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Carwash wastewater characteristics - a systematic review study

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ABSTRACT

Due to rapid population growth and climate change all over the world, wastewater treatment and reuse, coupled with their understanding of their characteristics, have been extensively developed. This study was carried out with a systematic examination of the carwash wastewater properties. The systematic review was conducted using "PRISMA" checklist and "carwash wastewater", "car wastewater", "vehicle wastewater", "carwash wastewater treatment" keywords. In general, 429 articles were chosen from these databases, which were included in this study after reviewing entry criteria only 56 of these articles. Most articles (56.36%) were related to Asia. Physicochemical, biological, heavy metals and resistant pollutants were investigated in this study. The results of the detailed analysis of articles published in the carwash wastewater domain have shown low organic and mineral pollutant composition. This suggests carwash wastewater as a reliable source of reuse. The most important features of carwash wastewater for human health are heavy metals, polycyclic aromatic hydrocarbons, polychlorinated biphenyls and surfactants, which should be considered. This study can be considered as a comprehensive research in the future of carwash wastewater.

Keywords: Carwash wastewater; Heavy metals; Wastewater treatment

1. Introduction

Population growth and urban development along with the development of industrial and agricultural processes have led to a sharp rise in demand for water resources [1,2]. Also, due to natural processes and human activities, water resources are always exposed to different types of pollution, which has exacerbated the effects of water shortage crisis [3,4].

Currently, several strategies are proposed and are used to deal with the water resource crisis, including improving irrigation methods in agriculture, water storage, water conservation and wastewater reuse [5–7]. Among the various existing methods, wastewater treatment and reuse are of significant importance [8,9]. In order to reuse wastewater in various sectors, strict regulations have been set by international organizations such as the World Health Organization (WHO) and the Environmental Protection

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Agency. Getting this level of treatment in industrial wastewater requires the application of various and advanced methods such as sand filtration, membrane filters, coagulation, chemical oxidation, adsorption, biological treatment and other methods [10–17].

Carwash industry is one of the most important industries with high water consumptions and production of wastewaters with various types of pollutants and detergents [12,18]. The most common compositions of carwash wastewater are suspended solids (SS), detergents and oil, and grease [19,20].

Conventional wastewater treatment methods are not very effective in removing these contaminants. Therefore, the use of advanced methods to remove them is absolutely necessary. Choosing the appropriate treatment method in addition to technical, economical and environmental issues requires full knowledge of the wastewater properties produced in these units [21,22]. Due to the lack of a comprehensive and reliable source of wastewater generated in carwash units, the present study was conducted with the aim of examining carwash wastewater through a systematic review.

2. Methodology

This systematic review was carried out to conduct all existing studies of literature according to the properties of wastewater treatment.

The aim of this study was to present, categorize and compare different methods to compare the range of pollutants and choose the methods used to treat it. This study was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement Moher et al. [23].

2.1. Information sources

This systematic review was performed to identify all reports of the carwash wastewater properties options by searching the PubMed, Scopus, Web of Science, Wiley, Ovid, Springer databases using the PRISMA checklist [23]. These searches were based on the use of keywords as well as MESH terms, assessing the reference lists of articles and consulting with the author's experts. The including criteria for the articles were as follows: The English language, described findings in the contributed characteristics and available electronically through our institution's subscription as a full-text publication. There is no date limit. The final search was conducted on September 15, 2017. Google Scholar and Google were also used as complementary sources to complete the results. To ensure the comprehensiveness of the search process, references of the sources that had the entry criteria were examined. To ensure the accuracy of the study process, all the search and selection stages of articles were done separately by two authors.

2.2. Search strategy

2.2.1. Protocol and registration

This study has been prepared according to the Preferred Reporting Items for Systematic Review Protocols (PRISMA) guidelines, and the review has been registered and approved by the Ethical Committee of Torbat Heydariyeh University of Medical Sciences (IR.THUMS.1398.021).

2.2.2. Eligibility criteria, information sources and search

The papers obtained from the initial search were subjected to a first screening by two authors (MS and EB) in terms of the title and abstracts to catch the most relevant documents. The duplicate citations were omitted by pooling and sorting the obtained results from all keyword combination searches and then placed on the basis of manual selection by the two authors as considering the inclusion/exclusion criteria. The duplicate papers on top of those that did not meet the eligibility criteria were also removed. Moreover, all article citations were screened to find other relevant papers and were used to include utilizing of the same criteria. Initial searches were conducted in accordance with the review protocol, and all possible publications were listed in a table. Our study was conducted on papers from the PubMed, Scopus, Web of Science, Wiley, Ovid and Springer's databases. The keywords of search in all databases included "carwash wastewater" OR "car wastewater" OR "vehicle wastewater" OR "carwash wastewater treatment" OR "treatment technology". Additional publications were also retrieved through a reference check the references of the papers. All studies were reviewed up to 15/9/2017.

After conducting systematics' search, the title and abstract of the documents were reviewed thoroughly and articles with entry criteria were selected and the rest were deleted. In the studies that cannot be decided as the title and abstract, the full text was reviewed (n = 104). The parameter's information extracted from the documents was reported as type of pollutant, concentration of pollutant, country, average and range of pollutants.

2.2.3. Study selection and data collection process

The papers obtained from the primary search were subjected to a first screening by two authors (MS and EB) in terms of the title and abstracts to catch the most relevant documents. The duplicate citations were removed by pooling and sorting the obtained results from all keyword combination searches and then were based on manually screening by the two authors as with considering the inclusion/exclusion criteria. All citations entered the Endnote software and the inclusion and exclusion criteria were examined. The databases were searched as a four-stage standard protocol, described in detail in the following sections, and summarized in Fig. 1. The duplicate papers on top of those that did not meet the eligibility criteria were also removed. Moreover, all article citations were screened to find the additional relevant papers and were acquired for inclusion utilizing the same criteria.

2.2.4. Data items and summary measures

Finally, after removing papers that lack criteria, we extracted data for instance first author paper, sample size, mean or range of pollutant concentration, pollutant measure unit. From each year of study publication, country of origin

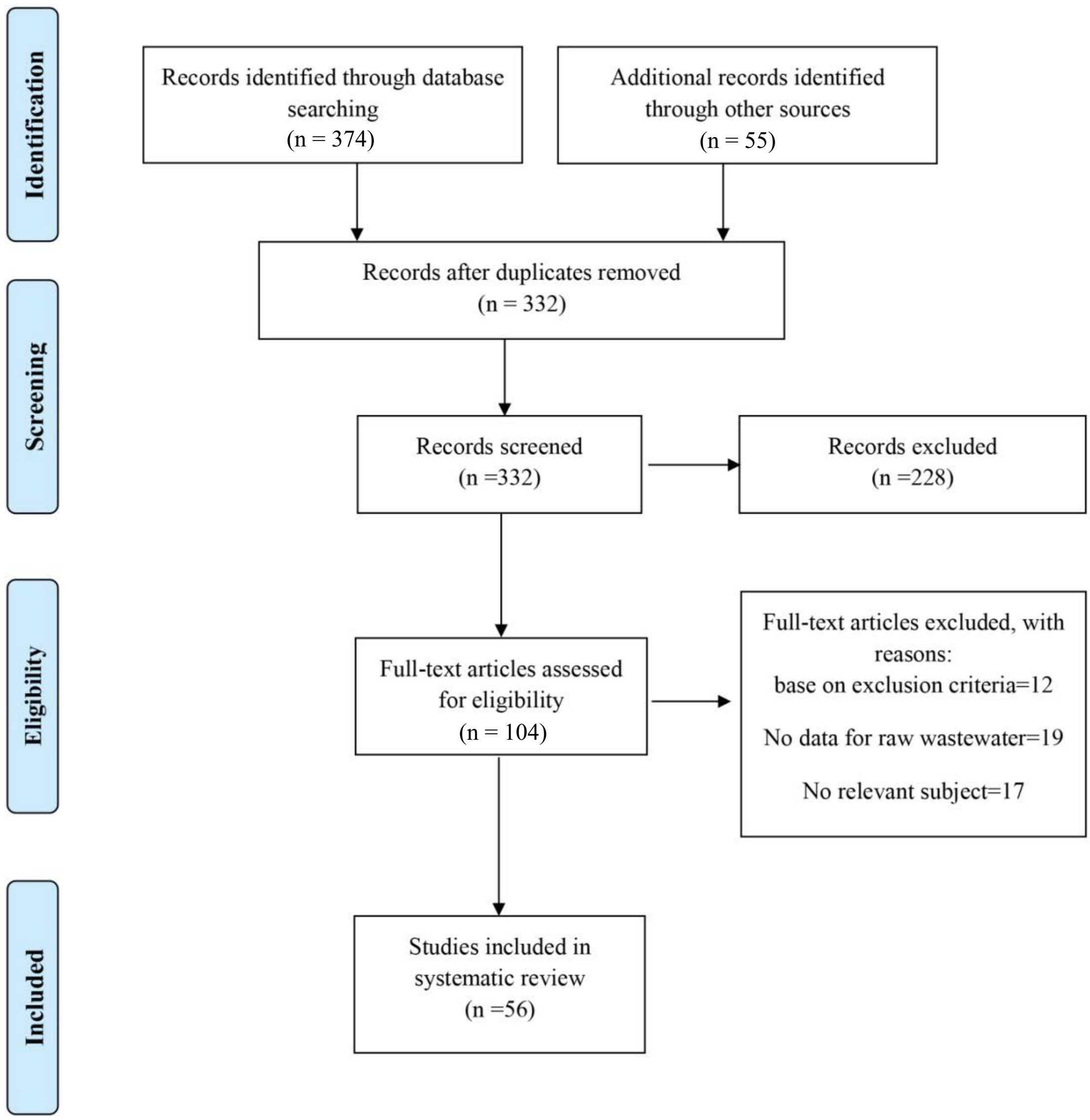

Fig. 1. Employed standard protocol for a literature review.

was also extracted. The extracted data were reported in the supplementary tables.

2.3. Analyses

We reported the mean of continuous variables with 95% confidence intervals (CI) or standard deviation (SD) or range. All analyses were made using Excel 2013.

3. Results

3.1. Study selection

In total, 429 articles were obtained from databases out of which, 228 were excluded from the study at the review stage of title and abstract. After reviewing the full text of the remaining articles (104), only 56 [10,12–14,18,19,21,24–72] were selected for appropriate input criteria, and other articles were excluded from the study in terms of their insufficient information or the review article.

3.2. Study characteristics

A review of 56 finally selected articles showed that these studies were conducted between 1996 and 2017, and Asia had the highest share in the publication of the papers (56.36%) (Search strategy for PubMed strategy attached). The results showed that around 31 articles were published in Asia, 8 in Europe, 7 in the United States, 7 in Africa, and 2 in Oceania. Details of the results are shown in supplementary Tables 1–4. In these tables, in addition to the number of samples and sampling location, the mean and standard deviation of input parameters such as physicochemical parameters (Table 1), biological (Table 2), heavy metals (Table 3) and the characteristics of resistant pollutants (Table 4) are mentioned separately.

Table 1
Reported concentrations of physicochemical parameters in carwash wastewater

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	References
Color							
Carwash WW	Nigeria	–	Hazen	22		Samples in dry season	[25]
Carwash WW	Nigeria	–	Hazen	25		Samples in rainy season	
Carwash WW	Mexico		(Pt Co units)	4,200		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Taiwan		(ADMI) American Dye Manufacturers Institute		30–50	Sedimentation tank	[67]
Carwash WW	Ireland		(Pt Co)	271		–	[65]
Carwash WW	Russia		deg	11.9		–	[55]
Temperature							
Carwash WW	Nigeria		(°C)	32		Samples in dry season	[25]
Carwash WW	Nigeria		(°C)	30		Samples in rainy season	
Washing vehicles WW	Algeria	3	(°C)	26		June	[47]
Washing vehicles WW	Algeria	3	(°C)		26–27.9	October	
Washing vehicles WW	Algeria	3	(°C)		21.7–23.2	Nov–Dec	
Carwash WW	Mexico		(°C)		25.1–28.1	Carwash cenote	[27]
Carwash WW	Malaysia		(°C)		27.0–28.4	Sample wastewater supplied from two stations, including stations Sin Huat and SCS carwashes	[10]
Carwash WW	Belgium		(°C)	14		Effluents from carwash WW	[68]
Carwash WW	Belgium		(°C)	11.2			
SS							
Carwash WW	Turkey		mg/L	2,300		Studied samples were from effluent of settling tank at the carwash	[37]
Carwash WW	Japan		mg/L		16–94	–	[41]
Carwash WW	Taiwan		mg/L		4–108	Lab-scale BioMF system	[43]
Carwash WW	Taiwan		mg/L		5.3–122	Full-scale BioMF	
Carwash WW	Brazil		mg/L	260 ± 20		Sample tested was collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		mg/L	170 ± 10			
Carwash WW	Brazil		mg/L	100 ± 10			
Carwash WW	France	5	mg/L	302 ± 208		Manual wash station	[59]
Carwash WW	France	5	mg/L	130 ± 67		High pressure water jet carwash	
Carwash WW	France	5	mg/L	45 ± 32		Self-service high-pressure water jet	
Washing vehicles WW	Pakistan	10	mg/L	308.5		Automobile Vehicle Service Stations	[70]
Carwash WW	Australia		mg/L	4.2		–	[13]

Washing vehicles WW	India		mg/L	242.6		Automobile washing center	[26]
Carwash WW	Egypt		mg/L	55		Wastewater tested was taken from a carwash wastewater tank located at the petrol station	[64]
Carwash WW	Syria		mg/L	49		–	[30]
Carwash WW	Taiwan		mg/L		30–200	Sedimentation tank	[67]
Carwash Station WW	Ireland		mg/L	55		Sample was collected from a carwash wastewater tank at a gas station	[66]
Carwash wastewater	Ireland		mg/L	55		–	[65]
Carwash WW	China		mg/L	250		Vehicle washing wastewater	[38]
Carwash WW	China		mg/L	240		Carwashing wastewater for washing large vehicle	[39]
Carwash WW	China	30	mg/L	341.77		Wastewater samples collected from 30 different caravans on sunny days	[69]
Carwash WW	France		mg/L	302 ± 208		Truck carwash	[19]
Carwash WW	France		mg/L	130 ± 67		Self-service carwash	
Carwash WW	France		mg/L	45 ± 32		Petrol station carwash	
Carwash WW	France		mg/L	297 ± 428		Subway wash station	
Carwash WW	France		mg/L	75 ± 3		Bus wash station	
Carwash WW	Thailand		mg/L	212		–	[53]
Carwash WW	Belgium		mg/L	1,486		Effluents from carwash WW	[68]
Carwash WW	Belgium		mg/L	2,458			
TS							
Raw carwash WW	China		mg/L		110–5,855.66	Wastewater taken from service station	[14]
Carwash WW	Brazil		mg/L	380 ± 20		Sample tested was collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		mg/L	770 ± 50			
Carwash WW	Brazil		mg/L	320 ± 20			
Carwash WW	South Africa		mg/L	1,058 ± 19.8		Different carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	16,262 ± 7.8			
Carwash WW	South Africa		mg/L	818 ± 3.5			
Carwash WW	South Africa		mg/L	756 ± 2.1			
Carwash WW	South Africa		mg/L	612 ± 6.4			
Carwash WW	South Africa		mg/L	892 ± 13.4			
Carwash WW	Mexico		mg/L	1,299		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
TSS							
Raw carwash WW	Iran	32	mg/L	291.35 ± 46.14		Samples were taken from above the sediment tank in an automatic carwash	[12]
Raw carwash WW	Iran	32	mg/L	193.55 ± 71.53		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	

(Continued)

Table 1 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	References
Washing vehicles WW	Algeria	3	mg/L		105–14,702	Nov–Dec	[47]
Carwash WW	Brazil		mg/L	68 ± 19		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		mg/L	89 ± 54		Campaign 2 – FCF-SC	
Carwash WW	India		mg/L	95		Automobile service stations (sample A)	[29]
Carwash WW	India		mg/L	260		Automobile service stations (sample B)	
Carwash WW	Brazil		mg/L	89 ± 54		Sample collected from hand wash wastewater recovery system	[71]
Carwash WW	Australia		mg/L	307		–	[13]
Carwash WW	Malaysia	3	mg/L		82 ± 25.238–147 ± 83.72	Weekdays	[50]
Carwash WW	Malaysia	3	mg/L		126 ± 75.147–202 ± 10	Weekends	
Carwash WW	Brazil		mg/L		85–279	Sample collected after oil removal process	[35]
Carwash Station WW	Malaysia	8	mg/L	85.00 ± 1.20		Station 1 – Full hand service	[42]
Carwash Station WW	Malaysia	8	mg/L	100.00 ± 0.62		Station 3 – Snow Foam	
Carwash Station WW	Malaysia	8	mg/L	325.00 ± 0.60		Station 2 – Full hand service	
Carwash WW	Malaysia		mg/L	186.3 ± 56.6		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		mg/L	93.33 ± 44.88			
Carwash WW	Malaysia		mg/L	14.33 ± 2.08			
Carwash WW	Malaysia		mg/L	22 ± 3.61			
Carwash WW	New Zealand	12	mg/L	285.9 ± 52.4		After washing, two vehicles were investigated	[52]
Carwash runoff	Canadian Province		mg/L	114.67 ± 27.57		Carwash Runoff Treatment Using Bioretention Mesocosms	[31]
Truck wash water	Texas		mg/L	114		Wastewater sampling is a wastewater from truck wash	[36]
DS							
Carwash WW	Brazil		mg/L	120 ± 20		Sample tested collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		mg/L	600 ± 50			
Carwash WW	Brazil		mg/L	210 ± 20			
TDS							
Carwash WW	Iran		mg/L		498–780	Local carwash	[60]
Carwash stations	Kuwait		mg/L	620		Carwash stations	[28]
Raw carwash WW	China		mg/L		577.33–644.33	Wastewater taken from service station	[14]
Carwash WW	Ethiopia		mg/L	≈400		Mosque and the carwash	[40]
Carwash	India		mg/L		650–775	–	[46]
Carwash WW	Brazil		mg/L	502 ± 90.5		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		mg/L	345 ± 27.5		Campaign 2 – FCF-SC	

Carwash WW	South Africa		mg/L	686 ± 8.5		Different carwash effluents in the city	[63]
Carwash WW	South Africa		mg/L	468 ± 13.4			
Carwash WW	South Africa		mg/L	506 ± 5.7			
Carwash WW	South Africa		mg/L	482 ± 13.4			
Carwash WW	South Africa		mg/L	362 ± 8.5			
Carwash WW	South Africa		mg/L	188 ± 4.9			
Carwash WW	Mexico		mg/L		500–1,700	Carwash cenote	[27]
Carwash WW	India		mg/L	970		Automobile service stations (sample A)	[29]
Carwash WW	India		mg/L	1,020		Automobile service stations (sample B)	
Carwash WW	Brazil		mg/L	345 ± 27.5		Sample collected from hand wash wastewater recovery system	[71]
Washing vehicles WW	Pakistan	10	mg/L	156.2		Automobile Vehicle Service Stations	[70]
Washing vehicles WW	India		mg/L	741		Automobile washing center	[26]
Carwash WW	Syria		mg/L	1,200		–	[30]
Carwash Station WW	Pakistan		mg/L	1,790		Masha Allah service station	[32]
Carwash Station WW	Pakistan		mg/L	210		Indus service station	
Carwash Station WW	Pakistan		mg/L	1,010		Al-noor service station	
Carwash Station WW	Pakistan		mg/L	850		Site area service station	
Carwash Station WW	Iran		mg/L		209–110	Sample was taken from the top of the sedimentation tank at Jamalzadeh carwash	[48]
Carwash WW	Brazil		mg/L		546–797	Carwash wastewater after the oil–water separator	[35]
Carwash WW	Malaysia		mg/L	556 ± 441		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		mg/L	432 ± 385			
Carwash WW	Malaysia		mg/L	445 ± 375			
Carwash WW	Malaysia		mg/L	314 ± 431			
Truck wash water	Texas		mg/L	876		Wastewater sampling is wastewater from truck wash	[36]
Carwash WW	Malaysia		mg/L		89.2–151.8	Sample wastewater supplied from two stations, including stations Sin Huat and SCS carwashes	[10]
Carwash WW	Russia		mg/L	511		–	[56]
Turbidity							
Carwash WW	Iran		NTU	170 ± 32.5		Local carwash	[51]
Carwash WW	Iran		NTU		151–159	Local carwash	[60]
Carwash WW	Malaysia		NTU	275.1		Carwash station	[18]
Raw carwash WW	Iran	32	NTU	137.2 ± 36.45		Samples were taken from above the sediment tank in an automatic carwash	[12]
Raw carwash WW	Iran	32	NTU	166.8 ± 51.72		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	

(Continued)

Table 1 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	References
Raw carwash WW	China		NTU		73–772	Wastewater taken from service station	[14]
Carwash WW	Japan		NTU		4.1–63.5	–	[41]
Carwash	India		NTU		132–140	–	[46]
Carwash WW	Brazil		NTU	85 ± 8		Sample tested was collected from gas station has a rollover carwash system	[21]
Carwash WW	France	5	NTU	126 ± 38		Manual wash station	[59]
Carwash WW	France	5	NTU	100 ± 68		High pressure water jet carwash	
Carwash WW	France	5	NTU	32 ± 9		Self-service high-pressure water jet	
Carwash WW	Brazil		NTU	89 ± 16.5		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		NTU	103 ± 57		Campaign 2 – FCF-SC	
Carwash WW	South Africa		NTU	382 ± 3.5		Different carwash effluent in the city	[63]
Carwash WW	South Africa		NTU	4,000 ± 29.7			
Carwash WW	South Africa		NTU	372 ± 7.8			
Carwash WW	South Africa		NTU	455 ± 8.5			
Carwash WW	South Africa		NTU	246 ± 7.8			
Carwash WW	South Africa		NTU	109 ± 0.7			
Carwash WW	India		NTU	56.3		Automobile service stations (sample A)	[29]
Carwash WW	India		NTU	195		Automobile service stations (sample B)	
Carwash WW	Brazil		NTU	103 ± 57		Sample collected from hand wash wastewater recovery system	[71]
Carwash WW	Egypt		NTU		90.5–386	Samples of real wastewater were prepared in a carwash	[34]
Carwash WW	Australia		NTU	1,000		–	[13]
Carwash WW	Indonesia		NTU	186.6		–	[44]
Carwash WW	Egypt		NTU	28.1		Wastewater tested was taken from a carwash wastewater tank located at the petrol station	[64]
Carwash WW	Mexico		NTU	898		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Egypt		NTU	160		Raw carwash wastewater	[24]
Carwash WW	Malaysia	3	NTU		68 ± 19.313–180.3 ± 51.926	Weekdays	[50]
Carwash WW	Malaysia	3	NTU		173.67 ± 58.76–216.33 ± 21.548	Weekends	
Carwash Station WW	Pakistan		NTU	82.4		Masha Allah service station	[32]
Carwash Station WW	Pakistan		NTU	493		Indus service station	
Carwash Station WW	Pakistan		NTU	180		Al-noor service station	
Carwash Station WW	Pakistan		NTU	322		Site area service station	

Carwash Station WW	Iran		NTU		118–1,400	Sample was taken from the top of the sedimentation tank at Jamalzadeh carwash	[48]
Carwash WW	Brazil		NTU		194–254	Carwash wastewater after the oil–water separator	[35]
Carwash WW	Taiwan		NTU		20–40	Sedimentation tank	[67]
Carwash WW	Malaysia		NTU	39.96 ± 51.90		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		NTU	173.67 ± 58.76			
Carwash WW	Malaysia		NTU	95.77 ± 28.54			
Carwash WW	Malaysia		NTU	110.83 ± 20.36			
Carwash Station WW	China		NTU		70–100	Sample from wastewater of a carwash	[62]
Carwash Station WW	Ireland		NTU	12		Sample was collected from a carwash wastewater tank at a gas station	[66]
Carwash wastewater	Ireland		NTU	12		–	[65]
Carwash WW	China		NTU	50		Vehicle-washing wastewater	[38]
Carwash WW	China		NTU	70		Carwashing wastewater for washing large vehicle	[39]
Carwash WW	Russia		NTU	37.8		–	[55]
Carwash WW	Malaysia		NTU		34.7–86.0	Sample wastewater supplied from two stations, including stations Sin Huat and SCS carwashes	[10]
Carwash WW	France		NTU	126 ± 38		Truck carwash	[19]
Carwash WW	France		NTU	100 ± 68		Self-service carwash	
Carwash WW	France		NTU	32 ± 9		Petrol station carwash	
Carwash WW	France		NTU	319 ± 478		Subway wash station	
Carwash WW	France		NTU	68.8 ± 14.4		Bus wash station	
pH							
Carwash WW	Iran		–	7.08 ± 0.03	3–7	Carwash station	[51]
Carwash WW	Nigeria		–	6.3		Samples in dry season	[25]
Carwash WW	Nigeria		–	5.9		Samples in Rainy season	
Carwash WW	Malaysia		–	6.96		Carwash station	[18]
Carwash WW	Kuwait		–	7.16		Carwash stations	[28]
Raw carwash WW	Iran	32	–	7.65 ± 0.02		Samples were taken from above the sediment tank in an automatic carwash	[12]
Raw carwash WW	Iran	32	–	7.31 ± 0.12		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	
Raw carwash WW	China		–		7.89–8.75	Wastewater taken from service station	[14]
Carwash WW	Turkey		–	8		Studied samples were from effluent of settling tank at the carwash	[37]
Carwash WW	Japan		–		6.5–7.3	–	[41]
Carwash WW	Taiwan		–		7.3–10.0	Full-scale BioMF	[43]
Carwash	India		–		6.3–7.5	–	[46]

(Continued)

Table 1 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	References
Washing vehicles WW	Algeria	3	–		6.63–6.79	June	[47]
Washing vehicles WW	Algeria	3	–		6.33–6.8	October	
Washing vehicles WW	Algeria	3	–		6.66–7.39	Nov–Dec	
Carwash WW	Brazil		–	7.5 ± 0.2		Sample tested was collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		–	7.1 ± 0.1			
Carwash WW	Brazil		–	7.1 ± 0.1			
Carwash WW	France	5	–	6.0 ± 0.8		Manual wash station	[59]
Carwash WW	France	5	–	9.1 ± 0.4		High pressure water jet carwash	
Carwash WW	France	5	–	7.0 ± 0.3		Self-service high–pressure water jet	
Carwash WW	Brazil		–	7.7 ± 0.6		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		–	7.4 ± 0.8		Campaign 2 – FCF-SC	
Carwash WW	South Africa		–	8.6 ± 0.1		Different Carwash effluent in the city	[63]
Carwash WW	South Africa		–	7.2 ± 0.2			
Carwash WW	South Africa		–	7.5 ± 0.1			
Carwash WW	South Africa		–	7.7 ± 0.2			
Carwash WW	South Africa		–	7.3 ± 0.2			
Carwash WW	South Africa		–	7.5 ± 0.3			
Carwash WW	Mexico		–		6.73–7.47	Carwash cenote	[27]
Carwash WW	India		–	7.49		Automobile service stations (sample A)	[29]
Carwash WW	India		–	7.86		Automobile service stations (sample B)	
Carwash WW	Brazil		–	7.4 ± 0.8		Sample collected from hand wash wastewater recovery system	[71]
Washing vehicles WW	Pakistan	10	–	8.3		Automobile Vehicle Service Stations	[70]
Carwash WW	Egypt		–		7.15–7.7	Samples of real wastewater were prepared in a carwash	[34]
Carwash WW	Australia		–	8.5		–	[13]
Carwash WW	Australia		–	7.63		–	
Washing vehicles WW	India		–	7.9		Automobile washing center	[26]
Carwash WW	Egypt		–	8.2		Wastewater tested was taken from a carwash wastewater tank located at the petrol station	[64]
Carwash WW	Mexico		–	7.3		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Egypt		–	7.4		Raw carwash wastewater	[24]

Carwash WW	Malaysia	3	–		7.85 ± 1.222–8.68 ± 1.621	Weekdays	[50]
Carwash WW	Malaysia	3	–		8.27 ± 0.6558–8.8 ± 0.507	Weekends	
Carwash WW	Syria		–	7		–	[30]
Carwash Station WW	Iran		–		7.2–7.6	Sample was taken from the top of the sedimentation tank at Jamalzadeh carwash	[48]
Carwash WW	Brazil		–		6–6.6	Carwash wastewater after the oil–water separator	[35]
Carwash Station WW	Malaysia	8	–	7.73 ± 0.85		Station 1 – Full hand service	[42]
Carwash Station WW	Malaysia	8	–	7.43 ± 0.37		Station 3 – Snow Foam	
Carwash Station WW	Malaysia	8	–	8.20 ± 1.66		Station 2 – Full hand service	
Carwash WW	Taiwan		–		7–7.6	Sedimentation tank	[67]
Carwash WW	Malaysia		–	8.3 ± 0.374		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		–	9.61 ± 0.07			
Carwash WW	Malaysia		–	8.0 ± 0.66			
Carwash WW	Malaysia		–	9.07 ± 0.59			
Carwash WW	Malaysia		–		8.8–9.5	MAHAJU Carwash Station	[61]
Carwash WW	Malaysia		–		9.5–10.6	Bandar U Carwash Station	
Carwash Station WW	China		–		6.5–8	Sample from wastewater of a carwash	[62]
Carwash Station WW	Ireland		–	8.2		Sample was collected from a carwash wastewater tank at a gas station	[66]
Carwash wastewater	Ireland		–	8.2		–	[65]
Carwash WW	China		–	8		Vehicle washing wastewater	[38]
Carwash WW	China		–	8		Carwashing wastewater for washing large vehicle	[39]
Truck wash water	Texas		–	6.3		Wastewater sampling in a wastewater from truck wash	[36]
Carwash WW	Russia		–	6.3		–	[55]
Carwash WW	Malaysia		–		6.51–8.74	Sample wastewater supplied from two stations, including stations Sin Huat and SCS carwashes	[10]
Carwash WW	France		–	12 ± 4		Truck carwash	[19]
Carwash WW	France		–	9.1 ± 0.4		Self-service carwash	
Carwash WW	France		–	7 ± 0.3		Petrol station carwash	
Carwash WW	France		–	13 ± 9		Subway wash station	
Carwash WW	France		–	7.2 ± 0.3		Bus wash station	
Carwash WW	Belgium		–	6.7		Effluents from carwash WW	[68]
Carwash WW	Belgium		–	7.3			
EC							
Carwash WW	Iran	–	µS/cm	760 ± 240			[51]
Carwash WW	Kuwait	–	µS/cm	940		Carwash stations	[28]

(Continued)

Table 1 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	References
Raw carwash WW	Iran	32	µS/cm	7,080 ± 1,400		Samples were taken from above the sediment tank in an automatic carwash	[12]
Raw carwash WW	Iran	32	µS/cm	7,050 ± 2,300		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	
Raw carwash WW	China		µS		1,159.7–1,289.6	Wastewater taken from service station	[14]
Carwash WW	Turkey		µS/cm	980		Studied samples were from effluent of settling tank at the carwash	[37]
Carwash WW	Ethiopia		µS/cm	≈800		Mosque and the carwash	[40]
Carwash WW	Japan		µS/m		7,700–1,800	–	[41]
Carwash	India		µS/cm		1,450–1,570	–	[46]
Washing vehicles WW	Algeria	3	µs/cm		6,540–6,590	June	[47]
Washing vehicles WW	Algeria	3	µs/cm		6,830–44,950	October	
Washing vehicles WW	Algeria	3	µs/cm		0–6,540	Nov–Dec	
Carwash WW	Brazil		µS/cm	300 ± 10		Sample tested was collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		µS/cm	370 ± 30			
Carwash WW	Brazil		µS/cm	290 ± 20			
Carwash WW	France	5	µS/cm	4,357 ± 2,884		Manual wash station	[59]
Carwash WW	France	5	µS/cm	1,457 ± 958		High pressure water jet carwash	
Carwash WW	France	5	µS/cm	490 ± 153		Self-service high-pressure water jet	
Carwash WW	Brazil		µS/cm	633 ± 125		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		µS/cm	469 ± 39.5		Campaign 2 – FCF-SC	
Carwash WW	South Africa		µS/cm at 25°C	1,220 ± 21		Different carwash effluent in the city	[63]
Carwash WW	South Africa		µS/cm at 25°C	832 ± 19			
Carwash WW	South Africa		µS/cm at 25°C	520 ± 28			
Carwash WW	South Africa		µS/cm at 25°C	506 ± 17			
Carwash WW	South Africa		µS/cm at 25°C	409 ± 3			
Carwash WW	South Africa		µS/cm at 25°C	281 ± 9			
Carwash WW	India		µS/cm	1,386		Automobile service stations (sample A)	[29]
Carwash WW	India		µS/cm	1,536		Automobile service stations (sample B)	
Carwash WW	Brazil		µS/cm	469 ± 39.5		Sample collected from hand wash wastewater recovery system	[71]
Carwash WW	Egypt		µS/cm		919–1,000	Samples of real wastewater were prepared in a carwash	[34]

Carwash WW	Australia		μS/cm	713		–	[13]
Carwash WW	Mexico		μs/cm	796,000		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Malaysia	3	μS		125–137	Weekdays	[50]
Carwash WW	Malaysia	3	μS		189–235	Weekends	
Carwash Station WW	Pakistan		μS/cm	3,590		Masha Allah service station	[32]
Carwash Station WW	Pakistan		μS/cm	430		Indus service station	
Carwash Station WW	Pakistan		μS/cm	2,020		Al-noor service station	
Carwash Station WW	Pakistan		μS/cm	1,700		Site area service station	
Carwash Station WW	Iran		μS/cm		419–2,200	Sample was taken from the top of the sedimentation tank at Jamalzadeh carwash	[48]
Carwash WW	Brazil		μS/cm		730–1,530	Carwash wastewater after the oil–water separator	[35]
Carwash WW	Malaysia		μS	224 ± 137		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		μS	265 ± 125			
Carwash WW	Malaysia		μS	235 ± 156			
Carwash WW	Malaysia		μS	387 ± 189			
Truck wash water	Texas		μs/cm	1,070,000		Wastewater sampling is wastewater from truck wash	[36]
Carwash WW	Malaysia		μS/cm		1.507–2.607	Sample wastewater supplied from two stations: Sin Huat and SCS carwashes	[10]
Carwash WW	France		μS/cm	4,357 ± 2,884		Truck carwash	[19]
Carwash WW	France		μS/cm	1,457 ± 958		Self-service carwash	
Carwash WW	France		μS/cm	490 ± 153		Petrol station carwash	
Carwash WW	France		μS/cm	790 ± 966		Subway wash station	
Carwash WW	France		μS/cm	381 ± 225		Bus wash station	
Carwash WW	Belgium		μS/cm	703		Effluents from carwash WW	[68]
Carwash WW	Belgium		μS/cm	310			

Table 2
Reported concentrations of chemical and biological parameter in carwash wastewater

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	Reference
BOD_5							
Carwash WW	Japan		mg/L		4.8–50	–	[41]
Carwash WW	South Africa		mg/L	354 ± 9.2		Different carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	650 ± 4.9			
Carwash WW	South Africa		mg/L	204 ± 4.2			
Carwash WW	South Africa		mg/L	114 ± 3.5			
Carwash WW	South Africa		mg/L	192 ± 6.4			
Carwash WW	South Africa		mg/L	27 ± 2.1			
Washing vehicles WW	Pakistan	10	mg/L	520		Automobile Vehicle Service Stations	[70]
Washing vehicles WW	India		mg/L	19		Automobile washing center	[26]
Carwash WW	Brazil		mg/L		203–496	Carwash wastewater after the oil–water separator	[35]
Carwash WW	Malaysia		mg/L	355.33 ± 65.68		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		mg/L	269.67 ± 143.73			
Carwash WW	Malaysia		mg/L	460 ± 53.51			
Carwash WW	Malaysia		mg/L	297 ± 70.76			
Carwash WW	Belgium		mg/L	280		Effluents from carwash WW	[68]
Carwash WW	Belgium		mg/L	320			
Raw carwash WW	Iran	32	mg/L	266.31 ± 78.86		Samples were taken from above the sediment tank in an automatic carwash	[12]
Raw carwash WW	Iran	32	mg/L	239.38 ± 70.52		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	
Carwash WW	Ethiopia		mg/L	≈340		Mosque and the carwash	[40]
Washing vehicles WW	Algeria	3	mg/L		250–2,350	October	[47]
Washing vehicles WW	Algeria	3	mg/L		200–400	Nov–Dec	
Carwash WW	Brazil		mg/L	133 ± 61		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		mg/L	68 ± 13		Campaign 2 – FCF-SC	
Carwash WW	India		mg/L	32.5		Automobile service stations (sample A)	[29]
Carwash WW	India		mg/L	52.5		Automobile service stations (sample B)	
Carwash WW	Brazil		mg/L	68 ± 13		Sample collected from hand wash wastewater recovery system	[71]
Carwash WW	Mexico		mg/L	150.96		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Syria		mg/L	100		–	[30]
Carwash WW	China	30	mg/L	53.05		Wastewater samples collected from 30 different caravans on sunny days	[69]

Carwash WW	Malaysia		mg/L		10.5–11.9	Sample wastewater supplied from two stations, including stations Sin Huat and SCS carwashes	[10]
COD							
Carwash WW	Iran		mg/L		870–1,230	Local carwash	[60]
Carwash WW	Malaysia		mg/L	220		Carwash station	[18]
Raw carwash WW	Iran	32	mg/L	924.17 ± 167.43		Samples were taken from above the sediment tank in an automatic carwash	[12]
Raw carwash WW	Iran	32	mg/L	856.01 ± 217.11		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	
Raw carwash WW	China		mg/L		141–1,019	Wastewater taken from service station	[14]
Carwash WW	Belgium		mg/L	316		Wastewater analysis from automatic carwash	[33]
Carwash WW	Belgium		mg/L	208		Wastewater analysis from automatic carwash	
Carwash WW	Turkey		mg/L	560		Studied samples were from effluent of settling tank at the carwash	[37]
Carwash WW	Japan		mg/L		7.7–41.7	–	[41]
Carwash WW	Taiwan		mg/L		15–20	Lab-scale BioMF system	[43]
Carwash WW	Taiwan		mg/L		42–345	Full-scale BioMF	
Carwash WW	Thailand		mg/L		≈60–170	Immobilized bacteria	[45]
Carwash	India		mg/L		150–175	–	[46]
Washing vehicles WW	Algeria	3	mg/L		1,152–1,504	June	[47]
Washing vehicles WW	Algeria	3	mg/L		3,463–20,781	October	
Washing vehicles WW	Algeria	3	mg/L		1,018–1,891	Nov–Dec	
Carwash WW	Brazil		mg/L	85 ± 6		Sample tested was collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		mg/L	64 ± 6			
Carwash WW	Brazil		mg/L	59 ± 6			
Carwash WW	France	5	mg/L	949 ± 462		Truck carwash	[59]
Carwash WW	France	5	mg/L	239 ± 145		Self-service carwash	
Carwash WW	France	5	mg/L	227 ± 59		Petrol station carwash	
Vehicle washing WW	Sweden		mg/L		120–4,200	Automatic light vehicle washing facilities	[54]
Vehicle washing WW	Sweden		mg/L		1,700–7,500	Automatic heavy vehicle washing facilities	
Carwash WW	Brazil		mg/L	241 ± 23.5		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		mg/L	191 ± 22		Campaign 2 – FCF-SC	
Carwash WW	India		mg/L	176.23		Automobile service stations (sample A)	[29]
Carwash WW	India		mg/L	246		Automobile service stations (sample B)	
Carwash WW	Brazil		mg/L	191 ± 22		Sample collected from hand wash wastewater recovery system	[71]
Washing vehicles WW	Pakistan	10	mg/L	1,330		Automobile Vehicle Service Stations	[70]

(Continued)

Table 2 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	Reference
Carwash WW	Egypt		mg/L		282–566	Samples of real wastewater were prepared in a carwash	[34]
Carwash WW	Australia		mg/L	433		–	[13]
Carwash WW	Australia		mg/L	776		–	
Carwash WW	Indonesia		mg/L	700		–	[44]
Washing vehicles WW	India		mg/L	79		Automobile washing center	[26]
Carwash WW	Egypt		mg/L	82		Wastewater tested was taken from a carwash wastewater tank located at the petrol station	[64]
Carwash WW	Mexico		mg/L	1,295		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Egypt		mg/L	1,020		Raw carwash wastewater	[24]
Carwash WW	Malaysia	3	mg/L		681.3 ± 27.392–721.7 ± 105.458	Weekdays	[50]
Carwash WW	Malaysia	3	mg/L		849.67 ± 233.140–893.33 ± 297.942	Weekends	
Carwash WW	Syria		mg/L	403		–	[30]
Carwash Station WW	Pakistan		mg/L	2.18		Masha Allah service station	[32]
Carwash Station WW	Pakistan		mg/L	4.08		Indus service station	
Carwash Station WW	Pakistan		mg/L	4.75		Al-noor service station	
Carwash Station WW	Pakistan		mg/L	3.01		Site area service station	
Carwash Station WW	Iran		mg/L		610–2,619	Sample was taken from the top of the sedimentation tank at Jamalzadeh carwash	[48]
Carwash WW	Brazil		mg/L		249–873	Carwash wastewater after the oil–water separator	[35]
Carwash Station WW	Malaysia	8	mg/L	190.0 ± 1.00		Station 1 – Full hand service	[42]
Carwash Station WW	Malaysia	8	mg/L	232.0 ± 0.6		Station 3 – Snow Foam	
Carwash Station WW	Malaysia	8	mg/L	485.0 ± 0.3		Station 2 – Full hand service	
Carwash WW	Taiwan		mg/L		50–300	Sedimentation tank	[67]
Carwash WW	Malaysia		mg/L	741 ± 315.53		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		mg/L	337.33 ± 101.55			
Carwash WW	Malaysia		mg/L	572.67 ± 84.91			
Carwash WW	Malaysia		mg/L	312 ± 164			
Carwash Station WW	China		mg/L		100–160	Sample from wastewater of a carwash	[62]
Carwash Station WW	Ireland		mg/L	82		Sample was collected from a carwash wastewater tank at a gas station	[66]

Car-wash wastewater	Ireland		mg/L	82		–	[65]
Carwash WW	China		mg/L	230		Vehicle-washing wastewater	[38]
Carwash WW	China		mg/L	260		Carwashing wastewater for washing large vehicle	[39]
Carwash WW	China	30	mg/L	229.6		Wastewater samples collected from 30 different caravans on sunny days	[69]
Carwash WW	Malaysia		mg/L		75.0–738.0	Sample wastewater supplied from two stations, including stations Sin Huat and SCS carwashes	[10]
Carwash WW	France		mg/L	949 ± 462		Truck carwash	[19]
Carwash WW	France		mg/L	239 ± 145		Self-service carwash	
Carwash WW	France		mg/L	227 ± 59		Petrol station carwash	
Carwash WW	France		mg/L	626 ± 1,008		Subway wash station	
Carwash WW	France		mg/L	317 ± 45		Bus wash station	
Carwash WW	Thailand		mg/L	3,636		–	[53]
Carwash WW	Belgium		mg/L	1,640		Effluents from carwash WW	[68]
Carwash WW	Belgium		mg/L	1,810			
Carwash WW	Iran		mg/L	(480–1,560) ± 207.3		Raw carwash wastewater	[51]
DO							
Carwash WW	Malaysia		mg/L	2.55		Carwash station	[18]
Raw carwash WW	China		mg/L	Nil to 0.90		Wastewater taken from service station	[14]
Carwash WW	Ethiopia		mg/L	<1		Mosque and the carwash	[40]
Carwash WW	South Africa		mg/L	0–1		Different carwash effluent the city	[63]
Carwash WW	Mexico		mg/L		2.98–4.68	Carwash cenote	[27]
Carwash WW	Australia		mg/L	2.47		–	[13]
Carwash WW	Belgium		mg/L	0.3		Effluents from carwash WW	[68]
Carwash WW	Belgium		mg/L	3.1			
Oil and grease content							
Carwash WW	Kuwait		mg/L	21.5		Carwash stations	[28]
Raw carwash WW	China		mg/L		1.3–83.7	Wastewater taken from service station	[14]
Carwash WW	Turkey		mg/L	125		Studied samples were from effluent of settling tank at the carwash	[37]
Carwash WW	Brazil		mg/L	<0.1		Sample tested collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		mg/L	<0.1			
Carwash WW	Brazil		mg/L	<0.1			
Vehicle washing WW	Sweden		mg/L		10–1,750	Automatic light vehicle washing facilities	[54]
Vehicle washing WW	Sweden		mg/L		65–1,200	Automatic heavy vehicle washing facilities	

(Continued)

Table 2 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	Reference
Carwash WW	Brazil		mg/L	6 ± 1		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		mg/L	11 ± 11		Campaign 2 – FCF-SC	
Carwash WW	South Africa		mg/L	≈13		Different carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	≈43			
Carwash WW	South Africa		mg/L	≈36			
Carwash WW	South Africa		mg/L	≈26			
Carwash WW	South Africa		mg/L	≈22			
Carwash WW	South Africa		mg/L	≈42			
Carwash WW	India		mg/L	135		Automobile service stations (sample A)	[29]
Carwash WW	India		mg/L	190		Automobile service stations (sample B)	
Washing vehicles WW	Pakistan	10	mg/L	1,070		Automobile Vehicle Service Stations	[70]
Carwash WW	Indonesia		mg/L	36		–	[44]
Carwash WW	Mexico		mg/L	368.82		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Malaysia	3	mg/L	1.78×10^{-3}		Weekdays	[50]
Carwash WW	Malaysia	3	mg/L		4.15×10^{-3}–2.08×10^{-3}	Weekends	
Carwash WW	Syria		mg/L	35		–	[30]
Carwash Station WW	Pakistan		mg/L	49		Masha Allah service station	[32]
Carwash Station WW	Pakistan		mg/L	17.6		Indus service station	
Carwash Station WW	Pakistan		mg/L	16		Al-noor service station	
Carwash Station WW	Pakistan		mg/L	11		Site area service station	
Carwash Station WW	Malaysia	8	mg/L	68.0 ± 0.4		Station 1 – Full hand service	[42]
Carwash Station WW	Malaysia	8	mg/L	80.0 ± 0.3		Station 3 – Snow Foam	
Carwash Station WW	Malaysia	8	mg/L	85.0 ± 0.6		Station 2 – Full hand service	
Carwash WW	Taiwan		mg/L		500–3,000	Sedimentation tank	[67]
Carwash WW	Malaysia		mg/L	1.78 ± 0.089		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		mg/L	1.78 ± 0.03			
Carwash WW	Malaysia		mg/L	1.27 ± 1.11			
Carwash WW	Malaysia		mg/L	1.25 ± 1.08			
Carwash Station WW	China		mg/L	5.0–25		Sample from wastewater of a carwash	[62]
Carwash WW	China		mg/L	6		Vehicle-washing wastewater	[38]
Carwash WW	China		mg/L	7		Carwashing wastewater for washing large vehicle	[39]
Carwash WW	China	30	mg/L	6.27		Wastewater samples collected from 30 different caravans on sunny days	[69]
Carwash WW	Russia		mg/L	9.4		–	[56]
Carwash WW	Thailand		mg/L	171		–	[53]

VSS							
Carwash WW	Taiwan		mg/L	0–48		Lab-scale BioMF system	[43]
Carwash WW	Brazil		mg/L	45 ± 4		Sample tested was collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		mg/L	31 ± 2			
Carwash WW	Brazil		mg/L	29 ± 3			
Carwash WW	France	5	% SS	22 ± 14		Truck carwash	[59]
Carwash WW	France	5	% SS	130 ± 67		Self-service carwash	
Carwash WW	France	5	% SS	77 ± 39		Petrol station carwash	
TOC							
Carwash WW	Taiwan		mg/L	5.9–18.0		Lab-scale BioMF system	[43]
Carwash WW	Brazil		mg/L	4.1 ± 0.2		Sample tested was collected from gas station has a rollover carwash system	[21]
Carwash WW	Brazil		mg/L	5.5 ± 0.5			
Carwash WW	Brazil		mg/L	2.9 ± 0.2			
Carwash WW	Australia		mg/L	198.72		–	[13]
Carwash WW	Taiwan		mg/L		10.0–50	Sedimentation tank	[67]
Carwash WW	Thailand		mg/L	1,294		–	[53]
Carwash WW	Belgium		mg/L	166.3		Effluents from carwash WW	[68]
Carwash WW	Belgium		mg/L	202.6			
Cl^-							
Carwash WW	Kuwait		mg/L	136		Carwash stations	[28]
Carwash WW	Turkey		mg/L	150		Studied samples were from effluent of settling tank at the carwash	[37]
Carwash WW	Ethiopia		mg/L	≈55		Mosque and the carwash	[40]
Carwash WW	Japan		mg/L		9–18	–	[41]
Carwash WW	South Africa		mg/L	64 ± 3.5		Different carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	40 ± 1.4			
Carwash WW	South Africa		mg/L	32 ± 3.5			
Carwash WW	South Africa		mg/L	27 ± 2.1			
Carwash WW	South Africa		mg/L	26 ± 2.1			
Carwash WW	South Africa		mg/L	14 ± 2.8			
Carwash WW	Mexico		mg/L		207–689	Carwash cenote	[27]
Carwash WW	India		mg/L	175.23		Automobile service stations (sample A)	[29]
Carwash WW	India		mg/L	234.1		Automobile service stations (sample B)	
Carwash WW	Brazil		mg/L	30.9 ± 4.5		Sample collected from hand wash wastewater recovery system	[71,72]
Washing vehicles WW	Pakistan	10	mg/L	112		Automobile Vehicle Service Stations	[70]
Washing vehicles WW	India		mg/L	92		Automobile washing center	[26]
Carwash WW	Mexico		mg/L	26.32		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]

(Continued)

Table 2 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	Reference
Carwash WW	Malaysia		mg/L		19.4–33.0	MAHAJU Carwash Station	[61]
Carwash WW	Malaysia		mg/L		18.2–25.4	Bandar U Carwash Station	
H_2S							
Carwash WW	Kuwait		mg/L	0.1		Carwash stations	[28]
Carwash WW	Brazil		mg/L	0.19 ± 0.01		Sample collected from hand wash wastewater recovery system	[71,72]
Ca							
Carwash WW	Kuwait		mg/L	75		Carwash stations	[28]
Carwash WW	Brazil		mg/L	16 ± 2		Sample collected from hand wash wastewater recovery system	[71]
Carwash WW	Mexico		mg/L	32.7		Carwash cenote	[27]
Fe							
Carwash WW	Nigeria		mg/L	0.2		Dry season	[25]
Carwash WW	Nigeria		mg/L	0.24		Rainy season	
Carwash WW	Kuwait		mg/L	0.6		Carwash stations	[28]
Raw carwash WW	Iran	32	mg/L	14.26 ± 7.18		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	[12]
Washing vehicles WW	Pakistan	10	mg/L	4.14		Automobile Vehicle Service Stations	[70]
Carwash WW	Russia		mg/L	4.3		–	[56]
K							
Carwash WW	Kuwait		mg/L	5		Carwash stations	[28]
Carwash WW	Mexico		mg/L	0.65		Carwash cenote	[27]
Mg							
Carwash WW	Kuwait		mg/L	17		Carwash stations	[28]
Carwash WW	Brazil		mg/L	2.2 ± 1		Sample collected from hand wash wastewater recovery system	[71]
Carwash WW	Mexico		mg/L	19.5		Carwash cenote	[27]
Na							
Carwash WW	Kuwait		mg/L	128		Carwash stations	[28]
Carwash WW	Japan		mg/L		4.1–16	–	[41]
Carwash WW	Brazil		mg/L	76.7 ± 11.5		Sample collected from hand wash wastewater recovery system	[71]
Carwash WW	Mexico		mg/L	46.9		Carwash cenote	[27]
SO_4							
Carwash WW	Kuwait		mg/L	188		Carwash stations	[28]

Carwash WW	Turkey		mg/L	190		Studied samples were from effluent of settling tank at the carwash	[37]
Carwash WW	Japan		mg/L		21–34	–	[41]
Carwash WW	Brazil		mg/L	22.6 ± 2.5		Sample collected from hand wash wastewater recovery system	[71]
Carwash WW	South Africa		mg/L	184 ± 2.1		Different carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	6 ± 2.1			
Carwash WW	South Africa		mg/L	144 ± 5.7			
Carwash WW	South Africa		mg/L	149 ± 3.5			
Carwash WW	South Africa		mg/L	34.5 ± 3.5			
Carwash WW	South Africa		mg/L	12.5 ± 3.5			
Carwash WW	Mexico		mg/L		30–80	Carwash cenote	[27]
Carwash WW	India		mg/L	59.32		Automobile service stations (sample A)	[29]
Carwash WW	India		mg/L	68.23		Automobile service stations (sample B)	
Washing vehicles WW	Pakistan	10	mg/L	268		Automobile Vehicle Service Stations	[70]
Washing vehicles WW	India		mg/L	14.8		Automobile washing center	[26]
Carwash WW	Mexico		mg/L	585.45		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Brazil		mg/L (sulfide)		3.9–5.1	Carwash wastewater after the oil–water separator	[35]
Carwash WW	Malaysia		mg/L		12.6–115.5	MAHAJU Carwash Station	[61]
Carwash WW	Malaysia		mg/L		16.1–100.4	Bandar U Carwash Station	
Phosphates							
Carwash WW	South Africa		mg/L		0.8–5.2	Different carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	24			
Carwash WW	South Africa		mg/L		0.8–5.2		
Carwash WW	South Africa		mg/L		0.8–5.2		
Carwash WW	South Africa		mg/L		0.8–5.2		
Carwash WW	South Africa		mg/L		0.8–5.2		
Carwash WW	Mexico		mg/L		0.007–0.01	Carwash cenote	[27]
Washing vehicles WW	Pakistan	10	mg/L	0.3		Automobile Vehicle Service Stations	[70]
Carwash Station WW	Iran		mg/L		11.4–38.2	Sample was taken from the top of the sedimentation tank at Jamalzadeh carwash	[48]
Carwash Station WW	Malaysia	8	mg/L	2.02 ± 1.4		–	[42]
Carwash Station WW	Malaysia	8	mg/L	3.40 ± 2.05		–	
Carwash Station WW	Malaysia	8	mg/L	10.18 ± 0.87		–	
Carwash WW	New Zealand	12	mg/L	6.1 ± 1.7		After washing, two vehicles were investigated	[52]
Carwash WW	Russia		mg/L	0.54		–	[55]
Carwash WW	Russia		mg/L	0.54		–	[56]

(Continued)

Table 2 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	Reference
TP							
Carwash WW	France	5	mg/L	35.5 ± 15.6		Truck carwash	[59]
Carwash WW	France	5	mg/L	28 ± 41		Self-service carwash	
Carwash WW	France	5	mg/L	0.5 ± 0.2		Petrol station carwash	
Carwash WW	Brazil		mg/L	1 ± 0.5		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		mg/L	1 ± 1		Campaign 2 – FCF-SC	
Carwash WW	Australia		mg/L	25		–	[13]
Carwash WW	Malaysia	3	mg/L		2.79–6.36	Weekdays	[50]
Carwash WW	Malaysia	3	mg/L		7.3–8.63	Weekends	
Carwash WW	Syria		mg/L	8		–	[30]
Carwash Station WW	Malaysia	8	mg/L	7.05 ± 2.2		–	[42]
Carwash Station WW	Malaysia	8	mg/L	9.40 ± 1.55		–	
Carwash Station WW	Malaysia	8	mg/L	30.93 ± 0.31		–	
Carwash WW	Malaysia		mg/L (phosphorus)	5.51 ± 0.31		2 Station sampling has been performed two times: first and weekend	[49]
Carwash WW	Malaysia		mg/L	2.79 ± 1.50			
Carwash WW	Malaysia		mg/L	7.3 ± 7.72			
Carwash WW	Malaysia		mg/L	10.34 ± 5.94			
Carwash WW	China	30	mg/L	0.96		Wastewater samples collected from 30 different caravans on sunny days	[69]
Carwash runoff	Canadian Province		mg/L	0.17 ± 0.12		Carwash runoff treatment using bioretention mesocosms	[31]
Carwash WW	France		mg/L	35.5 ± 15.6		Truck carwash	[19]
Carwash WW	France		mg/L	28 ± 41		Self-service carwash	
Carwash WW	France		mg/L	0.5 ± 0.2		Petrol station carwash	
Carwash WW	France		mg/L	14 ± 24		Subway wash station	
Carwash WW	France		mg/L	0.2 ± 0.1		Bus wash station	
Carwash WW	Belgium		mg/L	0		Effluents from carwash WW	[68]
Carwash WW	Belgium		mg/L	6.5			
TN							
Carwash WW	France	5	mg/L	12 ± 4		Truck carwash	[59]
Carwash WW	France	5	mg/L	9 ± 3		Self-service carwash	
Carwash WW	France	5	mg/L	10 ± 3		Petrol station carwash	
Carwash WW	Brazil		mg/L	5 ± 1		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		mg/L	9 ± 3		Campaign 2 – FCF-SC	
Carwash WW	Australia		mg/L	11.73		–	[13]

Carwash WW	China	30	mg/L	7.78		Wastewater samples collected from 30 different caravans on sunny days	[69]
Carwash WW	France		mg/L	12 ± 4		Truck carwash	[19]
Carwash WW	France		mg/L	9 ± 3		Self-service carwash	
Carwash WW	France		mg/L	10 ± 3		Petrol station carwash	
Carwash WW	France		mg/L	13 ± 9		Subway wash station	
Carwash WW	France		mg/L	<10 ± <10		Bus wash station	
Carwash WW	Belgium		mg/L	12		Effluents from carwash WW	[68]
Carwash WW	Belgium		mg/L	190			
NH_4							
Carwash WW	France	5	mg/L	0.6 ± 0.8	0.1–1.9	Truck carwash	[59]
Carwash WW	France	5	mg/L	0.3 ± 0.2	0.1–0.5	Self-service carwash	
Carwash WW	France	5	mg/L	0.2 ± 0.2	0.1–0.5	Petrol station carwash	
Carwash WW	Australia		mg/L	2.2		–	[13]
Carwash WW	Australia		mg/L	3.5		–	
Carwash WW	Syria		mg/L	4		–	[30]
Carwash WW	Russia		mg/L	0.6		–	[55]
Carwash WW	Russia		mg/L	0.6		–	[56]
Hardness							
Carwash WW	Turkey		mg/L	300		Studied samples were from effluent of settling tank at the carwash	[37]
Carwash WW	Japan		mg/L		22–42	–	[41]
Carwash WW	India		mg/L	314		Automobile service stations (sample A)	[29]
Carwash WW	India		mg/L	356.1		Automobile service stations (sample B)	
Washing vehicles WW	India		mg/L	400		Automobile washing center	[26]
Alkalinity							
Carwash WW	Mexico		mg/L		348–440	Carwash cenote	[27]
Washing vehicles WW	Pakistan	10	mg/L	582		Automobile Vehicle Service Stations	[70]
Washing vehicles WW	India		mg/L	305		Automobile washing center	[26]
Carwash WW	Mexico		mg/L	259.7		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash Station WW	Malaysia	8	mg/L	21.53 ± 0.64		Station 1-Full hand service	[42]
Carwash Station WW	Malaysia	8	mg/L	31.94 ± 1.22		Station 3-Snow Foam	
Carwash Station WW	Malaysia	8	mg/L	293.00 ± 0.12		Station 2-Full hand service	
Carwash WW	Taiwan		mg/L		20–30	Sedimentation tank	[67]

Table 2 Continued

Type of wastewater	Location	N	Conc. unit	Mean ± SD	Range	Description	Reference
Nitrate							
Carwash WW	France	5	mg/L	1.1 ± 0.4		Truck carwash	[59]
Carwash WW	France	5	mg/L	0.7 ± 0.2		Self-service carwash	
Carwash WW	France	5	mg/L	0.2 ± 0.1		Petrol station carwash	
Carwash WW	South Africa		mg/L	<0.2		Different carwash effluent in the city	[63]
Carwash WW	Mexico		mg/L		0.627–1.09	Carwash cenote	[27]
Carwash WW	Australia		mg/L	2		–	[13]
Carwash WW	Australia		mg/L	6.75		–	
Carwash WW	Mexico		mg/L	<5		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash Station WW	Malaysia	8	mg/L	0.29 ± 0.58		–	[42]
Carwash Station WW	Malaysia	8	mg/L	0.36 ± 0.76		–	
Carwash Station WW	Malaysia	8	mg/L	2.86 ± 0.25		–	
Carwash WW	New Zealand	12	mg/L	2.5 ± 0.7		After washing, two vehicles were investigated	[52]
Carwash WW	Russia		mg/L	<0.5		–	[56]
Nitrite							
Carwash WW	South Africa		mg/L	<0.1		Different Carwash effluent in the city	[63]
Carwash WW	Mexico		mg/L		0.0025–0.003	Carwash cenote	[27]
Carwash WW	Australia		mg/L	0.77		–	[13]
Carwash WW	Australia		mg/L	1.2		–	
Carwash Station WW	Malaysia	8	mg/L	0.13 ± 0.31		–	[42]
Carwash Station WW	Malaysia	8	mg/L	0.15 ± 0.47		–	
Carwash Station WW	Malaysia	8	mg/L	0.01 ± 0.72		–	
Carwash WW	Belgium		mg/L	3.1			

WW = Wastewater.

3.3. Results of individual studies

Table 1 shows the physico-chemical parameters of carwash wastewater in 56 selected papers according to which, the range of physico-chemical parameters such as temperature, total solids (TS), total suspended solids (TSS), SS, total dissolved solids (TDS), turbidity, pH and electrical conductivity (EC) was 11.26°C–32°C; 110–16,262; 14.33–14,702; 4–2,458; 89.2–1,790; 4.1–4,000; 5.9–13 mg/mL and 0–1,070,000 µS/cm. Regarding the biological parameters section biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), oil and grease indices were reported in the range of 4.28–2,350; 2–20,781; and 3,000–1.0 mg/L, respectively.

The range of hardness, alkalinity, nitrate, nitrite, and dissolved oxygen, chlorine (Cl), calcium (Ca), iron (Fe), magnesium (Mg), sodium (Na), sulfate (SO_4), phosphate (PO_4), total phosphorus (TP) and total nitrogen (TN) parameters in supplementary Table 2 were 22–400, 20–582, <0.2–6.75, 0.0025–1.2, 0–4.68, 9–689, 16–75, 0.2–14.26, 2.2–17, 4.1–128, 3.9–585.45, 0.007–38.2, 0–35.5 and 5–190 mg/L, respectively. Also, the range of heavy metals such as copper, chromium, lead and zinc was reported to be 0.18–13, 0–3, 0–5 and 0.0003–20 mg/L, respectively. According to supplementary Table 4, the range of surfactant (mg/L), methyl tert-butyl ether (MTBE) (mg/L), polychlorinated biphenyls (PCBs) (7) (mg/L) and Σ16PAHs (mg/L) was reported to be 0–68.33; 0.3–2.4; 0.19–1.16 and 0.037–1,256, respectively. Other values of the parameters are shown in the supplementary tables.

4. Discussion

Nowadays, with rapid growth of population and urban communities, it is demonstrated that the need to control environmental pollution is an important issue in different countries. Emergence of various diseases worldwide and widespread deaths caused by these incidents is a warning for human societies, which can lead to serious issues if not controlled by resources [73,74]. Water pollution and its associated problems result in the need for comprehensive and strategic solutions, such as treatment and reuse of wastewater. Considering the fact that choosing a proper treatment method requires full knowledge of wastewater characteristics, we examine the carwash wastewater and its pollutants in this work. The concentration of pollutants in the carwash wastewater, depending on the geographical area, general culture of local people, and in general, conditions for access to detergents and compounds can range from very low to very high compared with domestic wastewater. Therefore, the treatment and reuse of these wastewaters can be considered technical, economical and environmental for many industries [75–77]. In this section, carwash wastewater pollutants are analyzed.

5. Physico-chemical parameters

5.1. Temperature

The most important effect of temperature in wastewater treatment processes is the reduction of oxygen required by microorganisms [9,78,79]. According to the literature review, the lowest reported temperature for carwash wastewater was 11.2°C, expressed by Van der Bruggen et al. [68] in Belgium. Moreover, the highest recorded temperature was 32°C, reported in the Adams et al. study (Nigeria, 2016) in dry seasons [25]. According to these investigations, about 67% of the reported values were at temperatures above 25°C. Based on the results of this study, it can be concluded that the wastewater from the carwash industry has low dissolved oxygen content due to high temperature, which it should be considered in biological treatment processes.

5.2. Solids (TS, TSS, SS, TDS)

The disadvantage of high solids presence content in carwash water can damage pumps and treatment systems as well as problems in boilers [80–83]. The TSS are a key factor in water clarity, meaning that a higher TSS represents a lower water transparency [9]. Also, in carwashes, due to the use of high-speed water and intensity in washing the car body, it can destroy the car's body color.

According to the performed studies, the lowest total solids (TS) were reported by Bhatti et al. [14] to be 110 mg/L in Pakistan. The highest total solids were also reported by Tekere et al. [63], to be 16,262 mg/L. This study was conducted on six carwashes in the province of Gauteng in South Africa, where the total solids were reported between 16.262 ± 7.8 and 612 ± 6.4. The maximum TSS and SS were 14,702 and 2,458 mg/L, respectively, which were reported in Messrouk et al. [47] study in Algeria and Van der Bruggen et al. [68] in Belgium. Due to the high quantities of SS in the carwash wastewater, the treatment and removal processes of SS should be used to prevent any damage to the treatment equipment as well as car surfaces.

5.3. Turbidity

Generally, water with high turbidity is not used in industries due to sedimentation of solids and problems in boilers [9,83]. In the carwash industry, this parameter is usually important because the high turbidity (due to the high concentration of SS) can cause suspended particles into the vehicle's body and lose the color of the vehicle. Wastewater turbidity is mainly dependent on the source of water and the type of intake in various industries and activities of washing cars and in-site treatment systems [63]. The minerals may be the main source of turbidity in carwash wastewater caused by mud and dirt from cars. Typically, in the carwash industry, the turbidity can be very variable due to mud and oil created from different parts of the car. Furthermore, according to the studies, other factors of turbidity are the location of rural areas and easy access to soil and sand and other solids in high volumes in different parts of the car [13,18,34]. The highest reported turbidity rates were in Tekere et al. [63] with Nephelometric Turbidity Units value of 4,000 ± 7.29. Furthermore, the lowest values of raw wastewater turbidity were reported in the study by Hamada and Miyazak [41] studies in Japan in 2004 with values of 4.1 NTU. According to supplementary Table 1, it can be seen that carwash water turbidity was about 70 % % of the studies less than 200 years NTU. Due to the relatively high concentrations of turbidity in the effluent of carwash industry, for reuse of this effluent in industries, further

Table 3
Reported concentrations of heavy metals in carwash wastewater

Type of wastewater	Location	N	Concentration unit	Mean ± SD	Range	Description	Reference
Aluminum							
Carwash WW	Nigeria		mg/L	0.006		Dry season	[25]
Carwash WW	Nigeria		mg/L	0.008		Rainy season	
Carwash WW	Kuwait		mg/L	0.9		Carwash stations	[28]
Carwash WW	Mexico		mg/L	38.25		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Copper							
Carwash WW	Nigeria		mg/L	0.37		Dry season	[25]
Carwash WW	Nigeria		mg/L	0.25		Rainy season	
Carwash WW	South Africa		mg/L	≈2		Different Carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	≈13			
Carwash WW	South Africa		mg/L	≈2			
Carwash WW	South Africa		mg/L	≈3			
Carwash WW	South Africa		mg/L	≈2.5			
Carwash WW	South Africa		mg/L	≈1			
Carwash WW	Syria		mg/L	1		–	[30]
Carwash WW	New Zealand	12	mg/L	0.1808 ± 0.0841		After washing, two vehicles were investigated.	[52]
Nickel							
Carwash WW	Nigeria		mg/L	0.008		Dry season	[25]
Carwash WW	Nigeria		mg/L	0.02		Rainy season	
Cadmium							
Carwash WW	Nigeria		mg/L	0		Dry season	[25]
Carwash WW	Nigeria		mg/L	0		Rainy season	
Chromium							
Carwash WW	Nigeria		mg/L	0.006		Dry season	[25]
Carwash WW	Nigeria		mg/L	0.003		Rainy season	
Carwash WW	South Africa		mg/L	≈0		Different Carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	≈3			
Carwash WW	South Africa		mg/L	≈0			
Carwash WW	South Africa		mg/L	≈0			
Carwash WW	South Africa		mg/L	≈0			
Carwash WW	South Africa		mg/L	≈0			

Manganese						
Carwash WW	Nigeria		mg/L	0.002	Dry season	[25]
Carwash WW	Nigeria		mg/L	0.004	Rainy season	
Carwash WW	Kuwait		mg/L	0.1	Carwash stations	[28]
Arsenic						
Carwash WW	Nigeria		mg/L	0.008	Dry season	[25]
Carwash WW	Nigeria		mg/L	0.005	Rainy season	
Pb						
Carwash WW	Nigeria		mg/L	0.06	Dry season	[25]
Carwash WW	Nigeria		mg/L	0.03	Rainy season	
Raw carwash WW	Iran	32	mg/L	0.79 ± 0.72	Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	[12]
Carwash WW	South Africa		mg/L	≈0	Different Carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	≈5		
Carwash WW	South Africa		mg/L	≈4		
Carwash WW	South Africa		mg/L	≈0		
Carwash WW	South Africa		mg/L	≈0		
Carwash WW	South Africa		mg/L	≈0		
Carwash WW	New Zealand	12	mg/L	0.0464 ± 0.0386	After washing, two vehicles were investigated	[52]
Zinc						
Carwash WW	Nigeria		mg/L	6.25	Dry season	[25]
Carwash WW	Nigeria		mg/L	5.26	Rainy season	
Raw carwash WW	Iran	32	mg/L	5.52 ± 2.13	Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	[12]
Carwash WW	South Africa		mg/L	≈1	Different Carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	≈20		
Carwash WW	South Africa		mg/L	≈2		
Carwash WW	South Africa		mg/L	≈3		
Carwash WW	South Africa		mg/L	≈1.5		
Carwash WW	South Africa		mg/L	≈2		
Carwash WW	Syria		mg/L	2	–	[30]
Carwash WW	New Zealand	12	(μg/L)	0.3085 ± 0.1557	After washing, two vehicles were investigated	[52]

Table 4
Reported concentrations of resistant pollutants in carwash wastewater

Type of wastewater	Location	N	Concentration unit	Mean ± SD	Range	Description	References
Surfactant							
Carwash WW	Brazil		mg/L	11.7 ± 9		Campaign 1 – FCF-S	[71]
Carwash WW	Brazil		mg/L	21 ± 3.6		Campaign 2 – FCF-SC	
Carwash WW	Taiwan		mg/L ABS		3–20	Sedimentation tank	[67]
Carwash WW	Texas		ppm	<5.0		Wastewater samples collected from 30 different caravans on sunny days	[69]
Truck wash water	Canadian Province		mg/L	9.2 ± 1.15		Wastewater sampling in wastewater from truck wash	[36]
Carwash WW	Belgium		mg/L	27		Effluents from carwash WW	[68]
Carwash WW	Belgium		mg/L	17.9			
Nonionic surfactants							
Carwash WW	Belgium		ppm	26		Wastewater analysis from automatic carwash	[33]
Carwash WW	Belgium		ppm	39		Wastewater analysis from automatic carwash	
Carwash WW	Belgium		ppm	13		Effluents from carwash WW	[68]
Carwash WW	Belgium		ppm	1.6			
Anionic surfactants (as MBAS)							
Carwash WW	South Africa		mg/L	≈4		Different carwash effluent in the city	[63]
Carwash WW	South Africa		mg/L	≈2			
Carwash WW	South Africa		mg/L	≈6			
Carwash WW	South Africa		mg/L	≈3			
Carwash WW	South Africa		mg/L	≈4			
Carwash WW	South Africa		mg/L	≈1			
Carwash WW	Mexico		mg/L	68.33		Wastewater samples collected from outflow streams from a carwash (settled wastewater)	[58]
Carwash WW	Syria		mg/L	32		–	[30]
Carwash WW	Brazil		mg/L		11.26–22.3	Carwash wastewater after the oil–water separator	[35]
Carwash Station WW	Malaysia		mg/L	17.90 ± 8.09	7.75–33.16	Station 1 – Full hand service	[42]
Carwash Station WW	Malaysia		mg/L	54.00 ± 2.50	51.2–60.5	Station 3 – Snow Foam	
Anionic surfactants							
Carwash WW	Belgium		ppm	0		Wastewater analysis from automatic carwash	[33]
Carwash WW	Belgium		ppm	0.8		Wastewater analysis from automatic carwash	
Carwash WW	Belgium		ppm	14		Effluents from carwash WW	[68]
Carwash WW	Belgium		ppm	15.5			
Cationic surfactants							
Carwash WW	Belgium		ppm	7.9		Wastewater analysis from automatic carwash	[33]
Carwash WW	Belgium		ppm	4.3		Wastewater analysis from automatic carwash	

Carwash WW	Belgium		ppm	0		Effluents from carwash WW	[68]
Carwash WW	Belgium		ppm	0.8			
LAS							
Carwash WW	France	5	mg/L	0.014 ± 0.023		Truck carwash	[59]
Carwash WW	France	5	mg/L	20.12 ± 24.54		Self-service carwash	
Carwash WW	France	5	mg/L	0.719 ± 1.282		Petrol station carwash	
Carwash Station WW	China		mg/L		2.0–5.0	Sample from wastewater of a carwash	[62]
Carwash runoff	China	30	mg/L	29.42		Carwash runoff treatment using bioretention mesocosms	[31]
MTBE							
Carwash WW	France	5	µg/L	2.4 ± 5.4		Truck carwash	[59]
Carwash WW	France	5	µg/L	0.3 ± 0.7		Self-service carwash	
Carwash WW	France	5	µg/L	0.3 ± 0.6		Petrol station carwash	
Carwash WW	France		µg/L	2.4 ± 5.4		Truck carwash	[19]
Carwash WW	France		µg/L	0.3 ± 0.7		Self-service carwash	
Carwash WW	France		µg/L	0.3 ± 0.6		Petrol station carwash	
PCBs (7)							
Carwash WW	France	5	µg/L	1.16 ± 0.82		Truck carwash	[59]
Carwash WW	France	5	µg/L	0.41 ± 0.52		Self-service carwash	
Carwash WW	France	5	µg/L	0.19 ± 0.19		Petrol station carwash	
Foaming agents (MBAS)							
Raw carwash WW	Iran	32	mg/L	34.17 ± 14.21		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	[12]
Raw carwash WW	Iran	32	(mg/L)	31.22 ± 18.75		Samples were taken from above the sediment tank in an automatic carwash (24-h settled wastewater)	
Raw carwash WW	China		mg/L	35		Wastewater taken from service station	[14]
Σ16PAHs							
Vehicle-wash wastewater	Pakistan		µg/L	347 ± 81.4		–	[57]
Vehicle-wash wastewater	Pakistan		µg/L	1,256 ± 313			
Carwash WW	France		µg/L	1.778 ± 0.638		Truck carwash	[59]
Carwash WW	France		µg/L	0.372 ± 0.318		Self-service carwash	
Carwash WW	France		µg/L	0.319 ± 0.276		Petrol station carwash	
Carwash WW	France		µg/L	1.778 ± 0.638		Truck carwash	[19]
Carwash WW	France		µg/L	0.372 ± 0.318		Self-service carwash	
Carwash WW	France		µg/L	0.319 ± 0.276		Petrol station carwash	
Carwash WW	France		µg/L	0.037		Bus wash station	

purification and removal of turbidity to the desired level is completely required. Application of wastewater treatment methods such as the filtration membranes, can improve this indicator to achieve standard values in the industry for reuse.

5.4. pH

In chemical and biological processes, the proper pH range varies depending on the type of treatment processes [9,84]. Most detergents and pollutants are usually soluble in solutions with low pHs and thus can dissolve with trace elements and cause environmental and health problems [85]. Low pHs can also cause corrosion of water and wastewater facilities and pumps [86,87]. In contrast, high pHs may result in increased particulate matter, accumulation of toxic chemicals, and instability of solutions [88,89]. Decomposition of organic matters, entry of mineral acids resulting from various activities and domestic activities are the factors affecting the quantity of this parameter [25].

In carwash wastewater, problems with low pH can be indicated in dissolution of car color and corrosion of different parts of the vehicle. High pH levels can also lead to the destruction of color in cars by forming solid granules in high water pressures. According to the studies, the highest pH value was reported to be 13 in the study by Breton et al. [19]. There were about 93% of the values listed in Studies 6 – 9. In the carwash wastewater, variable pH was reported for the detergents used for washing machines. The lowest values of this parameter were reported to be 5.9 in the study by Adams et al. [25] in Nigeria. Overall, compliance with the standards for disposal of surface waters (pH = 5–9), carwash wastewater can fulfill these criteria in more than 90% of the cases [90,91]. Hence, based on pH values in different studies, it can be concluded that the carwash wastewater treatment processes do not require pH adjustment.

5.5. Electrical conductivity

The EC is directly proportional to the total soluble solids in water and the temperature is another effective factor which usually indicates the ambient temperature when recording the number [92]. The highest and lowest values recorded in studies were 1,070,000 and 0 μS/cm, respectively. The maximum value was reported in the study by Gomes et al. [36] in Texas, USA that was from collection of water from a truck wash tank at a carwash facility. The lowest reported values were in the study of Messrouk et al. [47], which differed in the range of 0–6,540. In 36.5% of the studies, the values of this parameter were reported low (less than 500).

Because of the high variation of EC indicator in carwash wastewater, it can be concluded that this index can be one of the effective factors in wastewater treatment and carwash wastewater treatment processes, and due to its direct association with TDS, it should be considered in purification processes as an effective parameter.

5.6. Chemical parameters

5.6.1. Hardness and alkalinity

Chemical parameters in the quality of water and wastewater are hardness and alkalinity. The hardness refers mainly to calcium and magnesium ions, but ions such as iron, strontium, barium, and manganese are involved in [93]. Hardness and especially carbonate hardness are the most important parameters of water quality in industry, which in some cases, cause of precipitation in pipes and surfaces and reduce energy, reduction of resources useful volume of and even explosion of steam boilers [9,94]. This parameter is usually expressed in mg/L $CaCO_3$. The hardness resources can be natural or artificial, originating from natural resources such as sedimentary rocks, and artificial sources can be found in chemical industries and mines [9,93]. The importance of hard water in the carwash wastewater is due to the formation of sediment particles in the washing system, which may be contributed by the water temperature [53,95,96].

The amount of reported hardness in different studies has a very variable domain (supplementary Table 2). The lowest level of hardness was reported in the study by Hamada and Miyazaki [41] in Japan to be 22 mg/L and the highest value was reported by Alam et al. [26] to be 400 mg/L in India. According to the reported ranges, it can be concluded that the wastewater quality is variable from very hard to very soft (>300) [50]. The hardness range in all studies was about 300–400 mg/L $CaCO_3$ except the study of Balkema et al. [22], which was reported less than 50. Alkalinity is also somewhat related to hardness and pH. The importance of this parameter in water, in addition to its bitter taste, is due to the formation of sediment resulting from the reaction of these ions with other elements and the possibility of blocking pipes and problems in boilers [9,94]. The lowest amounts of alkalinity were reported in Tu et al. [67] in Taiwan to be 20 mg/L. The highest levels of alkalinity were reported in the study by Yasin et al. [70] in Pakistan to be 582 mg/L.

5.6.2. Nitrogen (nitrate, nitrite, ammonium, total nitrogen)

The importance of nitrogen compounds in water resources and receiving waters can be considered for biological and chemical reactions as well as public health reasons. The algal bloom phenomenon associated with nitrogen compounds and methemoglobinemia disease is one of the main problems caused by discharge of wastewater containing nitrogen compounds in water resources. Different nitrogen compounds such as nitrite, nitrate and ammonium vary according to environmental conditions. Usually, in the early conditions, ammonium compounds are present at low pH and are gradually converted to nitrite and nitrate compounds and at high pH levels, which is converted to ammonia. In industrial wastewater such as carwash, discharging wastewater into receiving waters or sewer can show its importance by disturbing carbon-nitrogen-phosphorus ratios in biological processes. According to the studies, the lowest nitrate level in the study by Tekere et al. [63] was reported to be less than 0.2 mg/L. Moreover, the highest reported values were reported in the study by Boluarte et al. [13] to be 6.75 mg/L in Australia. In some of the studies, high values of 1 mg/L were reported [27,42,52]. In a study, the nitrate concentration in carwashes was reported with hand washing compared with high pressure machine washing [59]. The nitrite levels were also reported from a low level of 0.0025 mg/L in the study by Alcocer et al. [27] in Mexico to 1.2 mg/L in the study by Boluarte et al. [13] in Malaysia.

According to the studies conducted in 62.5% of the studies, the values were reported less than 0.2 mg/L. Ammonium is one of the important nitrogen compounds studied in various studies in carwash wastewater. In Sablayrolles et al. [59] in Toulouse, France, the lowest ammonium values were reported in carwash to be 0.2 mg/L. Similarly, the highest levels in the study by Baddor et al. [30] were reported in Syria. Total nitrogen is one of the most important indices in water and wastewater effluents quality. According to the studies, the lowest total nitrogen content in Zaneti et al. [71] reported in Brazil that it would be 5 mg/L. The highest values were reported in the study by Van der Bruggen et al. [68] (190 mg/L) in Belgium. High amounts of total nitrogen in carwash wastewater drained to water resources can cause many ecological and environmental problems [9,97].

5.7. Biological parameters

5.7.1. Biochemical oxygen demand and chemical oxygen demand

According to our results, the lowest reported BOD in carwash wastewater was in the Hamada and Miyazaki [41] in Japan (4.4 mg/L). The highest rates were reported in the study by Messeruk et al. [47] in Algeria, with values of 2,350 mg/L. By literature review, the range of this parameter in carwash wastewater is variable due to geographical area and type of material used for carwashing. Furthermore, in a small number of studies, BOD was reported to exceed 400 mg/L [35,49,63,70], and in 80% of cases, reported to be lower than 400 mg/L.

The highest COD values were reported in the study by Messrouk et al. [47] to be 20,781 mg/L, which is very high and needs treatment before discharging into the environment. The lowest value was 2.18 mg/L in the study by Bhattia et al. [32], which was due to the lack of extensive use of detergents and less car pollution. Regarding the range of BOD and COD, it can be concluded that the COD/BOD ratio is less than one to more than 8, which makes it difficult to select the treatment method. The closer this ratio is to one, would be better to choose biological treatments [9]. In some studies, which reported high COD values, it was also found that the levels of detergents, lubricants and grease were also high [54]. Generally, these parameters are in a more suitable range for industrial wastewater and can be used for treatment and reuse of wastewater in industries or agricultural uses.

5.7.2. Dissolved oxygen

Dissolved oxygen is also the chemical element of water and wastewater, which plays an important role in aquatic ecosystems and this parameter is vital in preserving the diversity of animals and plants [9,98]. This can show its importance in industrial applications regarding corrosion and oxidation reactions [99]. Basically, the wastewater with dissolved oxygen content is less than 50% saturated [27]. In carwash wastewater, the highest amount of dissolved oxygen was observed in the study by Van der Bruggen et al. [68] with a value of 3.1 mg/L, which can be due to a lower wastewater temperature, having a higher oxygen dissolution. Moreover, according to supplementary Table 2, the lowest recorded values reported to be zero in carwash wastewater. In these cases, usually the emissions of wastewater pollutants is very high and can pollute the receiving water sources to a very high degree and can pollute the receiving water sources to a very high degree.

5.7.3. Oil and grease

One of the most important problems of industrial wastewaters, which can have significant effects on the treatment systems and plumbing network, are oil and grease [9,100]. In carwash wastewater, due to the use of oil and grease in motor parts and vehicles, usually after washing, large quantities of this parameter enter the wastewater and have negative impacts on the environment [15,47,101]. The highest amount of oil and grease reported in the studies was 3,000 mg/L in the study by Tu et al. [67] in Taiwan. High levels of oil and fat in the received waters may reduce the dissolved oxygen in water and cause destruction of aquatic animals [9,102]. Moreover, in wastewater collection networks, it can cause problems by blocking and reducing the effective area of wastewater [9]. The recommended standard for oil and fat in Iran for the disposal of wastewater and returned waters to surface waters is 10 mg/L, according to studies, 33% of the values were below the standard.

5.8. Heavy metals

5.8.1. Copper (Cu)

Copper is one of the most important trace/heavy metals in the wastewater of various industries, including electricity and production of alloys industries [103,104]. Also copper compounds are used to disinfect and eliminate algae [105–107]. Its excessive consumption can cause problems and diseases such as Wilson [108]. The importance of this metal is when there is industrial wastewater with high-waste that enters the received waters. According to the WHO guidelines, it is allowed in drinking water up to 2 mg/L [84]. In carwash wastewater, the amounts of this metal were reported from very low to more than 10 mg/L. The highest amounts of copper (13 mg/L) were reported in the study by Tekere et al. [63]. The lowest was reported about 0.18 mg/L in O'Sullivan et al. [52].

5.8.2. Chromium (Cr)

Chromium is a heavy metal, which is available in water and wastewater with the oxidation states of +2 and +6 and is very toxic for humans. The reported instructions for total chromium compounds are 0.05 mg/L [9,84]. The highest and lowest amounts of chromium in carwash industry wastewaters were 3 and around 0 mg/L in Tekere et al. [63], which is very high. This metal was investigated in only two studies reported in the study by Adams et al. [25] in Nigeria. in accordance with dry or rainy seasons, chromium content was reported in the range of 0.003–0.0036 mg/L.

5.8.3. Lead (Pb)

One of the heaviest elements is lead, which is abundant in alloy industries, buildings, car batteries and water pipelines [109–111]. It is also used as a bumper and lubricant in gasoline, which has been stopped in the past decades [112–114]. Due to its toxic and harmful properties, lead can cause blood and brain problems, as well as kidney problems and abdominal pain [115,116]. The maximum standard values for this metal is 0.01 mg/L. This element exists in the air, soil and water, but the amount received by drinking water is higher [84]. The importance of this metal in wastewater is related to entering waters sources and its health impacts. The production source of this metal in carwash wastewater can be batteries and car parts and the arrival of lead salts into the wastewater. The highest and lowest lead content were reported in the study by Tekere et al. [63] with values of about 5 and 0 mg/L in South Africa. Only three studies examined this parameter and reported the range of this parameter between 0.03 and 0.79 mg/L.

5.8.4. Zinc (Zn)

Zinc another important metal is widely used in stainless alloys [117–119]. In carwash wastewater, this metal can be dissolved in water or other sources. Zinc is considered one of the main elements of metabolic processes in the body [120–122]. However, excessive consumption or even absence has harmful effects such as disturbances of stomach and its accumulation in the eyes and skin [122–125].

According to the WHO guidelines, consumption of more than 3 mg/L may be unpleasant for consumers but in the drinking water, it is allowed to increase by 15 mg/L [84]. According to the studies, the value of at least 0.3 μg/L was reported in New Zealand by O'Sullivan et al. [52].

The reported values are much lower than the published guidelines and can be discharged into the received waters [52]. However, the highest reported level in the study of Tekere et al. [63] was 20 mg/L, which is much higher than the guidelines. In general, due to the WHO guidelines, the discharge of carwash wastewater is not prohibited considering this element.

5.8.5. Aluminum (Al)

Aluminum is used mainly in various industries including building, transport and machinery [126–128]. The WHO guideline for this element in drinking water is 0.2 mg/L [84]. In carwash wastewater, due to washing the different parts of the car, this element may enter into wastewater and cause environmental problems such as fish mortality at low pH levels in receiving water sources [128,129]. In different studies, highest aluminum content was reported in Mexico by Rubí-Juárez et al. [58] with a rate of 38.25 mg/L, and the lowest values were found in Adams et al. [25] to be 0.006 mg/L. Regarding the extent of this element concentration in the carwash wastewater, it can be argued that due to the type of carwash and geolocation, the range of this element concentration can be very variable.

5.8.6. Nickel (Ni)

Nickel is mainly used in stainless steel and nickel alloys. It is an element of heavy metal, which has many environmental and health effects. The effects of this metal on health include lung, laryngeal and prostate cancers, respiratory problems and lung water [130,131]. The WHO guideline for drinking water is 0.07 mg/L. Nickel is important in wastewater due to the discharge of water resources or their application for irrigation. In the carwash wastewater, high amount of nickel was reported, due to the use of this alloy in machinery as well as its presence in the used water. The amount of nickel in the carwash wastewater was reported only by Adams et al. [25], ranging from 0.02 to 0.08 mg/L.

5.8.7. Cadmium (Cd)

Another major heavy metal with severe toxicity in water and food sources is cadmium, which causes acute effects and diseases [132–134]. Industrial wastewater is one of the important sources of discharge of this element in the received waters. The WHO guidelines is 0.003 mg/L [84], though, in the most wastes of the battery, dyeing, coating and electroplating industries, these values can be much higher [135–137]. Regarding the carwash wastewater was done only a study by Adams et al., which in this study the amount of cadmium in the rainy and dry seasons was recorded zero values [25].

5.8.8. Manganese (Mn)

Manganese is also an essential element of the body used in iron and steel industry, ferroalloy production and battery industry [138–140]. The WHO guideline for this element is 0.4 mg/L in drinking water [84]. According to the studies, the highest reported amounts related to Al-Odwani et al. [28] study in Kuwait with amount of 0.1 mg/L. Moreover, the lowest amount in the wastewater of carwash industry was reported in the study by Adams et al. [25] in Nigeria with a value of 0.002 mg/L. The standard of manganese-containing wastewater discharge into the surface water, the absorbent well and agricultural use is 0.1 mg/L [90]. Regarding the reported values, it can be argued that the carwash industry wastewater is suitable for the discharge into the receiving waters at this level from manganese.

5.8.9. Arsenic (As)

Arsenic is another toxic element in wastewater and water resources. The WHO's instruction for this element is 0.01 mg/L in drinking water [84]. Moreover, the standard discharge level of this element for surface water, the absorbent well and use in agriculture is less than 0.1 mg/L [90]. The study of arsenic content in the carwash industry was investigated only in one study as the highest and lowest amounts of arsenic was reported in the study of Adams et al. [25] to be 0.005 and 0.008 mg/L, respectively, which is less than the depletion standard for surface water and agricultural consumption.

5.9. Resistant pollutants

5.9.1. Surfactant

One of the most important pollutants in the industry in the recent decades, especially in carwash industry, can be chemical cleaners and detergents [12,101]. The importance of the surfactants is due to their resistance to the environment and their toxicity to aquatic organisms and humans [141–143]. In the carwash industries, due to oil pollution in the car and the need for washing these pollutants with detergents and cleaners, these pollutants are very crucial. Surfactants used in the carwash industry can be of anionic, cationic and non-ionic type, which given their availability and efficiency can be used to eliminate car pollution [11]. The highest levels of surfactants were related to anionic surfactants, which were reported in the study by Rubí-Juárez et al. [58] in Mexico (68.33 mg/L). The lowest reported amount of surfactant was zero, which were reported in the studies of Boussu et al. [33] and Van der Bruggen et al. [68] in Belgium. Also, according to the supplementary Table 4, the range of cationic, anionic and non-ionic surfactants were reported to be 0–7.9, 0–68/33 and 1.6–39 mg/L, respectively.

5.9.2. Methyl tert-butyl ether

Methyl tetra-butyl ether is one of the organic compounds belonging to the group of oxygenated hydrocarbons [144,145]. It is used in gasoline as an anti-knocking agent in motor of vehicles and also as solvents in various industries [146–148]. In the carwash wastewater, this substance may be introduced into the carwash through the use of solvents and vehicle colors. Only two studies explored this parameter in the carwash wastewater. The lowest reported value was 0.3 mg/L with the highest value was 2.4 mg/L [19,59]. It should be noted that both studies were performed in France in 2010 and the values were exactly the same.

5.9.3. Polychlorinated biphenyl

It is a mixture of volatile compounds, made of hydrocarbons and consists of two benzene rings and chlorine substituents on them [149,150]. These materials, used to improve basic oil properties and also as cooling and insulating materials in electrical equipment such as capacitors and transformers, are among PCBs [151,152]. Only one study examined the PCBs in the carwash wastewater in France [59]. According to the result of this study, the highest value of 1.16 μg/L and the lowest value of 0.19 μg/L were observed. These compounds include seven types of PCBs shown in the study [59].

5.9.4. Polycyclic aromatic hydrocarbons

Aromatic polycyclic hydrocarbons are a large group of stable organic chemical pollutants, which have more than two aromatic rings in their compounds [153–155]. These compounds are used in the fuel materials in vehicles, as well as various environmental sources such as water, soil and air [156–158]. Human exposure to these compounds is greater in the air, but these compounds are reported in water and wastewater [159]. In the carwash wastewater, the highest amounts of these compounds were reported by to be 1,256 μg/L in a study by Qamar et al. [57] in Pakistan, which included a total of 16 compounds. Moreover, according to various studies, the lowest amounts of these compounds were reported in Breton et al. [19] being 0.037 μg/L in France. The significance of these compounds is their carcinogenic potential [160–162].

6. Conclusion

Water scarcity and insufficient water resources impose exploring renewable sources to meet the worldwide demand. Carwash wastewater is considered as an important source, which can be recycled. This study systematically examines CWW properties in terms of physical, chemical, and biological contaminants. A wide range of pollutants included but not limited to solids, surfactants, BOD_5, COD, and heavy metals were specified in CWW at different concentrations. From recycling point of view, solids are the first parameters to be considered. However, removal of heavy metals, PAHs, PCBs, and surfactants is the greatest concern that leads to serious negative consequences not only on ecosystems but also on human being health. Based on the properties, physico-chemical and even biological treatment technologies, including adsorption, biological, electrochemical-based, and membrane technologies can be used in CWW treatment, this can be considered as a comprehensive research for future prospective of CWW recycling options.

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