



## Research article

## Clean vehicles, polluted waters: empirical estimates of water consumption and pollution loads of the carwash industry

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## ARTICLE INFO

## Keywords:

Civil engineering  
 Environmental science  
 Environmental analysis  
 Environmental assessment  
 Environmental engineering  
 Earth sciences  
 Water use  
 Wastewater  
 Kumasi  
 Carwash  
 Pollution load

## ABSTRACT

Carwash stations use large volumes of water and release harmful chemicals into the environment through their operations. While a significant body of literature has focused on exploring water use in the carwash industry, none has provided comprehensive information on both the pollution loads of the wastewater emanating from this industry and water consumption. Understanding how much water is used and the pollution loads of wastewater from this industry is useful to ensure adoption of water conservation measures and design wastewater recycling systems given the dwindling freshwater resources globally. This study estimated the freshwater quantities used to wash different vehicle types and the pollution loads of the resulting wastewater in the Kumasi Metropolis. Seven proxy carwash stations were purposively selected and monitored to estimate the water used to wash six different categories of vehicles. Composite wastewater samples from three carwash stations were analysed for concentrations of different contaminants which were used to compute pollution loads. Using R software, one-way ANOVA with Tukey's (HSD) post-hoc testing and 2-sample t-test at 95% confidence interval were employed to test statistical differences. After an 8-week monitoring campaign involving 3,667 vehicles, the study showed that average water used for each vehicle type were in the order: Motorbike - 97L (95% CI: 90–103L); Salon car - 158L (95% CI: 154–161L); SUV - 197L (95% CI: 191–203L); Buses/Coaches - 370L (95% CI: 351–381L); Articulated truck 1,139L (95% CI: 916–1,363L); Graders/Loaders - 1405L (95% CI: 327–2,483L). Overall, the carwash industry in the Metropolis uses about 1000m<sup>3</sup> of freshwater daily and discharges the resulting wastewater into waterways untreated. The wastewater has a low Biodegradability Index (0.3–0.4) and is characterized by a mildly alkali pH (7.6–8.6) with high levels of Sulphates (40.8–69.8 mg/L), COD (990–1413 mg/L), TSS (1260–3417 mg/L) and *E. coli* ( $2.3\text{--}4.7 \times 10^3$  CFU/100mL). Pollution loads of BOD and COD were up to 2tons/year and 6tons/year respectively. Stipulated effluent discharge guideline values were mostly exceeded – in some cases by up to 68 times. To avert the unbridled wastage of freshwater, the study recommends enforcement of wastewater recycling for all carwash stations and promulgation of a tax system that rewards stations that recycle wastewater and surcharges those wasting freshwater.

## 1. Introduction

For vehicle owners, commercial carwash stations provide an essential aftersales service by way of removing filth from their vehicles conveniently. But this comes at a huge cost to the environment. With every vehicle washed, a large volume of otherwise drinkable water is turned into heavily polluted water which ends up in waterways. Per available literature, about 150 L of water is used to wash a car in a commercial car wash facility (Tamiazzo et al., 2015) while between 400–600 L of water is required to wash trucks and buses (Almeida et al., 2010). Estimates from an empirical study in Sao Paulo suggest that, the carwash industry uses

more than 1.3 million gallons of freshwater daily (Almeida et al., 2010) while in Kuwait, about twice as much is used each day (Al-Odwani et al., 2007). This connotes that, for Kuwait – a country relying mostly on desalinated water, water for more than 25,000 people (water consumption - 450L/cap.day) is used by the car wash industry daily (Milutinovic, 2006; Mukhopadhyay et al., 2000). For Sao Paulo, the industry denies nearly 33,000 people (water consumption - 180L/cap.day) of potable water daily (TheWorldBank, 2012). The implications for urban water supply is grim considering the burgeoning urban populations, rapid expansion in vehicle ownership and increasing global water scarcity (Liu et al., 2017; Rijsberman, 2006; Sperling and Gordon, 2009).

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Worse still, the resulting wastewater from the carwash industry is usually laden with grime, oils and grease, heavy metals and detergents mostly ending up in waterways (Bhatti et al., 2011; Hashim and Zayadi, 2016). When discharged into waterbodies, the detergents in the carwash wastewater cause foams which reduce oxygen levels and destroys fish mucus membranes (Aboulhassan et al., 2006; Cooper and Kennedy, 2010; Effendi et al., 2017; Yuan et al., 2014). The oils in the wastewater can cover the gills of fish in receiving waterbodies and interfere with reoxygenation thereby inhibiting plant and animal growth (Alade et al., 2011; Tiwary, 2001). Heavy metals emanating from brake linings, tyres and engine oils can bioaccumulate in fish tissue and move up the food chain to reach humans (Adamiec et al., 2016; Hjortenkrans et al., 2007; Tiwary, 2001).

Without doubt, the irrational water use by the carwash industry undermines water security and threatens ecosystem health especially in the urban landscape. Against this backdrop, policy makers in the developed world have promulgated legislations to address these issues. In Belgium, about 15% of carwash stations recycle their wastewater while in Germany and Austria, recycling of at least 80% carwash wastewater is imposed (Boussu et al., 2007). Water use restrictions for the car wash industry are also enforced in The Netherlands and Scandinavian countries (Boussu et al., 2007). In Brazil, strict environmental legislations have spurred on the adoption of carwash wastewater recycling technologies (Etchepare et al., 2014; Rubio and Zaneti, 2009; Zaneti et al., 2011, 2012).

But, in the developing world, where much of the growth in urban population and vehicle numbers are expected in the coming years (Bose, 1998; Wu et al., 2014), very little has been done in terms of policy actions and regulations to address wasteful water uses. Even as water scarcity becomes more chronic in Cape Town (Sorensen, 2017), Accra (Stoler et al., 2012, 2013), and Nairobi (Reuters, 2018; Watson, 2018), the crackdown on wasteful water uses including the carwash industry has not been aggressive. In Ghana, the car wash industry is growing rapidly and has been fueled by the huge vehicle imports into the country. Available statistics indicate that, vehicle imports into Ghana quadruples every decade (Hesse and Ofori, 2014). Although earlier studies have reported the characteristics of wastewater from the car wash industry (Abagale et al., 2013; Aikins and Boakye, 2015; Hashim and Zayadi, 2016) and the water consumption pattern of the industry (Quayson and Awere, 2018), these are fragmented. These earlier studies provide separate pieces of information on the carwash industry and provide no information on the wastewater pollution load of this industry. However, the pollution load of wastewater is crucial for the design of appropriate systems for wastewater treatment and reuse (Bugajski et al., 2017; Karia and Christian, 2006). Water reuse for the carwash industry is very essential especially considering the dwindling freshwater supplies globally and the benefits from water reuse (Almeida et al., 2010). Additionally, in estimating the water used by carwash stations, the current approach, in available literature (Almeida et al., 2010; Brown, 2000; Ndi, 2018) is to divide the total water consumption at the carwash stations by the number of vehicles washed. This is a gross overestimation since water used per vehicle varies widely with vehicle size. An understanding of how much water is effectively used to wash each type of vehicle is therefore essential to be able to accurately predict water quantities used for carwashing purposes given any vehicle type and number. The current study estimates the water consumption per vehicle type and uses this to compute overall water consumption at the carwash station based on the number and type of vehicles washed. This information is relevant to the urban water utility supplying water to carwash stations to compare with meter readings or predict water needs by the carwash industry. Additionally, the study assesses the characteristics - pollutant concentrations and pollutant loads of wastewater from the carwash industry. Pollution load of wastewater provides a crucial information which helps in the design (sizing) of appropriate systems for wastewater treatment (Bugajski et al., 2017; Karia and Christian, 2006). This study provides a comprehensive analysis of the water use and wastewater characteristics of the carwash industry.

There is paucity of such comprehensive information in literature and therefore this study will be useful to policy makers and regulators in developing water conservation legislations, wastewater recycling legislations and effluent emissions standards for the car wash industry. The study is part of a broad Doctoral research aimed at ultimately developing a low-cost wastewater recycling system for the carwash industry in Ghana and other developing countries.

## 2. Materials and methods

### 2.1. Study area

Kumasi is the capital of Ghana's most populous region; Ashanti Region and serves as a major commercial hub in West Africa (Figure 1). With a population of more than 2 million people, Kumasi is the second largest city in the country but the fastest growing metropolis in the country (Ghana Statistical Service, 2013). It covers a land area of about 250 square kilometers and lies in the tropical forest zone. The city relies mostly on surface water for its drinking water supply but this is under the threat of industrial and domestic emissions (Domfeh et al., 2015; Maoulidi, 2010).

The city has the third largest registered vehicle population across the country with more than 200,000 vehicles (Tetteh-Addison, 2012). The humming economic life in the city and growing population have translated into a boom in the carwash industry. There are nearly 100 carwash stations in the Kumasi Metropolis and due to scarcity of paved roads and streets, car owners tend to wash their cars more frequently.

### 2.2. State of water resources in Ghana

Ghana has a tropical climate and is endowed with abundant water resources. The mean annual rainfall is 1180 mm (Ministry of Food and Agriculture, 2016) but generally decreases from the south-west of the country (2,000 mm/year) towards the north (950 mm/year) and the southeast (800 mm/year) (Lacombe et al., 2012; Ministry of Water Resources Works and Housing, 2007).

However, rainfall levels have been reducing over the years and are expected to decrease by about 3% across the country by 2040 (Asante and Amuakwa-Mensah, 2015; Environmental Protection Agency, 2015). Surface water is mainly sourced from three river systems: the Volta, Coastal and South-Western river systems (Ministry of Water Resources Works and Housing, 2007). The Volta river system is the largest river system in the country and includes the largest artificial lake in the world; Volta Lake (Logah et al., 2013). Overall, the river system constitutes more than two-thirds of the country's total land area. Three main geological formations supply groundwater for use in Ghana: the basement complex; the consolidated sedimentary formations underlying the Volta basin; and the mesozoic and cenozoic sedimentary rocks (Ministry of Water Resources Works and Housing, 2007). The basement complex underlies more than half (54%) of the country's land surface while 45% of the country's land surface is underlain by the consolidated sedimentary formations. Aquifer depths in these two major formations vary between 10m and 60m with aquifer yields reaching up to 6 m<sup>3</sup>/h. Water resources in the country are generally of good quality but are however under the threat of pollution and climate change. Uncontrolled disposal of untreated human excreta into the environment is not uncommon across the country. Both domestic and industrial wastewater in Ghana generally end up in water courses mostly without any form of treatment (Ingallinella et al., 2002). In certain parts of the country, drying of some previously perennial rivers in the dry season, flash floods, reduced water storage capacities in major dams, and reduction in groundwater recharge are becoming common as a result of climate change (Kankam-yeboah, 2010). Illegal mining is also wreaking a heavy environmental havoc through extensive pollution of streams and rivers in mining areas sometimes resulting in the shutdown of drinking water treatment plants depending on these waterbodies.

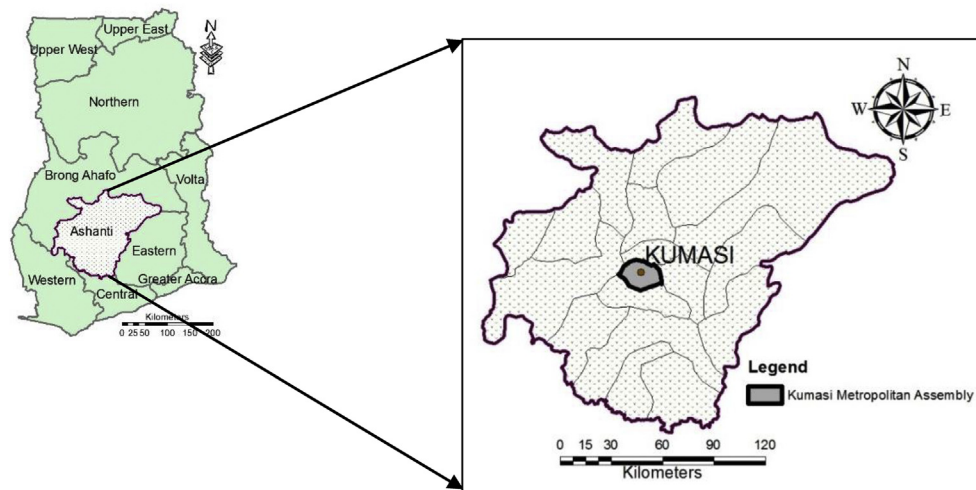


Figure 1. Map of Ghana showing the study area: Kumasi Metropolis.

### 2.3. Estimation of water quantities used at carwash stations in Kumasi

Field surveys were used to develop an inventory of carwash stations in the Kumasi Metropolis using the referral approach. By this approach, the city was zoned into four and in each zone, operators of carwash stations identified were asked to direct field personnel to the next car wash station within their zone. Fifty carwash stations in the Metropolis were identified within these zones and characterized. Data collected included location, source of water; washing method; nature of washing surface; and daily average number and types of vehicles washed. Seven carwash stations were purposively selected based on the consent of owners; location; washing surface, types of vehicles washed, source of water; and method of washing vehicles. These stations were used as proxy for all stations and monitored by trained field personnel for 6 days a week over an 8-week period. Firsthand information on the number of vehicles washed per day and the quantity of water used to wash different types of vehicles were obtained for these stations. This was used as a representation to estimate daily water consumption for all the fifty carwash stations identified in the metropolis.

The vehicles monitored at the washing stations were categorized into six groups – a categorization adapted from the classification of vehicles used by the Driver and Vehicle Licensing Authority of Ghana. These were Motorbikes/Mopeds with or without side cars; Saloon cars; Four-Wheel Drives/Sports Utility Vehicles/Pick-ups; Goods carrying vehicles including buses, coaches and vans; Heavy articulator vehicles; and Graders, loaders, forklifts, tractors, bulldozers, dumpers and rollers. All vehicles washed at the seven stations were monitored daily over the study period and categorized according to the type of vehicle using a tally sheet. To determine the peak period during the day for car wash activities, the time of day during which each vehicle was washed was recorded into four 3-hour time periods: 6am–9am; 9am–12noon; 12noon–3pm and 3pm–6pm. At each station, some vehicles were also purposely selected and monitored to determine the amount of water used per wash.

Two different washing methods were employed at the car wash stations: semi-automated and manual washing. Semi-automated washing in this study refers to using hand-held water spray wands to wash vehicles while manual washing refers to washing vehicles entirely by hand with sponge/foam, water and brush. Five of the selected stations were semi-automated while the remaining two were manual wash stations. Owing to this, two different approaches were also adopted to quantify the water volumes used to wash each vehicle. For manual wash stations, the total volume of water used to wash each vehicle was determined by providing operators with two graduated plastic buckets of known volumes for use in washing the vehicles. The total water used were therefore obtained by summing up the volume of buckets of water used during the washing

process. Conversely, for car wash stations using hand-held spray wands, operators were provided with graduated plastic buckets for washing but the total amount of water used per vehicle was computed as:

$$V_w = q_w t + \sum_{i=1}^n v_i$$

$V_w$  = total volume of water used for washing vehicle (L).

$q_w$  = Volumetric flow rate of spray wand used measured in-situ (L/s).

$t$  = time spent to wash vehicle using the spray wand (s).

$v_i$  = volume of water in graduated bucket at the  $i$ th time of use (L).

$n$  = total frequency of use of graduated bucket during entire car wash period.

The total amount of water used was recorded for each type of vehicle vis-à-vis the adopted vehicle categories.

### 2.4. Estimation of wastewater flows from carwash stations

The quantity of wastewater flowing from each station depends on water used and losses due evaporation and carryout. Therefore return flow values were estimated according to Brown (2002) and Oregon Department of Transportation (2014). Details of the computation are provided in Supplementary sheet (Table S1).

Daily volumetric wastewater flow of each of the seven car wash stations were estimated using the equation:

$$q_d = R \times W_d \sum_{i=1}^n p_i \times V_i$$

$q_d$  = Daily volumetric flow rate of wastewater of proxy car wash station (L/day).

$R$  = Estimated return flow of the car wash station (0.8 - paved based on Brown (2002); 0.5 for unpaved).

$i$  = category of vehicles.

$W_d$  = median number of vehicles washed per day (due to high variation in daily vehicles washed).

$p_i$  = proportion of vehicles in the  $i$ th category (%)

$V_i$  = volume of water used to wash vehicle in the  $i$ th category (L).

This was used as proxy to estimate the daily wastewater flow for the remaining 43 stations with similar operational characteristics regarding washing surface, method of washing vehicles, average number of vehicles washed daily, and types of vehicles washed.

To compute the overall daily wastewater flow from all the carwash stations, the stations were categorized under seven proxy carwash stations based on their similarity in characteristics. The sum of the product of wastewater generated from each proxy station and number of similar

stations was used to compute the daily wastewater flow as represented by the equation:

$$Q_d = \sum_{i=1}^n q_{d,i} \times c_i$$

$Q_d$  = Total daily wastewater flow (L/day).

$i$  = categories of car wash stations based on proxy stations

$q_{d,i}$  = daily wastewater flow rate of proxy car wash station representing  $i$ th category.

$c_i$  = number of car wash stations in  $i$ th station category.

### 2.5. Wastewater sampling and characterization

Wastewater characterization was conducted after monitoring the number of vehicles washed and water volumes used at the car wash stations. In-situ samples of car wash wastewater from three out of the seven car wash stations were purposely used due to budgetary constraints, characteristics of stations and lack of consent given by carwash operators. All the selected stations used hand-held spray wands to wash cars. Composite wastewater samples were collected from each of these stations during peak periods in the morning (9am-12noon). The samples were collected four times from each of the car wash stations once every week from the outfall sewer pipes joining the public drain.

Analytical parameters and the methods used for determining each of these parameters are shown in Table 1. All measurements were done according to standard protocols specified in the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

With the concentration and wastewater flows determined, the pollution load (P) of each pollutant for a carwash station was subsequently estimated from the equation below:

$$P_i = q_d \times C_i \times 365 \times 10^{-6}$$

$P_i$  = pollution load of the  $i$ th pollutant (kg/year) in a carwash station

$q_d$  = total daily volumetric flow rate of wastewater from car wash station (L/day).

$C_i$  = average concentration of the  $i$ th contaminant (mg/L).

365 = conversion factor for annual wastewater generated.

$10^{-6}$  = conversion factor for changing concentration mg into kg.

**Table 1.** Analytical methods/equipment used for measuring wastewater parameters.

Parameters	Method/Equipment
pH	EUTECH PC300
EC ( $\mu$ S/cm)	EUTECH PC300
TDS (mg/L)	EUTECH PC300
TSS (mg/L)	Gravimetric method
Settleable solids (mL/L)	Gravimetric method – Imhoff cone
Turbidity (NTU)	HANNA HI93414 Turbidimeter
COD (mg/L)	HACH 21259 Vial Digestion Solution for COD; HACH DR3900 Spectrophotometer
BOD (mg/L)	Winkler Method
Nitrates (mg/L)	Nitraver 5 Nitrite Reagent Powder Pillows; HACH DR3900 Spectrophotometer
Nitrites (mg/L)	NitriVer 3 Nitrite Reagent Powder Pillows; HACH DR3900 Spectrophotometer
Orthophosphate (mg/L)	Phosver 3 Phosphate Reagent Powder Pillows; HACH DR3900 Spectrophotometer
Sulphate (mg/L)	Sulfaver 4, Sulphate Reagent Powder Pillows; HACH DR3900 Spectrophotometer
Total Coliforms (CFU/100mL)	Membrane filtration
E. Coli (CFU/100mL)	Membrane filtration

### 2.6. Statistical analysis

R software (R version 3.4.3) was employed for all descriptive statistics, statistical analyses and graphs. Both t-test and one-way ANOVA with Tukey's (HSD) post-hoc testing and 2-sample t-test at 95% confidence interval were conducted to test statistically significant differences. Pearson Product-Moment Correlation was used to test the relationship between water use efficiency and vehicles washed per station.

## 3. Results and discussion

### 3.1. Characteristics and vehicle wash pattern at carwash stations

Carwash stations in the Kumasi Metropolis are usually located close to major roads to ensure conspicuity to drivers and usually concentrated in areas of high traffic density. Most of these stations depend on ground-water sources (mechanized boreholes and dug wells) due to the erratic flow of water from the urban water supply system and soaring water utility bills. Their impact on urban water supply is therefore insignificant as opposed to findings in Yaounde, Cameroon (Ndi, 2018) and Cape Coast, Ghana (Quayson and Awere, 2018) where carwash stations depend mostly on piped water supplied by the urban water utility. However, the dependence on a readily available and free source of water promote water wastage among the car wash stations in Kumasi and potentially dissuade operators from adopting wastewater recycling technologies. In Toluca, Mexico, where the car wash industry purchases water at a higher cost from water tankers, the industry conserves water (Fall et al., 2007). Almost all the carwash stations identified (92%; N = 50) employed hand-held spray wand to wash vehicles and none of them had a facility to treat the resulting wastewater.

Overall, 13,430 vehicles were washed at the seven car wash stations during the 48-day monitoring period. Out of this, almost half (48%) were Salon cars and about a quarter (24%) were 4 × 4/SUV/Pickups. This corroborates findings of Quayson and Awere (2018) which found Salon cars to be the dominant type of vehicle washed in car wash stations in Cape Coast, Ghana. The distribution of vehicles washed per day in each of these stations is shown in Figure 2.

Averagely, about 40 vehicles are washed per station daily (95% CI:37–43) and generally ranged between 3 and 127 vehicles (Figure 2). The variation of daily number of vehicles washed among the stations was found to be statistically significant ( $p < 0.05$ ). From field observations, it was found that the conspicuity of stations and availability of space to wash bigger vehicles, partly influenced the number of vehicles that are washed each day. Car wash station denoted as Manual 1 was located in the Central Business District of Kumasi where brisk commercial activities occur while Semi-automated 3 was located along the major road linking Kumasi to the national capital, Accra.

### 3.2. Water quantities used to wash vehicles

A total of 3,667 vehicles were observed in the seven stations to determine the water used per vehicle. The distribution of water quantities used to wash different vehicle types is shown in Figure 3.

Generally, the volume of water used per vehicle varied widely; between 24L and 1,961L per wash, with an average of  $207 \pm 183$  L (95% CI:202–213). Per the one-way ANOVA test, the average quantities used to wash each category of vehicle was statistically significant ( $p < 0.05$ ). Post-hoc test using Tukey's HSD showed that, no two pairs of vehicle categories used the same average water quantities for washing ( $p < 0.05$ ).

The mean quantity of water used to wash a Salon car was  $158 \pm 70$ L while for SUVs/Pickups and Buses, it amounts to  $197 \pm 105$ L and  $370 \pm 227$ L respectively. These findings are consistent with values reported in earlier studies (Al-Odwani et al., 2007; Huybrechts et al., 2002; Ndi, 2018; Quayson and Awere, 2018; Tamiazzo et al., 2015). The water quantities used to wash vehicles in Kumasi are however, relatively higher

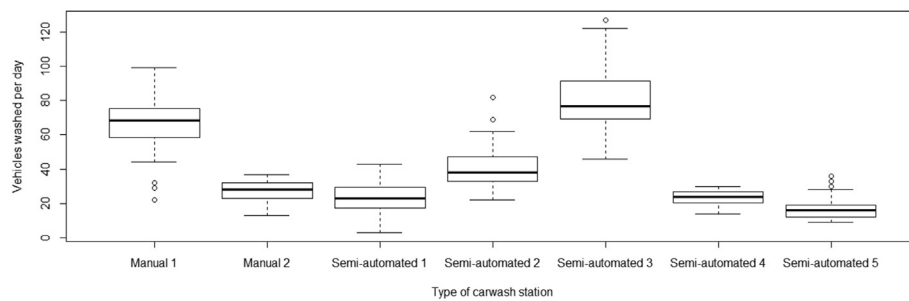


Figure 2. Distribution of daily number of vehicles washed in 7 proxy stations (N = 13,430).

than those in Cape Coast, Ghana (Quayson and Awere, 2018) and Toluca, Mexico (Fall et al., 2007) reportedly relying on pipe-borne water supply and water tanker services. This can be explained by the fact that, carwash stations in Kumasi have the liberty to pump any amount of water from aquifers without any price tag as opposed to Cape Coast and Toluca where water is billed.

Although vehicles in the categories of Heavy duty trucks and Graders were rarely washed, it consumed the highest water quantities per wash. Averagely, water used to wash vehicles in these categories at a time can equally wash between 7 and 9 saloon cars. Confirming findings in available literature, the quantity of water used to wash vehicles increased with increasing vehicle size (Huybrechts et al., 2002; Almeida et al., 2010; Tamiazzo et al., 2015). Motorbikes used the least volume of water for washing while Graders/Loaders used the highest water volumes for washing.

Generally, the volume of water used per vehicle was found to be influenced by the method of washing (Table 2). Except for Buses/Vans, water volumes used to wash each vehicle category showed a statistically significant difference ( $p < 0.05$ ) between semi-automated stations and manual washing stations.

Overall, semi-automated car wash stations saved up to 55% of water for each vehicle washed compared to those using the manual washing method. Similarly, Panizza & Cerisola (2010) reported that, water savings of more than twice can be achieved by using conventional car wash stations compared to manual wash. In Brazil, fully automated car wash stations save about 80% of water per vehicle washed (Zaneti et al., 2012).

Water use efficiency (litres per vehicle) at the car wash stations was determined from the ratio daily volumes of water used at the car wash station and the total number of vehicles washed daily. For this study, a higher water use efficiency indicates that water is used less efficiently since more water is used per vehicle and vice versa. Generally, the study found that, water use efficiency correlated negatively ( $r = -0.8$ ) with the number of cars washed daily [Figure 4]. This means that car wash stations washing more vehicles in a day use less water per vehicle.

This was found to be statistically significant per the Pearson's Product Moment correlation test ( $p = 0.029$ ). This finding confirms field observations during monitoring of the proxy car wash stations, in that,

operators at stations which washed few vehicles daily spent more time washing each vehicle thereby using more water in the process. Conversely, in stations highly patronized, operators spent less time per vehicle to be able to wash other vehicles waiting in queue.

### 3.3. Estimation of water consumption and wastewater flows

Daily water consumption for the seven carwash stations monitored during the study ranged between 2,395L/day and 15,480L/day based on the median number of cars washed daily (Supplementary sheet – Table S1). By matching the characteristics of the seven proxy stations with that of the remaining 43 identified car wash stations, it is estimated that close to half a million litres of water is consumed daily by these stations (Supplementary sheet – Table S1). However, considering that there are more than 100 carwash stations in the Kumasi Metropolis, this implies that about 1,000m<sup>3</sup> of water is potentially used by the carwash industry each day. This represents water for close to 9,000 people in the Metropolis based on the estimated per capita water consumption of 115L/day (Oduro-Kwarteng et al., 2009).

With the ever-increasing vehicle population, the car wash industry in the Metropolis could become a threat to potable water supply from groundwater considering the huge volumes of water used daily from this source. All over the Metropolis, there is evidence of growing dependence on groundwater for potable water supply amidst reducing precipitation and hence reducing groundwater recharge (Agbefu et al., 2016; Akple et al., 2011; Allabo, 2016). Studies show that groundwater is increasingly becoming the preferred drinking water source for various communities and institutions in the Kumasi Metropolis (Agbefu et al., 2016; Boakye, 2013). This is to reduce expenditure on pipe-borne water and avoid the intermittent water supply from the urban water utility. However, by 2020, per capita water availability in Ghana is predicted to be a little over 1000m<sup>3</sup> per year, making the country water stressed (Pagett and Acquah, 2012). Groundwater could potentially be in short supply at a time when surface water courses cannot supply adequate water quantities to urban residents owing in part to possible over abstraction by the carwash industry and other commercial uses. Moreover, since groundwater is generally hard, this could cause the carwash station operators to add

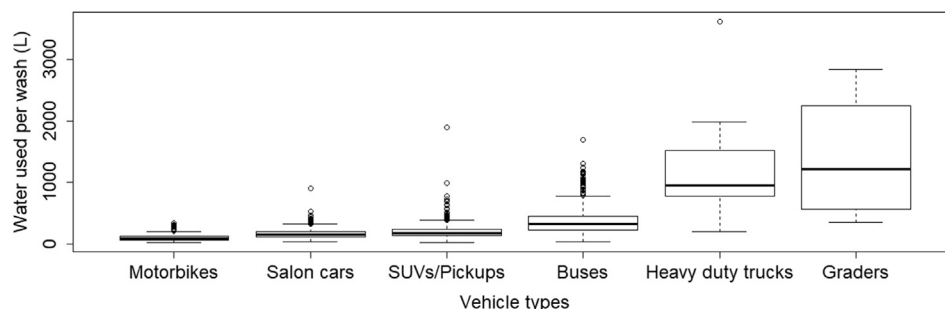


Figure 3. Overall water quantities used to wash vehicles (N = 3,667).

**Table 2.** Vehicle washing methods and water volumes used for washing.

Types of vehicle	Semi-automated stations (N = 2,424)			Manual washing stations (N = 1,270)			p-value
	n	Mean water volume±SD	95% CI	n	Mean water volume±SD	95% CI	
Motor bikes	193	105 ± 59	96–113	44	70 ± 38	59–81	<0.05
Saloon cars	1027	139 ± 64	136–143	622	188 ± 69	183–194	<0.05
SUVs/Pick ups	869	183 ± 104	177–190	298	236 ± 97	225–247	<0.05
Buses/Vans	298	236 ± 77	225–247	306	365 ± 178	346–385	>0.05
Heavy articulator	33	1139 ± 655	916–1362	-	Nil	-	-
Graders/Loaders	4	1129 ± 1381	-224–2482	-	Nil	-	-

Nil – Manual washing stations do not wash vehicles in this category.

more detergents to the water for washing which will eventually increase the level of Sulphates in the resulting wastewater which end up in waterways.

All the carwash stations identified release their wastewater into public drains which eventually empty into rivers. For the fifty carwash stations, more than a third of a million litres of wastewater is discharged into the environment. By extrapolation, the entire carwash industry, with more than 100 carwash stations, could generate some 700m<sup>3</sup> of wastewater daily. The industry is therefore turning freshwater from groundwater reserves into polluted wastewater which is eventually discharged into urban waterways. Water conservation and wastewater recycling are therefore needed to avoid similar situations in India where intense pumping and falling monsoonal precipitation is fueling a groundwater crisis (Rodell et al., 2009; Tiwari et al., 2009). This can be achieved by instituting mandatory water abstraction taxes tied to water quantities used at the car wash stations to compel operators to adopt water-saving practices. The stations can be categorized based on the number of vehicles washed so that an increasing block tax system can be applied to compel them to reduce water wastage. At present, most carwash stations use groundwater for free and therefore the water is undervalued. Since this comes at no cost, this high value water source will continually be turned into wastewater to eventually pollute watercourses in the absence of strict regulations. Therefore, putting a price tag on the water resource will ensure that water is used more efficiently at the carwash stations. New carwash stations should also be required to use spray wands to reduce water use and install wastewater recycling systems before permits are issued by the Environmental Protection Agency (EPA). Financial incentives including tax reliefs can be awarded to stations that adopt water conservation and recycling practices while huge taxes are levied on those stations that do not reuse their wastewater to influence them to adopt wastewater recycling.

Globally, technologies for recycling carwash wastewater abound. In the United States, Brown (2002) reported that, more than half of carwash stations use water recycling systems employing treatment processes including separation, oxidation, filtration, and membrane filtration or de-ionization. Flocculation column flotation systems have also been developed by Rubio and Zaneti (2009) for use in Brazil and has the

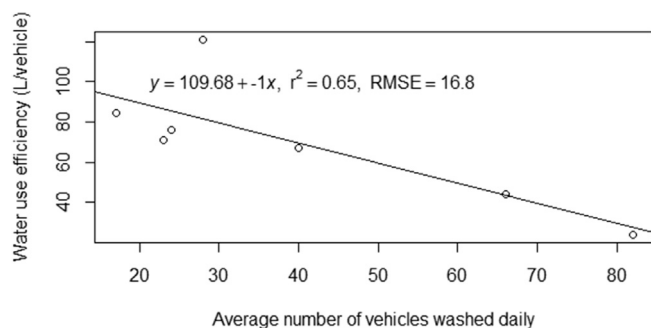
capacity to remove more than 90% of turbidity and suspended solids in water. Zaneti et al. (2011), have demonstrated the efficiency of flocculation-column-flotation system with sand filtration and chlorination units for treating carwash wastewater. The installation of such wastewater recycling systems not only conserves water but increases revenues for carwash operators. In Sao Paulo, available literature (Zaneti et al., 2011, 2012) indicate that, cost savings of about 32% for carwash operators can be achieved by the installation of carwash wastewater recycling systems. Therefore, apart from contributing to environmental sustainability, carwash stations can also increase their profit margins by installing wastewater recycling systems.

In Ghana's 1999 Environmental Assessment Regulations (1999), all new and existing developments that impact on the environment are required to be issued an environmental permit by the Environmental Protection Agency (EPA) for their operations. The EPA therefore needs to enforce this legal provision to ensure that environmentally-friendly practices are adopted by the carwash industry in the Metropolis to permanently address the issue of pollution of waterways and conserve water resources.

### 3.4. Characteristics of carwash wastewater

Table 3 presents the results of the characteristics of carwash wastewater from each of the three stations involved study compared with their respective EPA Guideline values and other studies. These stations, denoted as Stations 1, 2 and 3, represent Semi-automated stations 3, 4 and 5 respectively earlier used for the water use monitoring. Among them, Station 1 washed the least number of vehicles daily while Station 3 washed the highest number. Analysis of variance at 95% confidence interval revealed that, wastewater characteristics from the three carwash stations were statistically different except for COD, Nitrates, Nitrites and Total alkalinity which showed no statistically significant difference among the stations. Generally, wastewater discharges from multiple carwash stations are not expected to have the same quality owing in part to the extent of grime and cleaning products used. However, there can be similarities in some water quality parameters among stations as depicted in earlier studies on carwash wastewater characteristics (Fall et al., 2007; Hashim and Zayadi, 2016; Tekere et al., 2016).

The carwash wastewater had a neutral to alkaline pH reflecting the detergents used for washing the vehicles and consistent with other studies (Table 3). Electrical conductivity and Total Dissolved solids were however lower than those reported in related studies in Mexico (Fall et al., 2007) and South Africa (Tekere et al., 2016). Total suspended solids, Settleable solids and Turbidity were very high among the stations. Turbidity is generally influenced by the amount of particulate matter in wastewater (Kari et al., 2017). This therefore explains why the high levels of TSS and SS in wastewater, particularly from Station 1, translate into a high Turbidity and vice versa in Station 2 (Table 3). Additionally, the turbidity values recorded in this study were up to 14 times higher than results reported by an earlier study in the same study area (Aikins and Boakye, 2015). This is because, wastewater sampling for this study



**Figure 4.** Relationship between water use efficiency and number of vehicles washed.

**Table 3.** Characteristics of carwash wastewater.

Parameters	Station 1	Station 2	Station 3	Other studies	EPA GV	Pollution load (Kg/year) <sup>***</sup>
pH	8.6 ± 0.2	7.8 ± 0.4	7.6 ± 0.5	7.5 <sup>a</sup>  7.62 <sup>b</sup>	6–9	
EC (µS/cm)	376.1 ± 56.1	284.0 ± 53.4	463.9 ± 89.6	803 <sup>a</sup>	1500	
TDS (mg/L)	188.1 ± 28.0	141.8 ± 26.4	233.4 ± 47.2	1508 <sup>a</sup>	1000	
TSS (mg/L)	3416.7 ± 1619.5	1260.0 ± 910.7	2929.2 ± 451.6	3561 <sup>a</sup>	50	1206–14819
Settleable solids (mL/L)	28.5 ± 19.9	7.1 ± 7.1	16.6 ± 17.9		0.5	
Turbidity (NTU)	3649.2 ± 2149.7	1055.1 ± 731.8	1912.5 ± 465.9	264–314 <sup>b</sup>	75	
COD (mg/L) <sup>*</sup>	1413.3 ± 327.6	990.0 ± 262.5	1337.3 ± 479.5	4520 <sup>a</sup>	250	935–6130
BOD (mg/L)	492.5 ± 113.6	348.1 ± 92.7	571.7 ± 205.3	10.5–11.9 <sup>c</sup>	50	333–2136
Nitrates (mg/L) <sup>*</sup>	2.9 ± 2.3	5.0 ± 1.1	4.7 ± 1.8	2.0 <sup>d</sup>	-	3–13
Nitrites (mg/L) <sup>*</sup>	0.3 ± 0.3	0.6 ± 0.1	0.5 ± 0.1	0.8 <sup>d</sup>		0.3–1.5
Phosphate (mg/L)	7.0 ± 1.3	9.7 ± 2.6	6.2 ± 3.3	5–14 <sup>b</sup>		4–30
Sulphate (mg/L)	69.8 ± 7.7	41.9 ± 11.2	40.8 ± 1.0			29–303
Total Coliforms (CFU/100mL)	1.6 × 10 <sup>4</sup> ± 3.8 × 10 <sup>3</sup>	1.1 × 10 <sup>4</sup> ± 2.4 × 10 <sup>3</sup>	1.8 × 10 <sup>5</sup> ± 6.0 × 10 <sup>3</sup>	1.6 × 10 <sup>6</sup> –1.3 × 10 <sup>7</sup> <sup>e</sup>	100 <sup>**</sup>	
E. Coli (CFU/100mL)	4.7 × 10 <sup>3</sup> ± 1.6 × 10 <sup>3</sup>	2.3 × 10 <sup>3</sup> ± 8.8 × 10 <sup>2</sup>	5.2 × 10 <sup>3</sup> ± 1.9 × 10 <sup>3</sup>	4.5 × 10 <sup>1</sup> –2.4 × 10 <sup>3</sup> <sup>e</sup>	10 <sup>**</sup>	

<sup>\*</sup> Parameter variation among stations was not statistically significant at 95% confidence level.

<sup>\*\*</sup> Concentration in MPN/100mL.

<sup>\*\*\*</sup> Wastewater volumes based on median number of cars washed – Details in Supplementary Sheet – Table S2.

<sup>a</sup> Fall et al., 2007.

<sup>b</sup> Aikins & Boakye (2015).

<sup>c</sup> Lau et al., 2013.

<sup>d</sup> Rodriguez Boluarte et al., 2016

<sup>e</sup> Etchepare et al. (2014).

was done in the minor rainy season (September–October) when the ubiquitous untarred link roads in the Metropolis become muddy thereby transferring more particulate matter onto vehicles.

Particularly, Station 1 recorded the highest average levels of pH, Total Suspended Solids, Settleable Solids, Turbidity, Chemical Oxygen Demand and Sulphates (Table 3). The high level of sulphates in the wastewater from Station 1 is indicative of high usage of detergents at the station which translates into a high pH. Sulphate is a common additive in detergents usually applied as Sodium Lauryl Sulphate which is used to enhance foam density (Schliemann et al., 2014; Siva et al., 2015). When released into waterways, this can contribute to foaming (Richards, 2003; Vinod Dubey et al., Pandey, 2012) and together with Phosphorus and Nitrogen fuel eutrophication of waterbodies (Dodds and Smith, 2016; Pattusamy et al., 2013). Nutrients were however lower in the wastewater, being up to 5.0 ± 1.1 mg/L and 0.6 ± 0.1 mg/L for Nitrates and Nitrites respectively. For Phosphates, up to 9.7 ± 2.6 mg/L was recorded (Station 2). Mean biodegradability index (BOD/COD ratio) of the wastewater is between 0.3 and 0.4 which is typical of industrial wastewater and makes it difficult to be readily broken down in the environment (Samudro and Mangkoedihardjo, 2010). Preferably, the biodegradability index of wastewater should be close to 1 to make it readily biodegradable and hence easily treated by natural means (Kumar et al., 2010; Malik et al., 2017). High levels of coliforms were recorded in the wastewater consistent with that reported in Brazil (Etchepare et al., 2014) and this could potentially be from soil particles on the vehicles due to untarred roads in the Metropolis. The presence of these coliforms, especially *E. coli*, shows the microbiological risks associated with the carwash wastewater and therefore any attempt to treat it for reuse should, as a precaution, include a disinfection treatment step. This is to prevent onward transmission of diseases through contact with carwash operators.

Except for pH, EC and TDS, other water quality parameters of the wastewater exceeded their respective EPA-approved guideline value (Table 3). COD and BOD exceeded their respective stipulated effluent discharge values by up to 6 and 11 times respectively. However, physical parameters such as Turbidity, TSS and SS exceeded their stipulated effluent values by up to 68 times on the average, indicating the potential adverse effects on receiving waterways. Pollution loads for BOD and COD

were up to 2136 kg/year and 6130 kg/year respectively per carwash station. For Phosphates and Sulphates, up to 1.5 kg/year and 30 kg/year per carwash station were recorded. Particularly, the values of pollution load of the carwash wastewater are essential in the design of appropriate treatment systems to ensure reuse of wastewater. Without this, the treatment capability of any wastewater treatment system adopted can be compromised (Mikosz, 2015).

#### 4. Conclusion

This study found that the carwash industry in the Kumasi Metropolis rely mostly on groundwater for their activities. Averagely, about 40 vehicles are washed per station daily (95% CI:37–43), using about 200L of water per wash. Each station used up to about 16,000 L of water per day. This suggests that, some 1,000m<sup>3</sup> of water is used by the carwash industry (N = 100) daily in the Metropolis – equivalent to water used by 9,000 people daily. Almost all stations use spray wands to wash vehicles. These stations save more than half (55%) of water used per vehicle washed compared to those using only buckets and brush. Stations washing more vehicles per day tend to use less water per vehicle and vice versa. Overall, about 700m<sup>3</sup> of wastewater is generated by the carwash industry in Kumasi. The wastewater generally has a neutral to alkali pH (7.6–8.6) and characterized by high levels of Sulphates (40.8–69.8 mg/L), COD (990–1413 mg/L), TSS (1260–3417 mg/L) and *E. coli* (2.3–4.7 × 10<sup>3</sup> CFU/100mL). Biodegradability Index of the wastewater was between 0.3 and 0.4 while pollution loads of BOD and COD were up to 2tons/year and 6tons/year. EPA-approved effluent guidelines were mostly exceeded – in some cases by up to 68 times. With the rapidly increasing vehicle population, this could have grave implications for water supply since potable groundwater is being turned into highly polluted wastewater and discharged into waterways that supply potable water for residents.

This study therefore recommends that all new and existing carwash stations using groundwater must be allotted a water abstraction tax depending on water quantities used. Such a tax will compel operators to conserve water used. The carwash stations must also be compelled by the legal provisions in 1999 Environmental Assessment Regulations to install water recycling technologies. Financial incentives such as tax credits should be given to carwash stations that adopt water-saving technologies

in their operations. Further studies are required to develop appropriate wastewater treatment systems for the carwash industry and assess the financial implications of wastewater recycling on the carwash business in the Metropolis.

## Declarations

### Author contribution statement

Isaac Monney: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Emmanuel Amponsah Donkor: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Richard Buamah: Contributed reagents, materials, analysis tools or data; Wrote the paper.

### Funding statement

This work was supported by the Netherlands Government (VIA Water Project No. L15050 and NICHE 195) and the Regional Water and Environmental Sanitation Centre, Kumasi with funding from Ghana Government and the World Bank under the Africa Centres of Excellence project.

### Competing interest statement

The authors declare no conflict of interest.

### Additional information

Supplementary content related to this article has been published online at <https://doi.org/10.1016/j.heliyon.2020.e03952>.

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