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Original Research

Valuable and Sustainable Option for Reusing Carwash Wastewater in Nyarugenge District, Rwanda

Ritha Nyirandayisabye[1], Rosette Niyirora[2], Aline Igabe[1], Theogene Hakuzweyezu[3]*, Gratien Twagirayezu[4], Nadia Kaneza[5], Charles Ntakiyimana[6], Jean Nepomuscene Ntezimana[7], Olivier Irumva[8], Habasi Patrick Manzi[9], Theoneste Niyigaba[9]

[1]School of Civil Engineering, Fujian University of Technology, Fujian, 350108, China
[2]School of Civil Engineering, Lanzhou Jiaotong University, Lanzhou, 730070, China
[3]School of Civil Engineering, Lanzhou University of Technology, Lanzhou, 730050
[4]School of Environmental and Municipal Engineering, Lanzhou Jiaotong University, Lanzhou, 730070, China
[5]School of Civil Engineering, University of Rwanda, Kigali, Rwanda
[6]School of Traffic and Transportation, Lanzhou Jiaotong University, Lanzhou, 730070, China
[7]School of Health Sciences, University of Rwanda, Kigali, Rwanda
[8]School of Eco-Environmental Engineering, Guizhou Minzu University, Guiyang, 550025, China
[9]School of Public Health, Lanzhou University, Lanzhou 730000, China

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Abstract

Carwash wastewater has a considerable influence on environmental pollution due to rapid development and urbanization. Herein, to consummate that issue in an environmentally friendly manner, coagulation and sand filtration technologies were coupled in this study to investigate whether this combination could be a sustainable solution. Various metrics, such as potential hydrogen (pH), turbidity, chemical oxygen demand (COD), total suspended solids (TSS), oil, and grease amount, have been tested to assure the quality of the water that is treated. The findings reveal that the type of washed vehicle, carwash location, washing method, detergent type, and dose are contributing to environmental pollution. This study evinced considerable removal efficiency of pollutants, where turbidity, chemical oxygen demand, total suspended solids, oil, and grease concentration removal rates were 97.25%, 98.68%, 99.76%, and 94.42%, respectively. This study suggests that implementing this type of wastewater treatment plant in carwashes could effectively contribute economically and environmentally, as the effluent can be reused to save water usage.

Keywords: carwash, wastewater treatment, flocculation, coagulation

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*e-mail: thakuzweyezu@gmail.com

Introduction

In the world, the rapid development of numerous cities is inducing a high demand for cars and automobile services such as repair centers and washing stations [1, 2], thus polluting the environment by discharging untreated carwash wastewater into the freshwater ecosystems [3]. Car washes are one of the most significant contributors to water contamination due to their chemical characteristics [4, 5]. In addition, carwash wastewater contains many pollutants such as sand and gravel, suspended solids, turbidity, petroleum content, surfactants, detergents, heavy metals, hydrofluoric acid, ammonium bifluoride products, paint residues, volatile organic compounds (VOCs), organic matters, diesel detergents, and so on, which are toxic to humans and all living organisms [6-8]. Therefore, governments and environmental protection agencies should be concerned about the perils of discharging untreated carwash water into freshwater ecosystems [9, 10]. In Rwanda, wastewater treatment facilities have been constructed while cities have snowballed. However, most of them are decentralized with an appropriate environmental quality sustainability level due to the absence of central sewerage systems and inadequate resources to build sustainable wastewater infrastructure [11, 12]. Due to this, cost-effective, creative, and environmentally friendly, and sustainable wastewater approaches are urgently needed, particularly for carwashes. Consequently, on-site wastewater treatment may be a sustainable solution to reduce the number of pollutants in separate or combined urban sludge [13, 14]. In addition, regular cleaning of carwash areas and grit traps or catch basins is recommended to minimize or prevent debris such as paint chips, dirt, cleaning agents, chemicals, and oil and grease from being discharged into freshwater systems [15].

Recently, hydrophilic nanofiltration membranes NF270 were reported to be used in the carwash industry to recycle wastewater [16-18]. Kupiec et al. [19] investigated numerous automobiles washing techniques and water utilization, water contamination, and wastewater technologies such as biological water treatment and reverse osmosis. Zanetti et al. [20] have also worked on articles on carwash wastewater reclamation through the application of innovative flocculation–column filtration (FCF), sand filtration, and final chlorination as full-scale carwash wastewater recycling. Moreover, Boussu et al. [21] proposed a new technology in carwash wastewater treatment and water reuse, in which wastewater and reclaimed water are characterized by monitoring chemical, physicochemical, and biological parameters. It was shown that chemical coagulation using alum, bentonite powder, ferrous sulfate, and calcium chloride in the presence of bentonite powder might be used to remove oil and grease [22] thoroughly. Nevertheless, as water quality becomes more crucial, sustainable water recycling technologies are essential.

This study was aimed to investigate the impact of coagulation coupled with sand filtration on potential hydrogen (pH), turbidity, chemical oxygen demand (COD), and total suspended solids (TSS) during the recycling of carwash wastewater. To do that, a car wash wastewater treatment system based on coagulation, flocculation, alum, and filtration was developed and executed. Previous studies reported that the coagulation method for carwash wastewater treatment could reduce the turbidity and COD by over 80% [23]. In addition, Veréb et al. [24] showed that Na-bentonite and anionic polyelectrolyte for carwash wastewater treatment could reduce turbidity, COD, and extractable oil content at a level of 98%, 59%, and 85%, respectively. In the present study, turbidity, COD, TSS, oil, and grease concentration removal efficiencies were 97.25%, 98.68%, 99.76%, and 94.42%, respectively. This indicates that the present study for car wastewater treatment could be more effective. More importantly, the combination of coagulation and sand filtration technologies should be applied during the treatment of carwash wastewater. This study shows a promised solution for recycling car wash wastewater in the future. This study can be economical by reusing recycled wastewater and is also vital to minimize environmental issues by preventing dangerous substances in untreated sewage from seeping into groundwater, rivers, water bodies, and soil.

Materials and Methods

Study Area

This study was conducted in Nyamirambo and Kimisagara sectors (Kigali, Rwanda) (Fig. 1), where they occupy 8.746 km² and 3.313 km², respectively, and there are 4,607/km² population density and 14,113/km² population density, respectively [25]. There are many car washes in these sectors and a large population compared to other sectors. Furthermore, water scantiness and environmental pollution are major concerns due to car wash wastewater discharges into the municipal sewerage system.

Materials

In this study, three carwash wastewater samples were collected from a pit under the washing surface of the car at three different local service stations located in the Nyarugenge district, Kigali City, Rwanda. The collected water samples were from the wastewater previously used for washing, servicing, and maintenance vehicles in these stations. The samples were collected in the morning (9:00 AM) while working, where many cars came for the washing process. The physicochemical properties of an influent and effluent sample are given in Table 1. The treatment plant was composed of an aeration tank, coagulation and flocculation tanks, sedimentation tanks, sand

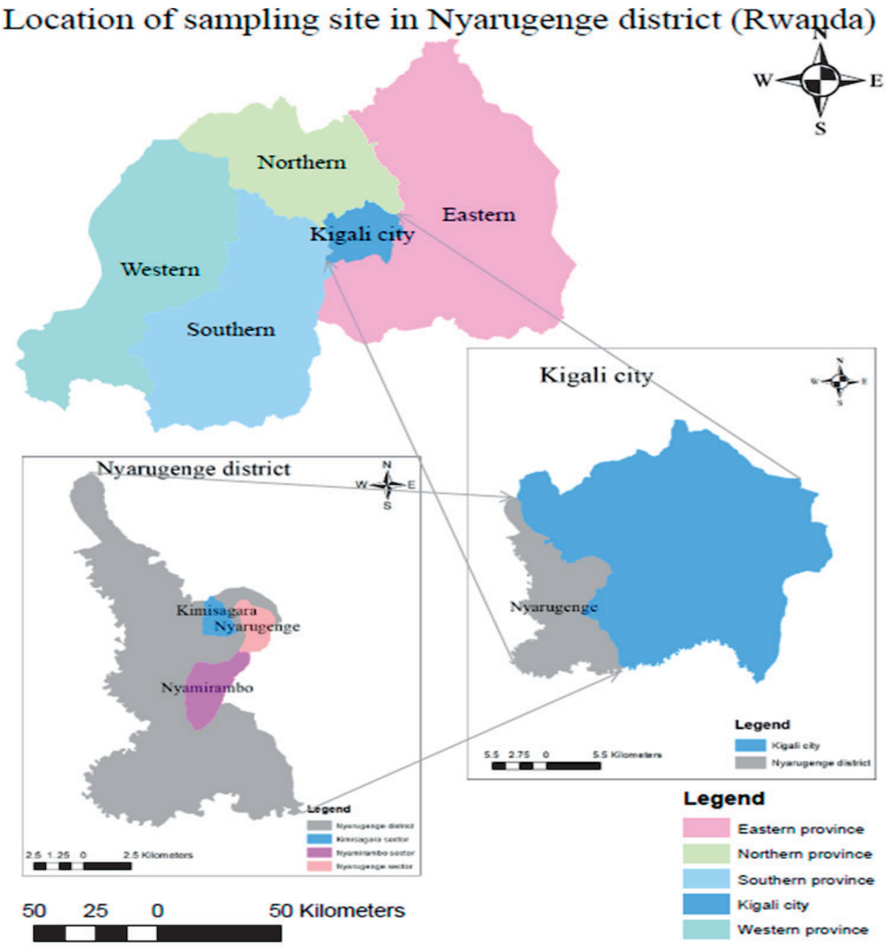

Fig. 1. Study area description.

filtration tanks, and a purified water tank provided by the University of Rwanda College of Science and Technology Nyarugenge campus.

Set up of Carwash Wastewater Treatment System

As depicted in Fig. 2, wastewater was feeding into a water tank followed by an aeration tank to remove debris and continue to a coagulation and flocculation tank where coagulant is used to remove and settle down the large particles. Then, continue in the sedimentation tank, followed by a sand filtration tank, and then continue in a purified water tank to reuse those carwashes. Final water was passing through beds of sand or other granular materials known as filtration. For the wastewater treatment process, sand filtration was done after the sedimentation process, and water enters the sand layer, passes through the gravel layer, and into the sand filter. The primary purposes of sand filtration are to remove bacteria, viruses, color, taste, and odors to produce clear and sparkling water. In addition, 95 to 98% of suspended impurities may be eliminated using sand filters.

Table 1. Treated parameters.

Parameters	Before treatment			After treatment		
Samples	A	B	C	A	B	C
pH	4.18	3.95	3.95	7.12	7.9	8.74
Turbidity	67.8	542	96.1	11.6	14.9	16.9
TSS	870	6050	380	10	14	4
COD	211	762.5	164	15	10	12
Oil and grease concentration	0.592	1.005	0.05	0.055	0.056	0.031

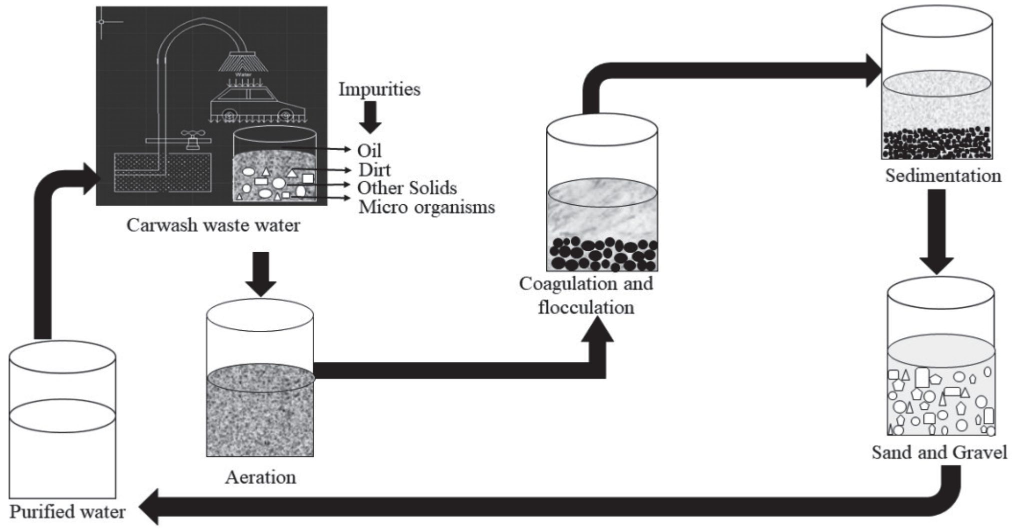

Fig. 2. Schematic representation Carwash wastewater treatment process.

Analysis of Physicochemical Properties

This study determined the physicochemical properties of influent and effluent wastewater. However, deionized water was used to clean each material. The samples were collected at a normal temperature of 24ºC and collected using the grab sampling technique into plastic bottles (3L) before being transported to the chemistry laboratory and environmental laboratory of the University of Rwanda College of Science and Technology, Nyarugenge campus for analysis of physicochemical properties. In this study, alum was used as a coagulant. The amount of coagulant that produces water with the lowest turbidity was considered the optimal coagulant dose. The standard metal salt alum (aluminum sulfate) was an excellent coagulant for water containing appreciable organic matter. The chemical formula used for commercial alum is $Al_2(SO_4)_3$;14$H_2$0. Once dissolved in water, aluminum forms hydroxo-complexes and solids [e.g., Al $(OH)_3$(s), Al $(OH)_2^+$, Al $(OH)_2{}^+$, Al $(OH)_4{}^-$. As a result, the pH of the water was lowered, especially if the alkalinity of the water was low. Since we had three samples, we prepared each one at a time. After sample preparation, we measured 100 ml of the sample. We poured it into a beaker, and we calibrated a multi-parameter meter (HACH, HQ40d) used to measure the pH and connect it to electricity.

A multi-parameter meter (HACH, HQ40d) was also used to measure turbidity, where a turbidity meter must be calibrated. We added sample water to the horizontal mark to the sample cells, wiped them gently with soft tissue, and placed them in the turbidity meter. A UV-VIS spectrophotometer determined the chemical oxygen demand (COD), total suspended solids (TSS) of the sample, and reference distilled water. However, COD was tested by feeding a 2.5 ml sample into tubes, then adding 2.5 ml of distilled water, and then 10 ml of standard KHP and 5ml of K2Cr2O7 solution were added tightly with shaking. Furthermore, tubes were put into the COD reactor, heated to 150°C, and refluxed for two hours. After that, tubes were placed in the test tube rack to cool them to room temperature before being tested using a spectrophotometer. TSS testing requires the calibration of the spectrophotometer first. Therefore, ten volumes of distilled water were mixed into 1 volume sample for all three samples. The water was poured up to the horizontal mark in each sample cell before placing it into the spectrophotometer. To use it as a benchmark, fill the sample cells to the horizontal line and observe the spectrophotometer until a steady reading is obtained.

As depicted in Fig. 3a), an eletavator was used to measure the amount of oil and grease present in the wastewater. Testing was done by cleaning the flasks and then placing them in the oven for five minutes to dry. After that, the flask was removed from the oven, then weighted and symbolized by W1. After that, 100 ml of sample and 100 ml of cyclohexane was measured and poured into a separating funnel shaken to mix the sample and the cyclohexane. Subsequently, as shown in Fig. 3b), the support and installation of the separating funnel were mounted. And then wait for some time so that the oil can be separated from the water. Afterward, the separating funnel was opened until the water was removed and went in the beaker below the separating funnel, and then it was closed. The retainer was poured into the flask. After that, the flask was mounted to the eletavator to start. A rotating evaporator was used to extract cyclohexane from oil and grease. The amount of oil and grease in the sample was reduced by boiling to extract the cyclohexane. Hot air in the oven was used to dry the oil and grease that evaporated from the cyclohexane solution. The weight of oil and grease was calculated using Eq. (1), where W_1 is the weight of the empty flask, W_2 is the weight of the flask after being removed from the oven. A jar test was conducted to determine the right amount of treatment chemicals.

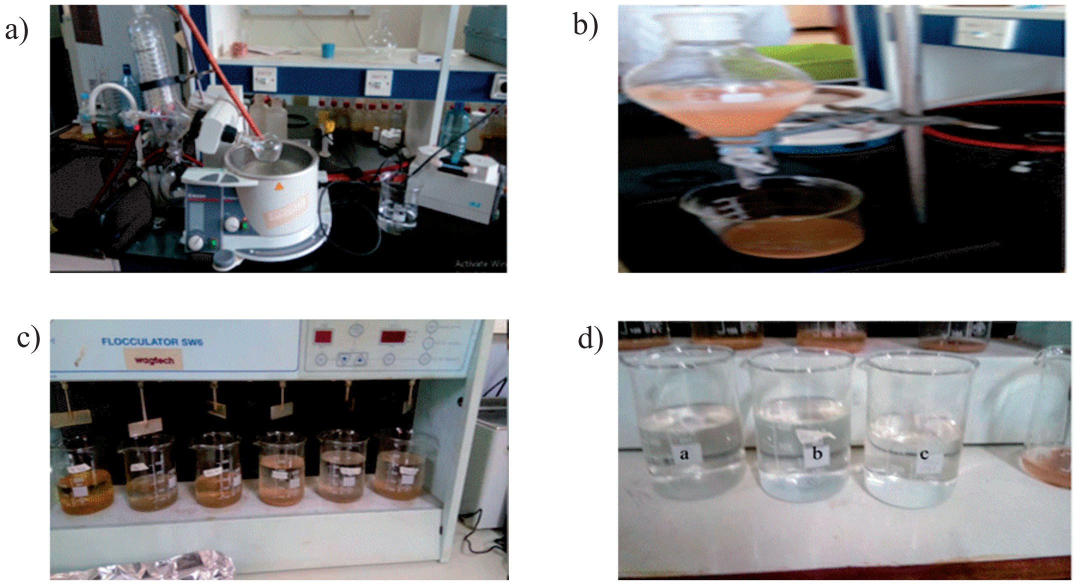

Fig. 3. Treatment process for oil and grease test: Elevator a) and Separating funnel b); Flocculation results: before treatment c) and after treatment d).

A stock alum and ferric chloride solution were prepared by dissolving 10 g powder in 1-liter of distilled water. Sodium carbonate solution was prepared by dissolving 10g of sodium carbonate in 1-liter distilled water. As depicted in Fig. 3c), six beakers for the jar test units were filled with 400 ml of samples for each and stirred at 100 rpm, as shown in Table 2. Alum was quickly added to each beaker and kept in rapid mixing for 1 minute before rotating it at 30 rpm for the next 30 minutes. Additionally, the samples were kept for 30 minutes to settle flocs. After that, as shown in Fig. 3d), a clear sample from each beaker without disturbing the settled sludge was siphoned out.

Results and Discussion

Effect of Treatment on Potential Hydrogen

Commonly, pH is a crucial parameter in wastewater treatment plants for coagulation, turbidity removal, disinfection, water softening, and corrosion control. As evinced in Table 1, analytical findings collected before treatment showed that the characteristics of raw carwash wastewater did not fulfill EQA 1974, regulation 2009 [26]. Therefore, car wash wastewater was treated to improve its features and prevent contamination of the environment. It was seen that the pH values recorded before treatment were lower than the limits of the standard. As shown in Table 1, the pH before and after treatment was 4.18 and 7.12, respectively. After adding alum, the pH was raised to the allowable limit for the disposal or reuse process. This indicated that the chemical coagulant used in the study is more efficient in adjusting carwash wastewater's pH value. This was also reported by Gheethi in Malaysia [27].

Effect of Treatment on Turbidity Test

It seems that the turbidity results obtained after treatment were lowered to a specified level to comply with the standard, which is remarkable

Table 2. Turbidity (NTU) data from Jar test.

	Coagulant (mg/l)	Alum turbidity results			Ferric Chloride turbidity results		
Beaker		A	B	C	A	B	C
1	0	39	686	259	398	510	232
2	10	5.11	349	108	98.8	15.1	25.7
3	20	2.48	6.56	2.87	299	6.07	56.9
4	30	6.69	4.85	3.81	205	28	236
5	50	9.86	25.3	2.6	188	67.9	109
6	100	10.7	42.5	21	9.57	28.8	58.8

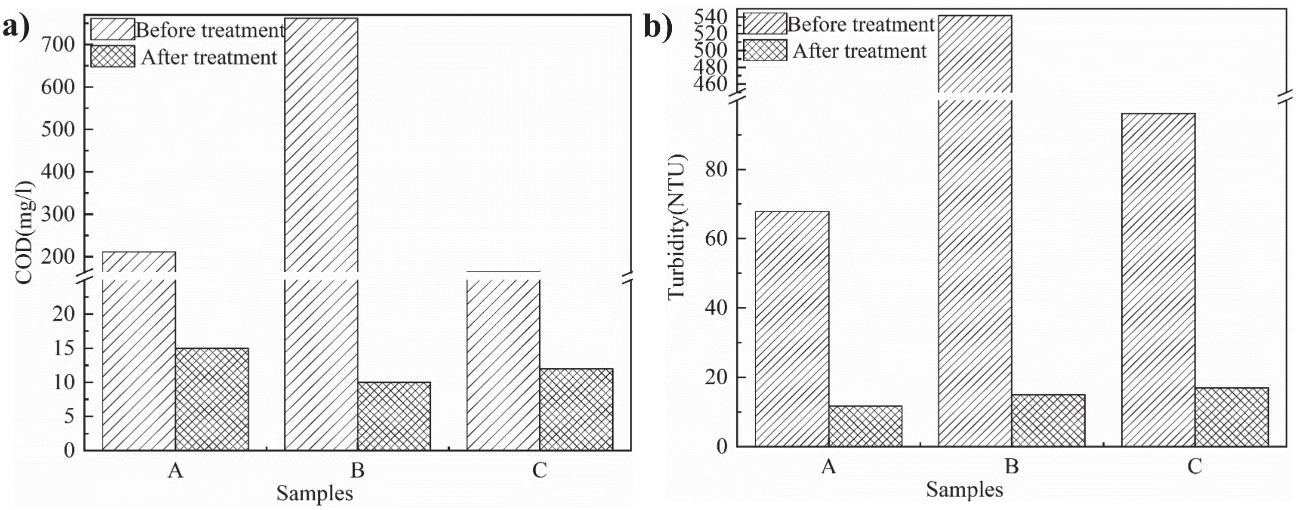

Fig. 4. Effect of treatment on turbidity a) and COD levels b).

evidence of the efficacy of wastewater treatment. Before treatment, the high turbidity value is due to the presence of dirt, mud, and brake particles in the wastewater, which is washed off from vehicles and are comparatively large molecule sizes of pollutants. This is consistent with results obtained by Syed et al. [28]. The coagulant effectively reduced turbidity from 67.8 NTU to 11.6NTU, from 542 NTU to 14.9 NTU, from 96.1 NTU to 16.9 NTU, as shown in fig.4a. The differences in turbidity among samples might be attributed to the carwash wastewater coming from different sources and the fact that the automobiles were not all the same.

Effect of Treatment on COD

As shown in Fig. 4b), pretreatment COD levels are higher than the maximum allowable under the environmental quality act 1974 regulatory limitations. The high concentration of COD might be related to the presence of detergents utilized during the washing process, which cause the oxidation process of the organic compound and then increases COD. Thus, chemical coagulation had the most significant contribution to pollutants reduction. For instance, there was COD removal of 752.5 mg/l for sample B after treatment.

Effect of Treatment on Total Suspended Solids

Analysis of TSS in wastewater is one of the most common laboratory procedures used to set and maintain environmental permit limits for particles in wastewater samples. As shown in Fig. 5a), the results indicate that effluent from water treatment is suitable and safe for washing cars. A similar finding was demonstrated by Mohamed et al. [29]. In this study, accurate completion of the final solids' removal after treatment (for example, simple B) was obtained, which converts the TSS weight

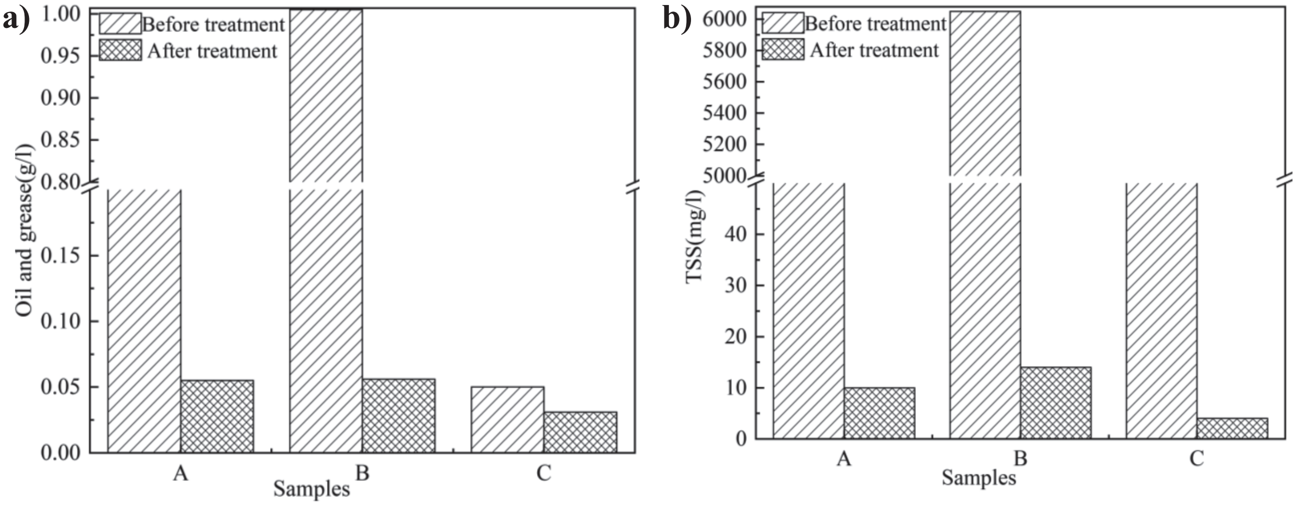

Fig. 5. Effect of treatment on TSS a), on oil and grease concentration levels b).

of the wastewater sample before treatment to the final concentration unit of 14 mg/L.

Effect of Treatment on Oil and Grease Concentration

As evinced in Table 1, the oil and grease content decreased after treatment (with an average percentage reduction of 91.4%). For instance, the amount of oil and grease detected in sample C after treatment was 0.031g/l. According to Fig. 5b), the differences in oil and grease reduction may be attributable to the washing methods and detergent dosage, and the detergent type and quality.

Effect of Treatment by the Use of Chemical Coagulants

In general, the use of chemical coagulants contributes significantly to pollution reduction. However, choosing a certain chemical coagulant is not a simple task. To select the coagulant used in this study, two commonly used coagulants (alum and ferric chloride) were tested individually with varying doses. It was found that the use of alum offered superior coagulation results and greatly decreased turbidity levels compared to ferric chloride (Table 2). The jar test determines the optimal coagulant dose, and the collected findings show that using an alum coagulant gives the best results. After that, alum was used in treatment, resulting in reusable water for rewashing cars.

Conclusion

In summary, the integrated treatment system evinced better results for the treatment of raw carwash wastewater whereby a high percentage reduction was obtained for most pollutants, such as Turbidity (97.25%), COD (98.68%), TSS (99.76%), and oil and grease concentration (94.42%). In particular, the coagulant and filtration unit was highly effective for carwash wastewater's primary treatment, which significantly contributed to pollution reduction. The use of alum coagulant presents high efficiency as it provides less turbidity when compared to ferric chloride. The parameters obtained after treatment indicate that treated carwash wastewater is appropriate to be reused again for car washing processes. This study suggests that this system should solve a problem caused by car wash wastewater. More importantly, this option is efficient, reliable, and economical.

Conflict of Interest

The authors declare no conflict of interest.

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