Original Research Article

Design of filtration system for aerated sewage water

Abstract

The study investigated the potential of sand and activated charcoal filtration systems to enhance water quality for irrigation by treating aerated sewage effluent from. Setup involved a 60cm deep sand filter connected as the inlet to another 30cm deep sand filter and this filter linked as the inlet to a 30cm deep charcoal filter. These filters were operated in series at hydraulic loading rates (HLR) of 60m/h and 10m/h. Notably, operating the filters in series at an HLR of 10m/h yielded superior effluent water quality compared to an HLR of 60m/h.System achieved significant removal efficiencies for turbidity, BOD5, COD, Total Nitrogen (Total-N), Total Phosphorous (Total-P) with 71.9%, 54.4%, 71.9%, 44.4%, 39.1%, and 42.9% with a 90cm deep sand filter at an HLR of 10m/h, and also with a combination of sand and charcoal filters at an HLR of 25m/h system achieved 81.6%, 80.3%, 63.5%, 47.5%, and 64.3% respectively.We also examined the chemical characteristics of both untreated and treated sewage water samples, revealing a hierarchy of cation and anion prevalence as follows: Na^{+}> Ca^{2+}> Mg^{2+}> K^{+} for cations, and Cl^{-}> HCO_3^{-}> SO_4^{2-}> CO_3^{2-} for anions. Our study demonstrates that the combination of aeration and sand filtration effectively ensures safety by preventing water body pollution and unpleasant odours with high-quality treated wastewater suitable for sustainable agricultural use.

Key words: Sand, Charcoal, filter media depth, Hydraulic loading rate, Pollutant removal.

1.Introduction

India, which accounts for 18% of the world's population, only has access to 4% of the global freshwater resources, and an overwhelming 80% of the available supply is used for agricultureDhawan (2017)**.**In the 21st century, one of the most pressing global challenges is the unequal access to abundant, clean waterSharma *et al.* (2018).According to estimates, around forty percent of the world's population will be affected by water scarcity during the subsequent five decadesLi and Wen (2016).TheUNDP (2017) report revealed that 800 million people presently experience water stress, with the number projected to rise to 3 billion by 2030. In this situation, opting for the reuse of treated sewage water becomes indispensable.

According to theWHO (2006) report, health hazards associated with sewage water are of greater concern, and this underscores the importance of pre-treating sewage water before reuse, to prevent potential risks to both human health and the surrounding environmentShaikh and Ahammed (2021). So, efficient wastewater treatment systems are essential not only for effective treatment but also as indicators of a municipality's development and community health, where the quality and extent of wastewater treatment influence their impact on nearby water sources when dischargedNaidoo and Olaniran (2014).

(Dalahmeh *et al.*, 2012; Katukiza *et al.*, 2014; Shaikh and Ahammed, 2021) used sedimentation, screening, and oil skimming as pre-treatment methods to enhance the efficiency of sand filters during filtration by diminishing organic load and mitigating media clogging. Shaikh and Ahammed (2021) study showed limited effectiveness in organic matter and nutrient removal through settling, with reductions of 8% for BOD, 13% for COD, and 3% for phosphate. In contrast, Katukiza *et al.* (2014) research achieved significantly better results, achieving 65% BOD, 60% COD, and 25% phosphate removal in just one hour of settling.

Sánchez-Monedero *et al.* (2008) stated that utilizing aeration system for biological treatment can substantially reduce the potential biological risks that wastewater treatment plant employees might encounter.Sand filtration's dual roles of adsorbing phosphorus, heavy metals, and biomass onto sand grains, as well as facilitating the biodegradation of organic matter, demonstrate its effectiveness as a wastewater treatment method, as supported by various studies(De Rozari *et al.*, 2016; Haouti *et al.*, 2018).Activated charcoal's highly porous structure and extensive surface area enable it to effectively eliminate a wide range of contaminantsJjagwe *et al.* (2021).

In Tamil Nadu Agricultural University Coimbatore, there is a facility for collection of sewage removal of organic matter through forced aeration. The treated water is to be passed through sand filtration and charcoal filtration before it is used for irrigating forage crops. The objective of this work is to characterize the depth of sand and charcoal for different hydraulic loading rate(HLR).

2.Materials and methods

2.2 Filter media characterisation

Silica sand(0.7-1.2mm) and coconut shell based activated charcoal(0.5-2.56mm) were used as filter media. The sand and activated charcoal wassieve analysed according toASTM (1998). Characteristics of silica sand and activated charcoal were studiedand shown in Table3.Effective size(D_{10}) values of sand and charcoal were 0.9mm and 0.82mm while the coefficient of uniformity values were 1.67 and 1.82.

The equations used to determine the coefficient of uniformity (Cu) and the coefficient of curvature for both silica sand and activated charcoal are as follows:

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{(D_{30})^2}{(D_{60} \times D_{10})} \quad (2)$$

Where C_u is the coefficient of uniformity, C_c is the coefficient of curvature, and D_{10}, D_{30} and D_{60} are the sizes of the sieve through which 10%, 30% and 60% of the media would pass.

Particle density of the media was determined by pycnometer method(Flint and Flint, 2002). Bulk density and porosity were determined as perKatukiza *et al.* (2014).

2.3 Experimental set up, design and operating conditions

2.3.1 Filter setup

Filter1

Sand filter of height 90cm, inner diameter 48cm is filled with silica sand(0.7-1.2 mm grain size) to a depth of 60cm.

Filter 2

Sand filter with inside diameter 48cm is filled with silica sand(0.7-1.2 mm) for a depth 30cm.

Filter 3

Filter with inside diameter 30cm is filled with activated charcoal(0.5-2.56 mm) for a depth of 30cm.

Prior to placing the media in the filter tanks, the filter media was thoroughly washed using tap water until the water obtained from the media ran clear.

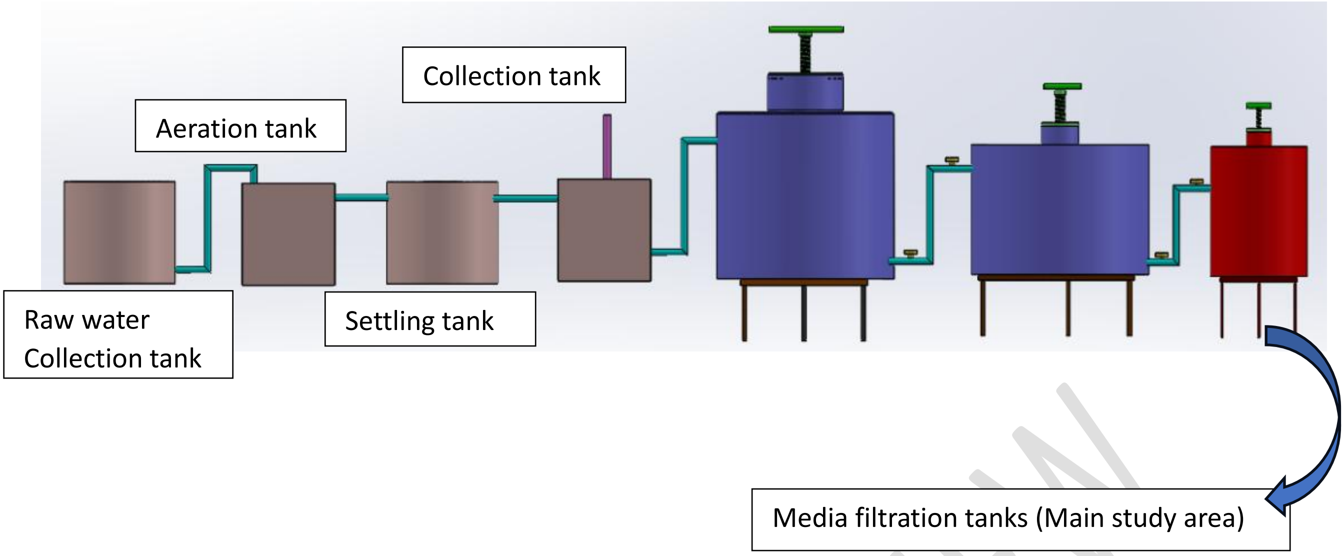


Fig1a: Schematic diagram of experimental set up

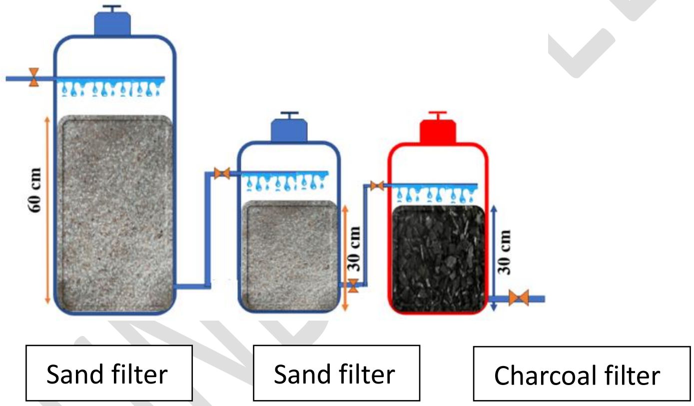


Fig1b : Schematic of sand and charcoal filtering system used in the study

Table1: Details of filter operation during the experimental study

S.No:	**Filter tanks**	**Filter media**	**HLR(m^3/m^2/day)**	
			Trial-1	**Trial-2**

1.	Filter1 &2	Silica sand	60	10
2.	Filter3	Activated charcoal	153	25

2.3.2 Operating conditions

The system was run for 2 weeks at HLR of 60m/h to ripen the filter until steady-state conditionsattained, i.e. when the differences between successive measurements of both COD and BOD were below ±1%Abdelhay and Abunaser (2021). Then thewater samples were collected for the analysis. We operated filters at a higher HLR of60m/h anda HLR of 10m/h.In series connection the outlet of (60cm depth) sand filter was connected as inlet to the sand filter (30cm depth).This filter outlet was connected as inlet to the filter with activated charcoal(30cm)(Fig 2).

2.3Sampling & Analytical methods

Raw sewage water is directed to the aeration tank. The organic matter and nutrients in the raw sewage water is removed in the aeration tank up to some extent. After aeration water is collected in a tank, where it is mixed thoroughly with a stirrer and then this treated water is used as the influent water for the filter tanks. Samples were collected in the morning between 10 AM and 11 AM.

Raw water samples, samples after aeration, and treated samples with sand and charcoal filtershave been collected and analyzed for determining physicochemical parameters using standard methods. pH using(Digital pH meter ISO 9001:2015), EC(Digital conductivity meter ISO:2008),Turbidity(Lovibond turbidity meter), Total suspended solids(APHA 23rd edition-2540D), total dissolved solids(APHA 23rd edition-2540C), dissolved oxygen(APHA 23rd edition-4500C), chemical oxygen demand(APHA 23rd edition-5220B), biological oxygen demand(IS 3025: part 44), total phosphorous(APHA 23rd edition-4500PD), Nitrate-nitrogen, Ammoniacal-nitrogen and total nitrogen(as per IS 3025: part 34).Sodium (Na) and potassium (K) concentration were determined by flame photometry(APHA 3500 Na-B and 3500 K-B). Sulphate was analysed by a turbidimetric method using a spectrophotometer.For the determination of calcium and magnesium, carbonate, bicarbonate, sodium, potassium, chloride and sulphate standard methods have followedAPHA (2017).

The efficiency of reduction due to filtering for each parameter analysed was calculated as follows;

$$E = \frac{C_{in} - C_{out}}{C_{in}} \times 100 \qquad (3)$$

where E is the efficiency(%), C_{in} is the influent concentration and C_{out} is the effluent concentration(Dalahmeh *et al.*, 2012).

Table2: Water quality parameters computed by the following equations

Equation	Reference
SAR $= \frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}}$	Richard (1954)
%Na $= \left\{\frac{Na^{+}+K^{+}}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}}\right\} \times 100$	Wilcox (1955b)
SSP $= \frac{Na^{+}X100}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}}$	Eaton (1950)
RSC $= (CO_3^{2-} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+})$	Richard (1954)
MH $= \frac{Mg^{2+}}{Ca^{2+}+Mg^{2+}} \times 100$	Szabolcs (1964)
PI $= \left[\left\{Na^{+} + \sqrt{HCO_3^{-}}\right\}/Ca^{2+} + Mg^{2+} + Na^{+}\right]$ ×100	Doneen (1964)

Statistical analysis

Multiple regression analysiswas conducted in SPSSsoftware to formulate regression models for different parameters. The results showed annegativeassociation between HLR and efficiency, whereas depth exhibited a positiveassociation with efficiency. The fitted model was highly significant ($p < 0.001$), with NH_4^+-N explaining the highest variation (90%), followed by Total-N (88% of R^2-value), while Turbidity and TSS were not statistically significant predictors of the dependent variable.

3. Results and Discussion

Table3:Characteristics of Silica sand andActivated charcoal

Parameter	**Unit**	**Parameter values of filter media used in this study**	
		Silica sand	**Activated charcoal**
Filter media size range	mm	0.7-1.2	0.5-2.56
Effective size(D_{10})	mm	0.9	0.82
D_{30}	mm	1.2	1.2
D_{60}	mm	1.5	1.5
Coefficient of uniformity C_u	-	1.67	1.82
Coefficient of curvature C_c	-	1.06	1.17
Bulk density	g/cm^3	1.43	0.625
Particle density	g/cm^3	2.79	1.46
porosity	%	48.81	57.19

Table4: Characteristics of raw sewage water and aerated effluent

Parameters	Units	Raw water				After aeration &settling				%Removal			
		Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD
Temperature		26.3	29.5	27.9	1.1	26.3	29.5	27.8	1.1	-	-	-	
pH	-	6.02	7.02	6.66	0.3	7	8.1	7.6	0.4	-	-	-	
EC	dS/m	1.81	2.44	2.13	0.2	2.1	2.7	2.4	0.2	-	-	-	
Turbidity	NTU	116	182	148	23	4.8	6.8	5.6	0.7	94.5	96.8	96	96
DO	mg/l	1.4	2.8	2.0	0.5	3	4.8	3.7	0.6	-	-	-	-
COD	mg/l	284	515	433	74	112	134	124	7.6	56	77.1	70	6.7
BOD_5	mg/l	210	375	288	51	28	52	41	9.0	76.2	88.6	85.6	3.9
TSS	mg/l	205	322	274	45	26	35	30	3.4	83.4	91.9	88.6	2.4
Ammo-N	mg/l	20	36.4	29.4	5.5	12	19	16.0	2.8	40	47.8	45.3	2.6
Nitrate-N	mg/l	2.7	3.8	3.3	0.4	1.6	2.4	2.0	0.3	36.8	44.8	40.7	2.7
Total-N	mg/l	50	78	64	9.7	31	50.2	39.7	6.5	35.6	38.6	37.9	1.0
Total-P	mg/l	10.1	18	14.3	2.9	6.3	12.8	9.1	2.0	28.9	43.6	35.9	4.9
Ortho-P	mg/l	6.7	9.6	7.8	1.0	2.7	6.5	4.6	1.4	30.5	59.7	41.9	11.8

*(Average of 9 samples presented in terms of mean and SD)

3.1 Characteristics of raw water and quality afteraeration and settling tank

Average pH of raw sewage water was slightly acidic to neutral and that of aerated and settled water was neutral to slightly alkaline(Table 4).EC of the sewage water increased after aeration. BOD_5:COD ratio of raw sewage water was 0.66, which indicates higher proportion of biodegradable organic matter relative to the overall organic load(as measured by COD).The study revealed thatBiochemical Oxygen Demand (BOD) dropped by 76.2%-88.6%. Chemical Oxygen Demand (COD) exhibited a reduction of 56%-77 Moreover, Total Suspended Solids (TSS) saw decline of 83.4%-91.9.The average removal rates for NH_4^+, NO_3^-, and Total-N were 45%, 40.7%, and 37.9%, respectively(Table4).

Table 5: Removal efficiency of the filtration system

Parameters	**Sand (Trial 1)**	**Charcoal (Trial 1)**	**Silica sand (Trial 2)**	**Charcoal (Trial 2)**	**Overall efficiency (With aeration and filter media)**	
					Trial 1	**Trial 2**
Turbidity	69.3	78.4	71.9	81.6	99	99

COD	43.8	47	54.4	63.5	85	90
BOD5	53.1	57	71.9	80.3	94	98
TSS	57.9	61.2	57.9	70.2	96	97
NH4+-N	30.6	31.7	49.9	55.8	63	76
NO3-N	34.5	34.7	44.5	49.1	61	70
Total-N	24.2	26	44.4	47.5	52	70
Total-P	32.9	40.1	39.1	64.3	59	76
Ortho-P	33.8	47.2	42.9	72.1	65	82

Table 6: Removal of pollutants using sand and charcoal media for filtration

Parameter	**Unit**	**Influent water**		**Silica sand (HLR 60 m/h)**						**Charcoal(HLR 153 m/h)**		**Influent water**		**Silica sand (HLR 10m/h)**						**Charcoal (HLR 25m/h)**	
				30cm		**60cm**		**90cm**		**120cm**				**30cm**		**60cm**		**90cm**		**120cm**	
pH	-	7.57	0.4	7.52	0.3	7.48	0.3	7.49	0.3	7.60	0.3	7.57	0.4	7.52	0.3	7.48	0.3	7.49	0.3	7.73	0.35
EC	dS/m	2.5	0.2	2.2	0.2	2.0	0.2	1.9	0.2	1.8	0.2	2.5	0.2	2.0	0.2	1.8	0.1	1.6	0.2	1.2	0.1
TDS	mg/l	1639	92	1240	160	1132	105	1101	106	1078	93	1640	92	1189	94	1068	67	1044	59	860	70
Turbidity	NTU	5.6	0.7	3.0	0.8	2.4	0.6	1.7	0.3	1.2	0.2	5.9	0.6	3.0	0.8	2.1	10.5	1.7	0.3	1.1	0.2
COD	mg/l	121.3	7.5	95.6	7.4	83.8	5.2	67.9	4.2	62.8	3.5	122.2	8.0	91.1	11.3	75.5	7.2	56.0	8.9	44.8	5.9
BOD_5	mg/l	40.9	7.1	29.2	4.2	25.2	3.58	19.0	2.7	17.5	2.6	37.6	8.0	24.7	3.9	17.1	2.1	10.3	2.2	7.2	1.7
TSS	mg/l	28.1	4.2	17.0	1.7	12.5	1.6	11.8	1.6	10.9	1.9	28.2	4.4	17.0	1.7	12.5	1.6	11.8	1.6	8.3	1.1
NH_4^+-N	mg/l	15.9	2.2	13.0	1.8	11.8	1.6	11.0	1.6	10.9	1.7	16.0	2.8	11.5	2.0	9.7	1.8	8.1	1.9	7.1	1.7
NO_{3-}N	mg/l	2.0	0.3	1.7	0.3	1.5	0.2	1.3	0.2	1.3	0.2	2.0	0.3	1.7	0.3	1.3	0.2	1.1	0.2	1.0	0.2
Total-N	mg/l	41.1	6.7	33.6	5.4	32.3	5.7	31.2	5.3	30.7	5.0	39.7	6.5	29.1	5.9	24.8	4.6	22.0	3.0	18.9	2.9
Total-P	mg/l	9.8	2.3	8.0	1.8	7.2	1.7	6.5	1.4	5.9	1.5	9.4	2.2	7.3	1.7	6.4	1.7	5.8	1.5	3.4	0.9
Ortho-P	mg/l	5.1	1.1	3.8	0.8	3.5	0.8	3.4	0.8	2.7	0.8	5.0	1.1	3.6	0.9	3.0	0.8	2.9	0.8	1.4	0.5

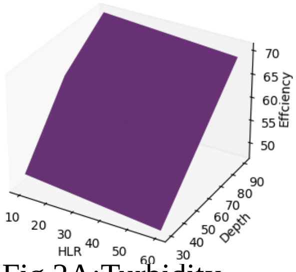


Fig 2A:Turbidity

y = -0.0765×hlr + 0.3565×depth + 41.5800

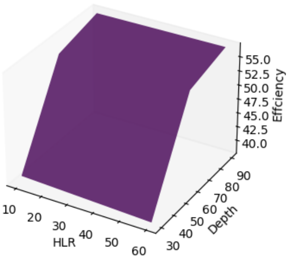


Fig 2B:Total Suspended Solids

y = -0.0025×hlr + 0.3155×depth + 31.9159

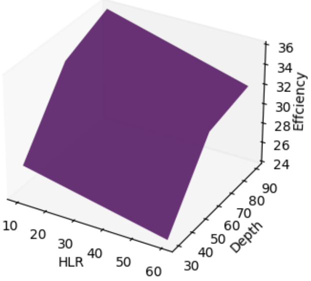


Fig 2C: Total Dissolved Solids

y = -0.0679×hlr + 0.1419×depth + 25.0526

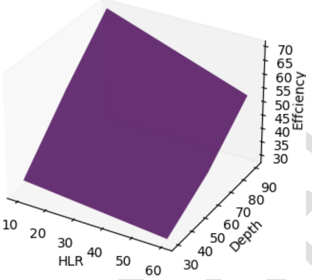


Fig 2D: Biological Oxygen Demand

y = -0.2626×hlr + 0.5301×depth + 23.6722

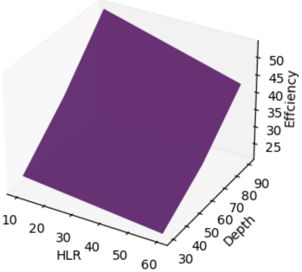


Fig 2E: Chemical Oxygen Demand

y = -0.1503×hlr + 0.4285×depth + 15.2326

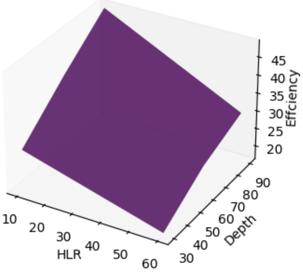
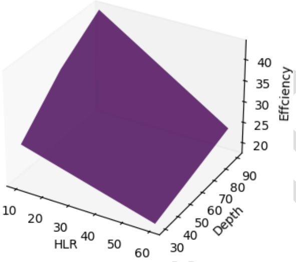


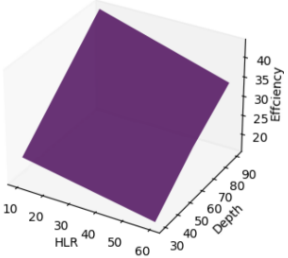
Fig 2F: Ammoniacal-N

y = -0.2918×hlr + 0.2858×depth + 25.0456



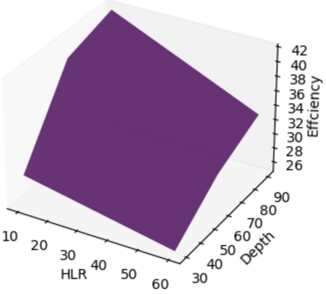
y = -0.3010×hlr + 0.1940×depth + 27.7448

Fig 2G: Total-N



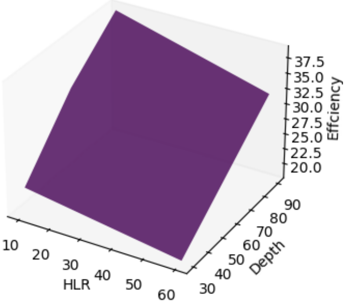
y = -0.1506×hlr + 0.3296×depth + 15.1948

Fig 2H: Nitrate-N



y = -0.1496×hlr + 0.1845×depth + 27.7870

Fig 2I: Ortho-P



y = -0.1153×hlr + 0.2630×depth + 16.7756

Fig 2J: Total-P

Fig 2A-2J: Physico-Chemical Parameters profile with 90cm Sand Media Treatment

Fig 2A-2J , each graph has been fitted with surface with 42 sampling points.

3.2 Filter tanks

Table 5 provides a summary of the fil results. The effluent characteristics of the filter tanks exhibited fluctuations in response to variations in influent values for all the parameters.

3.2.1 pH and EC

The pH of outlet water samples remained consistent across both the hydraulic loading rates, indicating independence from hydraulic loading. Inlet pH ranged from 7.01 to 8.1 with mean value of 7.57±0.4, decreasing to 7.0 to 7.82 for a 60cm depth of silica sand, with a slight increase at the charcoal outlet to a range of 7.20 to 8.20 with mean value of 7.73±0.35 at HLR 60cm/h (Table5). The system's pH level fell within the acceptable range of 6.5 to 8.5, consistent with the established standards set by Jeong *et al.* (2016).The most notable decrease in electrical conductivity (EC) was observed in the sand, declining from 2.5±0.2 dS/m to 1.6±0.2 dS/m at a flow rate of 10m/h and from 1.6±0.2 dS/m to 1.2±0.1 dS/m with charcoal at a flow rate of 25m/h (Table 5). However, its highest effectiveness was observed up to a depth of 60cm, with a slightly lower efficiency in the 60cm to 90cm range. Charcoal achieved its highest removal rate, reaching 18%, exclusively at an HLR of 25m/h, resulting in an effluent EC of 1.0 dS/m, which falls below the permissible limit outlined in Richards (1954). Meanwhile, the most substantial EC removal was observed within the upper 30cm layer of silica sand.

3.2.2 Turbidity and TSS

One of the most essential indicators to evaluate how effectively a filter is working is to evaluate in terms of turbidity removal Farooq and Al-Yousef (1993). Filter tanks achieved a consistent 99% turbidity removal rate at both the hydraulic loading rates(Table 6). Since the influent was aerated water with low initial turbidity, our investigation revealed no significant variations in turbidity and TSS removal associated with different HLR conditions. The effluent had a turbidity of 1.1±0.2 NTU and a TSS of 8.3±1.1 mg/l (as shown in Table5), with over 50% of the removal happening within the top 30cm of the sand layer (Fig 2A).

3.2.3 COD and BOD$_5$

The study's results demonstrated the superior performance of reducing COD and BOD$_5$ levels. Specifically, when influent COD was 121.3±7.5 mg/l, it decreased to 67.9±4.2 mg/l with silica sand at HLR 60m/h and after charcoal at HLR 153m/h it was 62.8±3.5 mg/l.

Similarly, at an influent COD of 122.2±8.0 mg/l, silica sand reduced it to 56.0±8.9 mg/l at HLR of 10m/h, while after charcoal filters achieved a reductionof 44.8±5.9 mg/l at HLR of 25m/h. Furthermore, BOD_5 levels decreased from 40.9±7.1 mg/l to 17.5±2.6 mg/l at an HLR of 60m/h and from 37.6±8.0 mg/l to 7.2±1.7 mg/l at an HLR of 10m/h with sand and charcoal (Table 5). These findings underscore the significant advantages of utilizing silica sand as a filtration medium for effective organic pollutant removal in wastewater treatment processes.

Organic matter not only contributes to water odour and colour issues but also serves as a microbial nutrient, leading to complications during the disinfection process, highlighting the importance of its removalUSA (2012).

BOD_5 and COD removal primarily occurs through adsorption and biological degradation facilitated by attached growth bacteria (Achak *et al.*, 2009; Assayed *et al.*, 2015). With media filtration we obtained 80.3% and 63.5% removal efficiency of BOD_5 and COD(Table 6). We achieved 93% BOD_5 removal at HLR 10m/h and 96% at 60m/h by aeration and sand media (Table 6), similar to Tusiime *et al.* (2022) findings of 96.5%, 99.1%, and 96.8% BOD_5 removal using sand media at different retention times. However, it is important to note that their influent BOD_5 was 1.6 times lower than our raw water BOD_5. We have attained a 94% BOD_5 removal efficiency with aeration and media filtration at a HLR of 10m/h and 98% at 60m/h (Table 6). These results are in line with those reported by Tusiime *et al.* (2022), where they achieved BOD removal rates of 98.8%, 99.5%, and 98.9% using sand and charcoal media at hydraulic retention times of 12h, 24h, and 36h, respectively.

3.2.4 Nutrient removal by the filter tanks

At different HLRs of 60m/h and 10m/h, the removal efficiencies for $NH_4^+ - N$, $NO_3^- - N$, and Total-N were measured. Results showed that at HLR 60m/h, average removal rates were 31.7%, 34.7%, and 26%, while at HLR 10m/h, they improved to 55.8%, 49%, and 47%, respectively with sand and charcoal(Table 6). When the initial total nitrogen concentrations were 41.1±6.7 mg/l and 39.7±6.5 mg/l, they decreased to 30.7±5.0 mg/l and 18.9±2.9 mg/l at HLR 60m/h and 10m/h, respectively (Table 5). Silica sand filter tanks achieved the highest Total-N removal efficiency of 34.5% and 44.5% at HLR 60m/h and 10m/h (Fig 2G).

Achak *et al.* (2009) explained that nitrogen removal involves denitrification, nitrification, microbial assimilation, and the physical-chemical adsorption of ammonium ions onto organic matter. The effluent total-N levels varied between 15.8 mg/l and 25 mg/l, with an average total nitrogen concentration of 20 mg/l, which falls within the acceptable limit set by(Israel).

In ourscenario, the decrease in NO_3^--N concentration from 2mg/L to 1mg/L suggests that denitrification was able to effectively convert nitrate into gaseous forms.The loss of $\mathrm{NH_4^+ - N}$ by volatilization occurs when the pH is between 7.8 and 8.4, according to Hammer and Knight (1994) .This situation is relevant to our inquiry since the influent from the filter tanks has a pH range of 7.5-8.01. The influent $\mathrm{NH_4^+ - N}$ concentration in the filter tanks was 16mg/l, and it was reduced to 7 mg/l in the effluent following sand and charcoal filtration. Dalahmeh *et al.* (2012) observed a low total-N removal efficiency of only 5% in sand filter (60cm depth) due to the absence of anaerobic conditions as the columns were exposed to air. In our study, where the filter tanks were enclosed, sand achieved higher removal rates of 21.6% at HLR of 60 m/h and 37.6% at HLR of 10 m/h (Fig 2G).

Phosphorous removal primarily occurs through biodegradation and adsorption on slimy layers that form on sand media, with precipitation and adsorption onto minerals as key removal mechanismsAbdel-Shafy *et al.* (2014). With silica sand(90cm), it was found that the removal rates for Total Phosphorus (Total-P) and Orthophosphate (Ortho-P) were 39% and 43% respectively (Fig 2I and 2J). However, with an additional layer of activated charcoal(30cm) the removal efficiencies increased significantly to 64% for Total-P and 69% for Ortho-P(Table 6). Notably, the activated charcoal demonstrated much betterperformance in removing phosphorus and orthophosphate at the lower HLR of 25m/h compared to a higher HLR of 153m/h (Table 5). With activated charcoal at HLR 25m/h, Total-P removed was 25% and Ortho-P was 29%. Overall Total-P removal with aeration and media filtration was 59% and 76%. In their study Tusiime *et al.* (2022), attained Total-P removal rates of 43.6%, 34.5%, and 33.6% at hydraulic retention times (HRTs) of 24, 36, and 48 hours, respectively, using sand media, while our filters showed comparable results when the influent Total-P ranged from 9 ± 4.9.

Parameters	Raw water	After aeration& settling	Silica sand	Activated charcoal	Silica sand	Activated charcoal
Ca^{2+}	3.5	2.7	2	1.9	1.7	1.6
Mg^{2+}	4.5	2.3	1.7	1.7	1.6	1.5
Na^{+}	11.5	10.2	8	7.7	7.1	6.8
K^{+}	0.9	0.7	0.5	0.5	0.4	0.4
CO_3^{2-}	0.7	0.5	0.3	0.3	0.4	0.3
HCO_3^{1-}	8.8	6.7	5.5	5.5	5.4	5.0
Cl^{-}	9.3	9.9	8.6	6.3	8.4	4.8
SO_4^{2-}	2.4	2.2	1.8	1.7	1.7	1.5

Table7: Characteristics of filter tanks influent

All the parameters(mean of 7 samples) expressed in meq/l.

Table8: characteristics of the treated sewage water for irrigation purpose

Sample	Irrigation purpose					
	%Na	**SAR**	**SSP**	**RSC**	**MH**	**PI**
Raw water	55.6	4.6	50.6	1.5	56.3	70.6
After aeration	63.5	5.1	58.4	2.2	46	81.4
HLR (60 m/h)						
Silica sand(90cm)	62.2	4.1	57.1	2.1	45.9	85.4
Activated charcoal(30cm)	60.4	3.7	54.9	2.2	47.2	85.4
HLR (10 m/h)						
Silica sand(90cm)	60.4	3.6	56.3	2.3	49.1	87.0
Activated charcoal(30cm)	61.9	3.5	57.9	2.6	48.1	93.1

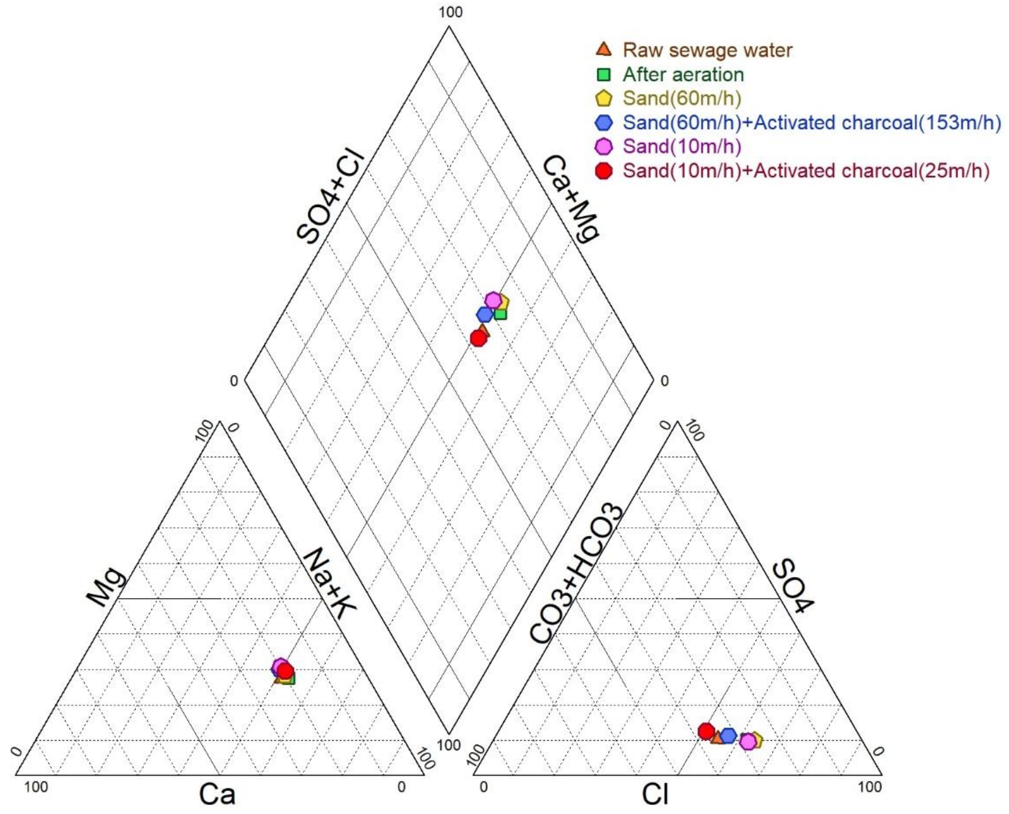
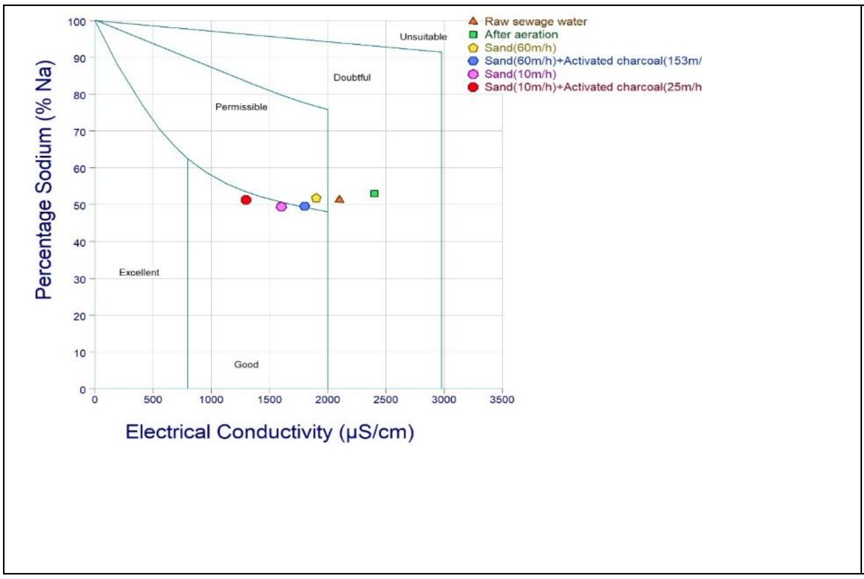


Fig3: Piper trilinear diagram for major ions of water samples



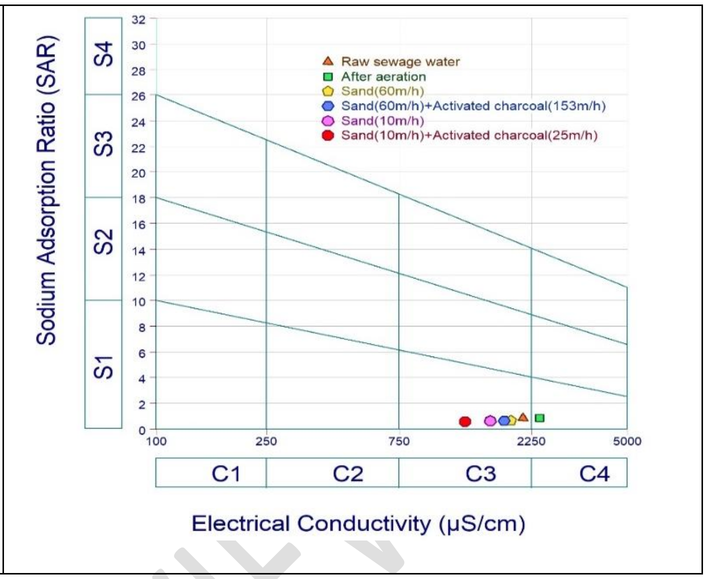


Fig4: Assessing the Suitability of WaterSamples for Irrigation Using the Wilcox diagram

Fig 5: suitability of water sample according to USSL diagram

Suitability of treated sewage water for irrigation purpose

The chemical characteristics of both untreated and treated sewage water samples were examined to assess their appropriateness for irrigation. The findings obtained have been presented in Table7 and 8.The hierarchy of cation and anion prevalence, based on milligram equivalents, was as follows: $Na^{+}>Ca2^{+}>Mg2^{+}>K^{+}$for cations and $Cl^{-}>HCO_3^{-}>SO_4^{2-}>CO_3^{2-}$ .The hydraulic loading rate had an impact on water quality, with a lower filtration rate leading to a decrease in concentration of ions. Ions were efficiently removed by sand down to a depth of 60cm, and beyond that, between 60cm and 90cm depth of sand, there was no alteration in ionic concentration.

The Piper diagram is a valuable tool for assessing water hydrochemistry and facies classification, featuring two triangular fields and a diamond-shaped field, with cations represented as a percentage of total cations in meq/l as a single point on the left triangle and anions on the right trianglePiper (1944).The trilinear diagram can expose both similarities and distinctions between water samples, as similar-quality water tends to cluster together. In the Piper trilinear classification, the water samples were fall under Na+, K+, and Cl− ionic type, with the observation that alkalis ($Na^{+} + K^{+}$) surpassed alkaline earth ($Ca^{2+} + Mg^{2+}$), and strong acids ($SO_4^{2-} + Cl^{-}$) exceeded weak acids ($CO_3^{2-} + HCO_3^{-}$) (Fig3).

Total dissolved solids(TDS)

Assessing groundwater quality for irrigation is crucial, with a focus on Total Dissolved Solids (TDS) as a significant parameter, driven by the need to address the presence of harmful solid contaminants in the water Matthess (1982).In our scenario, the TDS at a HLR of 10 m/h was 860±70 mg/l, falls within acceptable limits for irrigation purposes(Table 5).

Sodium hazard

Elevated sodium levels compared to calcium and magnesium concentrations can harm soil structureArveti *et al.* (2011).The average %Na in both untreated and treated water exceeded 60%, which is not in line with recommended levels for irrigation water(Richard, 1954; Wilcox, 1955a).Based on wilcox'splot, sand and activated charcoal treated samples fall under permissible class, raw sewage water sample and aerated sample fall under doubtful class for irrigation(Fig 4).The SAR values in the collected water samples varied between 3.5 and 5.1. Water samples fall under C3-S1(high salinity and low sodium hazard) classandaerated sample fall under C4-S1(very high salinity and low sodium hazard) class (Fig 5).

Magnesium hazard

Irrigation water samples with magnesium hazard values exceeding 50 are deemed unsuitable and harmful for irrigation purposesChaabane *et al.* (2017). In our samples, the magnesium hazard value remained below 50 (Table 7).

Permeability index

In the current study, the water samples fall in class I categoryDoneen (1964) and exhibited a permeability index exceeding 75%, signifying their suitability for irrigation (Table 7).

5. Conclusion

The study convincingly demonstrates that the utilization of a filtration system integrating aeration and media filtration, particularly using sand with activated charcoal, is an effective approach for sewage water treatment. This approach promotes reuse while also reducing health and environmental risks. It achieved higher removal efficiencies compared to previous studies, with 99% turbidity, 90% COD, 97% BOD_5, 70% Total-N, and 76% Total-P at HLR of 10m/h for sand and 25m/h for activated charcoal.At a hydraulic loading rate (HLR) of 10 m/h, the average TDS concentration in the filtered effluent was 860 mg/l and based on SAR and MH values it can be suggested that the treated water is permissible for irrigation use.

References

Abdel-Shafy, H.I., M. El-Khateeb, and M. Shehata. 2014. "Greywater treatment using different designs of sand filters." *Desalination and Water Treatment* 52 (28-30):5237-5242.

Abdelhay, A., and S.G. Abunaser. 2021. "Modeling and economic analysis of greywater treatment in rural areas in Jordan using a novel vertical-flow constructed wetland." *Environmental management* 67:477-488.

Achak, M., L. Mandi, and N. Ouazzani. 2009. "Removal of organic pollutants and nutrients from olive mill wastewater by a sand filter." *Journal of environmental management* 90 (8):2771-2779.

APHA. 2017. "Standard Methods for the Examination of Water and Wastewater (23rd ed.). Washington DC: American Public Health Association."

Arveti, N., M. Sarma, J. Aitkenhead-Peterson, and K. Sunil. 2011. "Fluoride incidence in groundwater: a case study from Talupula, Andhra Pradesh, India." *Environmental monitoring and assessment* 172:427-443.

Assayed, A., J. Chenoweth, and S. Pedley. 2015. "Assessing the efficiency of an innovative method for onsite greywater treatment: Drawer compacted sand filter–A case study in Jordan." *Ecological Engineering* 81:525-533.

ASTM. 1998. "Standard Test Method for Particle-Size Analysis of Soils, D 422-63. ASTM International, West Conshohocken, Pennsylvania."

Chaabane, S., K. Riahi, H. Hamrouni, and B.B. Thayer. 2017. "Suitability assessment of grey water quality treated with an upflow-downflow siliceous sand/marble waste filtration system for agricultural and industrial purposes." *Environmental Science and Pollution Research* 24:9870-9885.

Dalahmeh, S.S., M. Pell, B. Vinnerås, L.D. Hylander, I. Öborn, and H. Jönsson. 2012. "Efficiency of bark, activated charcoal, foam and sand filters in reducing pollutants from greywater." *Water, Air, & Soil Pollution* 223:3657-3671.

De Rozari, P., M. Greenway, and A. El Hanandeh. 2016. "Phosphorus removal from secondary sewage and septage using sand media amended with biochar in constructed wetland mesocosms." *Science of the Total Environment* 569:123-133.

Dhawan, V. 2017. "Water and agriculture in India." Background paper for the South Asia expert panel during the Global Forum for Food and Agriculture.

Doneen, L. 1964. "Notes on water quality in agriculture. Published as Water Science and Engineering Paper 4001, Department of Water, Science and Engineering, University of California, Davis.".

Eaton, F. 1950 *Significance of carbonates in irrigated waters. Soil Sci 69:127-128*

Farooq, S., and A.K. Al-Yousef. 1993. "Slow sand filtration of secondary effluent." *Journal of Environmental Engineering* 119 (4):615-630.

Flint, A.L., and L.E. Flint. 2002. "2.2 Particle Density." *Methods of soil analysis: Part 4 Physical methods* 5:229-240.

Hammer, D.A., and R.L. Knight. 1994. "Designing constructed wetlands for nitrogen removal." *Water Science and Technology* 29 (4):15-27.

Haouti, R.E., Z. Anfar, S. Et-Taleb, M. Benafqir, S. Lhanafi, and N.E. Alem. 2018. "Removal of heavy metals and organic pollutants by a sand rich in iron oxide." *Euro-Mediterranean Journal for Environmental Integration* 3:1-11.

Israel. "Sustainable Water Integrated Management-Support Mechanism (SWIM-SM); 4th Progress Report; LDK

Consulatants Engineers and Planners SA: Athens, Greece, October 2013." In.

Jeong, H., H. Kim, and T. Jang. 2016. "Irrigation water quality standards for indirect wastewater reuse in agriculture: a contribution toward sustainable wastewater reuse in South Korea." *Water* 8 (4):169.

Jjagwe, J., P.W. Olupot, E. Menya, and H.M. Kalibbala. 2021. "Synthesis and application of Granular activated carbon from biomass waste materials for water treatment: A review." *Journal of Bioresources and Bioproducts* 6 (4):292-322.

Katukiza, A., M. Ronteltap, C. Niwagaba, F. Kansiime, and P. Lens. 2014. "Grey water treatment in urban slums by a filtration system: Optimisation of the filtration medium." *Journal of environmental management* 146:131-141.

Li, J., and J. Wen. 2016. "Effects of water managements on transport of E. coli in soil-plant system for drip irrigation applying secondary sewage effluent." *Agricultural Water Management* 178:12-20.

Matthess, G. 1982. "The properties of groundwater." *(No Title)*.

Naidoo, S., and A.O. Olaniran. 2014. "Treated wastewater effluent as a source of microbial pollution of surface water resources." *International journal of environmental research and public health* 11 (1):249-270.

Piper, A.M. 1944. "A graphic procedure in the geochemical interpretation of water- analyses." *Eos, Transactions American Geophysical Union* 25 (6):914-928.

Richard, L. 1954. *Diagnosis and improvement of saline alkali soils: Agriculture. Handbook, US department of Agriculture, Washington DC, 160:60*.

Sánchez-Monedero, M., M.I. Aguilar, R. Fenoll, and A. Roig. 2008. "Effect of the aeration system on the levels of airborne microorganisms generated at wastewater treatment plants." *Water Research* 42 (14):3739-3744.

Shaikh, I.N., and M.M. Ahammed. 2021. "Effect of operating mode on the performance of sand filters treating greywater." *Environmental Science and Pollution Research* 28:38209-38223.

Sharma, N., A. Singh, and N. Batra. 2018. "Modern and emerging methods of wastewater treatment." *Ecological Wisdom Inspired Restoration Engineering*:223-247.

Szabolcs, I.a.D., C. 1964. *The influence of irrigation water of high sodium carbonate content of soils. In: Proceedings of 8th International Congress of Isss, Trans, 2, 803–812.*

Tusiime, A., H. Solihu, J. Sekasi, and H.E. Mutanda. 2022. "Performance of lab-scale filtration system for grey water treatment and reuse." *Environmental Challenges* 9:100641.

UNDP. 2017. "United Nations Development Programme. In Human Development Report 2016."

USA. 2012. "Guidelines for Water Reuse 600/R-12/618; Environmental Protection Agency: Washington, DC.".

WHO. 2006. *Guidelines for the safe use of wastewater, excreta and greywater (Vol. IV. Excreta and greywater use in agriculture). Geneva: World Health Organization.*

Wilcox, L. 1955a. "Classification and use of irrigation water. USDA, Circular 969, Washington, DC, 19p.".

Wilcox, L. 1955b. *Classification and use of irrigation water. USDA,*

Circular 969, Washington, DC, 19p.