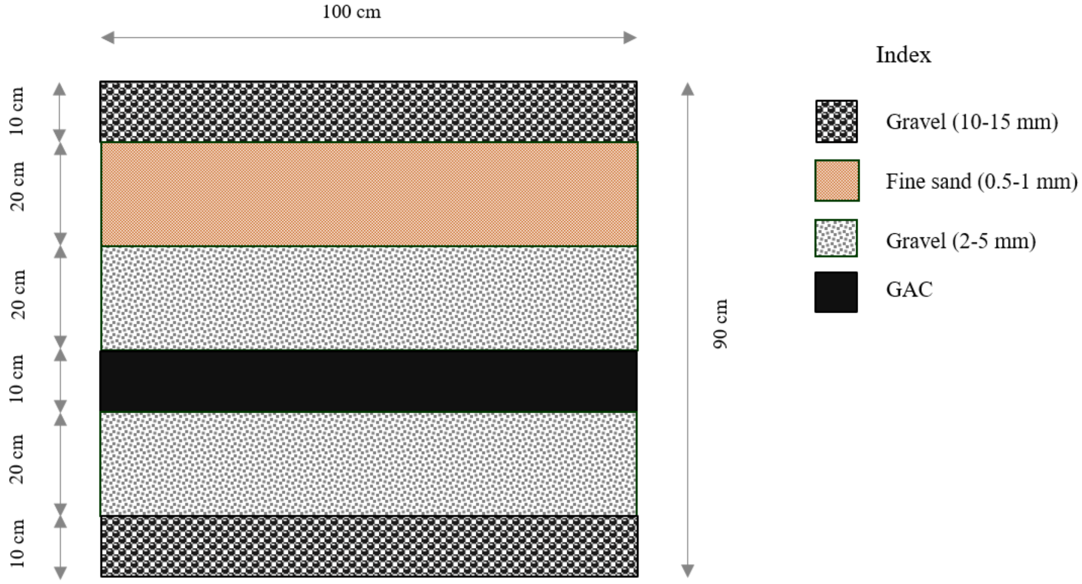

Figure 2: Cross section of filter tank.

Table 1: Characteristics of the GW after sedimentation process in this research compared with other studies.

Parameters	This work	Zipf et al. (2016) [20]	Couto et al. (2015) [21]	Abdel-Shafy et al. (2014) [22]	Parjane and Sane (2011) [13]	Jamrah et al. (2006) [23]
	Bathroom	Laboratory sinks in a University Campus	Kitchen sink and locker room of airport	Residential houses	Bathrooms, basins in a residential college	Shower
EC (μS/cm)	590.8 ±154.12	-	-	-	-	890
pH	6.97±0.19	7.7±0.6	7.6±0.31	-	8.12	7.42
TSS (mg/L)	76±16.08	-	76±37	124±30	184	94
COD (mg/L)	292.4±119.33	145.8±79.1	170±100	481±57	327	77
BOD (mg/L)	160±84.74	56.30±15.9	93±68	260±30	-	40.2
BOD_5/COD	0.52	0.39	0.55	0.54	-	0.52
SAR	0.027	-	-	-	15.86	3.04
Na (mg/L)	0.7					
Ca (mg/L)	36.8					
Mg (mg/L)	4.19					
TC (MPN/100 mL)	>1100	-	-	-	-	300

Also, SAR was found to be 0.027 which was very low compared to other studies but low SAR value shows good potential to be utilised for irrigation. TC concentration was found to be greater than 1100 MPN/100mL which may be due to dead skin, sweating from bodies and traces of urine and faecal matter present in bathroom GW [25, 26].

3.2. Performance and efficiency of treatment systems

Table 2 and Table 3 summarizes average treatment efficiency of gravel sand filter + GAC along with comparison of its effluent quality with WW discharge limit, irrigation guidelines of Nepal and other studies.

In treatment unit, the pH value seems to be unaffected by the filtration as both the inlet and outlet GW concentrations express similar value. However, conductivity of GW has slightly increased after filtration which could be due to release of ions from gravel. The filter unit shows TSS, COD and BOD concentration reduced by average 53%, 57% and 47%, respectively corresponding to 36 mg/L, 125.6 mg/L and 85.3 mg/L, respectively in the treated effluent. This low COD and BOD removal percentage can be compared to other similar studies in Table 3 consisting of sand filter and GAC. This low efficiency can be due to absence of biological treatment unit.

Despite low removal, the treatment unit's average effluent concentrations of pH, TSS and COD were within tolerance limits for WW to be discharged into inland surface water according to Government of Nepal (GON), 2011. But average effluent's BOD concentration was slightly higher than the discharge limit. Similarly, average EC, pH, TSS and SAR concentrations were all within the Nepal Water Quality (WQ) Guideline for irrigation water as shown in Table 2. TC residual value was found to be more random, usually more than 1100 MPN/100 mL which means that those water should be avoided for irrigation of crops likely to be eaten uncooked, sports fields and public parks [31]. However, use of disinfection followed after filtration can help reduce TC value to limit for various reuse application [32].

3.3. Analysis of cost and benefits

The cost component of producing treated GW contains the following parameters: the capital cost for constructing a GW treatment plant, the operation and maintenance (O&M) cost, and the energy cost. The capital cost for construction of treatment plant of capacity 1m^3 of GW per day is around $2480 (US dollars) excluding the cost for land. The price is based on total cost of filter media, pump, tanks and pipe in the Nepalese market. Similarly, for the operational cost, it depends on the energy consumed by the pump which is around $3 per year with rate of $0.073 per kWh in Nepal and for maintenance of effluent quality, laboratory test of parameters must be done every 3-4 months costing around $100 per year. More research is needed to find the service life of GAC which can be around 2-4 years depending on the strength of WW however long lifespan for sand filter (e.g. 30 years) has been well studied [24, 32]. The maintenance cost of filter includes cleaning, repairing and changing of filter media costing around $30 per year if service life of GAC is assumed to be 2 years. Table 4 compares operating cost/m^3 of various treatment plant.

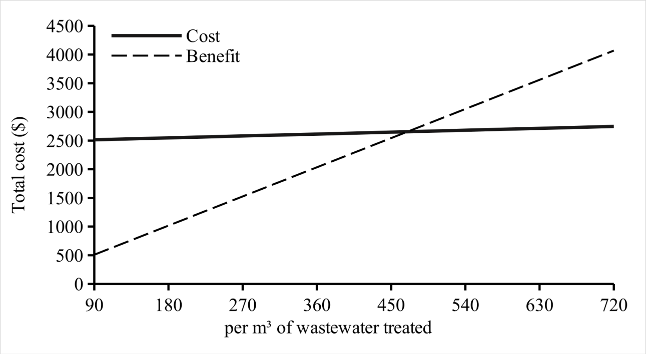

Figure 3: Cost vs benefit of GW treatment using gravel sand filter followed by GAC of 1 m^3/day capacity.

The benefits from on-site utilization of treated GW can be monetary, by reducing water demand and WW collection and treatment. Kathmandu like most of other urban Asian cities has been facing water supply deficit since long time and this deficit has been predicted to increase to 322 million litres per day by 2021 [34]. Due to supply deficit, 15 % of people rely on private vendors for tanker water costing $14.1-$15.75 for 5 m^3 of water supplied of potable quality [35]. Similarly, the typical cost for WW treatment is around $2.67 per m^3 [29].

The cost benefit analysis for successive GW treatment is shown in Fig. 3 where it can be clearly seen that benefits will exceed the cost after 500 m^3 of GW treatment and reuse.

It is to be noted that the cost-benefit analysis considered in this study is based on cost of tanker water and energy of Nepalese mar-

Table 2: Treatment efficiency of filter tank and comparison of filtered effluent with guidelines

Parameters	Sand filter + GAC		Removal Efficiency	Tolerance limits for WW to be discharged into inland surface waters from combined WWTP, (2011) [27]	Nepal WQ Guideline for irrigation water [28]
	Influent	Effluent			
EC (μS/cm)	590.8	627	-	-	4000
pH	6.97	7.18	-	5.5-9	6.5-8.5
TSS (mg/L)	76	36	53±14	50	50
COD (mg/L)	292.4	125.6	57±16	250	-
BOD_5 (mg/L)	160	85.3	47±7	50	-
SAR	0.027	0.026	-	-	2
TC (MPN/100 mL)	>1100	>1100			

Table 3: Mean values of the filtered GW at different stages (MV), with standard deviations and removal efficiencies (E) for TSS, COD, and BOD compared with other studies.

Reference	Type of treatment		TSS (mg/L)	COD (mg/L)	BOD (mg/L)
This study	Sand filter + granular activated carbon	MV	36	125.6	85.3
		E	53±14%	57±16%	47±7%
Zipf et al. (2016) [20]	Sand filter	MV		113.2 ± 60.9	49.05 ± 15.5
		E		21 ± 18%	13±9%
	Sand filter + granular activated carbon	MV		68.5 ± 52.4	25.13 ± 9.3
		E		56 ± 19%	56±9%
Alsulaili et al. (2017) [29]	Sand filter + UV	MV	9.8±8	26.7±18.2	13.4+5
		E	47	58.98%	53.47%
Couto et al. (2015) [21]	Anaerobic filter	MV	17±11	48±21	25±17
		E	77%	72%	73%
Dalahmeh et al. (2012) [12]	Charcoal	MV		48±10,	6±2
		E		94±2%	97±3%
	Sand	MV		245±106	112±16
		E		72±2%	75±6%
Friedler et al. (2005) [30]	RBC + sedimentation	MV	16±14.5	46±19.4	6.6±9.45
		E	63%	71%	89%

Table 4: Comparison of operation cost of different WWTPs.

Treatment technology	Annual operating cost ($)	Design flow (m^3/day)	Cost (\$/m^3)	Footprint (m^2)	Reference
Gravel-sand filter + GAC	133	1	0.36	1	This study
Bangkok WWTPs	450×10^6	99,200	62	-	Ghimire et al. (2011) [33]
Kuwait WWTP	-	-	2.67	-	Alsulaili et al. (2017) [29]

ket. Similarly, the cost for WW treatment per m^3 is compared to Kuwait WWTP because of similar scenario of being a developing country as Nepal. The filter media GAC is assumed to have life cycle of 2 years and that of sand is around 30 years.

4. Conclusion

The results showed that the GW from wash basins and shower after sedimentation process had average TSS concentration similar to weak strength domestic WW but average concentrations of COD and BOD similar to medium strength domestic WW. In addition, the use of filter tank consisting of gravel, sand and GAC showed TSS, COD and BOD concentration reduced by average 53%, 57% and 47% respectively at filtration rate of 1 m^3/day. The filtered effluent's of TSS and COD were able to comply with Nepal's WQ guidelines for irrigation and WW discharge limit of GON, 2011. But average effluent's BOD concentration was slightly higher than the discharge limit. Furthermore, microbial removal efficiency was found to be low so, use of disinfectant is recommended.

The treatment system is simple and require less area proclaiming huge scope for use in urban areas. Similarly, the system is sustainable and promising for GW treatment that can be run and maintained by low skilled manpower. Cost benefit analysis indicate payback after 500 m^3 of GW treatment and reuse, with monetary benefits by reducing the freshwater demand and WW collection and treatment.

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