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Evaluation of the efficiency of a gray water treatment system based on aeration and filtration

Maziar Kabiri, Abolfazl Akbarpour and Mohammad Akbari

ABSTRACT

Gray water is a great resource for replacing fresh water to be used in standardized usages. The use of treated gray water reduces water consumption and the entry of pollutants into the environment. However, if left untreated, it can be dangerous. The present study examines the efficiency of a gray water treatment system consisting of primary filter, aeration, secondary filter and ultraviolet disinfection unit. After examining the characteristics of gray water, the efficiency of this system was analyzed to remove the pH, TSS, BOD, COD, ABS and total coliform parameters. Then, the gray water treated through this system was compared with the environmental standard of Iran. The pH of the treated gray water was 7.5–7.6. The efficiency of this system for removing the BOD and COD parameters was 98–100 and 76–100%, respectively. This system had an efficiency of 96–97% to eliminate the ABS parameter. Also, this system was able to eliminate total coliform with 100% efficiency. Results showed that in the three series of experiments performed on this system, according to the Iranian standard, the treated wastewater is suitable for irrigation and agricultural uses. However, this system could not be licensed for the COD parameter regarding the discharge to surface water and absorbent wells.

Key words | gray water treatment, residential complex, reuse, reuse standards

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HIGHLIGHTS

- Investigating the amount of pollutants in gray water from three different locations and comparing the results with each other.
- Using a filter before the aeration tank and evaluating the removal efficiency of various parameters with this new system.
- Examining the presence of ABS parameter in gray water.
- Investigating removal efficiency of the ABS parameter with the proposed system.

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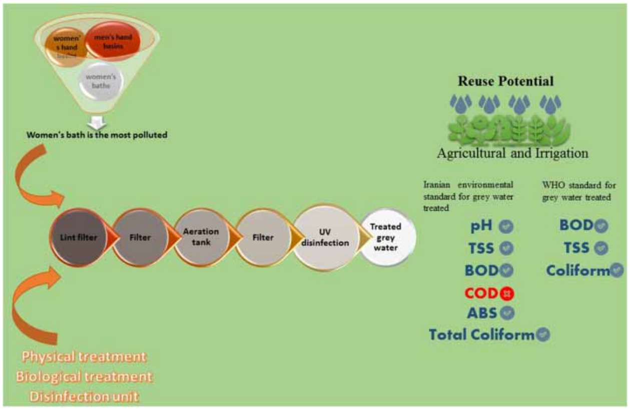
GRAPHICAL ABSTRACT



INTRODUCTION

Today, with the increasing trend of industrialization and urbanization, the use of water resources has become much higher than before, which can be considered as a serious obstacle to sustainable development (Shamabadi *et al.* 2015; da Silva *et al.* 2019). This trend has widened the gap between supply and demand in the use of water resources, so that one of every six people in the world does not have access to potable water (Ghaitidak & Yadav 2013; da Silva *et al.* 2019). This issue is more important in Iran where the rate of rainfall is low and the weather is rather warm. In Iran, unlike some other countries, drinking water is used for all household purposes. One way to deal with the shortage of water is to make use of alternative sources such as gray water (Alfiya *et al.* 2013; Al-Hamaiedeh & Bino 2010). Domestic wastewater is divided into two groups: black water and gray water. Gray water includes wastewater from showers, baths, hand basins, and laundries and black water includes wastewater from toilets (Al-Hamaiedeh & Bino 2010; Leal *et al.* 2012; Abdel-Kader 2013; Jabornig & Favero 2013; Boddu *et al.* 2016). Gray water includes a greater part of domestic wastewater (Friedler *et al.* 2005; Leal *et al.* 2012; Jabornig & Favero 2013), which is about 60–70% of the domestic wastewater produced (Kim *et al.* 2009; Abdel-Kader 2013). Although gray water is far less polluting than black water, there are risks to using it without an effective treatment. In the case of standard treatment, its use in applications such as flash tanks, car wash, irrigation, firefighting, and non-human consumption is without risks (Nolde 2000; Eriksson & Donner 2009; Kim *et al.* 2009; Bani-Melhem *et al.* 2015). Use of treated gray water not only reduces the consumption of freshwater resources but also lessens the amount of pollution entering lakes, rivers and groundwater (Abdel-Kader 2013). Therefore, the use of treated gray water reduces the volume of water consumed in homes and has been validated as a sustainable alternative source (Zita *et al.* 2015). Birjand is one of the cities in Iran that, due to low rainfall, is facing difficulties in supplying water. Rainfall in this city is low and irregular. Therefore, using treated gray water in this area would be a more stable source compared to rainwater usage (Leong *et al.* 2018). There are many villas in Birjand, which is why a large amount of water is spent on irrigating the green space of the house and cleaning the yard. Therefore, the use of treated gray water can significantly reduce potable water consumption (Al-Hamaiedeh & Bino 2010). So far, many systems with different technologies have been used. Generally, all systems are based on physical, chemical and biological processes or a combination of them. Each system has its advantages and disadvantages. For example, the rotating biological contactor (RBC) system is able to remove biodegradable materials and is odorless, but has high power consumption and a high probability of breakage

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of the shaft connected to the discs (Metcalf *et al.* 2007). A constructed wetland costs very little to operate and maintain, and is practically the cheapest way to treat gray water. However, it requires a large space that makes it unsuitable for urban areas and the other problem is that a large amount of water is lost due to evaporation. Although the reverse osmosis (RO) system is able to remove a high percentage of pollutants, it has high energy consumption (Prajapati *et al.* 2019). Membrane processes are of high quality in system output but require regular washing and membrane sedimentation is extremely high (Ding *et al.* 2017).

Due to the high contamination of this wastewater after examining the characteristics of gray water, Halalsheh *et al.* (2008) proposed the up flow anaerobic sludge blanket reactor (UASB) system. The proposed system was a low-cost one with flexible operation and maintenance. The treated gray water was suitable for irrigating fruit trees according to Jordanian standards. Kim *et al.* (2009) designed and reviewed a system consisting of an anaerobic tank, anoxic tank, oxic tank and membrane filter for the treatment of gray water. The system was successful in removing chemical oxygen demand (COD), turbidity, color, suspended solids, and total coliform. In this system, ozone was used in the disinfection unit. Li *et al.* (2009) found that the membrane bioreactor (MBR) system is suitable for high contamination and the RBC and sequence batch reactor (SBR) systems are more appropriate for moderate contamination. They also found that anaerobic processes are not suitable for the treatment of gray water due to poor efficiency in the removal of organic matter and surfactants. Oh *et al.* (2018) identified a physical filtration system with a disinfection unit for low-pollution treatment of gray water.

Gray water contains many compounds which are practically impossible to measure (Leal *et al.* 2012). Therefore, parameters related to organic matter, solids and microbiology are usually more significant (Pidou *et al.* 2008). Standards vary depending on the application and place of use of the treated wastewater; also, regional standards may differ. Normally, standards are less stringent for neighborhoods where there is less contact with humans (Pidou *et al.* 2008; Winward *et al.* 2008; Boddu *et al.* 2016). Countries that do not have specific guidelines for assessing the quality of treated wastewater can use WHO or EQS criteria (Eriksson & Donner 2009). For irrigation purposes, the Iranian standard allows pH = 6–8.5, BOD = 100 mg/L, COD = 200 mg/L, TSS = 100 mg/L, ABS = 0.5 mg/L and total coliform = 1,000 (in 100 mL) (Kashafi 2012).

In this study, after examining the specifications of gray water for the above parameters, a gray water treatment system was designed at domestic scale according to Iranian standards and the design and operational aspects of it were described. Whereas in the systems previously studied only one filtration unit was used after the aeration tank, this gray water treatment system consists of a membrane filter, aerobic tank and membrane filter, and an ultraviolet (UV) lamp was used in the disinfection unit. Finally, the performance of this system in eliminating the above parameters was examined and compared with Iranian standards.

MATERIALS AND METHODS

Sampling

Birjand is located in the South Khorasan province in Iran with a longitude of 59.12° and a latitude of 32.52°, and an altitude of 1,491 meters above the sea level. With an average rainfall of 168.5 mm and an average temperature of 16.5 °C, this city is one of those that has always faced water supply problems. Therefore, the use of treated wastewater in this city is most important. Birjand University, located in Birjand, uses drinking water for all its uses, even irrigating green spaces. Due to the problems in Birjand with supplying water and the lack of sufficient land area for the construction of a central treatment plant, this research was carried out to investigate and evaluate the efficiency of the system under study.

Dormitories are one of the main sources of gray water production at Birjand University. Separation of gray water from black water has been done only in the three dormitories of Towhid, Sadaf and Sarv. In addition, in these three dormitories, the hand basin sewers are separated from the bath sewers. Therefore, sampling of these three sites was taken as follows:

- Site 1: wastewater from the hand basins in Sadaf women's dormitory of Birjand University, which included six hand basins on three floors, collecting wastewater from a total number of 18 hand basins.

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- Site 2: wastewater from the hand basins in Sarv men's dormitory of Birjand University, which included six hand basins on two floors, collecting sewage from a total number of 12 hand basins.
- Site 3: wastewater from the baths in Towhid women's dormitory of Birjand University, which included four baths on three floors, collecting sewage from a total number of 12 baths.

The quality of gray water can vary greatly depending on the day and even the time. Therefore, for accurate characterization and reliable results, sampling was repeated on two different days and three different times. Sampling was carried out at 9a.m., 2p.m. and 9p.m. It was repeated on Tuesday and Friday. Finally, 18 samples were tested for BOD and COD values. Table 1 shows the number of each sample along with the location, time and day of sampling.

Table 1 | Number, location, time and day of sampling

Day	Time	Location	Number of sampling
Tuesday	9	Hand basins in Sarv men's dormitory	1
Tuesday	14	Hand basins in Sarv men's dormitory	2
Tuesday	21	Hand basins in Sarv men's dormitory	3
Tuesday	9	Hand basins in Sadaf women's dormitory	4
Tuesday	14	Hand basins in Sadaf women's dormitory	5
Tuesday	21	Hand basins in Sadaf women's dormitory	6
Tuesday	9	Baths in Towhid women's dormitory	7
Tuesday	14	Baths in Towhid women's dormitory	8
Tuesday	21	Baths in Towhid women's dormitory	9
Friday	9	Hand basins in Sarv men's dormitory	10
Friday	14	Hand basins in Sarv men's dormitory	11
Friday	21	Hand basins in Sarv men's dormitory	12
Friday	9	Hand basins in Sadaf women's dormitory	13
Friday	14	Hand basins in Sadaf women's dormitory	14
Friday	21	Hand basins in Sadaf women's dormitory	15
Friday	9	Baths in Towhid women's dormitory	16
Friday	14	Baths in Towhid women's dormitory	17
Friday	21	Baths in Towhid women's dormitory	18

Figure 1 shows the BOD and COD test results, separated for day and time of sampling.

According to Figure 1, gray water from the hand basins of women's dormitories has the highest rate of contamination with an average BOD of 93.3 mg/L and an average COD of 217/3 mg/L. Therefore, using this gray water is the best option for evaluating the performance of the designed system.

Analytical methods

According to Iranian standards, samples should be stored in a plastic container at 4 °C and tested within 6 hours (Kashafi 2012). Figure 2 shows a number of samples sent to the laboratory. All experiments were also performed in Shargh-Azmaye Kavir laboratory, which is approved by the Environmental Organization of Iran. The pH test was measured by Hanna's pH meter, model: HI9813-3. For the BOD test, the standard method of 2510D and the VELP Scientifica BOD meter were used. The COD and ABS experiments were performed using the 5220D and 4055C: Anionic Surfactant as MBAS standard methods, respectively, with the Lovibond Spectro Direct spectrophotometer. The TSS test was performed using the standard 2540D gravimetric method. Also, total coliform experiment was performed using the standard method of ISIRI42079221B and the most probable estimation method with a Behdad incubator.

Experimental pilot plant set-up

In order to set up a gray water treatment system, in addition to the cost of purchasing a treatment system, the cost of separating gray water from black water and the storage and distribution of treated wastewater in a pipe, separated from drinking water, should also be considered (Abdel-Kader 2013). Therefore, designing a simple, effective system which is cost-effective and easy to use is very important (Santos et al. 2012). In the first step, the sources generating wastewater and its pollutants must be identified. In the next step, the place in which the treated wastewater is consumed should be examined, also standards and restrictions should be controlled. In order to choose a suitable treatment system, consideration of types of treatment systems and

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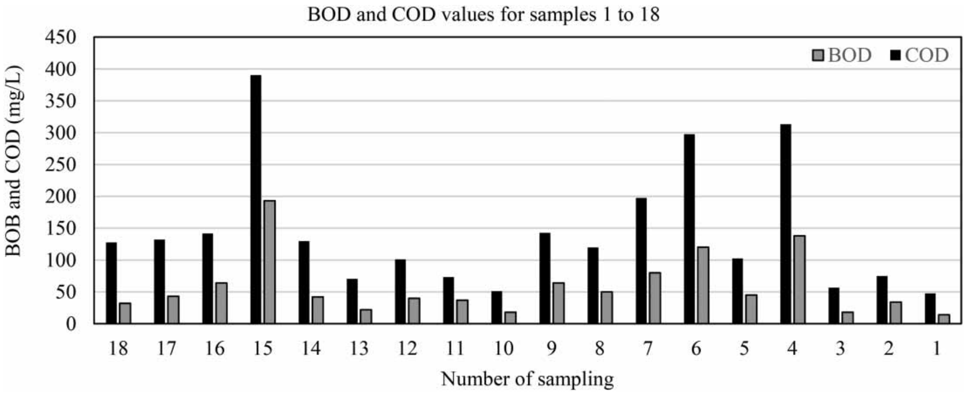

Figure 1 | BOD and COD values for samples 1–18.

Figure 2 | A number of prepared samples for the laboratory.

determination of advantages and disadvantages of each system is very important. Examination of treatment systems which are currently in use is also helpful.

Nowadays, most treatment systems used on the domestic scale are a combination of biological and physical treatment processes, since there are few studies on the use of chemical processes in gray water treatment. On the other hand, more equipment along with more accurate performance is needed to treat gray water using chemical processes, which makes it more difficult to be used at domestic scale. The concern about using a domestic wastewater treatment plant is smell production, which can be suppressed by using an aerobic biological process. On the other hand, the deployment of an anaerobe biological process requires long-term storage, which allows a larger storage tank to be included in the design and more space to be allocated to the treatment system. Due to the presence of many contaminants in the gray water, the use of the physical treatment process alone causes the filters installed in the system to lose their efficiency quickly and the check period becomes shorter.

According to the above, a combination of aerobic biological and physical treatment processes were used in the design of the treatment system. The aeration unit is the most time-consuming treatment unit. To reduce this time, a physical treatment unit is used which decreases the contaminants in the gray water. Therefore, less time is required to inject air into the wastewater. Finally, a filter was installed to remove finer contaminants and microorganisms that entered the wastewater during the aeration stage.

Gray water treatment systems based on aeration and filtration include lint filters, a primary filter, collecting tank, secondary filter, disinfection units and reuse tanks. Figure 3 shows the components of this system. The used lint filter is embedded to separate large components of raw gray water, such as hair and soap fragments. The raw gray water enters the primary filter after passing through the lint filter. This filter can remove gray water components up to the dimensions of 100 μm. The more polluted the gray water, the longer the aeration time will be. The primary filter reduces the amount of gray water contamination that allows aeration to be carried out in a shorter time. Wastewater enters the collecting tank with a volume of 120 L. The presence of a collecting tank prevents temperature shocks, pollution shocks and inflow shocks. Air pipes are installed at the bottom of this tank. In fact, the collecting tank simultaneously functions as

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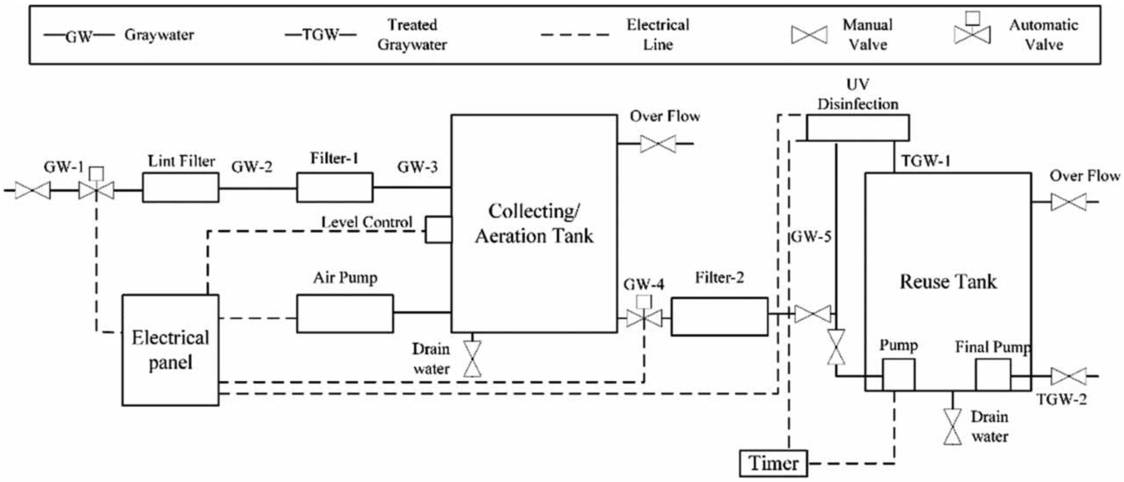

Figure 3 | Pilot map of the designed gray water treatment system.

the aeration tank. A level control sensor is embedded on the top of the collecting tank (aeration tank). The function of this sensor is that it does not turn on the aeration pump until the tank is completely full, which is very important to save electricity and to use the entire volume of the tank. The gray water in excess of the system volume flows directly into the municipal wastewater collection system. The gray water is aerated, after which the drain valve is opened onto the secondary filter. The secondary filter can remove wastewater components up to 1 μm in size. Figure 4 shows the actual pilot sample designed on a laboratory scale.

Disinfection system

After aeration, the gray water flows into the disinfection unit. Microbiological parameters are one of the most important parameters measured in wastewater treatment systems. Although there are different systems for treating gray water, a disinfection unit is required to meet the required standards (Leal *et al.* 2012). In general, ozone, chlorine and ultraviolet light are used for the disinfection process. Forming secondary compounds is probable in chlorination. Also, both chlorination and ozonation methods require a dosing pump and have a high initial construction cost. However, UV light bulbs cost relatively less than the other two methods. The UV lamp used in this system was of UV-C type from Aqua Safe Company (China), which performed disinfection operations by emitting a light of 254 nm wavelength. The UV lamp is inserted inside a steel housing that has an input and an output. UV radiation to the treated wastewater disinfects it. To save power, the UV lamp only turns on when the drain valve of the aeration tank is opened. There is also a pump at the bottom of the reuse tank that sends the treated gray water back to the disinfection unit. This is performed to maintain the microbiological quality of the treated wastewater.

Figure 4 | Image of the actual pilot sample designed on a laboratory scale.

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RESULTS AND DISCUSSION

Quality of the gray water

The designed system with the volume of 120 L was tested three times. In all three series of experiments the raw gray water had a different contamination amount. Table 2 shows the amount of each parameter for raw gray water in all three series of experiments.

Treatment efficiency

According to Table 2, the amount of pollution in test B is more than test A and test C is more than test B. GW1, GW2, GW3, GW4, GW5 and TGW1 in Figure 2 are sampling points. Sampling was performed for all three experiments (A, B, and C). Table 3 shows the measured parameters for tests A, B and C.

As it is clear in Table 3, raw gray water is slightly alkaline due to the use of detergents. The presence of a collecting tank prevents pH shock to a large extent. During the experiments, all samples were within the standard range. Only in test C, the GW1 and GW2 samples had a high alkalinity with pH = 8.3, which eventually reached 7.6 in the GW5 sample. This is because, in the two stages of filtration and aeration, the pollutants that increase the alkalinity of gray water are destroyed and removed.

Suspended materials in wastewater disrupt agricultural activities. The presence of these particles causes sedimentation in irrigation systems. Also, the presence of large amounts of TSS, even if there are no health risks, causes a negative mentality in consumers and their unacceptability. Therefore, according to the ultimate goal of this system, which is the treatment of gray water for irrigation and agricultural consumption, the TSS parameter is very important. In the TSS test, the efficiency of test A was 100% as TSS_{GW1} = 34 mg/L and TSS_{GW5} = 0 mg/L. In test B, TSS_{GW1} = 51.5 mg/L which was purified with 98% efficiency, also for the GW5 sample, it reached 1 mg/L. In test C of the TSS tests, it was decreased from 68 to 2.5 mg/L with the

Table 2 | Measured parameters of raw gray water in three tests

Total coliform (in 100 mL)	ABS (mg/L)	TSS (mg/L)	COD (mg/L)	BOD (mg/L)	pH	Experiment series
920	0.15	34	83.4	34.5	7.7	A
1,020	0.21	51.5	250	50	7.5	B
1,130	0.25	68	529	210	8.3	C

Table 3 | Characteristics of raw and treated wastewater during sampling

Experiment series	Parameters	GW1	GW2	GW3	GW4	GW5	TGW1
A	pH	7.7	7.3	7.4	8.4	7.6	–
	TSS (mg/L)	34	14	5	4	0	–
	BOD (mg/L)	34.5	33	31	1	0	–
	COD (mg/L)	83.4	81.3	70.5	5.3	0	–
	ABS (mg/L)	0.15	0.09	0.07	0.04	0.002	–
	Total coliform	920	430	350	540	280	0
B	pH	7.5	7.5	7.44	7.8	7.5	–
	TSS (mg/L)	51.5	45	20	16	1	–
	BOD (mg/L)	50	48	40	5	1	–
	COD (mg/L)	250	241	235.6	80	60.5	–
	ABS (mg/L)	0.21	0.12	0.1	0.06	0.007	–
	Total coliform	1,020	650	530	610	310	0
C	pH	8.3	8.3	8	8	7.6	–
	TSS (mg/L)	68	60	25	18	2.5	–
	BOD (mg/L)	210	200	150	20	5	–
	COD (mg/L)	529	520	510.2	86.6	77.8	–
	ABS (mg/L)	0.25	0.13	0.12	0.065	0.01	–
	Total coliform	1,130	660	570	630	300	0

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efficiency of 96.3%. Thus, the efficiency of this system in removing TSS in tests A, B and C is equal to 100, 98 and 96.3%, respectively. Figure 5 shows the TSS removal efficiency in tests A, B and C. The presence of a lint filter and two filters that can remove particles up to 100 and 1 μm, respectively, resulted in the optimal efficiency of this system in reducing TSS. The 100% reduction in Series A tests is probably due to the new filters. However, in two series of B and C tests, the real efficiency of the system to remove TSS parameter was obtained.

Figure 6 shows the efficiency of eliminating the BOD parameter in three test series. In the BOD experiment and in test A, the efficiency was 100% as $BOD_{GW1} = 34$ mg/L reduced to $BOD_{GW5} = 0$ mg/L. In test B, the BOD in the $BOD_{GW1} = 50$ mg/L reduced to $BOD_{GW5} = 1$ mg/L. The efficiency of the system in this test was 98%. In test C where there was more contamination in the gray water, $BOD_{GW1} = 210$ mg/L; while for the treated gray water with an efficiency of 97.6%, BOD_{GW5} reached 5 mg/L. Filters are effective in removing BOD and the BOD parameter has a greater tendency to be removed by filters in comparison with the COD parameter. In fact, removing solid parts of BOD is the responsibility of filters. Density of BOD remaining after passing through the filters is probably in the form of solution and colloid, which is removed by the aeration tank. On the other hand, it is expected that BOD is well removed in the aeration tank due to the preparation of required oxygen. The BOD/COD ratios are respectively 0.414, 0.2 and 0.397 in samples A, B and C. No BOD and COD were found in the treated wastewater of sample A and this ratio was 0.016 in the treated wastewater of sample B and 0.064 in sample C. This indicates that BOD is well removed (reduced) in the aeration tank and the final wastewater can no longer be treated biologically.

According to Table 1, the gray water of the women's basin with an average COD of 217.3 mg/L was the most polluted sample compared to the gray water of the male's basin with an average COD of 143.55 mg/L and the women's bathroom with an average COD of 67.5 mg/L. According to these values, it was found that the gray water of the basin has more COD than the bathroom. This could be due to the use of more detergents than water. Also, the gray water of the women's basin is more polluted than the men's basin. This is because women use cosmetics and more detergents than men. In the COD test, the COD_{GW1} reduced from 83.4 mg/L to $COD_{GW2} = 0$ mg/L in the first series of experiments (test A). In the B and C series of experiments, the GW1 samples reduced from 250, 529 to 60.5 and 77.8 mg/L, respectively. The efficiency of the system in tests B and C is 75.8 and 85.3%, respectively. Figure 7 shows the efficiency of COD removal for all three test series.

The ABS test measures alkyl benzene sulfonate. Alkyl benzene sulfonate exists in soap and has high cleansing power. Nowadays linear alkyl benzene sulfonate (LAS) is applied. However, detergents with ABS are still in use in Iran. In addition to detergents, ABS also exists in cosmetics. Few studies have investigated and measured the ABS parameter in gray water. The ABS level of raw gray water in all three series of experiments was within the allowable range of the Iranian standard. According to Table 3, the

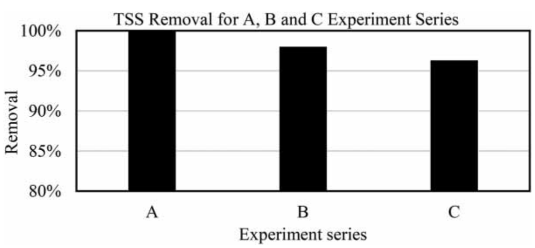

Figure 5 | TSS removal efficiency in test series of A, B and C.

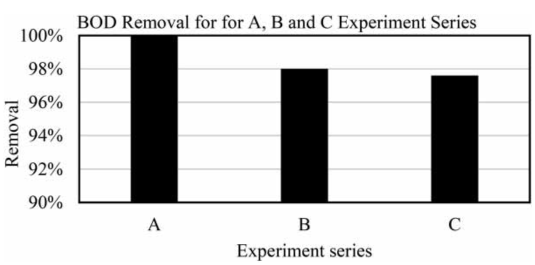

Figure 6 | Efficiency of elimination of BOD parameter in test series of A, B and C.

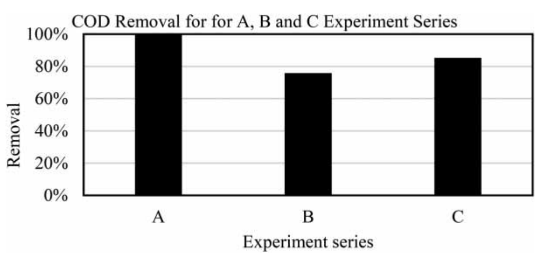

Figure 7 | Efficiency of elimination of COD parameter in test series of A, B and C.

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efficiency of ABS testing was 98.6% in test A, 96.6% in test B and 96% in test C. In the experiments, $ABS_{GW1} = 0.15$ mg/L decreased to $ABS_{GW2} = 0.002$ mg/L and $ABS_{GW1} = 0.21$ mg/L decreased to $ABS_{GW5} = 0.007$ mg/L. In test C, $ABS_{GW1} = 0.25$ mg/L reduced to $ABS_{GW5} = 0.01$ mg/L. Figure 8 shows the efficiency of removing ABS for three series of tests by the designed system.

If the better performance of UV disinfection systems is to be considered, the parameters that prevent light reaching the sewer must be removed before reaching the disinfection unit. Utilizing a UV-C lamp in the disinfection unit was quite effective. The disinfection properties of the UV lamp expire as soon as it is turned off. For this reason, a pump is installed in the storage tank to regularly pump the treated gray water to the disinfection unit in order to prevent the growth of microorganisms and maintain the microbial quality of the treated wastewater. The efficiency of the disinfection system in this study was 100% in all three series of experiments, and all coliforms were destroyed, and finally, no coliform was observed in the treated gray water.

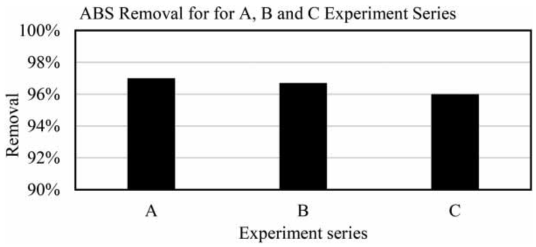

Figure 8 | Efficiency of removing the ABS parameter in test series of A, B and C.

Reuse potential

To investigate the reuse potential of gray water treated through this system, the measured parameters were compared with the Iranian environmental standard. Iran's environmental standard has set different permissible limits for various purposes. Table 4 shows a comparison of the

Table 4 | Comparison of Iranian standard for various uses of wastewater treated through the system

			Iranian environmental standard for agricultural and irrigation		Iranian environmental standard for absorbent wells		Iranian environmental standard for discharging in surface waters	
Experiment series	**Parameters**	**Wastewater treated through the system**	**permissible limits**	**System status**	**Permissible limits**	**System status**	**Permissible limits**	**System status**
A	pH	7.6	6.5–8.5	PASS	5–9	PASS	6–8.5	PASS
	TSS (mg/L)	0	40	PASS	–	PASS	100	PASS
	BOD (mg/L)	0	30	PASS	30	PASS	100	PASS
	COD (mg/L)	0	60	PASS	60	PASS	200	PASS
	ABS (mg/L)	0.002	1.5	PASS	0.5	PASS	0.5	PASS
	Total coliform (in 100 mL)	0	1,000	PASS	1,000	PASS	1,000	PASS
B	pH	7.5	6.5–85	PASS	5–9	PASS	6–8.5	PASS
	TSS (mg/L)	1	40	PASS	–	PASS	100	PASS
	BOD (mg/L)	1	30	PASS	30	PASS	100	PASS
	COD (mg/L)	60.5	60	FAIL	60	PASS	200	FAIL
	ABS (mg/L)	0.007	1.5	PASS	0.5	PASS	0.5	PASS
	Total coliform (in 100 mL)	0	1,000	PASS	1,000	PASS	1,000	PASS
C	pH	7.6	6.5–8.5	PASS	5–9	PASS	6–8.5	PASS
	TSS (mg/L)	2.5	40	PASS	–	PASS	100	PASS
	BOD (mg/L)	5	30	PASS	30	PASS	100	PASS
	COD (mg/L)	77.8	60	FAIL	60	PASS	200	FAIL
	ABS (mg/L)	0.001	1.5	PASS	0.5	PASS	0.5	PASS
	Total coliform (in 100 mL)	0	1,000	PASS	1,000	PASS	1,000	PASS

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Table 5 | Comparison of WHO standard for various uses of wastewater treated through the system

Experiment series	Parameters	Wastewater treated through the system	WHO standard for irrigation of ornamental fruit trees and fodder crops (A)		WHO standard for irrigation of vegetables likely to be eaten uncooked (B)	
			Permissible limits	System status	Permissible limits	System status
A	TSS (mg/L)	0	<140	PASS	<20	PASS
	BOD (mg/L)	0	<240	PASS	<20	PASS
	Thermotolerant coliforms (in 100 mL)	0	<1,000	PASS	<200	PASS
B	TSS (mg/L)	1	<140	PASS	<20	PASS
	BOD (mg/L)	1	<240	PASS	<20	PASS
	Thermotolerant coliforms (in 100 mL)	0	<1,000	PASS	<200	PASS
C	TSS (mg/L)	2.5	<140	PASS	<20	PASS
	BOD (mg/L)	5	<240	PASS	<20	PASS
	Thermotolerant coliforms (in 100 mL)	0	<1,000	PASS	<200	PASS

permitted environmental standard in Iran for reusing wastewater with gray water treated through the designed system. According to Table 4, the gray water treated by this system failed to meet the Iranian environmental standard for the COD parameter in the B and C series of tests for discharging in surface waters and absorbent wells, but the treated gray water is quite suitable for agricultural and irrigation purposes. The inability of this system to reach the permissible standard value for the COD parameter is due to the lack of a chemical treatment unit. Discharging the treated gray water in absorbent wells or surface water is not reasonable unless it is not possible to use gray water for other purposes. In fact, the aim of this study was to refine the raw gray water to use for irrigation and agriculture, which was achieved.

In 2006, the World Health Organization introduced a standard for microbial parameters. This guideline outlines microbiological requirements without considering the other physical and chemical parameters (WHO 2006). Table 5 shows the comparison of the WHO standard for reusing wastewater with gray water treated through the designed system (WHO 2015).

CONCLUSIONS

Reusing treated gray water, in addition to reducing freshwater consumption, also lessens the volume of wastewater entering the environment. Most gray water treatment systems require an operator in addition to the high initial construction cost. On the other hand, the volume of the produced treated wastewater is in excess of the domestic consumption. Also, smaller systems that are used on a domestic scale may not be as efficient as removing contaminants of the gray water. Therefore, it is important to design an effective system that is commensurate with the amount of domestic consumption. Sampling the raw gray water from three different production sources in 18 shifts, it was found that the gray water from women's hand basins had a higher pollution load than men's basins and women's bathrooms. Thus, in the next experiments designed to evaluate the performance of the treatment system, this wastewater was used. This study, after examining the characteristics of gray water produced at Birjand University in Birjand, showed that using an aeration process including two filters and a UV disinfection unit can be an effective system in treating gray water. This system worked perfectly well, especially regarding removing the total coliform parameter. Based on the obtained results, the efficiency of the system designed for the TSS, BOD, COD, ABS and total coliform in the critical state was 96.3, 97.6, 758, 96 and 100% respectively.

For different uses, the Iranian standard and WHO has set a different allowable range for water pollutant parameters. This study examined the parameters of pH, TSS,

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BOD, COD, ABS, and total coliform. The results of these experiments showed that in all but two cases the application of treated gray water in this system can be suitable for discharging in wells, groundwater recharging, and agricultural applications. According to the Iranian standard, in only two cases was the COD parameter higher than the allowable level for groundwater recharge and discharge in the absorber well. Also, according to the standard of the World Health Organization this treated wastewater can be used for the irrigation of decorative trees, fodder products, and plants that are consumed uncooked.

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DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

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