



Assessment of Petroleum Derived Pollutants in Car Wash Wastewater from Al-Karkh district of Baghdad

Ghufran Saad Aljanabi^{1*}  , and Adel Mashaan Rabee²  

^{1,2} Department of Biology, College of Science, University of Baghdad, Baghdad, Iraq

*Corresponding Author.

Received: 18/January/2026

Accepted: 20/April/2026

Published: 20/October/2026

<https://doi.org/10.30526/39.4.4419>



© 2026. The Author(s). Published by College of Education for Pure Science (Ibn Al-Haitham), University of Baghdad. This is an open-access article distributed under the terms of the [Creative Commons Attribution 4.0 International License](https://creativecommons.org/licenses/by/4.0/)

Abstract

Car wash operations are major sources of urban water pollution, particularly in rapidly growing cities in countries with weak environmental regulations and little wastewater treatment infrastructure, such as Iraq. In this study, we characterized the chemical composition of raw car wash wastewater in Baghdad and assessed their potential ecological risk to receiving water bodies. Wastewater Samples were collected from eight car wash stations in the Al-Karkh district of Baghdad. Wastewater samples were analyzed for organic contaminants by gas chromatography mass spectrometry (GC-MS), and physicochemical parameters, including pH, chemical oxygen demand (COD), total suspended solids, nutrients, and oil & grease were measured using standard analytical methods. GC-MS analysis revealed the presence of aromatic hydrocarbons, long chain alkanes, fatty acids, esters, and surfactant related compounds, suggesting contributions from fuel leakage and detergent residues. The effluents were very acidic (pH 4.1) and had extremely high COD values of 1200 mg/L, which far exceeded international discharge limits. Elevated levels of total suspended solids (TSS), nutrients, and oil and grease indicate a high potential for oxygen depletion, eutrophication, and accumulation of persistent organic pollutants in receiving waters. This study to the best of our knowledge represents the first GC-MS based characterization of car wash wastewater in Baghdad and provides essential baseline data for environmental monitoring. The findings clearly indicate the need for practical and cost effective pretreatment and management strategies to mitigate the ecological impacts of car wash discharges on local aquatic ecosystems.

Keywords: Car wash wastewater, gas chromatography mass spectrometry, physicochemical properties, organic contaminants, urban water pollution.

1. Introduction

One of the most significant global environmental challenges is water pollution, largely caused by rapid industrialization, urbanization, and poor wastewater management¹. Large amounts of untreated effluents are constantly dumped into natural waters, introducing complex mixtures of organic and inorganic contaminants that affect water quality, reduce biodiversity, and upset the ecological balance². Car wash wastewater is a growing but frequently ignored source of urban pollution. Produced in large quantities every day in heavily populated areas, car wash wastewater contains detergents, surfactants, petroleum hydrocarbons, lubricating oils, waxes, suspended solids, and nutrient rich compounds³⁻⁵. Uncontrolled discharge of these effluents leads to high chemical oxygen demand (COD), total suspended solids (TSS), and oil and grease levels, and nutrient enrichment accelerates eutrophication and oxygen depletion. Moreover petroleum derived hydrocarbons and phenolic compounds exert direct toxic effects on aquatic biota and have high bioaccumulation potential leading to long term ecological and human health risk⁶.

Globally, numerous studies have highlighted the environmental concern associated with car wash effluents. Investigations carried out in Brazil and Indonesia demonstrated that untreated car wash wastewater is characterized by high levels of chemical oxygen demand, oil and grease, surfactants, and hydrocarbon related contaminants, which frequently exceed international guideline limits for discharge and reuse⁷⁻¹⁰. These results highlight the worldwide scope of the problem and the necessity for effective treatment technologies especially in developing countries that do not have adequate environmental monitoring and wastewater treatment. In Iraq several studies have reported significant petroleum hydrocarbon contamination of the Tigris River mainly due to unregulated urban and industrial discharges^{11,12}. Car wash wastewater which contains petroleum-based and detergent related compounds similar to those found in surface waters could be another contaminant source, but there have been no comprehensive studies that link the chemical profiles of car wash wastewater to ecological risk despite the widespread use of car wash facilities in Baghdad. This work aims to provide baseline data for future monitoring programs and to support the development of cost effective management and treatment strategies for small scale car wash facilities in Iraq, assessments linking their chemical composition to potential environmental risks are lacking.

This study fills this gap by examining the physicochemical properties of untreated car wash wastewater that was gathered from eight stations in the Al-Karkh District of Baghdad. It also uses GC-MS to identify the main organic pollutant.

2. Materials and Methods

2.1. Study Area

The study was conducted in Baghdad City focusing on eight car-wash stations located within the Al-Karkh District.

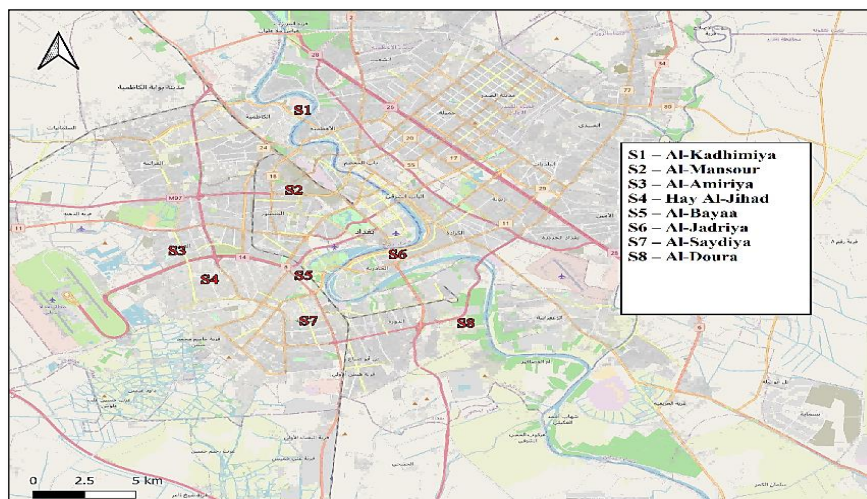


Figure 1. Map illustrating the spatial distribution of selected car-wash sampling stations (S1–S8) across Al-Karkh districts, Baghdad.

The sites were selected to represent typical facilities differing in washing activity, washing methods, and wastewater discharge routes. Eight stations were chosen from densely populated and high-traffic areas to provide adequate spatial coverage and represent typical car-wash discharges within the district.

2.2. Sample Collection and Handling

In November 2023, grab samples (1 L) were collected during regular operating hours using pre cleaned amber glass bottles that had been rinsed three times with the sample water prior to final filling. This period was selected because it represents stable weather conditions following the dry summer season, when car-wash activity and runoff contamination are typically consistent. Samples were stored in insulated coolers under dark, cold conditions and transported promptly to

the laboratory for analysis. All measurements were performed on the same day of collection to minimize compositional changes before analysis by (GC-MS) and physicochemical testing.

2.3. GC-MS Analysis

Liquid–liquid extraction (LLE) was carried out using n-hexane according to the U.S. EPA Method 3510C¹³. A separatory funnel was filled with 250 mL of wastewater, and three successive extractions were performed using 30 mL portions of n-hexane. The combined extracts were dried over anhydrous sodium sulfate, filtered, and concentrated to approximately 1.0 mL under a gentle nitrogen stream. Extracts were stored in amber GC vials until analysis. GC-MS analysis was performed using an Agilent 7820A gas chromatograph coupled with a 5977E mass selective detector (Agilent Technologies, USA)¹⁴, at the Ibn Al-Baitar Center, Ministry of Industry and Minerals, Baghdad. The separation was achieved using an HP-5MS UI column (30 m × 0.25 mm × 0.25 µm). Helium (99.99%) was used as the carrier gas at a constant flow rate of 1.0 mL/min. The injection volume was 1 µL in splitless mode, with an injector temperature of 250 °C and a transfer line temperature of 280 °C. The oven was programmed as follows initial temperature 60 °C (held for 3 min), increased to 180 °C at a rate of 7 °C/min.

2.4. Physicochemical Analysis

Physicochemical parameters were analyzed according to the Standard Methods for the Examination of Water and Wastewater¹⁵ pH was measured using a BP3001 digital pH meter (BP Instruments, Germany)¹⁶. Total suspended solids (TSS) were determined gravimetrically using Whatman 90 mm glass-fiber filters (15).COD was analyzed by the closed reflux dichromate method (APHA 5220-B)¹⁷, with absorbance measured using a WTW photometer (Weilheim, Germany)(18).TP was determined following the Murphy and Riley method¹⁹. NO₃⁻ was analyzed colorimetrically using the NitraVer-5 reagent with a HACH DR/2010 spectrophotometer¹⁵. NO₂⁻ was determined using APHA Method 4500-NO₂⁻ B (15).SO₄²⁻ was measured using APHA Method 4500-SO₄²⁻¹⁵. Alkalinity was determined by titration (APHA 2320-B)²⁰. Oil and grease were extracted using S-316 solvent and analyzed with a Horiba OCMA-350 oil content analyzer (Horiba, Japan)¹⁵.

2.5. Statistical Analysis

All physicochemical parameters were expressed as mean values with their corresponding standard deviations (SD) calculated from three independent replicates (n = 3). Statistical analyses comparing the eight sampling stations were conducted using IBM SPSS version 26 whereas data organization and figure preparation were completed in Microsoft Excel 2021. One way analysis of variance (ANOVA) was performed to examine overall differences among stations followed by Tukey post hoc test to identify specific pairwise variations (p < 0.05). Graphical outputs such as stacked bar and pie charts were generated to illustrate the spatial variation of the measured parameters across the study area.

3. Results

3.1. GC–MS Results

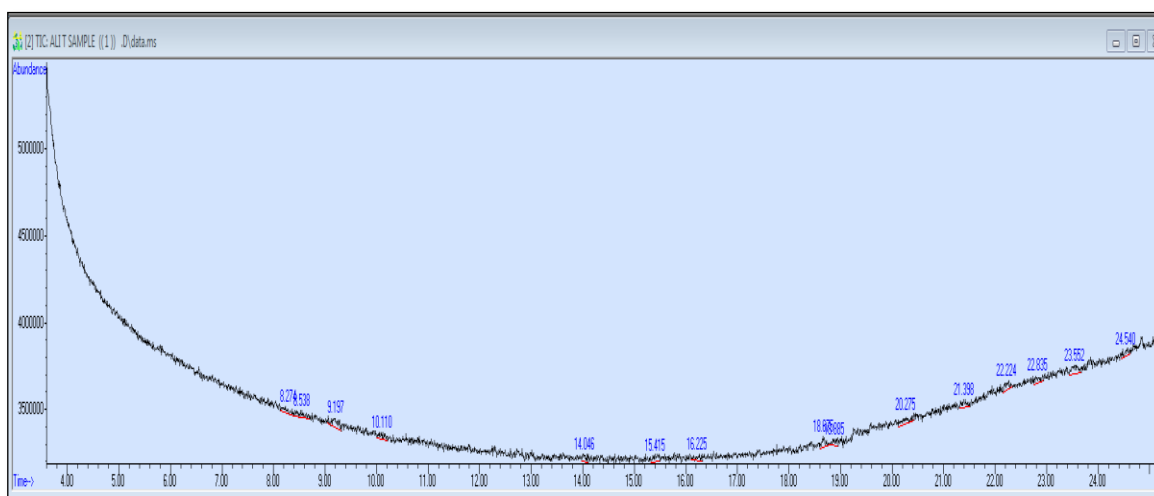
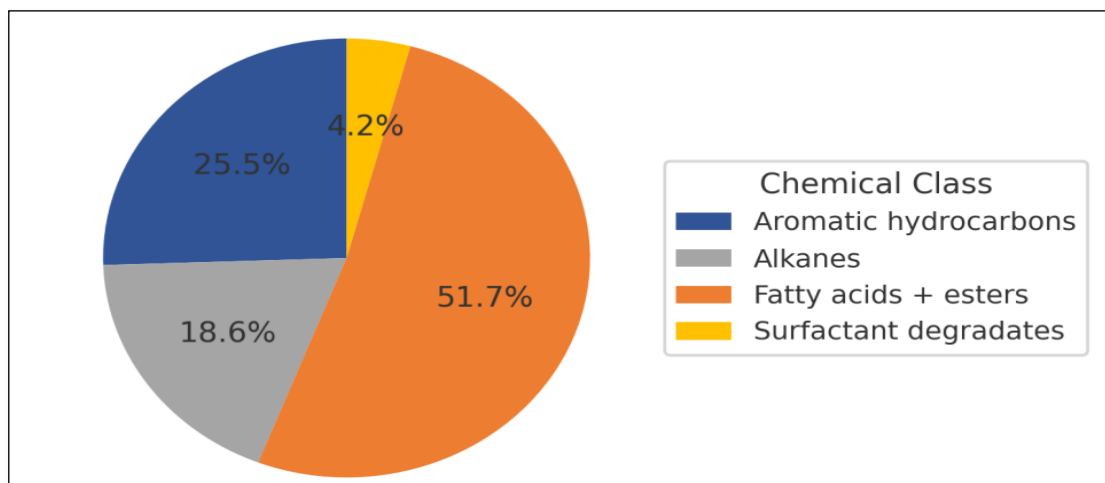
Samples collected from the eight car-wash stations were analyzed by GC-MS to characterize the organic composition of the untreated wastewater. The total ion chromatogram revealed a complex mixture of organic compounds, including aromatic hydrocarbons, long-chain alkane s, fatty acids, fatty acid esters, and surfactant-related compounds (**Table 1** and **Figure 2**).

The results showed that fatty acids and their esters were the most dominant compounds in the car wash wastewater samples. Aromatic hydrocarbons came next, followed by alkanes, while surfactant related compounds were present in much lower amounts (**Figure 3**).

Spatial comparison among stations demonstrated noticeable variability in the relative contribution of each compound class. Some stations exhibited higher proportions of aromatic hydrocarbons, whereas others were characterized by a greater abundance of fatty acids and ester derivatives, indicating heterogeneity in the organic composition of the wastewater among the investigated sites (**Figure 4**).

Table 1. GC–MS identified compounds in untreated car-wash wastewater from Station 1, showing retention times (RT), relative peak areas (%), compound names, chemical classes, and CAS number

Peak No.	RT (min)	Area (%)	Identified Compound	Chemical Class	CAS#
1	8.278	6.19	Toluene	Aromatic hydrocarbon	108-88-3
2	8.538	8.72	Ethylbenzene	Aromatic hydrocarbon	100-41-4
3	9.195	10.0	m-Xylene (1,3-dimethylbenzene)	Aromatic hydrocarbon	108-38-3
4	10.113	5.28	p-Xylene (1,4-dimethylbenzene)	Aromatic hydrocarbon	106-42-3
5	14.042	5.41	o-Xylene (1,2-dimethylbenzene)	Aromatic hydrocarbon	95-47-6
6	15.419	6.06	Cumene (isopropylbenzene)	Aromatic hydrocarbon	98-82-8
7	16.223	4.8	Styrene	Aromatic hydrocarbon	100-42-5
8	18.673	6.88	Nonylphenol (mixed isomers)	Surfactant degradate	84852-15-3
9	18.881	5.35	n-Decane	Alkane	124-18-5
10	20.274	8.89	n-Dodecane	Alkane	112-40-3
11	21.399	5.75	n-Tetradecane	Alkane	629-59-4
12	22.222	6.05	Hexadecanoic acid (Palmitic acid)	Fatty acid	57-10-3
13	22.836	5.33	Methyl palmitate	Fatty acid ester	112-39-0
14	23.555	9.43	Octadecanoic acid (Stearic acid)	Fatty acid	57-11-4
15	24.541	5.86	Methyl stearate	Fatty acid ester	112-61-8

**Figure 2.** GC–MS total ion chromatogram (TIC) of Station 1 wastewater sample**Figure 3.** Distribution of compound classes in car-wash wastewater samples.

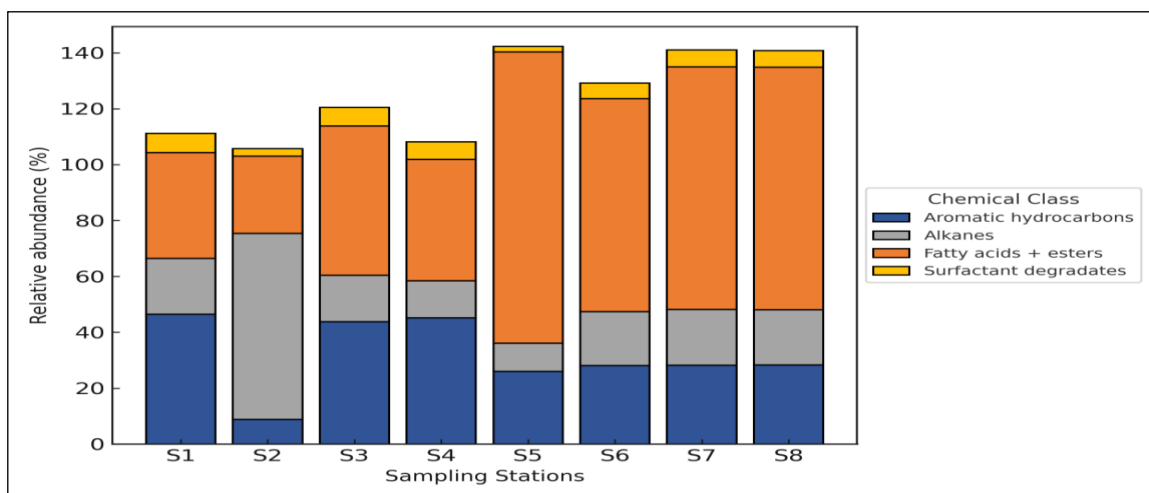


Figure 4. Spatial variability of compound classes among stations based on GC–MS results.

3.2. Physicochemical parameter

A summary of the international permissible limits for the investigated water quality parameters (WHO, USEPA, IFC) is provided in (Figure 5) for reference.

The pH values of the car-wash effluents ranged from 4.08 ± 0.00 at Station 6 to 5.16 ± 0.10 at Station 7. All samples were acidic and fell below the internationally accepted range for surface and effluent waters (6.5–8.5) 30,31. One-way ANOVA indicated highly significant differences among stations ($p < 0.001$), and Tukey's HSD test revealed distinct groupings between sampling sites (Figure 5a).

Alkalinity concentrations varied between 11.33 ± 0.15 and 19.57 ± 0.03 mg/L as CaCO_3 . The lowest alkalinity was recorded at Station 5, whereas the highest value was observed at Station 7, indicating marked spatial variability in buffering capacity among the investigated locations (Figure 5b).

Nitrate (NO_3^-) concentrations ranged from 61.88 ± 1.26 mg/L at Station 5 to 99.81 ± 1.06 mg/L at Station 3. All measured values exceeded the guideline limits set by WHO (50 mg/L) and USEPA (10 mg/L) 30,31. The highest nitrate levels were observed at Stations 3 and 7, with statistically significant differences among stations ($p < 0.001$) (Figure 5c).

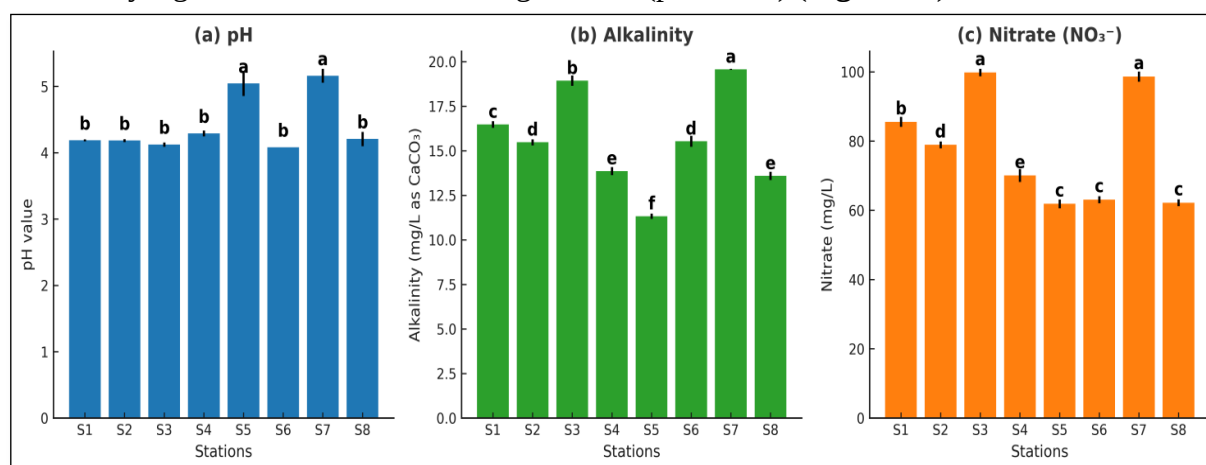


Figure 5. Variation of pH (a), alkalinity (b), and nitrate (c) across eight car-wash stations (mean $\pm$ SD, $n = 3$). Different letters indicate significant differences among stations according to Tukey's HSD test ($p < 0.05$).

3.2.1. Nitrite, phosphate, and total phosphorus

The concentrations of nitrogen and phosphorus related nutrients exhibited pronounced spatial variability among the eight car-wash stations, with highly significant differences detected by

one-way ANOVA ($p < 0.001$) (Figure 6).

Nitrite (NO_2^-) concentrations ranged from 13.44 ± 0.07 mg/L at Station 5 to 22.63 ± 0.23 mg/L at Station 3, indicating marked differences in nitrogen species among the investigated sites (**Figure 6a**). Phosphate (PO_4^{3-}) levels varied between 87.64 ± 0.54 mg/L at Station 5 and 126.25 ± 2.30 mg/L at Station 3, with statistically significant variation among stations as confirmed by Tukey's HSD test ($p < 0.05$) (**Figure 6b**). Total phosphorus (TP) concentrations ranged from 1.46 ± 0.01 mg/L at Station 5 to 2.09 ± 0.03 mg/L at Station 3, showing a spatial distribution pattern similar to that of phosphate, and significant differences among the eight sampling locations ($p < 0.001$) (**Figure 6c**).

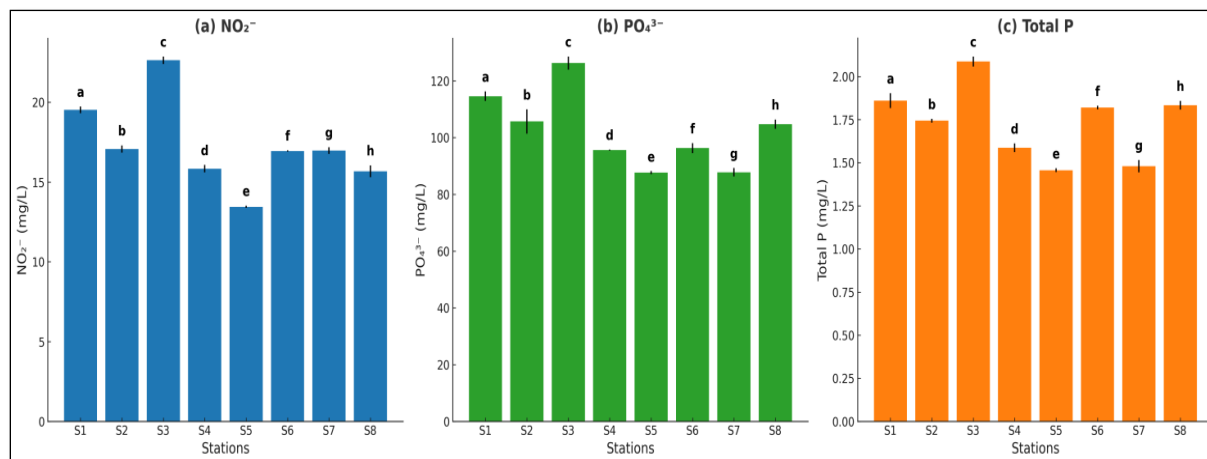


Figure 6. Variation of nitrite (a) nitrite, (b) phosphate, (c) total phosphorus across eight car-wash stations (mean $\pm$ SD, $n = 3$). Different letters indicate significant differences among stations according to Tukey's HSD test ($p < 0.05$).

3.2.2. Chemical Oxygen Demand, Total Suspended Solids, and oil & grease

The concentrations of total suspended solids (TSS), chemical oxygen demand (COD), and oil and grease showed highly significant differences among the eight car-wash stations, as indicated by one-way ANOVA ($p < 0.001$) followed by Tukey's HSD post hoc test ($p < 0.05$) (**Figure 7**). TSS concentrations ranged from 168.41 ± 2.21 mg/L at Station 5 to 216.82 ± 0.38 mg/L at Station 6, with all measured values exceeding the maximum permissible limit of 50 mg/L for wastewater discharges. COD values varied between 901.54 ± 16.30 mg/L at Station 7 and 1261.16 ± 7.22 mg/L at Station 3, substantially surpassing the WHO and USEPA guideline value of 250 mg/L for treated effluents.

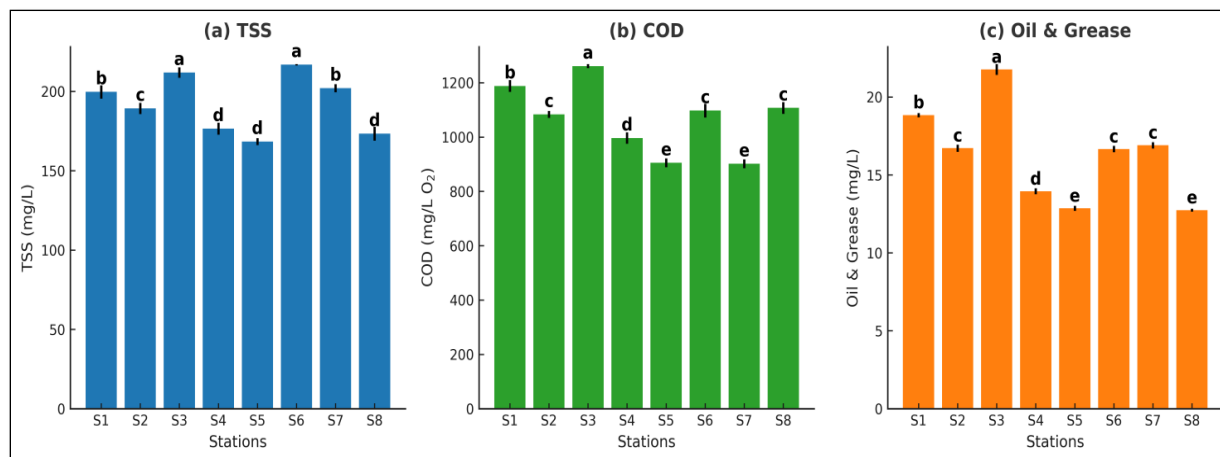


Figure 7. Variation of total suspended solids (a)Total suspend solids (b)chemical oxygen demand (c)and oil and grease across eight car-wash stations (mean $\pm$ SD, $n = 3$). Different letters indicatesignificant differences among stations according to Tukey's HSD test ($p < 0.05$)

4. Discussion

The identified chemical is likely to represent entrained inputs of petroleum from sources such as fuels and lubricants, detergents and wax thinners applied during washing down²¹⁻²⁴. Other compound class distributions were reported for car wash effluents from Brazil and Indonesia²⁵, indicating that these discharges may represent multi pollutant mixtures, instead of being dominated by the presence of hydrocarbons only. Conversely, operation and service conditions are also an important factor in source signature, as evidenced by the relatively higher hydrocarbon fractions in regions with poor vehicle maintenance and handling of fuel²⁶. The heterogeneity of alkanes across the stations studied reflects the contributions from exhaust related residues, tire wear, and lubricant leaks, this result is consistent with previous studies that suggested the chemical composition of car wash wastewater is site specific and affected by maintenance procedures and washing practices^{27,28} as well as washing intensity, traffic load, and local environmental conditions.

To summarize, the combined GC-MS results clearly show that car wash wastewater in Baghdad is a considerable and currently unregulated source of various organic pollutants and that the potential long term ecological and public health risk is considerable, warranting immediate improvement in wastewater management and more rigorous environmental control to reduce long term ecological and public health risks. Physicochemical parameters of the car wash wastewater were examined to evaluate water quality status and to determine the degree of contamination at the eight sampling stations. The measured parameters were compared to international guideline values^{29,30} to illustrate the extent of deviation from acceptable environmental standards.

The generally low pH of the effluents is likely due to the presence of acidifying residues such as detergent ingredients, lubricating oils, and surfactant breakdown products that together reduce the bicarbonate buffering system and cause corrosive conditions. Similar acidic discharges from car wash facilities and urban effluents have been reported in Baghdad³¹.

Such low pH conditions increase the solubility of metals and enhance the mobility of petroleum derived hydrocarbons increasing their bioavailability and ecological risk in receiving water bodies³²⁻³⁴. The low alkalinity values also reflect carbonate and bicarbonate losses due to intensive detergent and surfactant inputs that reduce the buffering capacity and increase the susceptibility of downstream waters to pH fluctuations and metal release³².

The high nitrate concentrations are most likely related to the oxidation of nitrogen containing surfactants and microbial nitrification of organic nitrogen residues found in washing products. Similar nitrate enrichment has been observed in other studies in Iraq and Egypt^{35, 36} where cleaning agents were identified as significant nutrient loads.

These observed differences in species of nitrogen and phosphorus between stations likely reflect differences in detergent formulation, washing practices, and the effectiveness of wastewater treatment systems. The high nitrite concentration at Station 3 may be due to the incomplete oxidation of ammonia based surfactants, as well as increased inputs of organic nitrogen from detergent residues, whereas lower nitrite levels at other stations may be due to dilution effects or further oxidation of nitrite to nitrate by nitrification. Concentrations recorded were well above international guideline values^{37,38}, which suggest that nitrite concentrations in surface and effluent waters should be maintained below 1 mg/L to avoid ecological and physiological disturbances, such as methemoglobinemia, in aquatic organisms and humans. The simultaneous enrichment of phosphate and nitrite at Station 3 indicates that detergents containing phosphate and cleaning agents rich in nitrogen are used extensively during washing operations. These concentrations significantly surpass the effluent discharge regulations in Iraq³⁹.

Elevated phosphate levels are a major cause of eutrophication because they promote excessive algal growth, hasten the loss of oxygen, and eventually cause aquatic habitats to deteriorate and biodiversity to disappear^{40, 41}. This suggests that detergent ingredients are an important contributor to phosphorus loading in these types of effluents, and that similar levels of phosphate

enrichment have been observed in car wash wastewater in other countries⁴²⁻⁴⁴. Total phosphorus burden consists of both dissolved and particulate phosphorus fractions, as the distribution of total phosphorus and orthophosphate are highly correlated.

It is commonly known that concentrations greater than 0.2 mg/L are sufficient to cause eutrophication and degrade water quality^{40, 41}.

As a result, the high TP levels found in this study demonstrate the serious environmental risk connected to the release of untreated wastewater from car washes. Concurrent nitrite, phosphate, and total phosphorus enrichment offers unmistakable proof of combined nitrogen and phosphorus loading, which can increase primary productivity, increase biological oxygen demand, and cause long-term ecological stress in receiving aquatic ecosystems.

Differences in vehicle load washing frequency, detergent formulation, and the effectiveness of on-site sedimentation pits or filtration units are reflected in the observed spatial variations in TSS, COD, and oil and grease among the investigated stations. Soil particles, tire wear debris, and emulsified oil detergent flocs released during washing operations are the main causes of elevated TSS levels. Such particles accumulate and decrease light penetration, inhibit photosynthetic activity, and promote sediment deposition in receiving water bodies⁴⁵. Suspended solids also provide sorption surfaces that transport and maintain hydrophobic organic compounds and trace metals in aquatic environments⁴⁶.

High levels of COD indicate a significant load of organic material that contains surfactants, petroleum hydrocarbons, and wax-based ingredients found in car wash products⁴⁷. This organic enrichment can quickly deplete dissolved oxygen and stress aquatic organisms or cause hypoxia when microbial degradation occurs⁴⁸.

Contamination by oil and grease is primarily a result of fuel residues and lubricating oils that typically form surface films and can inhibit microbial activity and reduce oxygen transfer at the air-water interface⁴⁹⁻⁵¹. Residual oil limits primary productivity and impacts trophic structure by increasing turbidity and decreasing light penetration. In combination, the elevated TSS, COD, and oil and grease concentrations indicate that untreated car wash effluent is a significant source of environmental stress that can degrade water quality, cause oxygen depletion, and threaten the integrity and function of aquatic ecosystems.

5. Conclusion

The results of this study confirmed the presence of a mixture of organic and nutrient pollutants in the Baghdad car wash wastewater, with hydrocarbons, fatty acids, esters, and detergent residues comprising the main contaminants, indicating the presence of a variety of typical washing agents such as lubricants, fuels, waxes, and detergents then are released to the environment, and the physicochemical results support the hypothesis that these pollutants have severe negative impacts on the environment through their ability to facilitate the accumulation of persistent organic compounds in the environment and to promote nutrient and oxygen depletion, disrupting the ecosystem balance and reducing aquatic biodiversity of urban freshwater bodies. The results also indicate the requirement for improved wastewater management in Iraq using simple and low cost pretreatment methods such as sedimentation tanks, oil & grease separators, and biological filtration that will significantly reduce the pollutant load before discharge to improve local water quality, establish a baseline for a standard for sustainable operation of small car wash stations, and inform future studies including heavy metal analysis, microbial toxicity testing, and seasonal monitoring to assist in the development of effective national strategies to protect the aquatic ecosystems of Iraq.

Acknowledgment

We thank the Department of Biology, College of Science, University of Baghdad, Baghdad, Iraq, for the sample analysis in the laboratory.

Conflict of Interest

The authors declare that they have no conflict of interest

Funding

No funding.

References

1. Yu Q, Sun Z, Shen J, Xu X, Han Q, Zhu M. The nonlinear effect of new urbanization on water pollutant emissions: Empirical analysis based on the panel threshold model. *J Environ Manage.* 2023;345:118564. <https://doi.org/10.1016/j.jenvman.2023.118564>
2. Jahan S, Singh A. Causes and impact of industrial effluents on receiving water bodies: a review. *Malays J Sci Adv Technol.* 2023;3(2):111–121. <https://doi.org/10.56532/mjsat.v3i2.144>
3. Kazembeigi F, Bayad S, Nasab AY, Parseh I. Techno-environmental study on the consequences of carwash wastewater and its management methods. *Heliyon.* 2023;9(9):e19764. <https://doi.org/10.1016/j.heliyon.2023.e19764>
4. Torrens A, Sepúlveda-Ruiz P, Aulinas M, Folch M. Innovative Carwash Wastewater Treatment and Reuse Through Nature-Based Solutions. *Clean Technol.* 2025;7(1):12. <https://doi.org/10.3390/cleantechnol7010012>
5. Sarmadi M, Zarei AA, Ghahrchi M, Sepehrnia B, Meshkinian A, Moein H, et al. Carwash wastewater characteristics - a systematic review study. *Desalin Water Treat.* 2021;225:112–148. <https://doi.org/10.5004/dwt.2021.26972>
6. Kowsalya E, et al. Treatment of carwash wastewater and its reuse. *Int J Recent Technol Eng.* 2020;8(5):3605–3610. <https://doi.org/10.35940/ijrte.E6030.018520>
7. Zaneti R, Etchepare R, Rubio J. More environmentally friendly vehicle washes: water reclamation. *J Clean Prod.* 2012;37:115–124. <https://doi.org/10.1016/j.jclepro.2012.06.017>
8. Zaneti R, Etchepare R, Rubio J. Car wash wastewater reclamation: full-scale application and upcoming features. *Resour Conserv Recycl.* 2011;55(11):953–959. <https://doi.org/10.1016/j.resconrec.2011.05.002>
9. Fikri E, Putri AN, Prijanto TB, Syarif O. Study of liquid waste quality and potential pollution load of motor vehicle wash business in Bekasi City, Indonesia. *J Ecol Eng.* 2020;21(3):128–134. <https://doi.org/10.12911/22998993/118288>
10. Cuput EL, Mensah L, Bentil E, Amponsah V, Agbekey BK. Heavy metal contamination from fuel station run-off and carwash wastewater: An assessment of ecological risk and experimental treatment. *Heliyon.* 2024;10:e29167. <https://doi.org/10.1016/j.heliyon.2024.e29167>
11. Hassan FM, Al-Obaidy AH, Noor AR, Alansari N. Pathway of total petroleum hydrocarbon in a lotic ecosystem: water and sediment of Tigris River, Iraq. *Arab. J Geosci.* 2025; 15(8):211-218. <https://doi.org/10.1007/s13201-025-02505-2>
12. Oleiwi AS, Al-Dabbas M. Assessment of contamination along the Tigris River from Tharthar–Tigris Canal to Aziziyah, Iraq. *Water.* 2022;14(8):1194. <https://doi.org/10.3390/w14081194>
13. United States Environmental Protection Agency. Method 3510C: separatory funnel liquid-liquid extraction. Washington (DC): USEPA; 1996.
14. Agilent Technologies. Agilent 7820A GC and 5977E MSD User Manual. Santa Clara (CA): Agilent Technologies; 2014.
15. American Public Health Association (APHA). Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington (DC): APHA; 2017.
16. BP Instruments. BP3001 pH Meter Instruction Manual. 2016.
17. WTW GmbH. WTW Photometer Operating Manual. Weilheim, Germany: WTW GmbH; 2015.
18. Murphy J, Riley JP. Determination of phosphate. *Anal Chim Acta.* 1962;27:31–36. [https://doi.org/10.1016/S0003-2670\(00\)88444-5](https://doi.org/10.1016/S0003-2670(00)88444-5)
19. HACH. Water Analysis Handbook. 8th ed. Loveland (CO): HACH Company; 2016.
20. APHA, AWWA, WEF. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Method 2320 B: Alkalinity by titration. Washington (DC): American Public Health Association; 2017.
21. Chaudhuri UR. Fundamentals of petroleum and petrochemical engineering. Boca Raton (FL): CRC Press; 2011.
22. Lebiocka M, Montusiewicz A, Grządka E, Pasieczna-Patkowska S, Montusiewicz J, Szaja A.

- Hydrodynamic Cavitation as a Method of Removing Surfactants from Real Carwash Wastewater. *Molecules*. 2024;29:4791-4799. <https://doi.org/10.3390/molecules29204791>
23. Eriksson E, Baun A, Mikkelsen PS, Ledin A. Chemical hazard identification and assessment tool for evaluation of stormwater priority pollutants. *Water Sci Technol*. 2005;51(2):47–55. <https://doi.org/10.2166/wst.2005.0031>
24. Sablayrolles C, Vialle C, Vignoles C, Montrejaud-Vignoles M. Impact of carwash discharge on stormwater quality (Toulouse, France). *Water Sci Technol*. 2010;62(12):2737–2746. <https://doi.org/10.2166/wst.2010.929>
25. Starzec K, Supel P, Kaszycki P. Biological Purification of Heterogenous Car Wash Effluents: Selection of Tolerant Bacteria and Development of Microbial Consortia for Pollutant Biodegradation. *Sustainability*. 2025;17:8414. <https://doi.org/10.3390/su17188414>
26. Fayed M, Shewitah MA, Dupont RR, Fayed M, Badr MM. Treatability study of car wash wastewater using upgraded physical technique with sustainable flocculant. *Sustainability*. 2023;15:8581. <https://doi.org/10.3390/su15118581>
27. Rai R, Sharma S, Gurung DB, Sitaula BK, Shah RD. Assessing the impacts of vehicle wash wastewater on surface water quality through physico-chemical and benthic macroinvertebrates analyses. *Water Sci*. 2020;34:39–49. <https://doi.org/10.1080/11104929.2020.1731136>
28. Kuan WH, Hu CY, Ke LW, Wu JM. A review of on-site carwash wastewater treatment. *Sustainability*. 2022;14:5764. <https://doi.org/10.3390/su14105764>
29. World Health Organization (WHO). Guidelines for Drinking-Water Quality. Geneva: WHO; 2017.
30. United States Environmental Protection Agency (USEPA). National recommended water quality criteria. Washington, DC: USEPA; 2023.
31. Al-Alossy I, Al-Obaidy AH, Hassan FM. Chemical pollution in Iraqi car-wash discharge. *Iraqi J Environ Sci*. 2022;18(2):94–105.
32. Tchobanoglous G, Burton FL, Stensel HD. Wastewater engineering: treatment and reuse. 4th ed. New York: McGraw-Hill; 2003. p. 1-8–1-11.
33. Olubanji LA, Gbolahan SS, Kazeem AK, Olukayode O. Assessment of wastewater generated from car wash in the Ijebu Ode area of Nigeria. *Med Health Sci Eur J*. 2024;8(1):1–7. <https://aspjournals.net/Journals/index.php/mhsej/article/view/558>
34. Woźniak P, Dubicki M, Gryta M. Microbiological Hazard Analysis of Car Wash Wastewater. *Polish Journal of Environmental Studies*. 2023;32(4):3871–82. <https://doi.org/10.15244/pjoes/163565>
35. Abdel-Satar AM, Ali MH, Goher ME. Indices of water quality and metal pollution of Nile River, Egypt. *Egypt J Aquat Res*. 2017;43(1):21–29. <https://doi.org/10.1016/j.ejar.2016.12.006>
36. Aljanabi ZZ, Al-Obaidy AHMJ, Hassan FM. A novel water quality index for Iraqi surface water. *Baghdad Sci J*. 2023;20(6):Article 50. <https://doi.org/10.21123/bsj.2023.9348>
37. Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological profile for nitrate and nitrite. Atlanta, GA: U.S. Department of Health and Human Services; 2017.
38. World Health Organization (WHO). Nitrate and nitrite in drinking-water. Geneva: WHO; 2022.
39. Iraqi Standard Specification. Effluent disposal standards. Baghdad: Central Organization for Standardization and Quality Control; 1967.
40. International Finance Corporation (IFC), World Bank Group. Environmental, health, and safety (EHS) guidelines. Washington, DC; 2007.
41. Litke DW. Phosphorus control measures. US Geological Survey Report; 1999.
42. Tekere M, Sibanda T, Maphangwa KW. An assessment of the physicochemical properties and toxicity potential of carwash effluents from professional carwash outlets in Gauteng Province, South Africa. *Environ Sci Pollut Res*. 2016;23:11876–11884. <https://doi.org/10.1007/s11356-016-6370-5>
43. Tomczak W, Woźniak P, Gryta M, Grzechulska-Damszel J, Daniluk M. Cleaning of ultrafiltration membranes: long-term treatment of car wash wastewater as a case study. *Membranes (Basel)*. 2024;14(7):159. <https://doi.org/10.3390/membranes14070159>
44. International Finance Corporation (IFC). General EHS guidelines. Washington, DC; 2007.
45. Kang J, Liu X, Dai B, Liu T, Haider FU, Zhang P, Habiba, Cai J. Tyre Wear Particles in the Environment: Sources, Toxicity, and Remediation Approaches. *Sustainability*. 2025;17:5433. <https://doi.org/10.3390/su17125433>
46. Menéndez-Pedriz A, Jaumot J. Microplastics interactions. *Toxics*. 2020;8:40. <https://doi.org/10.3390/toxics8020040>

47. Awad ES, Hassan HM, El-Sayed SM. Membrane techniques for the treatment of carwash wastewater: a review. *Chim Techno Acta*. 2023;10(1):85–97. <https://doi.org/10.15826/chimtech.2023.10.1.07>
48. Al-Saedy RN, Al-Hassany JS, Al-Ramahi FKM. Evaluation of the quality of some water stations on the Tigris River using the Iraqi water quality index (Iraq WQI). *Ibn Al-Haitham J Pure Appl Sci*. 2025;38(4):701–710. doi:10.30526/38.4.36
49. Emenike EC, Adeleke JA, Emmanuel SS, et al. Extraction of various crude oil fractions from water by sorption: an overview. *Water Air Soil Pollut*. 2025;236:608. <https://doi.org/10.1007/s11270-025-08236-z>.
50. Sazzad MRI, Rahman MM, Hassan T, Al Rifat A, Al Mamun A, Adib AR, et al. Advancing sustainable lubricating oil management: re-refining techniques, market insights, innovative enhancements, and conversion to fuel. *Heliyon*. 2024;10:e39248. <https://doi.org/10.1016/j.heliyon.2024.e39248>.
51. Hashim NH, Zayadi N. Pollutants characterization of car wash wastewater. *MATEC Web Conf*. 2016;47:05008. <https://doi.org/10.1051/matecconf/20164705008>.