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Stormwater Quality from Gas Stations in Tijuana, Mexico

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ABSTRACT: There are many potential sources of stormwater pollutants in urban areas; one of these sources is gas stations, which are numerous and spread city-wide. A study was conducted to evaluate the water quality of runoff from gas stations in the city of Tijuana, Mexico. Pollutant loads in runoff from gas stations in the study area were higher than in other published studies. The estimated loads from gas stations of oil and grease (OG), total suspended solids (TSS) and chemical oxygen demand (COD) were 39.9, 265.3 and 168.6 Kg/ha, respectively. These values of OG, TSS and COD were 57, 41 and 18 times higher than the values reported in another similar study conducted in the US. The possible reasons for these differences may lie in the different cleaning processes utilized in gas stations, in the mechanical conditions of the cars that enter the sites and the urban characteristics surrounding the gas stations. The results from this study show that runoff from gas stations can be a main contributor of pollutants such as suspended solids, heavy metals, oil and grease to stormwater and water bodies.

Key words: Tijuana, Pollution, Gas station, Urban runoff, Oil, Grease

INTRODUCTION

Oil pollution in water bodies through different sources and the subsequent treatment methods have been widely considered by different researchers (Hassani et al., 2009; Abduli et al., 2007; Bagherzadeh-Namazi *et al.,* 2008; Onwurah *et al.,* 2007; Otitoloju, 2010; Adekunle et al., 2010; Jafari and Ebrahimi, 2007; Nouri *et al.,* 2010; Durán and González, 2009). Stormwater has become a significant contributor of pollutants to water bodies. These pollutants can be inorganic (e.g. heavy metals and nutrients), or organic such as polycyclic aromatic hydrocarbons and phenols from asphalt pavement degradation (Sansalone and Buchberger, 1995). Extensive research has been conducted to evaluate heavy metals and other pollutants in stormwater from urban sites (Makepeace *et al.,* 1995; Estebe *et al.,* 1998; Gromaire-Metz *et al.,* 1999), focusing mainly on diffuse pollution sources constituted by impermeable surfaces such as parking lots, roads and roofs. However, only a limited number of studies related to stormwater quality from gas stations have been conducted. Stormwater runoff from gas stations can be considered an important point pollution source in urban areas (Khan et al., 2004); although individual gas stations tend to use small land resources they are, nevertheless, numerous and wide-spread in urban areas. Gas station runoff has also been identified as one of the main sources of oil and grease in stormwater. Oil and grease in gas station stormwater runoff comes from engine oil, gasoline spills, fuel additives, lubricants, hydraulic fluids and dry deposition of automobile exhaust (Khan *et al.,* 2004). Gnecco et al. (2006) measured the concentration of pollutants from a gas station and an auto dismantler facility; they found that the pollutant loads from these point pollution sources were higher than in urban runoff. The mean chemical oxygen demand (COD) concentration in the gas station runoff was 2.4 times higher than the concentration in runoff from the sampled urban site. Zinc and copper concentrations were approximately 4 times higher. However, the mean lead concentration was approximately five times lower in the gas station runoff than the mean concentration from the sampled urban site.

Borden *et al.,* (2002) analyzed methyl tert-butyl ether (MTBE) and aromatic hydrocarbons in stormwater of different land uses and gas stations and found median concentrations of MTBE (1.29 µg/L), benzene (0.09 µg/L) and toluene (0.15 µg/L).

Different studies have found that stormwater quality is directly related to the anthropogenic activities surrounding the sampling sites and that pollutants in stormwater can be more concentrated due to longer dry periods in these places. It is also

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known that the first flush of runoff contains the highest concentration of pollutants (Taebi and Droste, 2004). The aim of this work was to (evaluate) determine the physicochemical parameters and heavy metal (Cr, Cd, Pb, and Ni) concentrations of stormwater runoff from gas stations.

The city of Tijuana is located in the northwest corner of Mexico on the US-Mexico border (Fig. 1). This region is characterized by its semi arid climate; the rainy season extends from autumn to early spring. The average annual rainfall for the period of 1998-2005 was 268 mm (CNA, 2008).

A high percentage of the automobiles that circulate in Tijuana are used cars imported from the US because they are cheaper than New Mexican cars; many of them are not in optimal conditions and may leak motor oil or brake fluid. It is estimated that approximately 78% of the cars in Tijuana are older than 13 years and only about four percent are seven years old or newer. Pollutants from these vehicles end up on the street surface and are washed away by stormwater. It is estimated that Tijuana has a total of 160 gas stations all of which represent a potential source of stormwater pollutants.

The city's combined sewer system regularly overflows because it cannot cope with the extra volume of water during rain events. Another urban feature of Tijuana is the number of vacant lots in the urban area and the steep cut slopes in the hills exposed to erosion, which in rain events can contribute suspended solids to stormwater. According to the municipal planning authorities 22% of the area in Tijuana is vacant lots and approximately 36% of the total vacant lots have slopes of more than 35% (Implan, 2002).

Moreover, a number of unpaved roads can still be found in areas that are considered completely urbanized. In these areas, soil can be transported to paved roads by car tires and then transported by runoff.

MATERIALS & METHODS

The sampling sites selected were in an approximate surface area of 30 km^2 located in the northeast and east of the city of Tijuana. Nine sites were sampled between 2005 and 2008. Five of them were gas stations, three sites have predominantly residential land use, and one is located in an area with predominantly commercial land use. Ten rain events were sampled between 2005 and 2008. The criteria to select the rain events were

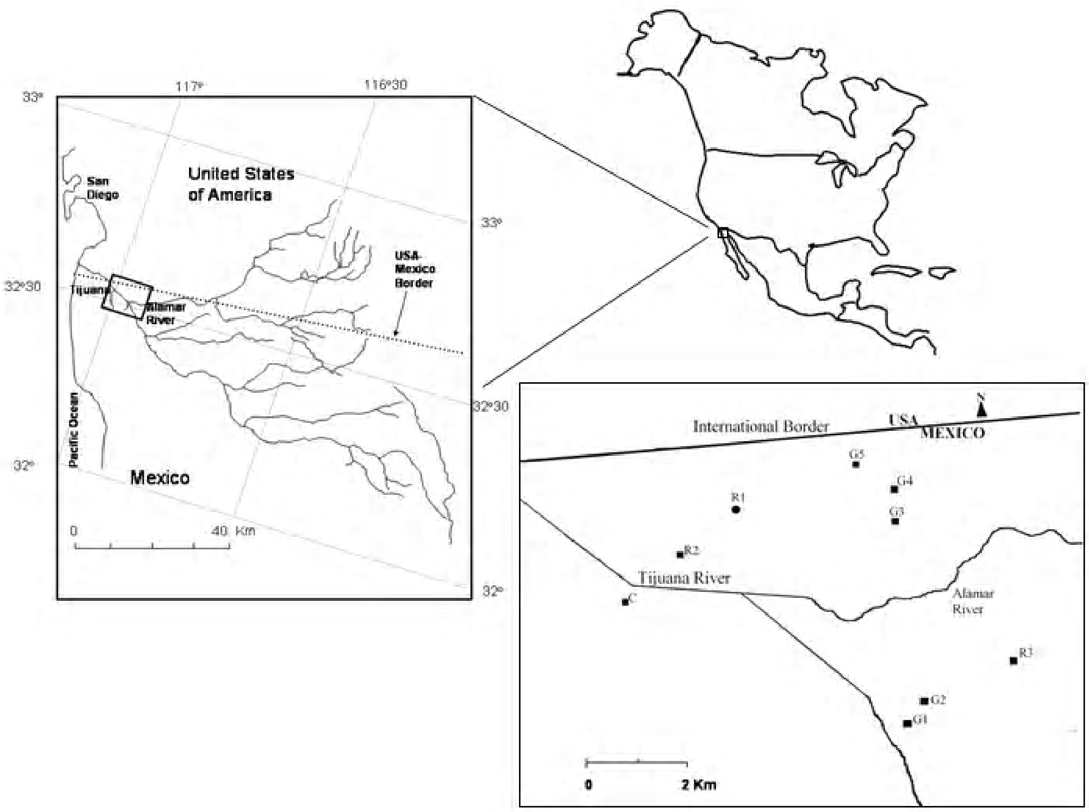

Fig. 1. The study area showing the sampling points (modified from Wakida *et al.,* 2007)

that the storm was preceded by at least 72 hours of dry weather and a rainfall higher than 2.5 mm (USEPA, 1990). Table 1 shows the rainfall data of the rain events sampled in this study. Three duplicate grab samples were taken directly in the street pipes that conduct the stormwater out of the gas stations, except for site G4, where samples were taken in an area where water was stagnant. In the other sites (R1, R2, R3 and C) the samples were taken directly from road and drain runoff. The duplicate samples were collected in different stages of the rain events.

The selection criteria for gas stations were that they have a conduit that carries stormwater to the street. Only one of the sites has a small area with a crevice in the pavement where water accumulates (G4). Three of the gas stations also have diesel dispatchers (G1, G2 and G5) and one has a car wash on the premises (G2). The drainage area of the gas stations was between 1176 to 2772 m^2, the largest being site G1. The commercial land use (C) site has a drain located in an area close to a horse racing track and a golf course with an approximate drainage area of 113 ha. Site R1 drains an area of approximately 13 ha with a lower population density (92 inhabitants/ha), populated by high-income families. The residential R2 site has an open channel that drains an area with houses owned by low-income families. The approximate population density is 63 inhabitants/ha and the drainage area is about 44.6 ha. A number of auto repair shops are found in the area that drains site R2. The drainage area of site R3 is 2 ha and is densely populated (> 200 inhabitants/ha). Samples were analyzed for chemical oxygen demand (COD), total phosphate (TP), nitrate, sulphate, total suspended solids (TSS), total dissolved solids (TDS), oil and grease (OG) and heavy metals (Cr, Cd, Ni and Pb). These physicochemical parameters are commonly analyzed in stormwater studies. The heavy metals analyzed were selected for their toxicity.

Heavy metals were analyzed by atomic absorption using a spectrophotometer with a graphite furnace (Perkin-Elmer 3100, graphite furnace HGA 600). TSS analysis was performed according to the Mexican Standard NMX-AA-034-SFCI-2001. Oil and grease were analyzed under Mexican Standard NMX-AA-005-SFCI-2000, in which oil and grease are adsorbed in diatom soil and then extracted with hexane, evaporated and later weighed. Nitrate was measured using the cadmium reduction method, COD by the reactor digestion method, sulphate by the turbidity method and phosphate by the acid persulphate digestion method. Unit loads for runoff in gas stations and residential sites were calculated based on the equation

L=10000 SMC X P X RC where L is the unit load (Kg/ha), SMC is the site mean concentration (kg m^{-3}), P is rainfall depth (m) and RC the runoff coefficient. For the gas stations an RC of 0.95 was used and for the residential sites the RCs used were those estimated by Winckell and Le Page (2003) for these urban basins in Tijuana. An RC value of 0.7 was utilized for sites R1 and R2 and an RC value of 0.8 for R3.

RESULTS & DISCUSSION

Sulphate, TDS, TP, Cr and Pb concentrations showed a tendency to decrease concomitant with the advance of the rainy season. This phenomenon is due to the “washing” effect of the deposited material by stormwater runoff, which has been reported by another study conducted in Los Angeles, USA (McPherson et al., 2005). No clear tendency of concentration reduction was observed for nitrate, OG, TSS, COD, Cd or Ni. This may be the result of different amounts of rainfall or of a constant input of these pollutants in the study sites. For example, the frequent entrance of cars with oil leaks to the gas station sites can produce the accumulation of oil and grease on the surface.

The range and mean of the physicochemical parameters analyzed in all the rain events are shown in Table 2. The highest mean concentration (1084 mg/L) of oil and grease (OG) was found in gas station G1 and the maximum OG concentration was found in G1 (3436 mg/L), where diesel spillages were observed in the load

Table 1. Rainfall characteristics of the sampling events

Rain event	Date (month-day-year)	Average rainfall intensity (mm/hr)	Maximum rainfall intensity (mm/hr)	Total rainfall (mm)	Dry days previous to rainfall event (days)
1	10-17-05	1.33	2.0	4.3	172
2	11-10-05	1.00	1.0	2.8	14
3	02-27-06	2.71	6.0	6.9	47
4	03-10-06	1.62	2.0	8.1	11
5	04-04-06	2.11	4.0	8.1	18
6	11-30-07	1.74	4.0	13.7	55
7	01-06-08	1.33	2.0	11.2	26
8	01-26-08	1.25	2.0	5.0	18
9	02-03-08	1.12	2.0	7.9	7
10	02-14-08	2.07	5.0	25.0	11

Table 2. Range, mean (in brackets) and standard deviation (third row) values for physicochemical parameters in stormwater runoff from the sampling sites (all the parameters in mg/L, except pH, electrical conductivity (EC) in μs/cm

Site	pH	EC	TDS	NO_3	SO_4	COD	TP	TSS	OG
G1	5.8-8.6	320–5170	180-2720	<0.1-15	48-1400	250-22600	0.4-25	1912-11561	149-3436
	(7.31)	(1289.22)	(667.77)	(2.91)	(337.11)	(5139.44)	(6.73)	(4235.45)	(1083.77)
	0.99	1518..42	799.18	4.83	426.40	7023.71	7.24	3830.86	1397.50
G2	6.0 – 8.5	110– 4900	60- 830	0.2-1.9	14 - 440	75-910	0.2 -8	291-2129	0-1732
	(7.20)	(1032.20)	(283.30)	(1.50)	(130.90)	(465.00)	(3.50)	(580.70)	(621.00)
	0.89	1525.15	243.8	1.55	146.31	252.18	3.20	770.10	683.41
G3	6.2 -8.6	40–320	40-168	0.1- 8.7	6 -30	195-1432	0.1-3	294-880	0-730
	(7.30)	(256.30)	(137.3)	(1.40)	(23.30)	(497.2)	(1.90)	(544.60)	(241.10)
	1.08	165.17	84.19	2.98	21.08	433.83	0.97	272.66	285.07
G4	5.4 -8.3	90-1040	60-547	0.2-23	40-260	90-1630	0.1-4.9	231-4834	nd-1134
	(7.10)	(441.10)	(233.00)	(4.00)	(94.70)	(640.70)	(2.50)	(1746.80)	(339.80)
	1.02	310.50	158.53	7.27	98.86	529.51	1.58	1630.15	427.68
G5	5.9-8.6	150-1250	80-630	0.1-19.6	10-150	220-2950	2-16	204 - 6717	20-716
	(7.10)	(421.00)	(268.70)	(3.00)	(85.60)	(1423.80)	(4.50)	(1990.20)	(416.11)
	1.09	326.64	191.02	6.02	88.89	868.86	4.09	2443.45	667.36
R1	7.0-8.1	240-2970	130-1500	0.3-4.2	50-630	123-2135	2.2-17	121-798	6.2-138
	(7.40)	(1041.40)	(535.70)	(2.00)	(227.90)	(644.10)	(6.80)	(275.60)	(45.20)
	0.62	1100.2	554.46	1.44	255.73	752.5	5.30	304.10	54.07
R2	5.4-8.2	360-980	190-500	0.1- 7.3	60 - 220	205-1350	1.8-6	613-3081	40-870.4
	(7.00)	(731.30)	(375.90)	(2.70)	(148.50)	(950.30)	(4.00)	(1471.80)	(305.96)
	0.94	204.96	105.08	2.80	51.73	407.90	1.34	896.83	360.86
R3	5.9- 7.6	280-770	130-420	<0.1 -1.1	40 -170	60-2005	0.3-14	182-900	188-795
	(7.20)	(486.70)	(255.00)	(0.40)	(125.00)	(895.50)	(5.20)	(515.70)	(356.70)
	0.89	272.88	135.16	0.54	92.63	748.07	4.57	314.78	306.2
C	5.6-7.7	260-1180	140-590	<0.1-3.5	49-150	230-2050	0.4-5.2	10-1427.3	12-650
	(7.0)	(610.00)	(308.80)	(1.20)	(82.40)	(652.70)	(2.60)	(715.10)	(175.30)
	0.9	335.50	158.50	1.40	58.50	581.10	1.30	623.0	245.70

TDS: total dissolved solids; COD: Chemical oxygen demand; TP: total Phosphorus; TSS: total suspended solids; OG: Oil and grease

area. Generally, the highest oil and grease concentrations were observed in gas stations, although the mean concentration from R2 was 306 mg/L. The high concentrations of oil and grease found in almost all the sampling sites may be a result of crankcase oil leakage from ill-maintained cars and diesel spillages in the gas stations. Other possible sources of OG are runoff from auto repair shops and surface deposition of grease on the street from food businesses and soil, especially for the R1 and R2 sites. The percentage of petroleum hydrocarbons in water samples from R1 and R2 was 33 and 28% respectively. This analysis was conducted using the EPA's 1664 method that uses silica gel to separate hydrocarbons from compounds of vegetable and animal origin. These results show that a high proportion of the OG in these sites comes from vegetable and animal sources. A recent study by Garcia Flores et al., (2009) analyzed the concentration of polycyclic aromatic hydrocarbons (PAH). They found ratios in the R2 site between low molecular weight (LMW) PAH and high molecular weight (HMW) PAH that were lower than 1. LMW/HMW PAH ratios have been used for the identification of PAH sources (Soclo *et al.,* 2000). LMW/HMW ratios <1 are derived from pyrogenic sources, such as the incomplete combustion of fossil fuels or wood. On the other hand, LMW/HMW ratios >1 are from petrogenic sources such as fuel oil or light refined petroleum products. Used crankcase oil has a petrogenic profile which becomes pyrogenic when oil is contaminated through contact with exhaust gases in the engine cylinders (Wang *et al.,* 2000). These results indicate that the main source of the petroleum hydrocarbon fraction of OG in stormwater runoff comes from used crankcase oil, since traffic in these areas (R1 and R2) is low.

The highest mean TSS concentration found was in G1 (4235 mg/L). TSS concentrations were also high at the G4, G5 and R2 sites, all of which were over 1000 mg/L. The probable reason for the high concentration of solids in G1 and G5 is that both gas stations are located in front of a steeply cut hill, from which sediments are transported into these sites by stormwater. High TSS concentrations in G4 are probably due to the nature of the sampling site where water is stagnant and favours the accumulation of solids. The high concentrations of sediments in the G5 and R2 sites come from the unpaved roads located in the area that drains the R2 site. The entrances to the G5 site are located on two unpaved roads, so that car and truck tires regularly transport soil into the station. A steep cut slope prone to erosion is adjacent to the channel of the R2 site; moreover this catchment has approximately 20% pervious surface, most of which is unpaved streets where water flows to the sampling site.

The highest TSS concentrations were observed at almost all the sites in those rain events with the highest amount of rainfall (rain events 6 and 10). The G2 and G3 sites were the exception, probably because they do not have any of the characteristics mentioned above such as being close to sources of solids (unpaved roads and steeply cut hills).

The heavy metals analyzed (Pb, Cr, Cd and Ni) were detected in most of the sites because they are related to traffic (Ezer, 2009; Ewen & Anagnostopoulou, 2009). The mean and range concentrations for the heavy metals analyzed from all the sites are shown in Table 3. The highest mean concentrations were usually found in the gas station sites; site R2 was the exception for Ni (20 $\mu g/L^{1}$). The highest mean concentrations for Pb and Cr were found in gas station G4 (171 and 361 µg/L, respectively) and the highest mean concentration for Cd was at G3 (21 µg/L). It should be noted that the highest concentrations found for Pb and Cr were in the G1 site, where concentrations as high as 631 µg/L (Pb) and 6895 µg/L (Cr) were observed in the samples. These gas stations (G1 and G4) were the sites where more cleaning problems were observed (gas and diesel spillages) and both are located adjacent to heavily trafficked roads (> 24000 vehicles per day).

The Ni mean concentration of the R2 site was higher than those observed for all the gas station sites. These higher mean concentration can be explained by the substantial number of auto repair shops and related businesses that are located in the drainage area of the R2 site.

Nickel can be generated by the normal wear of bearings, bushings and other moving parts in engines, while lead is used as a filler material in tires. Chromium is also used in automobile engine parts, so it is no surprise to detect this metal in runoff from gas stations. The most probable sources of cadmium in runoff include wear and tear of tires and brake pads and corrosion of galvanized metals (Makepeace et al., 1995). The Pearson correlation coefficient indicates whether there is a relationship between two groups of values. A strong correlation may indicate that the sources are similar or that the analytical method measures related properties (Han *et al.*, 2006). A strong and significant correlation between Cd and TDS was found in G1 and G2 ($R>0.80$, $P<0.01$). This is in agreement with other studies where Cd is mainly associated with dissolved solids (Morrison *et al.,* 1984) and colloidal material (Harrison and Wilson, 1985) in stormwater. A very strong correlation in site G2 was observed between

Table 3. Range, mean (in brackets) and standard deviation (third row) of heavy metal concentrations in µg/L

	G1	G2	G3	G4	G5	R1	R2	R3	C
Pb	6-631 (205.1) 307.5	4-256 (105.4) 103.6	12-441 (186.3) 156.4	8-424 (170.8) 177.9	30-423 (151.8) 155.4	2.5-517 (122.9) 178.9	3-245 (126.5) 163.8	20-119 (69.5) 36.7	5-195 (69.6) 75.8
Cr	Nd-6895 (934.9) 2411.8	1-97.6 (24.3) 37.0	2.5-190 (71.9) 79.8	2.5- 1993 (360.9) 722.4	1-209 (42.3) 69.8	2.5-128.6 (56.2) 64.3	Nd-167 (45.0) 58.9	2-125 (67.3) 56.9	2.5-138 (51.4) 57.8
Cd	0.3-45 (13.6) 17.3	0.7 - 26 (9.5) 16.0	0.3-68 (14.1) 25.7	1 - 49 (10.8) 17.9	0.8 - 42.4 (10.2) 15.3	0.3-26 (5.5) 10.0	1- 44.0 (9.5) 15.8	0.7-1.4 (0.9) 0.3	1.5 – 92 (21.0) 35.7
Ni	5-29.9 (12.7) 10.9	5 - 18.6 (9.5) 5.0	Nd-15 (6.5) 5.4	2 - 12.0 (8.2) 7.1	2 -25.2 (9.0) 8.6	1-10.9 (6.7) 4.1	Nd- 82 (19.6) 27.6	2 - 13.45 (7.5) 4.2	1 a 17 (8.8) 6.0

Nd: not detected

TSS and Ni (0.95, P<0.01). Ni is associated with suspended solid and organic matter (CCREM, 1987; Dannecker et al, 1990). Very strong, significant correlations (0.94 and 0.89) were found for Cr and OG in sites G1 and G2, suggesting a common source of these pollutants in these sites, which may be the leakage of used oil from cars. A strong significant correlation between COD and OG was found in gas stations G2, G3 and G4 (R value between 0.80 and 0.88, P<0.01), which may indicate that a high COD in these sites comes from the OG concentrations. The estimated pollutant loads from gas stations in this study and other studies are presented in Table 4. To the best of our knowledge, the published research on runoff quality from gas stations is sparse. The only two studies found were used for this comparison. The pollutant loads in the gas stations in this study were higher than those reported in the other studies. The COD and TSS loads are in the order of 18 and 41 times higher, respectively, than those found in the study conducted by Rabanal and Grizzard (1995) in Maryland, USA. The discrepancy in COD loads may be explained by differences in climate conditions (humid vs semi arid), the cleaning processes utilized in the gas stations, the mechanical conditions of the cars that enter the stations and the solids transported by runoff and car tires. The load of oil and grease in gas stations in Tijuana is 57 times higher than the 0.7 Kg/ha reported by Rabanal and Grizzard (1995). This is very likely due to the diesel and crankcase oil spillages in the gas stations in Tijuana. The mean concentrations of oil and grease gas station stormwater runoff in Tijuana was five times higher than the mean concentration of 50 mg/L stated by Khan et al., 2004 in gas stations in Thailand. The COD and TSS load from a study conducted in Genoa, Italy are 6 and 24 times lower, respectively, than the concentrations in this study. The high solid concentrations in gas station runoff in Tijuana may be the result of solids carried by car tires from unpaved roads and runoff from adjacent eroded steep hills. This source of solids is less probable in the other studies because the gas stations sampled were located on freeways, without the urban characteristics found in the gas stations in Tijuana. Another reason could be the different cleaning processes used in the gas stations. Whereas, the gas station in Maryland is periodically cleaned with a high pressure water flow (Rabanal and Grizzard, 1995), in Tijuana's gas stations the paved surface areas are cleaned occasionally and manually using brooms. Heavy metals in runoff from gas stations in Tijuana are much more concentrated than in the US and Italian studies. The chromium load was approximately 40 times higher, Cd median concentration was 6 times higher, and Pb load was 9 times higher than the gas station runoff in Maryland, USA. Lead load in the Italian gas station study was around 57 times lower than the load in the gas stations sampled in Tijuana. The comparison of pollutant load for residential land use sites in different studies are shown in Table 5. One of the more significant

Table 4. Comparison of estimated pollutant load in gas stations between this study and other studies (Kg/ha)

Parameter	Tijuana, Mexico[1]	Maryland, EU[2]	Genoa, Italy[3]
TSS	265.25	6.35	11
COD	168.57	9.23	27.3
TP	0.34	0.03	-
NO_3-N	0.47	-	-
Oil and grease	39.93	0.7	-
Cr	0.043	0.001	-
Ni	0.001	-	-
Cd	0.001	0.001	-
Pb	0.017	0.002	0.0003

[1]This study; [2]Rabanal y Grizzard (1995); [3]Gnecco et al. (2006)

Table 5. Comparison of estimated pollutant loads of different urban catchments (all values in Kg/ha)

Parameter	Malaysia		Saskatoon, Canada[c]	Dallas-Fort Worth Texas[d]	Tijuana, Mexico[e]
	Skudai[a]	Johor Bahru[b]			
Drainage area (ha)	3.3	171.4	616	4 -65	2-45
TSS	7.5	55	57	3.71	76.15
COD	9.0	12	24	3.20	54.0
TP	0.05	NA	0.24	0.01	0.35
NO_3-N	0.35	0.2	NA	NA	0.12
Pb	0.001	0.001	NA	0.001	0.005

[a]Yusop et al. 2005; [b]Nazahiyah et al. (2007); [c]McLeod et al. (2006), [d]Baldys et al. (1998), [e]This study

differences was found in the COD load. Mean COD load found in residential areas in Tijuana were 2 and 5 times higher than the load values reported in the studies from Canada (24 Kg/ha) and Indonesia (12 Kg/ha), respectively. This difference of COD concentrations can be explained in terms of catchment size. The Canadian and Indonesian studies used a much larger area. Other probable reasons could be the differences in climates and the high OG content found in stormwater runoff from residential areas in Tijuana. The maximum OG concentrations in R2 and R3 were 870 and 795 mg/L (Table 2).

The load of TSS in stormwater runoff from residential sites in Tijuana is higher than that reported by other studies. This may be the result of a higher soil erosion rate as a result of the shanty settlements on land with high slopes (> 35%) and the percentage of unpaved roads that reach 20% in site R2.

CONCLUSION

The results from this study have shown that the pollutant concentrations in runoff from gas stations in Tijuana are higher than those reported by studies conducted in other countries. The COD and TSS loads in gas station runoff were in the order of 18 and 41 times higher, respectively, than in a study carried out in Maryland, US. The high TSS and COD concentrations observed in this study may be produced by poor cleaning conditions and crankcase oil leakage from cars.

A higher load of COD was observed in stormwater from residential areas in Tijuana than in other published studies. This may be the result of higher OG concentrations in runoff due to crankcase oil leakages observed in many streets and parking lots in Tijuana. Our results show that stormwater runoff from gas stations can be a significant source of pollutants to urban runoff in a city of a developing country with a semi arid climate. The results presented here will be helpful in evaluating the contribution of pollutants to stormwater from gas stations, and may provide decision tools for the implementation of pollution control measures in these facilities.

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