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Treating gray water by anaerobic digestion in order to use in landscape irrigation

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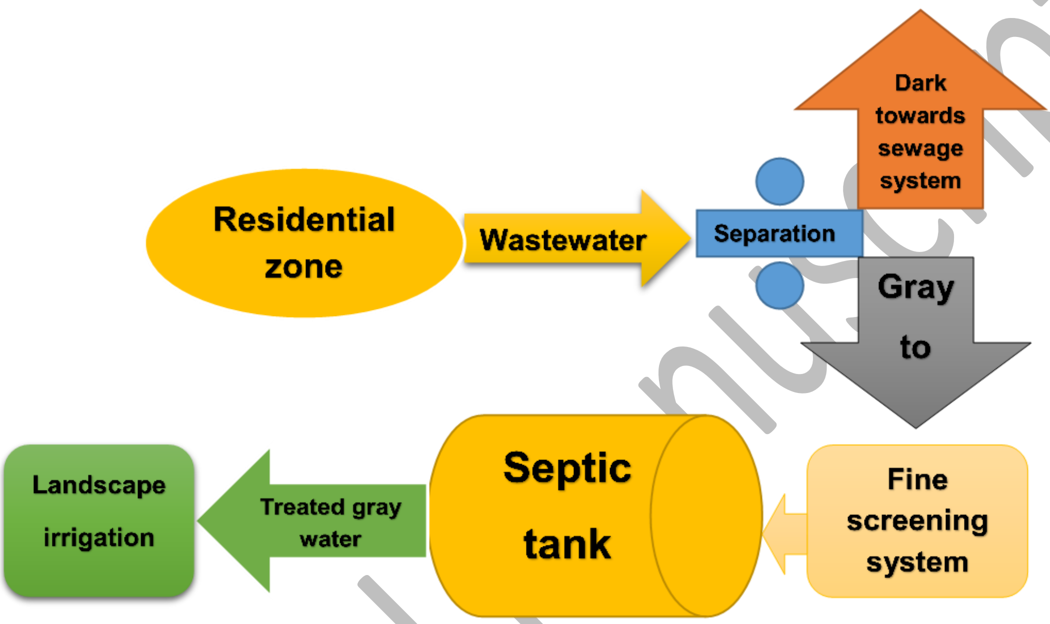
GRAPHICAL ABSTRACT



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ABSTRACT

Wastewater output has increased considerably as a result of global population growth. Efforts to manage wastewater are expanding globally. Bio-based methods are useful and effective for treating a wide range of wastewaters, especially those from homes. In this research, the gray water stream at Sari Agricultural College in the north of Iran was treated using an anaerobic biological method. The purpose of this study was to determine whether using treated gray water for landscape irrigation was feasible or not. A fine screening pre-treatment system and a septic tank system were created in order to achieve this goal. After the first stage screening of superfluous solid components, anaerobic digestion was carried out for 26 hours at a temperature of between 14 and 16 °C in a 5 m^3 septic tank. Treatment method function was revealed by measuring and comparing the pollutant indices with the permissible rates. The obtained data were: BOD 19.5 mg/L, COD 185 mg/L, Suspended Solid (SS) 90 mg/L, Organic Matter (OM) 80 mg/L, NO_3 26 mg/L, PO_4 6.25 mg/L, Oil and Grease (O&G) 9.3%, pH 5.9-7.1. The permissible rates for these indices are 100, 200, 200, 300, 30, 6.75, 10, and 6.8-7.1, respectively. The treated gray water was allowed to be utilized as irrigation water. After irrigating, the landscape did not face any negative effects. Nonetheless, the high acidity was owing to the detergents in effluent and this was the main reason provides a vast range of microelements leading to poisoning plants in a long period.

1. Introduction

Regarding to the increasing in the world population in last decades, the wastewater production rate has steadily increased. Thus, it is one of the most menacing threats for human, animals, and the environment. Arranging some novel methods to manage this pollution is vital to protect the beneficiaries. It is clearly shown; first of all, wastewater destructs the environment and affects other creatures by this action. Therefore, it is logical to control their contamination in production sources. In this case, the presented methods will be more effective an economical. The receiving water sources drop due to the wastewater effluents' quality (Akpor and Muchie, 2011). This might be credited with wastewater effluent that has been left untreated or treated insufficiently, which can promote eutrophication in receiving water bodies. Furthermore, it produces circumstances outside that facilitate the growth of cyanobacteria toxin-producing waterborne diseases.

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Recreational water users are also at risk, as is anybody else who comes into contact with the contaminated water. Even while a wide range of microorganisms are helpful to wastewater systems, many of them are thought to have played an essential role in a number of waterborne sicknesses (Akpor and Muchie, 2011).

In regards to urban wastewater, there are two distinct types; first kind is known as dark water and the second one is gray water. Those components are completely different and it is because of their production sources. In addition, each one has unique managing methods and equipment. Generally, pollution control of dark water is more difficult than gray one. Wastewater from showers, baths, sinks, kitchens, washing machines, and laundry machines, excluding toilet water, is referred to as gray water. Treatment options include physical, chemical, biological, and natural treatments, or a combination of these (Edwin, Gopalsamy, and Muthu, 2014). After a suitable treatment, gray water can be recycled for a variety of purposes, including car washing, floor washing, ground replenishment, gardening and plant irrigation, and agricultural irrigation. As it mentioned, toilet is the only source that produces dark water in cities. Therefore, it helps the managers on the way to plan for the pollution control methods. The physical, chemical, biological, nutritional, ground element, and heavy metal properties of different gray water supplies are all thoroughly described in the content (Edwin, Gopalsamy, and Muthu, 2014). Because the diversion procedures are not suitable for residential use based on the contaminant loads, treatment is required before storage and reuse (Edwin, Gopalsamy, and Muthu, 2014). From decades ago, people have tried to find the ways to consume this used water in some different activities. Eventually, they have found that this water is not potable even if that has been treated. However, it does not mean the gray water should be disposed. This polluted stream becomes consumable with doing a few steps in local water treatment plants. There are many activities can consume this water. Industry, agriculture, and construction are some of those. Whenever treated appropriately to lower the risks of microbiological and chemical contamination to levels suitable for its intended reuse applications, gray water can be an inexpensive supply of water. Gray water pretreatment with cartridge filtration, microfiltration, and aerobic biofiltration is able to be evaluated for membrane flow, chemical oxygen demand reduction, and salt rejection (Boddu *et al*., 2016). Typically, the amount of gray water found to be 50–80% of the household wastewater regarding to countries' consuming habits (Gross *et al*., 2007). Thus, it is logical to recycle and reuse that. To this aim, there is need to provide and compare some treatment methods before implementing them. Therefore, reviewing and assessing the prior studies can be helpful so much. Researchers and authorities are both responsible against wastewater treatment. Local authorities must offer rebates and subsidies in order to financial assist the installation of a system for recycling gray water, eventually attaining the goal of water sustainability. Researchers should collaborate closely with these entities to monitor the gray water recycling systems (Oh *et al.*, 2018). Grey water treatment helps to use of techniques for managing water consumption, especially in urban settings. It can help the water sector become more sustainable (or at the very least, less unsustainably). Moreover, Its subsequent application for many uses is one of the solutions for demand control that has a significant potential to save water (Memon *et a*l., 2005). On the treatment ways, the biological and comprehensive programs successfully treat grey water overall, with the elimination of organics being especially successful. However, Methods that integrate many techniques to ensure efficient handling of all the fractions have the highest overall performance (Pidou *et al.*, 2007).With considering all gray water's details, it is obviously clear this liquid can considered as a feedstock in some treatment processes. Thereby, choosing the best and most practical method to implement is done by assessing this feedstock's components.

Sari agricultural college is one of the initiative schools in Iran, which work on agriculture and the environment counteractions. In this school, there are always some plans in view to reduce the environmental pollution. It has been tried to provide and establish the systems, which are compatible with the environment. However, a problem that had not been solved and kept getting worse every year. Wastewater is the subject of discussion, and because of its high potential for pollution, it must have been studied and scheduled. In this college, the main process to manage the produced wastewater was a simple system. Gray and dark waters were together gathered and transmitted into a pool. Trucks discharged pool intermittently and this chain had been repeating for years.

The scheduled method simultaneously follows two aims, which not only controls the wastewater pollution, but also, provides a suitable water resource as a way to irrigate. Investigating The findings of the chemical testing showed that the usage of gray water from residential and commercial buildings for agricultural uses was acceptable and could be trusted (Ibraheem, Alshammari, and Alwan, 2020). It is possible to effectively irrigate with treated gray water without damaging the soil or plant growth. However, raw gray water has the potential to drastically alter soil characteristics, which could have an impact on how water moves through the soil and how toxins are transported in the vadose zone (Travis *et al*., 2010). The short-term effects of gray water on the chemical and physical characteristics of the soil were determined. In the treatment plot, the soil bulk density (BD) dropped somewhat from 1.45 g/cm3 at the start of the trial to 1.34 g/cm^3, demonstrating appropriate soil conditioning throughout the trial of gray water irrigation (Pandey, Srivastava, and Singh, 2014).

2. Materials and methods

As previously mentioned, the wastewater system was integrated, and in order to separate it, the previous structure was removed and two collecting systems were constructed. In this case, there were two distinct dark and gray waters' outlets. Dark water volume sharply decreased because its production source was just toilet, while, the gray water outlet volume was significantly notable. Following the installation of the new system, the gray water stream dropped to 4.6 m^3 and its pollution potential decreased. However, complementary processes were still required to turn that into a usable water supply for irrigation.

2.1. Sampling and measurement

Gray water is a compound stream. Table 1 shows these components in the sampled gray water in the case study place.

Table 1. Different gray water sources and their components

Gray water sources	Components
Washing machines	Suspended solids (SS), Organic matter (OM), Oil and Grease (O&G), High pH, NO_3, PO_4
Dish washer machines	SS, OM, Bactria, High pH, Detergents, Fatties, Oil, Grease
Bath	Bactria, SS, OM, Detergents, Soap, O&G
Kitchen sinks	Bactria, SS, OM, Detergents, O&G

The quantity of small solid particles that function as colloids and stay suspended in water or wastewater is known as suspended solids (SS). The measurement of suspended solids is one way of gauging water (Verma, Wei, and Kusiak, 2013). Total suspended solids (TSS) are another type of SS. They are considered as one of the main contaminants that degrade water quality, increase the expense of treating water or wastewater, reduce fish populations, and generally pull down the aesthetics of the water (Bilotta and Brazier, 2008). Organic matter (OM) refers to the carbon-based compounds that are present in the wastewater. NO_3 and PO_4 are both derived from the detergents and they are the main reason to eutrophication phenomenon. Oil, grease, detergents, fatties, and soap are all the remains from using the detergents and/or washing processes.

Samples for the analysis were collected from the treatment system outlet (final treated gray water). A part of treated gray water was taken out immediately after the first cycle of treating. Samples were analyzed by using the standard methods of analysis of water and wastewater of APHA (Rice and Bridgewater, 2017). During this examination, each indicator was analyzed and its data organized in a table to make a comparison with the standard data. Sampling determined most of compounds were organic. In addition, there was solid pieces in stream that should have been taken into account in designing the treatment method.

2.2. Fine screening

A simple separator was employed on the way to separate the solid substances before transmitting the gray water into septic tank. The treatment way was consisted of two stages (screening and anaerobic digestion). For the first stage, a fine screening system was designed. It was necessary to take some components out from the gray water flow. Screening helps to remove the solid compounds and makes the raw wastewater suitable to treat by biological methods. It is also a promising option for removing the inorganic components.

One of the principal benefits of a fine screening system is its greatly reduced area requirements, which are around one tenth of what a primary settling tank would require. In particular, fine screening should be considered as a cost-effective and efficient upgrade option for small sewage treatment plants that do not require pretreatment. Fine screening can provide high rates of COD/BOD elimination. which can lessen the strain on biological treatment systems downstream and boost clarifying capacity (Kink, 2016).

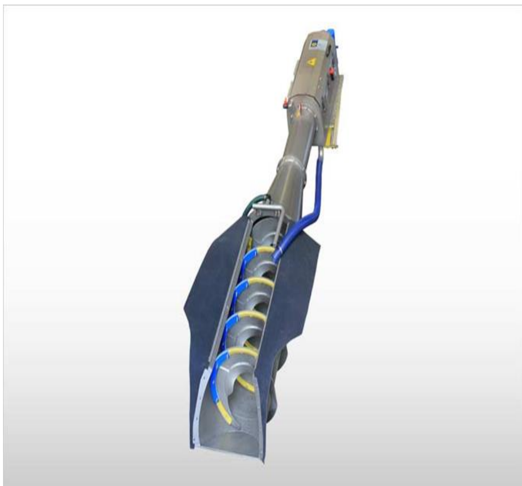

Fig. 1. Schematic of employed fine screening system.

2.3 Anaerobic digestion

Anaerobic digestion (AD) was the main process, with screening following in first. To do the AD an ideal situation was needed. The basic prerequisites for AD are provided by the septic system. Septic tanks are continuously supplied with domestic wastewater at three different hydraulic retention times (HRTs), ranging from 24 to 72 hours (Nasr and Mikhaeil, 2015). Reusing wastewater that has not been contaminated by feces, or gray water, can help lessen the world's water shortage, particularly in arid and semi-arid areas. Gray water is frequently treated using biological techniques (Khalil and Liu, 2021). Biological treatment systems are more appropriate for treating gray water in local treatment systems and septic system is the best one (Toifl, Diaper, and O'halloran, 2008). In this research, the used septic tank was made of polyethylene and was a modular type in order to easy installation. Fig. 2 shows the septic tank that was buried in land. Different septic systems are utilized depending on the local conditions. A septic tank and a trench or bed subsurface wastewater infiltration system both make conventional wastewater treatment system (Singh, Kazmi, and Starkl, 2015).

Fig. 2. Septic tank buried in land.

2.4 New septic system design

Single-family home or small business are the users of conventional septic system (Subramani and Akela, 2014). Nonetheless, it was changed with considering the final purpose of doing this research. Instead of incorporating the drainfield, a fine screening system was installed before the septic tank. That was because of using the outlet in irrigation. Fig. 3 illustrates a conventional septic system. In the conventional system, the main purpose is recycling the treated water into the underground water resources. Thus, its effects will be appear in the future and is similar to a replacing method that aims to protect the frequently used sources. The gravel/stone drainfield pattern has been around for many years (Vinod Kumar, Puthuvayi, and Robi, 2022). With this procedure, a shallow stone or gravel underground trench is filled with wastewater that is discharged from the septic tank. Then, a geofabric or comparable material is positioned above the trench. Therefore, keep sand, dirt, and additional pollutants away from the clean stone. When effluent enters the soil under the gravel/stone trench, it is further cleaned by bacteria after going through the stone. Because of their comparatively wide total footprint, gravel/stone systems might not be appropriate for all home locations or circumstances (VEAL, 2021). By using the natural layers in gravel/stone process, there is no need to any extra facilities. Ultimately, the overall project budget decreases; additionally, gravel/stone layers function as either rapid or slow sand filters without requiring frequent cleaning. During this study, a multiple work was done step by step, where each step was a complementary for the next step. Additionally, an innovative design was used in place of the conventional septic tank system. That was for utilizing the outlet in landscape irrigation.

Fig. 3. The conventional septic system.

2.5. Treatment process

Eventually, the designed system was implemented and septic tank filled. Every element listed in table 1 came into interaction with anaerobic microorganisms and the growth phase started. During the AD, HRT was 26 h. The selected process was a low-temperature anaerobic digestion (LTAD) which known as psychrophilic anaerobic digestion (PAD). LTAD has been employed by cold (<20 °C), low-strength, large volume waste streams (such as many municipal and industrial wastewaters in temperate states) because of the best performance (McKeown *et al*., 2012). The ideal temperature for PAD is lower than 20 °C (Akindolire, Rama, and Roopnarain, 2022). In present study that was between 14-16 °C. In this range, psychrophilic organisms proliferate steeply and the highest digestion happens. COD/BOD_5 ratios (Table 2) indicate potential for biodegradability for wastewater treatment options except for laundry gray water. However, comparison of the COD:N:P ratio with the optimal value of 100:20:1 indicates severe nitrogen deficiency. COD:BOD rate for the combined gray water is 3:1 and may increase up to 4:1, in this case that is much higher than of residential wastewater (Edwin *et al.*, 2014).

Table 2. Key ratios for biodegradability of gray water.

Gray water source	COD/BOD_5 ratio	COD:N:P ratio
Shower	2.7	100:3.2:0.3
Wash basin	2.5	100:2.6:0.3
Kitchen	1.2	100:2.8:4.3
Laundry	8.3	100:1.2:1.2
Combined	3.1	100:2:1.9

COD and BOD are two indicators that their ratio should have been decreased to an acceptable amount. In this case, gray water can be used for irrigation and/or other activities. In addition, removing suspended particles, oil and grease, turbidity, microbes, and maintaining the appropriate pH level in treated water are all necessary for gray water to meet the non-potable water quality standard (Manna, 2018). To remove all components from gray water, pretreatment and complementary treatment steps are performed (fine screening and AD). Pretreatment was used for separating the coarse particles, O&G to prevent obstruction throughout the ensuing therapies. Fine screening can be used to get rid of solid particles (size < 6 mm). Prior to beginning any physicochemical or biological treatment, the pretreatment phase must be completed (Parjane and Sane, 2011). On the way to prepare the gray water for irrigating, the components, which were shown in table 1 should have been removed or decreased. After performing AD process, the ratio of any existent compounds decreased gradually. The pretreatment process removed oil, grease, soap, lipids, and other materials like leaves and cloth. After this stage was completed, the septic tank was filled with raw gray water that was acceptable and the necessary circumstances were set up to prepare an ideal environment for the activation of anaerobic microorganisms. All parameters were kept under control during the process, and regular pH measurements were carried out to determine the ideal range for AD. Temperature is another crucial indicator and to achieve the ideal range, the septic tank was covered with insulation and buried in the ground. Lack of air inside the tank is vital in AD. Air gaskets were used to seal the septic tank hatches as well as the inlet and outlet spouts. The outlet flow, which was more transparent than the entrance flow, made the alterations easy to see. Moreover, scum over the liquid in the septic tank was recognizable. In the end, revealing the indicators' ratio was the key step. This step involved sampling one liter of treated gray water and measuring the indicators listed in the Table 1.

2.6. Irrigation

Treated gray water stored in a pool and surface irrigation was done three turns in a month. During the irrigation period, other water sources were not used and this step's observations were recorded to compare with the previous situation.

3. Results and discussion

The obtained results were categorized into two sections, either is experimental and practical. According to results, first section shows if AD process was successful or not and another one determines the observations which were obvious after irrigating. The measured amounts showed that the data obtained through this research and the data from the references did not differ significantly. For instance, BOD concentration was 19.5 mg/L. Maximum allowable limit for discharging effluent in the environment is 20 mg/L but for irrigation usage it would be 100 mg/L (Mangkoedihardjo, 2006). Moreover, COD rate was found 185 mg/L while, the permissible rate to discharge is 200 mg/L (El-Fadel, Bou-zeid, and Chahine, 2003). It can be acceptable up to 500 mg/L (Samudro and Mangkoedihardjo, 2010). SS is the mass (mg) or concentration (mg/L) of two inorganic and organic matters, which can be found in the water column of a stream, river, lake or reservoir by turbulence. That contains the particulates matter with a diameter of less than 62 µm (Waters, 1995). The permissible rate of this indicator is 30 mg/L for all disgorges and for irrigation is 200 mg/L. It was found to be 90 mg/L in this research samples. SS concentration is generally more than 350 mg/L in all waste waters and the permissible rate is up to 40 mg/L for disgorging in the environment (Raman and Narayanan, 2008). Even so, in this research samples, this was detected 90 mg/L and its range was acceptable by considering the treatment method. Because this method is known as a primary treatment step and not an advanced system. Biological pre-treatment or main treatment methods can be applied to remove organic matter from discharge in an energy-efficient way (Van Gijn *et al.*, 2021). OM has an unavoidable role in the environment (Bolan *et al.*, 2011). The OM amount in the soil has an impact on water retention capacity, nutrient absorption, and the soil's potential to supply nutrients for plants to grow. The amount of oxygen that fish can breathe in a stream is determined by the organic matter content of wastewater that is released into it. Organic materials make up about 40% of the filterable solids and 75% of the suspended solids (Levine, Tchobanoglous, and Asano, 1985). In recent treatment system's outlet, OM concentration was 280 mg/L. Another indicator is NO_3 that should be decreased in wastewater stream in the effluent of wastewater treatment plants. NO_3 can range up to 30 mg/L (Kass *et al.*, 2005). It was measured as 26.5 mg/L in present study. One of the compounds that needs to be mitigated is PO_4, which together with NO_2 are damaging aquatic life. Biological treatment processes are able to decrease phosphate concentration for almost 60%. The limitation levels are 2.2 mg/L phosphorus (6.75 mg/L PO_4) (Raman and Narayanan, 2008). In this research samples, it was figured out 6.25 mg/L and was near to the highest range of permissible rate. Finally, O&G contents and pH range were analyzed, respectively. The obtained data pointed out low contents of O&G. In general, less than 10% of treated wastewater is consisted of these compounds El-Gawad, (2014) and in caught samples it was 9.3%. Moreover, pH range was between 5.9-7.1 where the acceptable range is 6.8-7.1 (Kesalkar, khedikar, and Sudame 2012). Acidity in the treated flow was derived from the detergents in the gray water (Heidari, 2012). Acidity increases the availability of some microelements to toxic levels, particularly aluminum and manganese (Rorison, 1980).
All mentioned findings were summarized in table 3 and compared with the permissible ranges. Going through this table, the differences between measured and permissible values are recognizable.

Table 3. Measured rates against the permissible ranges of indicators

Indicators	Measured range	Permissible range
BOD	19.5 mg/L	100 mg/L
COD	185 mg/L	200 mg/L
SS	90 mg/L	200 mg/L
OM	280 mg/L	300 mg/L
NO_3	26.5 mg/L	30 mg/L
PO_4	6.25 mg/L	6.75 mg/L
O&G	9.3%	10%
pH	5.9-7.1	6.8-7.1

O&G indicator means the amount of O&G content, which is still present in gray water stream. All permissible ranges are flexible regarding to the purposes of their treatment. If final consumers are not human or creatures, they can rise. Nonetheless, it makes logical to keep their ranges below the permissible limits.

4. Conclusions

Comparing the obtained data with the standard rates, it is obviously apparent that within this study's findings and permissible levels there were not many significant differences. All indicators except the pH were lower than the highest permissible levels. Nonetheless, pH was between 5.9-7.1, whilst, the permissible range is 6.8-7.1. As a result, it concludes that the lowest rate, which was lower in samples, must be over 6.8. With a glance at table 3, it is explicitly recognizable that the used method to treat gray water was practical and could decrease the pollutants ratio. BOD, OM, and SS were satisfactorily decreased. It was because of the biological treatment method. The problem with irrigation was that the soil became acidic due to low pH. Excessive acidity is the cause of a wide variety of microelements that plants get and leads to plant poisoning. However, there are a number of ways to manage this unpleasant aspect, so it should not be a barrier to using a septic tank system to treat gray water.

Conflict of Interest

There is not any conflict of interest between the authors.

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Data Availability Statement

Corresponding author will permit using the datasets used on request.

Author Contribution

Reza Kheyri: English editing, method designing, calculations, analysis and statistical analysis of data, analysis and interpretation of information and results.
Mohammad Ali Maysami: Supervisor, review and control of results, finalization of the article.
Ali Alishah: Sampling, testing and data collecting.

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