

Article

Activated Carbon and Coconut Coir with the Incorporation of ABR System as Greywater Filter: The Implications for Wastewater Treatment

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Citation: Sabara, Z.; Anwar, A.; Yani, S.; Prianto, K.; Junaidi, R.; Umam, R.; Prastowo, R. Activated Carbon and Coconut Coir with the Incorporation of ABR System as Greywater Filter: The Implications for Wastewater Treatment. *Sustainability* **2022**, *14*, 1026. <https://doi.org/10.3390/su14021026>

Academic Editors:
Federica Raganati
and Paola Ammendola

Received: 26 December 2021

Accepted: 11 January 2022

Published: 17 January 2022

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Abstract: Greywater refers to wastewater generated from domestic activities, which do not contain fecal contamination. Therefore, this study aims to treat greywater in Makassar city to speed up the water cycle and enable reuse, as an environmental conservation strategy. The water parameters measured were pH, Turbidity, Total Suspended Solid (TSS), Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). According to the results, the greywater's BOD, COD, and TSS contents were 49.98 to 54.88 mg/L, 509 to 655 mg/L, and 404.40 to 464.65 mg/L, respectively, all of which exceed WHO wastewater quality standards. The use of a wastewater treatment installation comprising a combination of Activated Carbon (AC) and Coconut Coir (CC) with the incorporation of the Anaerobic Baffle Reactor (ABR) system as a greywater filter successfully reduced the city's greywater pollution. In addition, the new BOD content fulfills the environmentally safe wastewater standards, while the new COD and TSS contents were 152 mg/L to 184 mg/L and 59.68 mg/L to 77.42 mg/L, respectively, which are close to the WHO domestic wastewater quality standards.

Keywords: activated carbon; coconut coir; biological oxygen demand; greywater filter; chemical oxygen demand; pH

1. Introduction

In Indonesia, wastewater pollution remains a significant challenge. Wastewater is generated from domestic and industrial usage, as well as from rainfall runoff, and usually contains substances that tend to interfere with environmental sustainability [1]. Based on the source of production, wastewater is categorized into two major types: Domestic, which is discharged from housing, offices, trade, buildings as well as similar facilities, and industrial, which is discharged from factories [2].

Domestic wastewater is further categorized into two types: Greywater and blackwater. Greywater refers to wastewater generated from domestic activities, which do not contain fecal contamination, for instance, dishwashing, laundry, and baths, and is considered to be less polluted, compared to industrial wastewater [2,3]. Meanwhile, blackwater refers to wastewater with fecal contamination [4].

The organic, inorganic, and gaseous contents [5] of domestic sewage have the capacity to pollute the environment and cause various diseases [3]. In addition, some of these materials are decomposed by microorganisms into compounds with unpleasant odors [6].

Wastewater comprises 99.7% water and 0.3% foreign materials, including organic and inorganic solids, colloids, and dissolved materials [7].

The properties of wastewater are categorized into physical parameters, for instance, color, temperature, turbidity, and odor; chemical parameters, for instance, BOD, COD, pH, and the content of hazardous chemicals, including nitrogen, phosphorus, and chloride; as well as biological parameters, which refer to the content of various living organisms, including fungi, bacteria, and similar aquatic organisms [7,8]. Wastewater treatment technology is a key aspect of environmental conservation aimed at removing pollutant materials from wastewater using three treatment methods: Physical processing, chemical processing, and biological processing [9].

In Indonesia, the water crisis has become a major problem comprising excessive water consumption in certain sectors (domestic, office, industrial, public facilities, as well as social facilities), improperly managed distribution clean water distribution, and scarcity of potable water. According to the distribution of domestic water consumption in Indonesia, about 80% of the water used for daily domestic activities is wasted; however, this water has the potential to be recycled and reused including 4.3% for consumption, 4.0% for toilet, 64.8% for washing, 13.4% for vehicle wash, and 13.5% for watering plants. [10].

To minimize the pollution of water bodies by domestic wastewater in Makassar City, the appropriate technology strategies must be implemented to increase the effectiveness of domestic wastewater treatment. Currently, the city's greywater wastewater treatment facilities are poorly managed and financed. This means a low-cost wastewater treatment strategy must be implemented as an environmental management effort. Furthermore, the greywater quality parameters must be measured before and after treatment to determine whether the water fulfills the WHO standards or requires further processing [11].

Chemical Interaction Process and Material Properties

Previous studies investigated the filtration process using a combination of a Gravity-Driven Membrane (GDM) and Granular Activated Carbon (GAC) [12]. Generally, this combination is similar to ABR and Membrane Filters with AC as the main composition [13]. Filtration with GDM-GAC comprises physical, chemical, and biological processes, and has been proven to remove suspended and colloidal particles, as well as microorganisms present in water [14].

According to other studies, the use of layered filters with a single layer of sand (0.55 m thick) is effective in the retention of solids in suspension, such as algae, and other organic materials. A study on the removal of pesticides and nitrates from water by deep filtration reported significant nitrate removal using sand materials [15]. The sand filter system improves water quality significantly, consequently providing high efficiency in removing turbidity and suspended solids.

In addition to removing turbidity and odor from water, sand-filtering technology and activated carbon effectively remove viruses, bacteria, protozoa, and algae. Turbidity generally refers to the measure of the transparency of a fluid containing particulate matter in the form of inorganic solids (for instance, mud, sand, or clay) or organic matter (for instance, algae and bacteria) [16]. A previous study investigated the development of a filtration system with sand, gravel, and activated carbon (Figure 1) for rainwater treatment [9] and discovered that activated carbon obtained from coconut shells and activated using salt produced an effluent that fulfilled drinking water standards [5] for parameters of pH, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS). Table 1 shows the physicochemical properties of the filtration materials analyzed in a previous study [17].

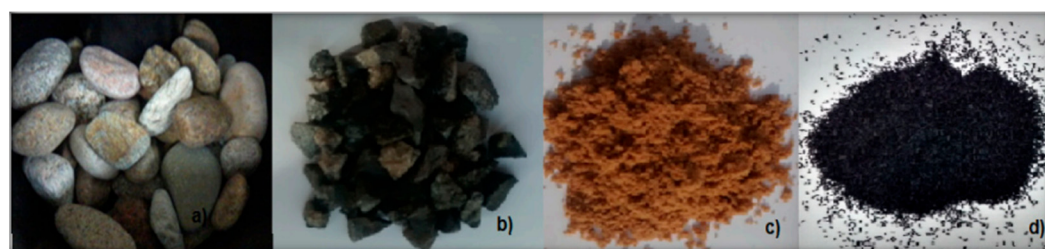


Figure 1. Images of the filtration materials: (a) Rolled pebbles; (b) gravel; (c) sand; (d) activated carbon.

Based on particle size, activated carbon is generally categorized as powdery or granular (PAC or GAC, respectively). PAC has a particle size $<80\ \mu\text{m}$, with an average size of 10 to $50\ \mu\text{m}$, while GAC has a larger particle size of 0.2 to 5 mm [18]. Another form of activated carbon is powder AC, which has been compressed with a thermoplastic binder (beam AC) [19]. An activated carbon block was developed as a substitute for asphalt, which passes water up to 80% quicker compared to conventional asphalt. However, due to the present challenge of microplastic pollution, powder AC with thermoplastic compression is not recommended for water filters [20].

Table 1. The average values and standard deviation of the parameters used for the physicochemical characterization of sand, gravel, and activated carbon [9]. Adopted with permission from Teixeira, C.A. and Ghisi, E (2019).

Parameter	Sand	Gravel	Activated Carbon
pH	6.8 ± 0.1	8.8 ± 0.1	6.7 ± 0.1
Volatile matter content (%)	1.0 ± 0.1	2.9 ± 0.1	50.8 ± 0.1
Moisture content (%)	2.38 ± 0.01	0.05 ± 0.01	48.73 ± 0.01
Ash content (%)	1.11 ± 0.01	6.96 ± 0.01	6.25 ± 0.01
Specific mass (g/cm^3)	2.61 ± 0.01	2.69 ± 0.01	1.27 ± 0.01
Bulk density (g/cm^3)	1.47 ± 0.02	1.38 ± 0.02	0.63 ± 0.02
Void index (%)	43.8 ± 0.1	48.8 ± 0.1	32.9 ± 0.1
Iodine number (mg/g)	-	-	665.85 ± 0.01

2. Materials and Methods

This study was conducted from April 2021 to August 2021, in several stages: The preparation stage, data collection, pre-treatment analysis, filtration, and post-treatment analysis. The filtering process comprised three stages: Coagulation and flocculation in wastewater, physical separation with an Anaerobic Baffle Reactor (ABR) system, and chemical separation with Active Carbon (AC) and Coconut Coir (CC) as the Membrane Filter (MF).

Wastewater sampling was performed before and after the filtration process at 3 points of office locations and business centers around Dr. Ratulangi street, Makassar, Indonesia (Figure 2), as well as at the point where the sewer enters the city's water flow. Meanwhile, the laboratory analysis was carried out at the Oceanography Laboratory, Faculty of Marine and Fishery Sciences, Hasanuddin University, Makassar, Indonesia, using the parameters of Turbidity, pH, BOD, COD, and TSS.

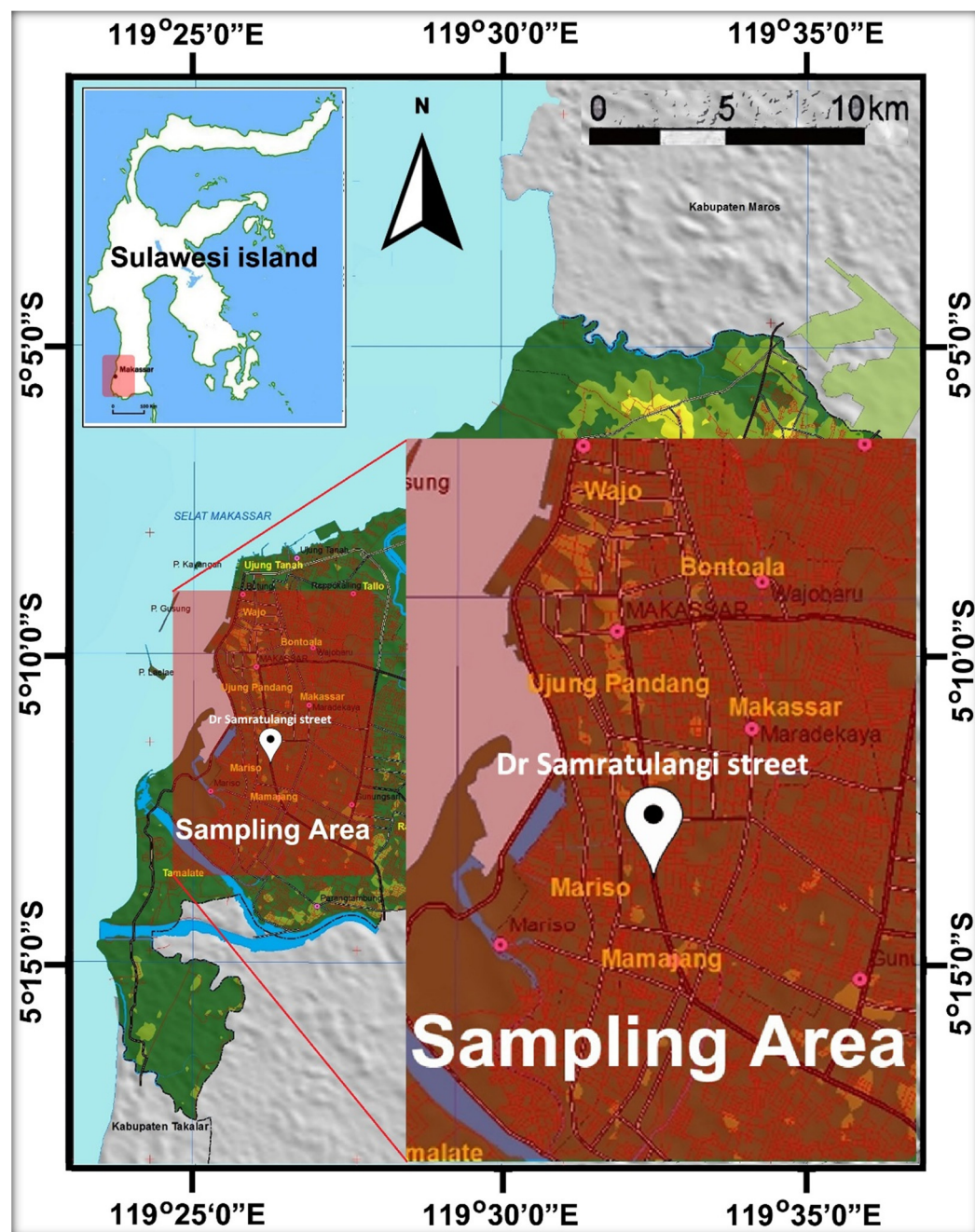


Figure 2. A map of the sampling site in Dr. Ratulangi street, Makassar, Indonesia.

2.1. Coagulation and Flocculation Processes

The coagulation process refers to the destabilization of colloidal particles by adding a chemical compound called a coagulant, for instance, alum, lime, Powder Active Carbon (PAC), polyelectrolyte, and any other substance that has the ability to neutralize the colloidal charge and bind the particles into flocs or agglomerates [21]. In industrial wastewater treatment, the coagulation–flocculation process reduces turbidity and improves the effluent’s color. A previous study defined coagulation as the process of adding coagulant into the water treatment system to agglomerate fine particles, enabling more rapid settling, and in some cases, eliminating the pathogens present [22,23].

Coagulation and flocculation processes are closely related because the flocculation process’ success depends on the coagulation process [16]. These two processes require certain chemicals to aid the formation of floc and are influenced by several factors, including the concentration of coagulant to be added, temperature, pH, and alkalinity

[11]. The coagulant concentration used must be adjusted to the wastewater's properties and the optimum coagulant concentration is usually determined using the Jar test. The Jar test is a test of a sample that is inserted into a bottle to see if there is a change in the color of the water sample if it is left for a long time [2]. Generally, samples containing oxide, hydroxide, carbonate, or sulfide with an acidic pH will be easily oxidized in a closed bottle [3]. Several factors influence the coagulation process, including the water quality parameters, for instance, dissolved gases content, color, turbidity, taste, odor, and hardness [23]. Figure 3 shows the coagulation and flocculation processes.

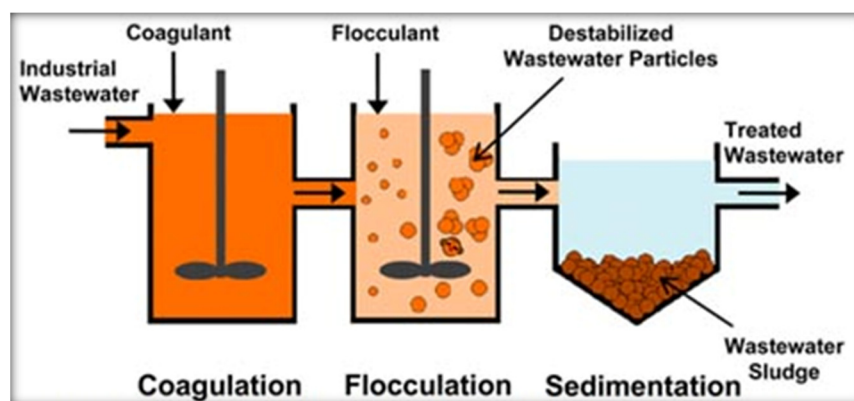


Figure 3. A diagrammatic representation of the wastewater coagulation and flocculation processes.

2.2. Anaerobic Baffled Reactor (ABR) Process

An Anaerobic Baffle Reactor (ABR) is used for physical wastewater treatment, which is the foremost stage of wastewater treatment, aimed at removing large and easily settleable suspended or floating materials [24,25]. Common physical processes used for greywater treatment include screening, sedimentation, flotation, and others [25].

The screening process is usually the first process carried out to prevent solid materials, for instance, leaves and non-biodegradable objects, which tend to interfere with subsequent treatment stages. Meanwhile, sedimentation refers to the deposition of colloidal particles, which are suspended by gravity because the specific gravity of the particles is greater, compared to the density of water. In cases where particles with lower density are found, the sedimentation process is usually accompanied by a coagulation process. Subsequently, flotation is carried out to separate any floating materials, including oil and fat, which can interfere with the later treatment stages [26].

2.3. Membrane Filter (MF) Process with Activated Carbon (AC) and Coconut Coir (CC)

MF is used for chemical wastewater treatment, which is aimed at removing non-settling particles, heavy metals, phosphorus compounds [27], and toxic organic substances [9]. Common chemical processes used for greywater treatment include ion exchange filtration [15].

Ion exchange treatment uses ion exchange resins with dissolved salts (ions) in water, while AC treatment is carried out to remove aromatic compounds (for instance, phenol) and other dissolved organic compounds, specifically in cases where the wastewater is intended for reuse. Chemical wastewater treatment processes are highly effective, but equally expensive due to the cost of acquiring the required chemicals [28].

This study performed an MF process with PolyVinyl Chloride (PVC) pipe as a container, as well as AC, CC, gravel, and sand. Based on Figure 4, wastewater flows by gravity through a tap installed below the treated water reservoir to regulate the effluent [29].

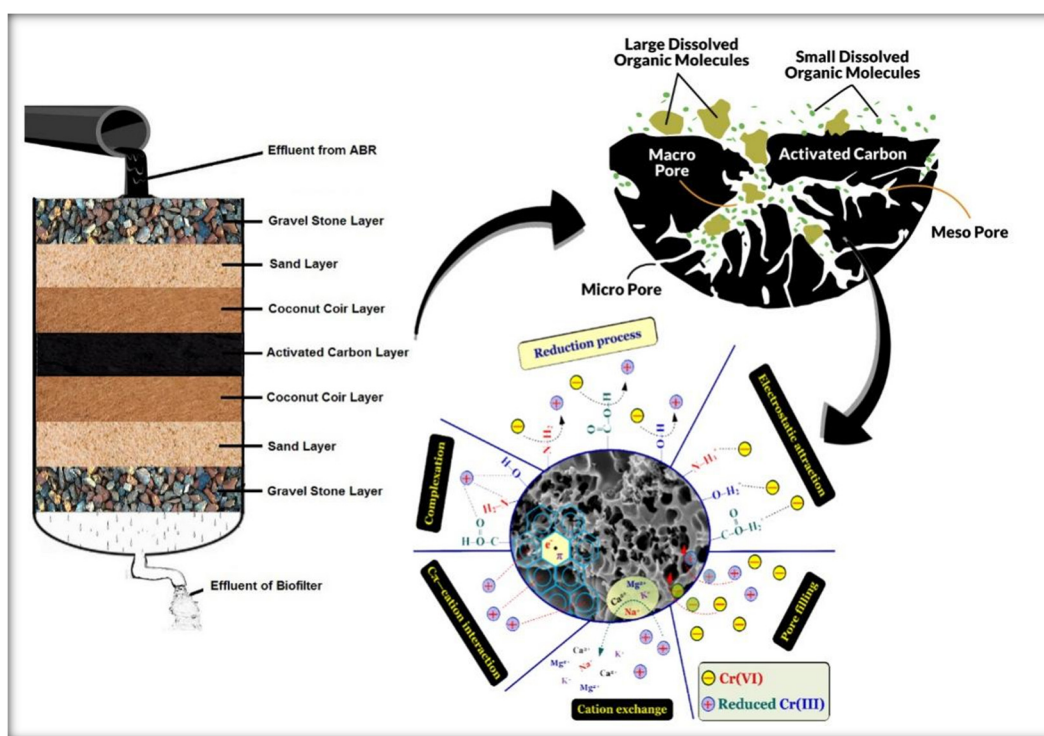


Figure 4. A schematic representation of MF with seven layers (AC and CC as main materials). AC's powerful absorbency capacity can soak up both large and small organic molecules into its pores [28]. Adopted with permission from Tran, H.N. and Chao, H.P. (2019).

Based on the internal structure, AC has heterogeneous-diameter pores ranging from macro (>50 nm) to meso (2–50 nm) and micro (<2 nm) sizes. All pores in AC have highly branched internal porosity (Figure 4), which serves the major function of binding adsorbate species. Meanwhile, based on the chemical structure, AC is categorized as graphite [18]. Certain unwanted impurities or chemicals in water tend to combine with AC, forming various functional groups, for instance, phenols, carboxylic acids, and pyridines. The elemental composition of AC is 80% carbon, and 20% is oxygen, as well as nitrogen. Consequently, the physical and chemical properties of AC are bound to influence the adsorption capacity for different organic and inorganic species [7].

The greywater filter (wastewater treatment) is a combination of ABR and MF technologies. This tool can be regarded as a low-cost filter manufactured with easily obtainable, environmentally friendly, and easy-to-use materials. A portable greywater filter is an alternative technology equipped with sedimentation and a purification chamber [18]. Figure 5 is a sketch of a series of a greywater filter with ABR and MF technologies showing the compartments assigned to (a) the initial waste collection tank for coagulation and flocculation; (b) the wastewater catchment tank (ABR); (c) the membrane filter (biofilter with 7 layers) reactor; and (d) the final treated wastewater (greywater).

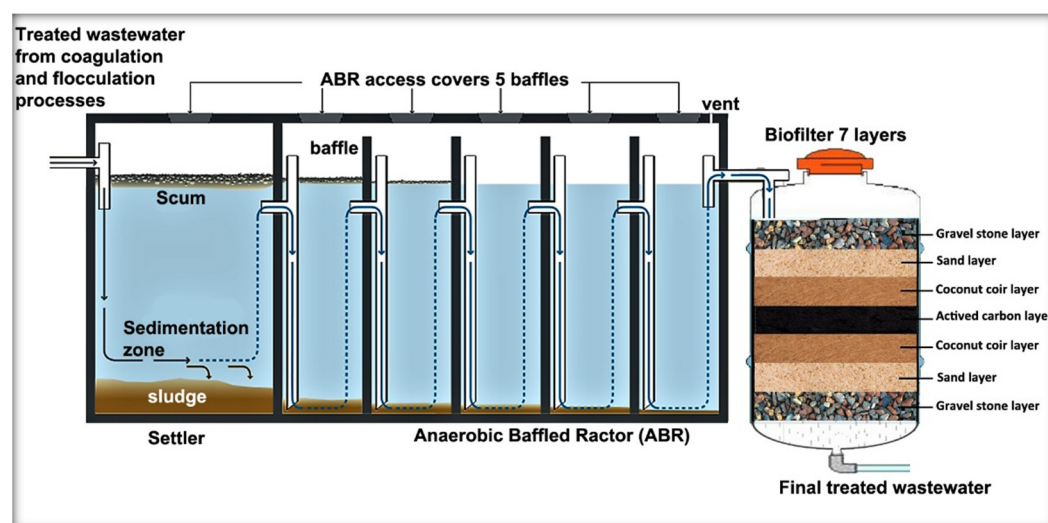


Figure 5. A schematic representation of the greywater filter using a combination of Anaerobic Baffled Reactor (ABR) and Membrane Filter (MF) technologies. Modified from [25].

3. Results

The determination of water content was carried out by various methods such as potentiometry for pH, Winkler titration for BOD levels, spectrophotometry for COD, and gravimetry for TSS. The Winkler titration method is one of the methods used to determine the oxygen content in water based on an oxidation-reduction reaction [30]. Table 2 shows the results of the laboratory analysis performed before the filtering process.

Table 2. The quality parameters of the greywater before filtering and the results of laboratory analyses performed on the greywater samples AL 1 and AL 2, after the filtration, using sample AL 3 as control (without filtration).

No	Parameter	Method	Unit	Sample Value			Maximum Limit (WHO)	Information
				AL 1	AL 2	AL 3 (Control)		
Before	Turbidity	Turbidimetry	NTU	313	257	108	-	-
	pH	Potentiometry	-	6.23	5.96	7.62	6–9	E
	BOD	Winkler Titration	mg/L	49.98	54.88	14.7	30	NE
	COD	Spectrophotometry	mg/L	655	509	284	100	NE
	TSS	Gravimetry	mg/L	464.65	404.40	181.63	30	NE
After	Turbidity	Turbidimetry	NTU	48.73	16.25	108	-	-
	pH	Potentiometry	-	6.78	6.86	7.62	6–9	E
	BOD	Winkler Titration	mg/L	19.40	17.80	14.7	30	E
	COD	Spectrophotometry	mg/L	184	152	284	100	NE
	TSS	Gravimetry	mg/L	77.42	59.68	181.63	30	NE

AL = Greywater; E = Eligible; NE = Not Eligible; AL3 = control (without filtration).

Based on Table 2 (before the filtering process), the BOD, COD, and TSS levels for samples AL1 and AL2 did not fulfill the WHO quality standards of wastewater, therefore they required further treatment to reduce the level of pollution [25]. The coagulation–flocculation process was expected to slightly reduce the greywater’s pH, BOD, COD, and TSS. According to previous studies, the success of the coagulation and flocculation processes not only affected the pH, BOD, COD, and TSS values but also affected the temperature [7].

The greywater filter with ABR and MF system comprises two parts: The main part, which is the gravity system reservoir, and the layer material part for filtering/absorption

of chemical compounds [25]. The function of the ABR is to filter out large waste, for instance, moss, stone, and other sediments. Subsequently, the wastewater that enters the biofilter layer (MF) experiences a “water–rock interaction” process, as in the concept of ion-exchange chromatography [14].

The greywater filter using ABR and MF technologies was tested on samples AL1 and AL2, which were highly polluted, based on the domestic wastewater quality standard threshold [31]. In the experiment, a significant improvement in the greywater turbidity was observed after the trial, while Table 2 (after filtering process) shows the pH, BOD, COD, and TSS values of the greywater after passing through the greywater filter.

4. Discussion

4.1. pH (Degree of Acidity)

Based on the pH measurements performed using the potentiometric method, the new pH levels fulfill the quality standards set by WHO [11]. The acidity of water is determined by the concentration of hydrogen ions and affects the survival of biological life in water. The normal pH for aquatic life is 6 to 9, and microorganisms are unable to survive in extreme pH conditions [32]. According to the results, the pH of the greywater before and after filtration using ABR and MF were within the WHO standards for greywater [13]. However, filtration with ABR and MF increased the pH of samples AL 1 and AL 2 from 6.23 and 5.96 to 6.78 and 6.86, respectively. This is probably due to AC’s ability to balance the pH of water. Figure 6A shows AC is effective in neutralizing the pH of wastewater, and this is consistent with previous studies where similar results were reported. The error bar in Figure 6A–D describes the range of tolerances in all types of tests being measured.

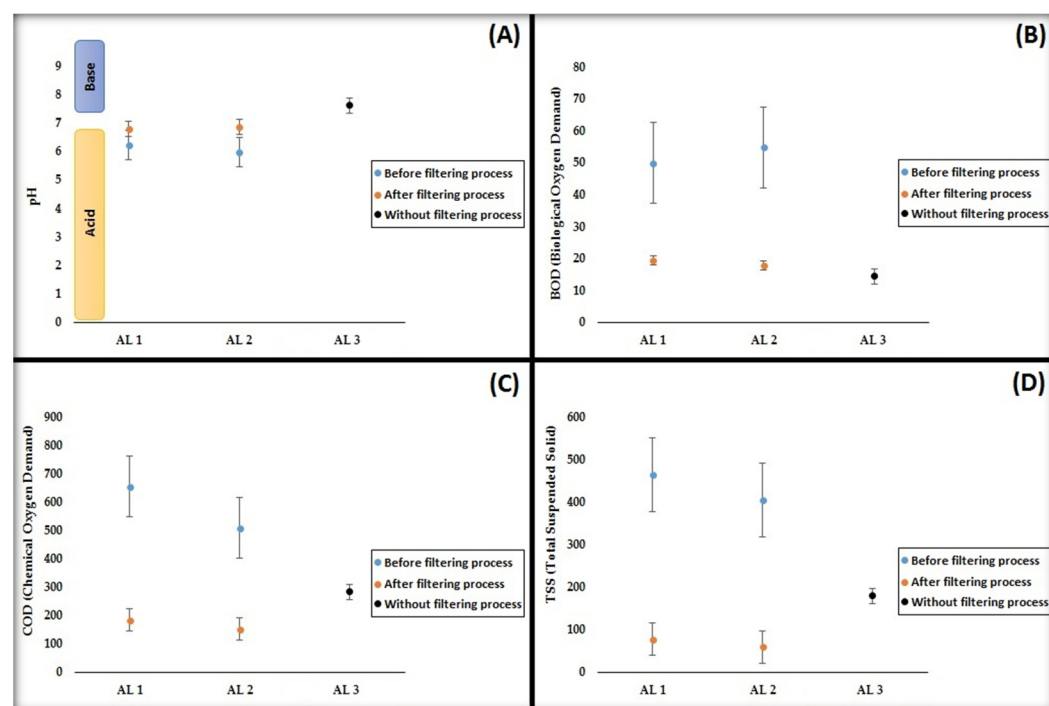


Figure 6. (A) Changes in the pH (degree of acidity) of greywater before and after greywater filtering; (B) changes in the BOD (Biological Oxygen Demand) before and after greywater filtering; (C) changes in COD (Chemical Oxygen Demand) before and after greywater filtering; (D). Changes in TSS levels before and after greywater filtering.

4.2. BOD (Biological Oxygen Demand)

BOD refers to the level of oxygen required by microorganisms to decompose or oxidize organic matter in water [13]. The high level of BOD in the greywater before processing indicates the presence of liquid waste, which is hard to decompose properly [26]. This shows the need for a microbial treatment to completely decompose the organic pollutants present in wastewater [16]. The BOD test performed using the Winkler titration method obtained values of 49.98 mg/L and 54.88 mg/L for samples AL1 and AL2, respectively. These values exceed the WHO standard threshold for domestic wastewater (30 mg/L).

A significant reduction in the greywater's BOD levels to 19.4 mg/L and 17.80 mg/L for samples AL 1 and AL 2, respectively, was recorded after filtration using ABR and MF technologies. The new BOD levels obtained are within the WHO domestic wastewater standards (Figure 6B).

4.3. COD (Chemical Oxygen Demand)

COD refers to the amount of oxygen required in water to support the decomposition reactions of chemical pollutants and is expressed in ppm (parts per million) or mg/L [16]. The measurement of effluent COD is another form of measuring the oxygen demand in wastewater. The greywater's COD levels measured using the spectrophotometric method were discovered to be quite high before filtration, at 655 mg/L, 509 mg/L, and 284 mg/L, for samples AL 1, AL 2, and AL 3, respectively [12]. These values do not fulfill the WHO wastewater standard threshold (100 mg/L).

A significant reduction in the COD levels to 184 mg/L and 152 mg/L, for samples AL 1 and AL 2, respectively, was recorded after greywater filtration using ABR and MF technologies. These new values also exceed the WHO wastewater standard threshold of 100 mg/L. However, the results confirm filtration using ABR and MF technologies effectively reduces the COD of wastewater (Figure 6C).

4.4. TSS (Total Suspended Solid)

TSS is a measure of the solids responsible for turbidity, which are not dissolved, do not settle immediately, and comprise particles of smaller size and weight, compared to sediment [16]. A TSS value above the standard threshold is bound to cause sedimentation, thereby reducing the carrying capacity of rivers or water bodies [33]. In this study, the TSS evaluation of greywater using the gravimetric method showed the TSS levels exceed the WHO standard threshold [11] at 464.65 mg/L, 404.40 mg/L, and 181.63 mg/L, for samples AL 1, AL 2, and AL 3, respectively.

A significant reduction in the TSS levels to 77.42 mg/L and 59.68 mg/L was observed for samples AL 1 and AL 2, respectively. These values also exceed the WHO wastewater standard threshold of 30 mg/L. However, these results confirm filtration using ABR and MF technologies effectively reduces the TSS of wastewater (Figure 6D).

5. Conclusions

Based on this study's findings, a greywater filter using ABR and MF technologies with AC and CC as the main materials, effectively reduces the turbidity, BOD, COD, and TSS levels, while increasing the pH of the wastewater. The BOD levels were reduced from 49.98 mg/L and 54.88 mg/L to 19.4 mg/L and 17.80 mg/L, for samples AL 1 and AL 2, respectively. These results have fulfilled the WHO standard threshold of 30 mg/L. Similarly, the COD levels reduced from 655 mg/L and 509 mg/L to 184 mg/L and 152 mg/L, for samples AL 1 and AL 2, respectively. The TSS levels also reduced from 464.65 mg/L and 404.40 mg/L, to 77.42 mg/L and 59.68 mg/L, for samples AL 1 and AL 2, respectively. The new COD and TSS values obtained still exceed the WHO standard threshold for greywater; however, these results confirm greywater filtration using ABR and MF technologies effectively reduces the COD and TSS levels of wastewater. In addition, the

materials for manufacturing the greywater filter are easily obtainable, inexpensive, and can be developed independently; therefore, this tool is an implementation of portable filtration with low-cost production.

Author Contributions: Conceptualization: Z.S. and S.Y.; methodology: Z.S.; software: R.J.; validation: A.A., Z.S., and S.Y.; formal analysis: R.U.; investigation: A.A.; resources: K.P.; data curation: A.A.; writing—original draft preparation: A.A.; writing—review and editing: R.U.; visualization: R.P.; supervision: S.Y.; project administration: A.A.; funding acquisition: Z.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available in a publicly accessible repository.

Acknowledgments: The authors are grateful to the anonymous reviewers for their valuable comments and efforts to improve this manuscript.

Conflicts of Interest: The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

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