Original Research Article

Evaluating the Efficacy of Sand Filtration for Greywater Treatment: Impact of Column Length on Water Quality and Irrigation Suitability

Abstract

Aims: This study explores the efficacy of sand filtration in treating greywater (GW) collected from a hostel.

Methodology: An experimental setup was designed using five connected polyvinyl chloride (PVC) pipes filled with sand sourced from the Cauvery River. The GW was filtered through sand columns of varying lengths (40 ft, 60 ft, 80 ft, and 100 ft), with the filtered water analyzed for various physio-chemical parameters.

Results: The results indicate that sand filtration significantly reduces the levels of total suspended solids (TSS), electrical conductivity (EC), and other anions and cations, including chloride (Cl^-), sulphate (SO_4^{2-}), and sodium (Na^+). The pH of the untreated GW was initially alkaline but was reduced to near-neutral levels after treatment with the 100 ft sand column. Key water quality indices such as Sodium Adsorption Ratio (SAR), Sodium Ratio (SR), and Soluble Sodium Percentage (SSP) were within safe limits post-treatment, making the filtered GW suitable for irrigation.

Conclusion: The study concludes that sand filtration is an effective method for treating GW, particularly when longer sand columns are used, though further research is needed to optimize the filtration process for specific contaminants.

Keyword: Greywater Treatment, Sand Filtration, Water Quality Indices, Irrigation Water, Column Filtration Length.

Introduction

The need for water is growing daily because of increased industrialization, population growth, climate change, and the careless use of available water supplies. Ninety-seven percent of Earth's total water resources are contained in the oceans, with the remaining three percent accessible for direct use. Of this three percent, just one hundredth of the water is thought to be available for human use (Eakin and Sharman 2010). In most regions of the world, water scarcity is one of the most serious and noticeable threats to environmental integrity and public health. Using innovative methods for wastewater recycling, it is possible to promote sustainable development and safeguard the quantity and quality of water bodies while addressing the growing demands on this limited and essential resource (Pappalardo et al., 2010).

There are two categories of waste water: the first is known as "Blackwater" and comprises the water that is released from toilets. It is high in pathogens. In addition to nitrogen and phosphorus, it also has a high concentration of organic matter (Juma et al., 2018). The second kind is known as "grey water (GW)" which is water collected from the sewage discharge of sinks, bathtubs, showers, and clothes washers. It gets its name from the fact that when it is left for a long time, its colour changes to grey (Nolde, 2000). More than 60% of all domestic wastewater originates from GW running from showers, washing machines and bathroom sinks. This suggests that GW is a desirable resource for irrigation if managed responsibly and in accordance with environmental guidelines. Grey water is an additional source that should be used in addition to the total amount of water used in this water crisis scenario (Packialakshmi et al., 2015). Various water-demanding activities, such as agriculture, gardening, landscape irrigation, golf courses, fire suppression, air conditioning, soil compaction, building, toilet flushing, and public park irrigation, can be accomplished with recycled GW (Emmerson and Emmerson 1998).

According to Vengeswaran and Sundaravadivel (2004), the main concerns regarding GW reuse have been related to public health attitudes and the deployment of inadequate technology for the reuse option. Numerous scholars have examined the features of GW in relation to fixtures, lifestyle choices, and settlement types (Alsulaili and Hamoda, 2015). Thus, a low-cost technique for GW treatment was tried to restore the depleting water supplies for future sustainability, which can then lessen the extraction of groundwater.

There are numerous methods and tools available for treating water. Depending on the rate of pollution or the location, these methods may vary. But the fundamentals remain the same. Numerous water treatment methods, including sedimentation, filtration, disinfection, fluoridation, etc., might be mentioned. However, the focus of this work is on filtration, more especially "slow sand filtration (SSF)". This procedure is acknowledged as a viable filtration technology for eliminating organics, water-borne pathogens, and lowering turbidity (Guchi, 2015). It is also recognized as a good technology for all forms of wastewater treatment in rural regions. A sand medium is used in an SSF system's filtration process, which removes impurities from the water by allowing it to percolate through a variety of physical, chemical, and biological processes. ~~John Gibb created the first documented SSF system in Scotland in 1804 to generate drinking water (Zearley and Summers, 2012).~~ Since then, this method has been extensively employed to produce drinking water as well as to enhance the quality of wastewater prior to its reuse or release into the environment.

Therefore, our research encompasses the following three objectives:1.To evaluate the effectiveness of sand filtration in reducing physio-chemical parameters in GW.2. To investigate the impact of varying sand column lengths on GW quality improvement.3. To assess the suitability of sand-filtered GW for irrigation based on key water quality indices.

Materials and methods

Soil column setup

The experimental study consists of five opaque Polyvinyl chloride (PVC) pipes with internal diameter of 15 cm (6 inches) and a length of 6.096 m (20 feet (ft)). The five pipes were connected to make a 100ft length and kept in a horizontal position (by giving wooden support from the ground level) with a slight slope in order to filter the waste water through sand medium. Sand was collected from the Cauvery River bank which is inThanjavur city. For column experiment the sand passing through 4.75 mm and retained on 600µ IS sieve were used. The PVC pipe was filled with sand and ensure that no empty space should be noticed and outlet valve was fitted at the bottom and iron sheet fixed inside the valve.

Sample collection

The studies were executed in a Dr.M.S.Swaminathan Agricultural College and Research Institute, Thanjavur, India. For experiment purposes, the Greywater (GW) was collected from the boy's hostel at same campus. The GW from the hostel is collected in a tank and passed through the sand filter with height of 40ft, 60ft, 80ft and 100ft at the inlet side and the filtered water is drained at the outlet and collected in a clean sampling bottle. The same process is repeated for sand filters of different heights with three replications. The filtered GW sample is collected and labeled by height of the filter medium for further water quality analysis.

Sample analysis

The pH of the raw GW sample was measured using a pH meter(Fisher Scientific Accumet Basic AB15), which was first calibrated with pH 4 and 7 solutions(Jackson, 1973). Electrical conductivity (EC) was determined using a Systronic conductivity meter with an operating at 27°C(Baruah and Barthakur, 1999).Total suspended solids (TSS) were measured by the method described by Baruah and Barthakur, (1999).The chloride (Cl^-) content of untreated and treated water samples was analyzed by precipitating chloride as silver chloride through titration with standard silver nitrate in the presence of potassium chromate(A.O.A.C, 1950).Sulphate (SO_4^{2-}) was estimated by Turbidometric method based on precipitated as barium sulfate by adding barium chloride with gum acacia at pH 4.8, maintained by a sodium acetate-acetic acid buffer(Baruah and Barthakur, 1999).The Carbonate (CO_3^{2-} ,) and Bicarbonate(HCO_3^-)determined by titrating the solution with standard sulphuric acid using phenolphthalein indicator. (Baruah and Barthakur, 1999).The major cations Sodium (Na^+), Potassium(K^+), Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were analyzed in ion chromatography using American Standard Test Method D6919-17 (ASTM, 2017). Sodium Ratio (SR), Sodium Adsorption Ratio (SAR), Soluble Sodium Percentage (SSP), and Permeability Index (PI) calculated based on following empirical formula,

List 1 Quality parameter formula

Quality parameter	**Formula**
Sodium Ratio (SR)	$SR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$
Sodium Adsorption Ratio (SAR)	$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$

Soluble Sodium Percentage (SSP)	$SSP = \frac{Na^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} * 100$
Permeability Index (PI)	$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{2+} + Mg^{2+} + Na^{+}} * 100$

Statistical analysis

Statistical test of mean for the replicated water quality parameters andTukey HSD test at the 0.05 level (95 %) conducted using Origin (Pro) software, 2024, produced by Origin Lab Corporation, Northampton, MA, USA.

Results and Discussions

The physical and chemical properties of untreated and treated GW samples at different sand column filter length represented in tables 1.

Physical parameters

Electrical conductivity (EC) measures water's ability to transmit electric current, influenced by dissolved ions and temperature, with higher EC indicating more ions and total solids(Dewangan et al., 2023). In this study, untreated water with an EC of 0.767 dS/m, considered highly saline, was reduced to 0.338 dS/m after treatment with a sand filter at 100 ft length, lowering its salinity. High EC content of untreated GW due to bathing and washing activities in hostel.Total suspended solids (TSS) consist of fine particles like microorganisms, algae, mineral particles, and organic matter suspended in water.Untreated GW, identified as highly hazardous due to its high soluble salt content (1350 mg/L), showed decreasing hazard levels at depths of 40, 60, and 80 ft, reaching a low hazard condition at 100 ft (400 mg/L).The relatively high levels of TSS in GW, much of which originates from the kitchen and laundry, may be attributed to washing activities. These include cleaning clothes, shoes, all of which can introduce sand, clay, and other materials that contribute to increased TSS (Oteng-Peprah et al., 2018). The reduction of TSS and EC after sand filtration due to coarse particles aid in the removal of TSS, while fine particles are effective at removing ions through adsorption and ion exchange mechanisms (Chidambaram et al., 2003).

Table 1. The physio-chemical properties of untreated and treated GW samples at different sand column filter length.

Quality parameters	**Sample**				
	Untreated	**40 ft**	**60 ft**	**80 ft**	**100 ft**
pH	8.78±0.11	8.34±0.15	8.28±0.17	7.94±0.19	7.76±0.10
EC (dS/m)	0.767±0.02	0.658±0.02	0.423±0.02	0.345±0.01	0.338±0.01
TSS (mg/L)	1350±8.55	1020±2.65	970±5.55	700±4.57	400±7.70
Cl^{-} (mg/L)	85.2±1.72	71±1.15	63.9±1.03	35.5±0.55	21.3±0.48
Ca^{2+} (mg/L)	64±1.66	60.8±1.17	56±1.28	48±0.62	32±0.45
Mg^{2+} (mg/L)	28.8±0.22	25.92±0.42	24±0.56	19.2±0.16	19.2±0.11
CO□$^{2-}$(mg/L)	0.23±0.01	0.19±0.01	0.13±0.01	0.10±0.01	0.06
HCO□$^{-}$ (mg/L)	463.6±5.84	427±10.22	390.4±8.13	366±8.95	353.8±1.66
SO□$^{2-}$(mg/L)	62.5±1.47	40±0.21	37.5±0.10	18.5±0.22	7.5±0.12
Na^{+} (mg/L)	65±0.97	54±0.22	48±0.30	39±0.51	29±0.66
K^{+} (mg/L)	28±0.63	25±0.45	19±0.44	16±0.41	13±0.13
*Means of replicated data presented in mean ± SEM					

Chemical parameters

pH measures the concentration of hydrogen and hydroxyl ions in water, indicating its acidic, neutral, or basic nature on a scale from 1 to 14. In this study, untreated GW with a pH of 8.78, initially strongly alkaline, was reduced to 7.76, becoming mildly alkaline after treatment with a 100 ft sand column.Sample at 40, 60, 80 ft are moderately alkaline. According to Rakesh et al., (2020), Most of the samples tended to be alkaline due to the presence of alkaline substances, such as sodium hydroxide, commonly found in detergents. The main chemical components in GW were identified as byproducts of these detergents, which contain surfactants that serve as the primary active agents in most cleaning products.

All samples showed chloride (Cl^-) levels below the toxic threshold. The untreated samples contain 85.2 mg/LCl^- and it reduced to 21.3 mg/L at 100 ft column length. Since the Cl^- levels in the GW samples were found to be significantly low, the likelihood of infection may be higher. Cl^- acts as a strong disinfectant, so lower concentrations correlate with higher infection risks (Winward et al., 2008). All samples had sulphate (SO_4^{2-}) content below the toxic level, indicating normal sulphate levels. However, treatment with a sand filter further reduced the sulphate concentration from 62.5 mg/L to 7.5 mg/L.Braga et al. (2014) reported as, the low SO_4^{2-} levels observed might be attributed to the reduced use of sodium lauryl sulfate, a common surfactant in cleaning products, cosmetics, and personal care items.There was a low carbonate content in the untreated and treated GW sample. Carbonate in untreated GW 0.23 mg/L and 0.06 mg/L in 100 ft sand column. The bicarbonate level of all the samples is under safe condition. High bicarbonate reported in untreated GW (463.6 mg/L) and content decreased with increased in sand column length. Lowest (353.8 mg/L) in 100 ft sand column.

Water hardness is determined by the total concentrations of calcium (Ca) and magnesium (Mg). All samples initially had problematic Ca levels, but treatment with a sand column reduced the toxic Ca level from 64 mg/L to 32 mg/L at 100 ft sand column. While the Mg content in untreated samples (28.8 mg/L) and those at 40 (71 mg/L) and 60 ft (63.9 mg/L) depths was problematic, it was within normal limits at 80 (35.5 mg/L) and 100 ft (21.3 mg/L).Chemical reactions that occur during the use of soaps and detergents can also lead to the precipitation of Ca and Mg compounds, which may then be washed away into the GW. All samples had sodium (Na) levels within normal limits, with the raw water's Na concentration decreasing from 65 mg/L to 29 mg/L after treatment with a 100 ft sand filter. Na-based soaps also contribute significant quantity of Na into GW. While the potassium (K) levels in the raw water (28 mg/L) and at 40 ft (25 mg/L) were slightly problematic, they were within normal limits at 60 (19 mg/L), 80 (16 mg/L), and 100 ft (13mg/L) depths.High levels of cations in GW result from the use of hostel cleaning products, laundry practices, chemical additives, and bathing activities. These factors collectively contribute to the mineral composition of GW, making it rich in various cations.

Sand filtration can effectively remove certain anions and cations from water by physical adsorption and absorption, although its efficiency varies depending on the specific ion and the filter design.Increased bed length enhanced water decontamination efficiency by providing additional adsorption sites for physical and chemical pollutants (Barkouch et al., 2018).Slower filtration rates allow more time for adsorption and ion exchange processes to occur, improving removal of some ions (Abdiyev et al., 2023).

Water Quality Indices

The water quality indices of untreated and treated GW samples represented in figure 1. The Sodium Adsorption Ratio (SAR) is used to estimate the likelihood of Na+ increasing its presence on exchange sites at the expense of other cations.Since all samples have an SAR of less than 10, they are classified as having a low sodium hazard, indicating no significant risk. The high SAR value in untreated GW (1 meq/L) and lowest in GW treated by 100 ft (0.787 meq/L) sand column.The sodium ratio of the untreated GW sample is 0.503meq/L and the water treated at 100ft sand column has the sodium ratio of 0.393meq/L, hence it is good.The excess of Na ions in water can classify it as saline or alkaline, depending on whether it is associated with chloride/sulfate or carbonate/bicarbonate ions. The quality of irrigation water is traditionally assessed based on Na levels using the Soluble Sodium Percentage (SSP).If SSP value exceeds 60%, water is considered unsuitable for irrigation(Khan and Abbasi, 2013). In our experiment, the ranges from 30.86% in untreated GW to 26.6% in 100 ft sand column which is in safe condition.

High Na levels in irrigation water can lead to significant soil permeability issues. Permeability is influenced not only by Na but also by the presence of CO_3^{2-} and HCO_3^-, which can precipitate as $CaCO_3$ or $MgCO_3$, thereby reducing Ca and Mg in the water and increasing the proportion of Na.If permeabilityindex (PI)value exceeds 65%, water is considered unsuitable for irrigation. Hence untreated sample, samples at 40ft, 60ft, 80ft are unsuitable for irrigation. But the sample treated at 100ft having the PI 64.5% (i.e., less than 65%), it is suitable to use as irrigation water.The treatment of GW in the 100ft sand filter column gives the best results by reducing the sodium content to the normal level(Adagbaet al., 2022).

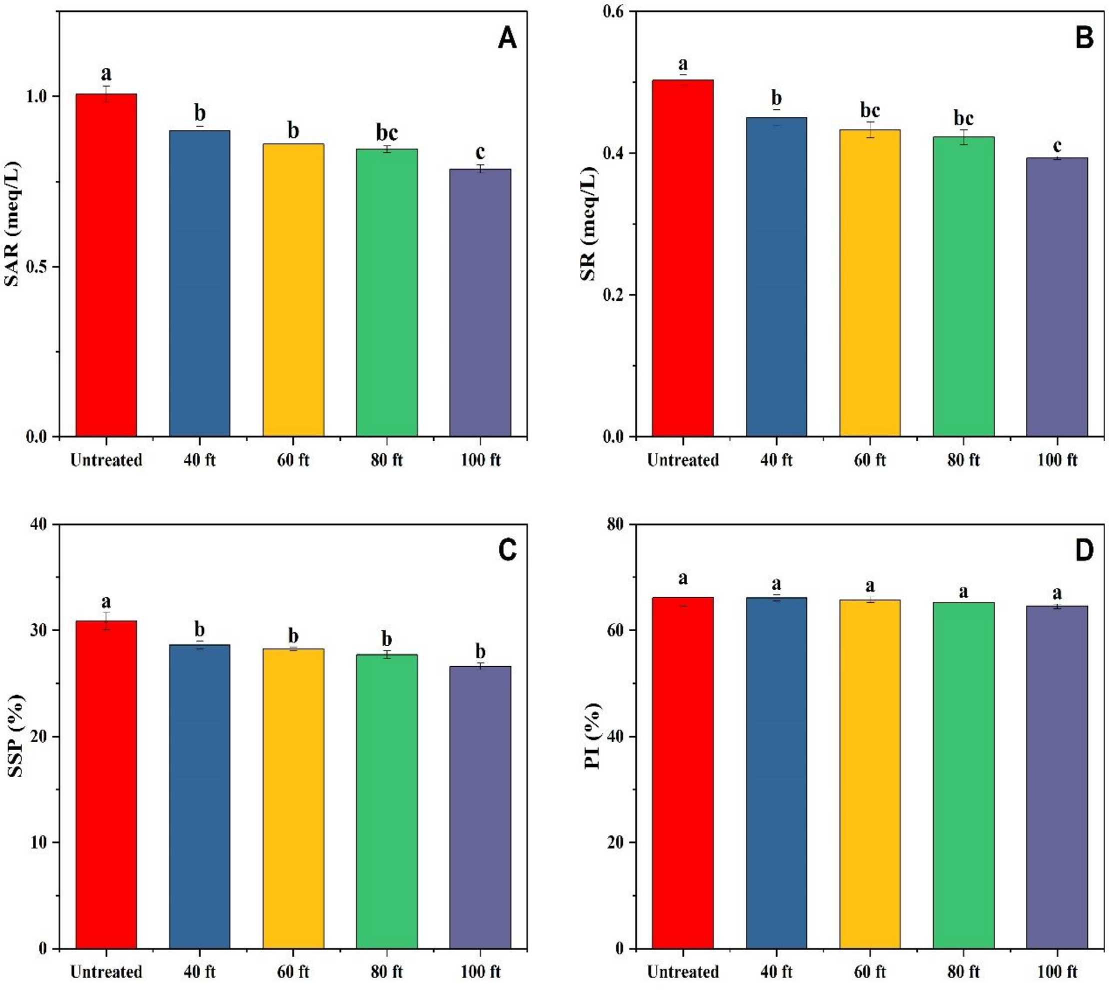

Figure 1. A) Sodium Ratio (SR), B) Sodium Adsorption Ratio (SAR), C) Soluble Sodium Percentage (SSP), and D) Permeability Index (PI) of untreated and treated GW at different soil column length.

Conclusion

This study investigated the efficacy of sand filtration in treating GW from hostel. The treatment of waste water in the 100ft sand filter column gives the best results by reducing the pH, EC, TSS and the hardness to the normal level. The toxicity level of the anions and cations like Cl^-, SO_4^{2-}, HCO_3^-, Na^+ , K^+ were also reduced to the normal level. The length and diameter of the sand column filtration determines the purity of water. Hence the treated GW can be used as irrigation water, since it has no toxicity which is evaluated by the irrigation water quality standards. The findings highlight the potential of sand filtration for GW treatment but emphasize the need for further research to optimize the process and address specific contaminant removal challenges.

Statements &declarations

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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1.

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3.

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