Treatment of Greywater using Modified Sand Filters

Gaurav Gupta[1], Vikas Vyas[1], Ankit Mina[1], Jenisha Devnani[1], Kavya Kulshrestha[1], Kumkum Maurya[1]

Department of Civil Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur 302017 (INDIA)

Email: **gaurav.gupta@skit.ac.in**

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Abstract- The influence of various modified slow sand filters was assessed for the greywater generated from a student dining hall. The conventional sand filter and different material layers introduced in each sand filter media were Sawdust (SD) and Activated Carbon (AC) in the powdered form. To improve the performance of the filter, the middle layer of the sand is modified with Iron scraps as the zero-valent iron (ZVI). With the assistance of the four filters, the evaluation was made on the effect of the pH, electrical conductivity, hardness, alkalinity, and the removal of turbidity, BOD, and TDS. According to the results, an Activated Carbon filter (ACF) shows 85.87% turbidity removal, 38.4% total solid removal has been shown in ACF, and 55% BOD removal can be achieved through ACF. Zero-valent-Iron filter (ZVIF) has immensely increased the value of EC and pH.

Keywords– Zero-valent iron (ZVI), Sawdust (SD), Activated Carbon (AC)

1. INTRODUCTION

Greywater is used to wash dishes, launder clothes, or bathe. Greywater is defined as wastewater excluding wastewater from toilets and urinals.

From the total wastewater generated in a household around 50-80% is greywater. It is significantly less polluted when compared to wastewater [1]. Greywater contains grease, hair, food particles, and other impurities and may still be suitable for reuse. The used water is high volume; low strength wastewater so there remains a very high potential for reusing it after a small degree of treatment.

By treating greywater to some extent, it can be used for many non-portable purposes, so it helps to reduce the pure water supply- demand to some extent and it also decreases the load on the wastewater treatment plant. Notably, the characteristics of greywater are highly influenced by the living standard in a household, availability of water, and consumption. Electrical conductivity(EC) and pH are high in the greywater due to the use of sodium hydroxide-based soaps in laundry. The performance of the modified sand fitter is dependent on the pH of influent greywater to remove metals and inactivated microbes from greywater with lower removal at higher pH values [2, 3]. In greywater, the variation in the composition of organic matter is substantially high.

Greywater can be classified into two types i.e., light greywater and dark greywater. The source of light greywater is the wastewater obtained from the bathroom, wash-basins, and the greywater generated from the kitchen and laundry, which falls under the category of dark greywater. We have selected dark greywater to experiment in our study.

2. MATERIALS AND METHODS

2.1 Materials

The study emphasizes on the four varieties of sand filters that are used in the treatment of kitchen greywater by introducing different materials in the sand filter media. These materials include Activated Carbon (heated charcoal), Sawdust (minute wood particles obtained from sawing), Zero-Valent Iron (Fe0 is metallic iron having zero charge on every individual atom), and Conventional Sand filters. The objectives of this study are as follows: (i) to see the influence of the modified sand filters over conventional sand filter media; (ii) to develop improved & modified operating methods; (iii) to increase the overall efficiency of conventional sand filters by some modifications; (iv) to minimize the cost of construction of the filter; and (v) to implement an environment-friendly technique towards treatment of wastewater.

It also includes the attempts conducted to observe the performance and changes in the efficiency of treating greywater by integrating different modifications in sand filters. In this study, four filters were prepared out of which three of them had one extra layer of different material (here it is, AC, SD, ZVI) in sand filter media.

The sawdust used in the making of the filter layer is in the form of powdered dust of wood which originates from the products made of the wood. It is cheap and easily available in local community markets or mechanical labs in college.

The ZVI generated from the by-product of the finished products of iron used in this study is in the form of iron scrap which is easily available, inexpensive. ZVI is useful for removing organic, inorganic, and microbial contamination from the greywater to a large extent [4, 5]. So, it is readily available in the mechanical workshop of our college. In many studies for the treatment of surface water [6], tap water [7], pond water [8], and irrigation water [9] ZVI is used in the sand filter modification. The suitability of sawdust and charcoal for treatment of greywater has also been explored in the recent past [12, 13]. The selection of Activated Carbon in water treatment is justified due to its effective adsorbent strength for removing organic pollutants, including color, odour, and taste compounds. It is a highly porous material that has a large surface area and is chemically stable, making it an ideal material for adsorption.

2.2 Experimental set-up, operation, and analysis

2.2.1 Experimental set-up

Four modified slow sand filters constructed for performing experimental work were made from plastic containers. The height of the containers is approximately 36 cm and the diameter 25 cm; thus, the total approximate volume of all filters is calculated as 17.671 litres or 17671.46 cm^3.

As shown in Fig. 1, the fine sand used (in the layer 3 & layer 5) in the filter has grain size, coefficient of uniformity, and effective size (D_{10}), of 0.15 mm to 1.18 mm, 2.64 and 0.20 mm respectively. Coarse sand (in layer 2) and gravel (in layer 1; bottom-most) of 1.18 to 4.75 mm and 4.75 mm to 12 mm size respectively, were used to support the sand media. Naturally available sand and gravel were used for the preparation of the filters. The size of the gravels, coarse sand, and fine sand range between 4.75 to 12mm, 1.18 to 4.75mm, 1.18 to 0.15mm respectively. Sieve analysis was done to find out the coefficient of uniformity (CU) and the effective size (D_{10}). By sieve analysis, the filter media had D_{10} equivalent to 0.20 mm and CU equals 2.9. The process of washing of gravel and sand for multiple times was opted for impurity removal purposes by tap water until the clear washed water drained out.

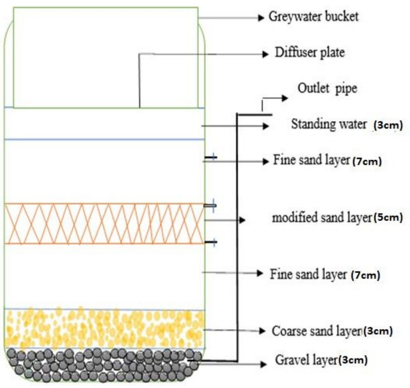

Figure 1: Schematic representation of filters

Figure 2: Original picture of the filters

Figure 3: Lateral drain arrangement in filters

For the preparation of modified sand filters, sand and gravel were collected from the casting yard of the college. Sieving was done to get the desired sand size for coarse sand, fine sand, and gravel. For fine sand, sieving was done by using IS sieve of size 1.18 mm and 150 µm. The particles retained between these sieves were used as fine sand for the filters for putting in layer 3 & layer 5. Aiming at coarse sand, sieving was done by using IS sieve of size 1.18 mm and 4.75 mm. The soil retained between these sieves was used as coarse sand for the filters and putting it in layer 2. For gravel, sieving was done by using IS sieve of size 4.75 mm and 12 mm. The gravel retained between these sieves was used as gravel for filters to put it in layer 1; the bottom-most layer. The identical plastic water cans were arranged as filter columns. The original photograph of the filters is shown in Fig. 2. The filter follows the general guidelines mentioned by IS 11401 (Part 2) [11]. The underdrain system shown in Fig. 3 and the outlet pipe were fitted in the filters and the pipes were made of PVC.

In the bottom-most part of the filter columns, gravel was packed in a layer of 3 cm height, coarse sand in the next 3 cm, fine sand in the next 7 cm, material layer + fine sand in the next 5 cm layer, and fine sand of 7 cm height. Thus, the volume of each filter unit came out to be 17.671 litres or 17671 cm^3. As discussed above, modifying materials used in the filter columns were activated carbon, sawdust, zero valent iron, and fine sand was filled in the material layer in the case of the conventional sand filter.

2.2.2 Operation procedure of filters

In this study, a total of 10-liter kitchen greywater samples was collected daily from the mess of Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India. This sample was allowed to settle for 1hr in the settlement tank. After 1 hr of settlement, daily 2 litre sample was fed into each filter and effluent was collected from the effluent pipe to test different parameters like pH, turbidity, electrical conductivity, TDS, alkalinity, hardness and BOD.

Influent and effluent turbidity was measured by Turbidity meter. The total solids (TS), biochemical oxygen demand (BOD), pH, Electrical Conductivity (EC), alkalinity and hardness before and after filtration were analyzed according to Standard Methods [10].

2.2.3 Analysis

All the tested parameters are listed in the table 1. Filters were operated for 25 days. The total study time was 25 days. Test are mentioned in IS code: 3025

Table 1: Tests performed on influent and effluent

Test performed	**Instrument / reagent involved**	**Frequency**
pH	pH meter	Daily
Turbidity	Turbidity meter	Daily
Electrical conductivity (EC)	Conductivity meter	Daily
Alkalinity	Titrationwith H_2SO_4	Daily
Hardness	Titrationwith EDTA	Daily
Total Solids	Hot airoven	Weekly
BOD	Incubator	Weekly

3 RESULTS AND DISCUSSION

3.1 Influent greywater characteristics

The characteristics of kitchen greywater used in the study are summarized in Table 2. The concentration of the parameters varied widely during the study. For example, the range of turbidity between 115 to 372 NTU, pH 4.26-8.4, Electrical Conductivity (EC) 3.84- 11.98mhos/cm, total alkalinity 280- 1248 mg/L as $CaCO_3$, total hardness 436 to 1115 mg/L as $CaCO_3$.

Table 2: Characteristics of influent greywater

Parameters	**Min-Max**	**Avg. ± S.D.**
pH	4.26-8.4	6.1628 ±1.55
Turbidity (NTU)	115-372	237.16 ±64.94
Electrical conductivity (mhos/cm)	3.84-.56	6.62 ± 2.0
Alkalinity (mg/L)	280-1248	824.28±235.82
Hardness (mg/L)	530-1460	1033.8±260.36
TS (mg/L)	622-1002	738.5 ±154
BOD (mg/L)	I198-248	220.5 ±19.2

3.2 Performance of modified sand filters

3.2.1 Effect on pH

The average value of pH during the filtration is shown in Fig. 4(a) and the daily variation in the pH is shown in Fig. 4(b). The kitchen greywater pH is directly related to the type of chemicals that are used for washing purposes, utensil cleansing soaps, and gels. The influent greywater pH ranged between 4.26 to 8.4 with a mean of 6.1628 ± 1.55, which is closer to the neutral pH of water.

After the filtration effluent pH slightly increases in all the filters. The average pH after filtration of the effluents 6.64 ± 0.37, 7.01 ± 0.69, 6.678 ± 0.45, and 6.56 ± 0.55 were noted in Conventional Filter (CF), Zero-Valent Iron Filter (ZVIF), Activated Carbon Filter (ACF) and Sawdust Filter (SF) respectively. The increment in pH indicates that the effluent has a more basic nature than the influent, and the concentration of H+ ions decreased.

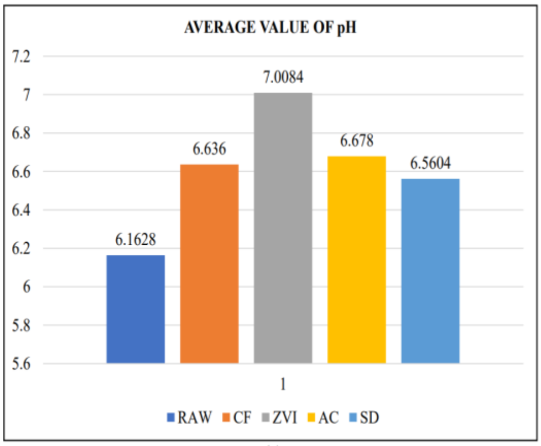

Figure 4(a): Average value of pH

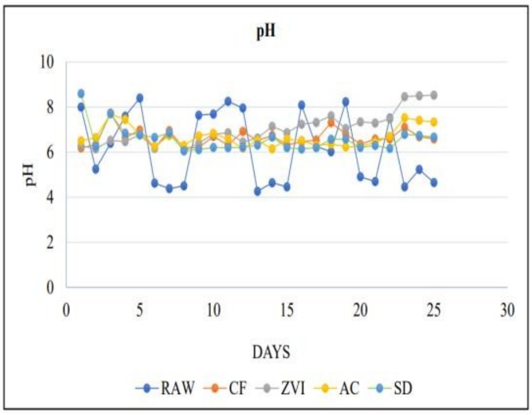

Figure 4(b): Daily variation in the pH

3.2.2 Effect on turbidity

Influent had high turbidity ranging between 115 to 372 NTU with a mean of 237.16 ± 64.94 NTU. Effluent turbidity came out to be 2 to 72 NTU with a mean of 50.88 ± 20.98 NTU for Conventional Filter (CF), 9 to 157 NTU with a mean of 66.16 ± 44.71 for Zero-Valent Iron Filter (ZVIF), 5 to 123 NTU with a mean of 30.52 ± 30.08 for Activated Carbon Filter (ACF) and 23 to 241 NTU with a mean of 87.28 ± 52.0 for Sawdust Filter (SF). The overall turbidity removals of 69.93%, 78.09%, 85.87%, and 61.22% were noted in CF, ZVIF, ACF, and SF, respectively. Outcomes of average turbidity removal during the filtration are shown in Fig. 5(a), and daily variation in the turbidity removal is shown in Fig. 5(b).

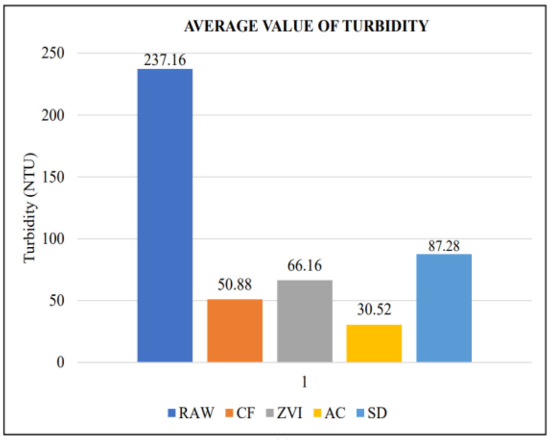

Figure 5(a): Average turbidity removal

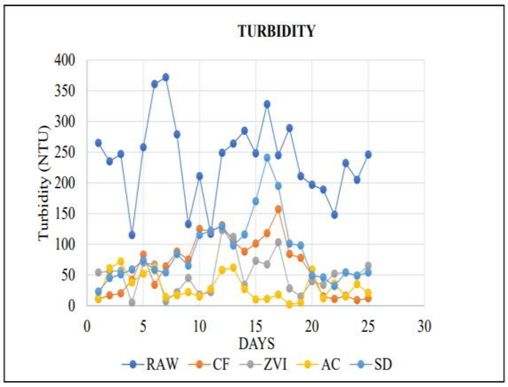

Figure 5(b): Daily variation in the turbidity removal

3.2.3 Effect on electrical conductivity

The Electrical Conductivity (EC) is related to the concentration of dissolved ions. Outcomes of the average value of EC during the filtration are shown in Fig. 6(a) and daily variation in the EC is shown in Fig. 6(b). In this study, the influent electrical conductivity of the raw water sample ranged between 3.33 to 11.98 mhos/cm with a mean value of 6.22 ± 2.11 mhos/cm. The effluent electrical conductivity was in the range of 4.22 to 8.11 mhos/cm for Conventional Filter (CF) had an average value 6.48 ± 1.07 mhos/cm, 4.83 to 8.72 mhos/cm for Zero-Valent Iron Filter (ZVIF) had an average value 6.96 ± 0.88 mhos/cm, 4.42 to 8.61 mhos/cm for Activated Carbon Filter (ACF) and had an average value of 6.73 ± 0.97 mhos/cm and 4.49 to 8.68mhos/cm for Sawdust Filter (SF) had an average value 6.48 ± 1.09 mhos/cm.

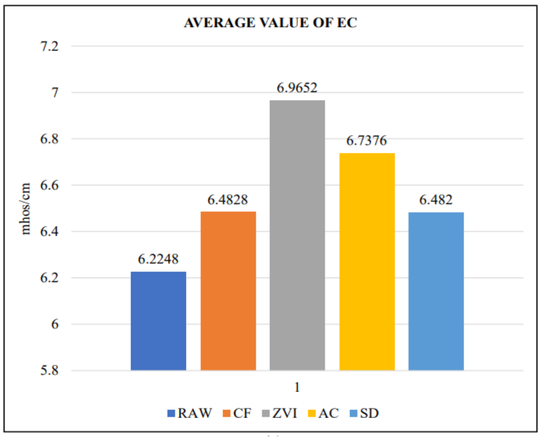

Figure 6(a): Average value of EC

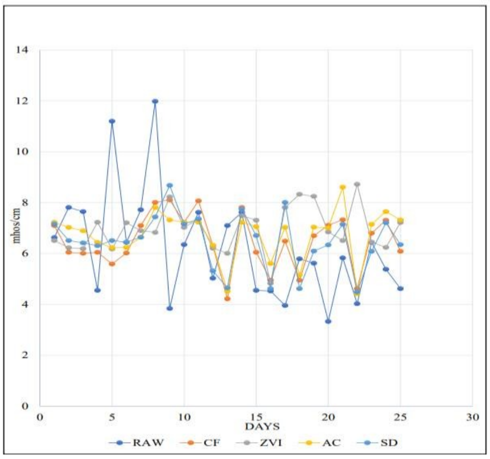

Figure 6(b): Daily variation in EC

3.2.4 Effect on Alkalinity

The alkalinity is defined as the capacity of water to neutralize acids. The alkalinity in the water is present due to the salts of weak acids. The major form of alkalinity in the form of bicarbonate. Alkalinity plays an important role in the treatment of natural waters and wastewater. The alkalinity of any sample can be calculated by titrating the sample with H_2SO_4 of normality 0.02N adding phenolphthalein and methyl orange as indicators. The average value of alkalinity is depicted in Fig. 7(a) and the daily variation in the alkalinity is shown in Fig. 7(b). The influent greywater alkalinity: 824.28 ± 235.82 mg/L as CaCO3. After the filtration, the effluent alkalinity came out to be 1564.2 ± 260.978 mg/L as $CaCO_3$, 1610.6 ± 297.56 mg/L as $CaCO_3$, 1593.2 ± 304.09 mg/L as $CaCO_3$ and 1465.4 ± 355.88 mg/L as $CaCO_3$ for CF, ZVIF, ACF and SF**.**

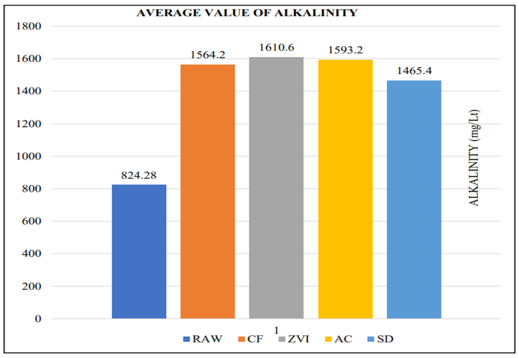

Figure 7(a): Average value of alkalinity

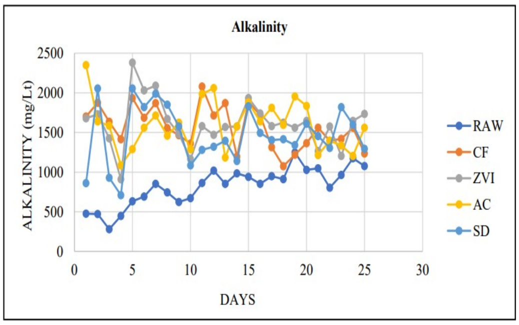

Figure 7(b): Daily variation in the alkalinity

3.2.5 Effect on Hardness

Hardness is defined as the presence of carbonate, bicarbonate, sulphate, and chloride of calcium and magnesium salts. Hard water is unfit for drinking, bathing, and washing and it also forms scales in boilers. Hence it is important to know the concentration of hardness-producing substances present in the water sample. Once it is calculated, for the treatment of water the amount of chemicals required can be calculated. Hardness can be calculated by the complex metric titration method. A standard solution of ethylene diamine tetra acetic acid (EDTA) is used to calculate hardness of water. The average value of hardness is depicted in Fig. 8(a) and the daily variation in hardness is shown in Fig. 8(b). Influent greywater hardness is 1033.8 ± 260.36 mg/L as $CaCO_3$. After the filtration, the effluent hardness came out to be 973.8 ± 265.98 mg/L as $CaCO_3$, 906.2 ± 212.12 mg/L as CaCO3, 666.36 ± 130.77 mg/L as $CaCO_3$ and 1033.4 ± 265.001 mg/L as $CaCO_3$ for CF, ZVIF, ACF and SF.

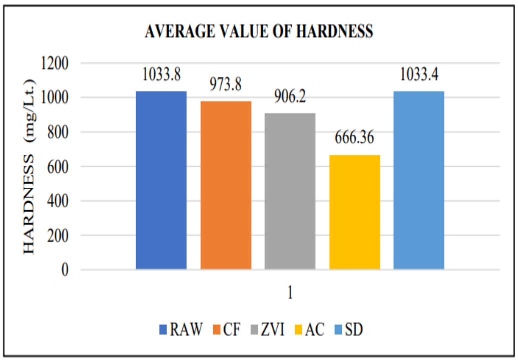

Figure 8(a): Average value of hardness

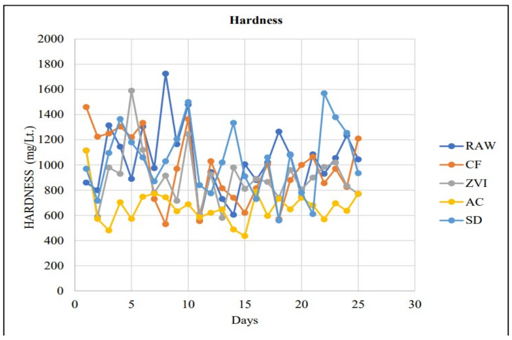

Figure 8(b): Daily variation in hardness

3.2.6 Effect on total solids

In this study, the influent total solid of the raw greywater sample ranged between 622 to 1002 mg/L with a mean value of 738.5 ± 154. The effluent total solid came out to be 460-668 mg/L with a mean value of 534 ± 79 mg/L for Conventional Filter (CF), 420 to 612 mg/L for Zero-Valent Iron Filter (ZVIF) with an average value of 489 ± 75 mg/L, 336 to 546 mg/L for Activated Carbon Filter (ACF) had an average value of 449 ± 79 mg/L and 446 to 650 mg/L for Sawdust Filter (SF) had an average value of 520 ± 77 mg/L. The average percentage removal of total solids was 26.83% in CF, 33.1% in ZVIF, 38.4% in ACF, and 28.74% in SF.

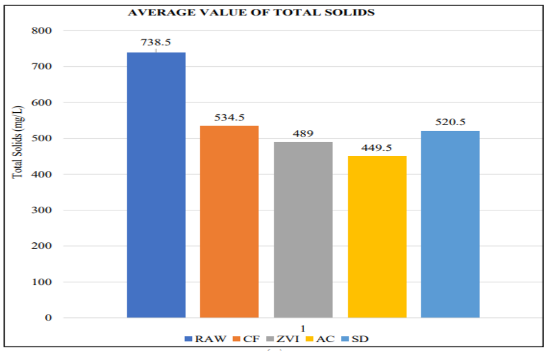

Figure 9(a): Average value of total solids

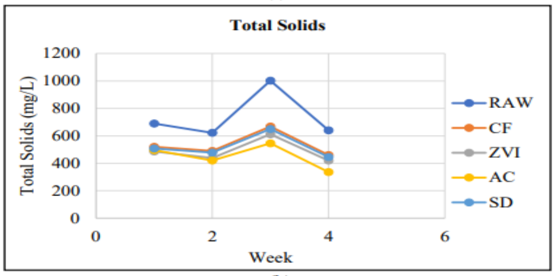

Figure 9(b): Weekly variation in total solids

3.2.7 Effect on Biochemical Oxygen Demand (BOD)

Dissolved oxygen (DO) is measured at the beginning of the analysis and after a 5 day incubation period, the difference in the DO between the beginning and end of the analysis is used to calculate the BOD_5. The influent BOD_5 of the raw greywater sample ranged between 198 to 248 mg/L and had an average value of 220 ± 19 mg/L. The mean effluent BOD was 122 ± 10, 102 ± 10, 99 ± 10, and 108 ± 10 mg/L, respectively for Conventional Filter (CF), Zero-Valent Iron Filter (ZVIF), Activated Carbon Filter (ACF) and Sawdust Filter (SF). The % BOD_5 removal came out to be 44% for CF, 53% for ZVIF, 55% for ACF, and 51% for SD. The higher BOD removal is in ACF due to the adsorption of more organic matter on the larger surface area.

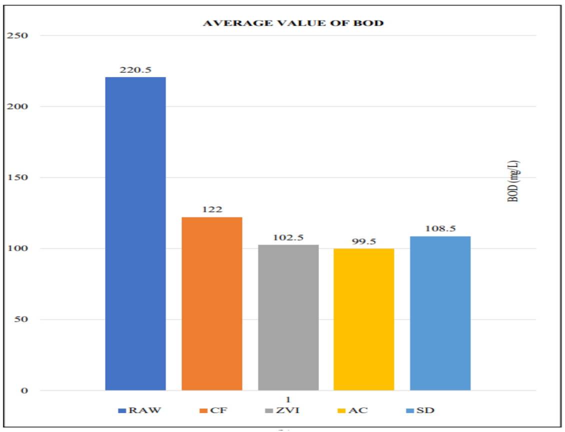

Figure 10(a): Average value of BOD5

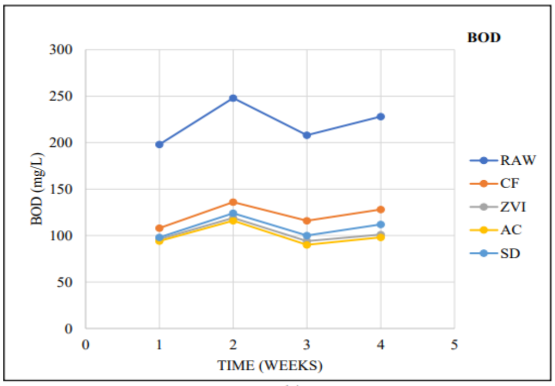

Figure 10(b): Weekly variation in BOD_5

4. CONCLUSION

In the present study, the potential of sand filters modified with zero-valent iron (ZVI), Activated Carbon (AC), Sawdust (SD), and Conventional Sand filters was evaluated for the treatment of greywater. The ZVIF shows a significant increase in pH, thus it is more effective incomparison to others. The overall turbidity removals 69.93%, 78.09%, 85.87%, and 61.22% were noted in CF, ZVIF, ACF, and SF respectively. The percentage removal of turbidity is the highest in ACF, so the most effective modified filter in turbidity removal is ACF. Among all the modified filters, ZVIF has significantly increased the value of EC in comparison to theothers hence it is more effective in the case of Electrical Conductivity followed by ACF. The average percentage removal of total solids was26.83% in CF, 33.1% in ZVIF, 38.4% in ACF, and 28.74% in SF. ACF is the most effectivein the removal of total solids followed by ZVIF.The % BOD removal came out to be 44% for CF, 53% for ZVIF, 55% for ACF, and 51% for SD. ACF is the most effective in BOD removal.

The modified sand filters developed in this study can be used for household treatment of greywater. Based on the study, a conclusion can be made that the addition of Activated Carbon (AC) has been very effective due to its larger surface area, least cost, and easy availability. ACF shows the best result towards turbidity removal and the most significant removal of Total Solids as well as of BOD removal through the Activated Carbon modified sand filter. On the other hand, ZVIF produces the best results in effective pH as well as in electrical conductivity.

REFERENCES

[1] K.A. Thompson, E.W. Valencia, R. Scott Summers, S.M. Cook, Sorption, coagulation, and biodegradation for greywater treatment, Water Sci. Technol. 81 (2020) 2152–2162, https://doi.org/10.2166/wst.2020.273.

[2] Y. Liu, S. Li, Z. Chen, M. Megharaj, R. Naidu, Chemosphere Influence of zerovalent iron nanoparticles on nitrate removal by Paracoccus sp, Chemosphere 108 (2014) 426– 432, https://doi.org/10.1016/j.chemosphere.2014.02.045.

[3] J. Dong, Y. Zhao, R. Zhao, R. Zhou, Effects of pH and particle size on kinetics of nitrobenzene reduction by zero-valent iron, J. Environ. Sci. 22 (2010) 1741– 1747, https://doi.org/10.1016/S1001-0742(09)60314- 4.

[4] C. Noubactep, E. Temgoua, M.A. Rahman, designing iron-amended biosand filters for decentralized safe drinking water provision, Clean - Soil, Air, Water. 40 (2012) 798–807, https://doi.org/10.1002/clen.201100620.

[5] I. Bradley, A. Straub, P. Maraccini, S. Markazi, T.H. Nguyen, Iron oxide amended biosand filters for virus removal, Water Res. 45 (2011) 4501–4510, https://doi.org/10.1016/j.watres.2011.05.045.

[6] C.M. Marik, B. Anderson-Coughlin, S. Gartley, S.

Craighead, R. Bradshaw, P. Kulkarni, M. Sharma, K.E. Kniel, The efficacy of zero-valent iron-sand filtration on the reduction of Escherichia coli and Listeria monocytogenes in surface water for use in irrigation, Environ. Res. 173 (2019) 33–39, https://doi.org/ 10.1016/j.envres.2019.02.028.

[7] D. George, M.M. Ahammed, Effect of zero-valent iron amendment on the performance of biosand filters, Water Sci. Technol. Water Supply 19 (2019) 1612–1618, https://doi.org/10.2166/ws.2019.032.

[8] S. Kim, K. Eckart, S. Sabet, P.C. Chiu, A.R. Sapkota, E.T. Handy, C.L. East, K.E. Kniel, M. Sharma, Escherichia coli reduction in water by zero-valent iron–sand filtration is based on water quality parameters, Water. 13 (2021) 2702, https:// doi.org/10.3390/w13192702.

[9] D.T. Ingram, M.T. Callahan, S. Ferguson, D.G. Hoover, D.R. Shelton, P.D. Millner, M.J. Camp, J.R. Patel, K.E. Kniel, M. Sharma, use of zero-valent iron biosand filters to reduce Escherichia coli O157:H12 in irrigation water applied to spinach plants in a field setting, J. Appl. Microbiol. 112 (2011) 551–560, https://doi.org/10.1111/j.1365-2672.2011.05217.x.

[10] American Public Health Association, APHA Method 9221: Standard Methods for the Examination of Water and Wastewater. (2012).

[11] IS 11401 (Part 2) (2004): General Requirements for Slow Sand Filters, Part 2: Design, Construction, Operation and Maintenance.

[12] Adugna, A. T., Andrianisa, H. A., Konate, Y., Ndiaye, A., & Maiga, A. H. (2015). Performance comparison of sand and fine sawdust vermi-filters in treating concentrated grey water for urban poor. Environmental Technology, 36(21), 2763–2769. https://doi.org/10.1080/09593330.2015.1046951

[13] Adonadaga, Melvin-Guy & Alimoh, S.C. & Ampadu, Boateng. (2020). Effectiveness of Some Selected Natural Filter Media for On-Site Small-Scale Treatment of Medium Strength Greywater. Journal of Applied Sciences and Environmental Management. 24. 887-893. 10.4314/jasem.v24i5.25.